The 10th Gulf Water Conference

Water in the GCC States

The Water-Energy-Food Nexus

22-24 April 2012, Doha - Qatar - Grand Hyatt Doha Hotel

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The Water-Energy-Food Nexus

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Prof. Dr. Waleed K Al-Zubari
Chairman, Conference Scientific Committee

Unlike other natural resources, water has great importance as indispensable for human survival, a strategically vital resource, and an essential input for the development process for nations. In the GCC countries, situated in one of the driest region of the world, water management and its sustainable provision to the various development activities has grown to be one of the most important and challenging tasks faced by the water authorities in these countries due to limited available natural water resources on one hand, and the escalating sectoral water demands resulting from unprecedented population and economic growth on the other.

Currently, the water challenge is considered as one of the major and most critical challenge facing the GCC countries. This challenge is expected to grow with time due to the scarcity of natural freshwater resources and the heavy financial and economic burden to be borne in the provision of non-conventional water resources (represented mainly by desalination), and due to the direct links between water and the accelerating socioeconomic development efforts in these countries. Furthermore, the water challenge is compounded by its multiple nexuses with the various development sectors, such as water and human health, water and environment, water and food, water and energy, and many other interdependencies, which carry within them many cross-cutting issues of social, economic, legal, technical, and political nature.

Amongst the most important inter-dependencies in the GCC countries is the water-energy nexus, where all the sectors of the development process rely on the sustainable provision of these two resources. In addition to the central and strategic importance of water and energy in the GCC countries, these two resources are highly interdependent and inter-related, especially in the field of water production and supply, where the scarcity of natural water resources is considered as the major factor for the increase in energy demand, and the availability of fossil fuel resources in the GCC is the most important factor in providing water in these countries through desalination. In addition, supply and demand for water and energy are inextricably linked in these countries. Furthermore, it is expected that the water-energy nexus becomes more challenging and more complicated in the future due to the impacts of climate change, where available water resources are expected to be further reduced and water demands are increased in the region, while the GCC are working towards meeting their obligations in reducing their emissions of greenhouse gases.

On the other hand, the water-food linkage represents another important and vital nexus in the GCC countries, where the agriculture sector consumes more than 80% of the total water uses and more than 90% of groundwater uses in these countries. Despite these high percentages of water consumption and agricultural support and subsidies programs in most of the GCC countries, the agricultural sector contribution to GDP remains very low, and these countries remain highly dependant on food imports. The growing challenge in this nexus is that agricultural expansion and production is being stimulated by the increase in food demand in the region and growing international food prices on one hand, while on the other hand this will contribute even further to the over-exploitation of natural water resources and their depletion and quality degradation. This trend not only threatens the sustainability of natural water resources, but also imposes higher threats on the future of the agriculture sector itself. Moreover, it is expected that this issue will be exacerbated due to the growing pressures on agricultural production due to the expected impacts of climate change represented by reduction in rainfall rates, increase evaporation rates, and increase the frequency of extreme events.

Undoubtedly, the sustainable provision of water, energy, and food under the current accelerating population and economic growth rates in the GCC countries represents one of the major challenges faced by these countries, and the ways and approaches in which these challenges will be faced will have a significant impact on the living standards, human development, and sustainable development of these countries for decades to come. Therefore, in view of the increasing demands on these three resources in the GCC and due to the strong interdependencies and relationships between them, an integrated planning and management approach for water, energy, and agriculture, becomes an important and vital task to meet the demand on these resources and their future sustainability in the region.

Through addressing the topics of sustainable water resources management in the GCC countries, the Tenth Gulf Water Conference focuses on the water-energy-food nexus, as well as other water interrelationships such as water, health, and environment. The conference looks at and considers best practices, experiences and models of the sustainable planning and management for water, energy, and food, and the necessary social, economic, legislative, and technical considerations.

As at the previous WSTA conferences, the overall goal of the Tenth Gulf Water Conference is to encourage scientific studies and research in the different fields of water resources, to create a forum of open discussion and exchange experiences among the GCC countries, as well as the Arab countries, that the WSTA engendered through the nine previous conferences.

The specific objectives of the convening conference are: 1) Raising awareness to the importance of considering and dealing with the strong inter-sectoral linkages between water, energy, and agriculture, and identifying the major inter-relations, inter-dependencies,

challenges, and opportunities of these resources today and in the future in the GCC countries; 2) Facilitating an open discussion platform to share knowledge and experiences between researchers, executives, decision and policy makers, and other stakeholders, on modern methodologies and techniques used in the planning and preparation of medium- and long-term national strategies for the sustainable management of water, energy, and food in the GCC countries, and other dry regions; 3) Formulating a research framework and strategy for the needed research in the field of identifying the role and value of energy in the various water sectors in the GCC countries; 4) Formulating a research framework and strategy for the needed research in the field of rational and efficient water use in the agricultural sector and maximizing its value added; 5) Building a network between individuals, institutes, NGOs in the GCC countries, the Arab countries, and other countries that are interested in scientific research in the water-energy-food nexus.

The conference contains 80 presentations, selected by the Conference Scientific Committee from over 140 abstracts received from the conference call of papers. Many of these were modified to meet the standards of the Scientific Committee review. The conference papers were reviewed by more than 30 regional and international water science and technology experts, with each paper reviewed by two reviewers. Twenty two keynote speakers were invited from GCC water-related government agencies, supporting organizations and renowned regional and international experts to give scientific presentations in respective technical sessions. The Conference is supported by the Arabian Gulf University (AGU); United Nations University (UNU); United Nations Environment Program/Regional Office for West Asia (UNEP/ROWA); WHO Center for Environmental Health Activities (WHO/CEHA), and United Nations Economic and Social Commission for West Asia (ESCWA, Lebanon), United Nations Development Program/Regional Bureau of the Arab States (UNDP/RBAS), European Desalination Society (EDS), and International Desalination Association (IDA).

Conference sessions will be held on 9 topics: Sustainable Water Resources Planning and Management; Water Security and Food Sustainability; Water Energy Nexus; Conventional Water Resources Management; Desalination Management; Municipal Water Management; Agricultural Water Management; Wastewater Sector Management and Reuse; and Water, Health, and the Environment.

The Scientific Committee wishes to express its deep appreciation to the Government of the State of Qatar and KAHRAMAA for hosting and co-organizing the conference, and to the many Qatari, regional, and international sponsoring agencies, organizations, and companies, who kindly supported and endorsed this conference by providing their generous funds, keynote speakers, and political support.

Organization of the Gulf Water Conferences requires considerable time and effort. As in the previous WSTA conferences, individuals from various sectors (industry, government, and

academia) have come forth and given generously their time; special thanks are due to the members of the Organizing Committee and the Scientific Committee, and Scientific Papers Reviewers.

Finally, the Scientific Committee wishes to acknowledge the immeasurable contributions made by the authors and their research associates who were not only willing to rework and modify their manuscripts, but also had to meet an extremely tight time schedule.

The Scientific Committee sincerely hope that this conference will achieve its objectives and is both enjoyable and rewarding for you.

Prof. Dr. Waleed K Al-Zubari
Chairman, Conference Scientific Committee
Water Resources Management Program
College of Graduate Studies
Arabian Gulf University

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DAY ONE
Sunday, 22 April, 2012

SESSION 1:
WATER SECURITY AND FOOD SUSTAINABILITY

Keynote: Fahad bin Mohammed Al-Attiya, Executive Chairman QNFSP, Qatar, Water: A Shared Resource and Shared Responsibility

Mr. Fahad Bin Mohammed Al Attiya was appointed chairman of the QNFSP by His Highness the Heir Apparent Sheikh Tamim Bin Hamad Al-Thani in 2008. Following his schooling in Qatar, Mr. Al-Attiya joined the Qatar Armed Forces as an officer cadet at which time he was accepted to and educated at the Royal Military Academy, Sandhurt, in UK. After Sandhurt he served with the elite Grenadier Guards in the UK and following that with the Special Forces in Qatar.

Mr. Al-Attiya read law at Westminster University, and attended his LPC at BPP Law School in London. He has served at the Legal Directorate of the Armed Forces in Qatar, and as a military lawyer. In 2007 Mr. Al-Attiya joined the office of the Heir Apparent at the Emiri Diwan as legal counsel, a position he still holds. He is also on the Legislation Council of Qatar. In November 2008 the Heir Apparent directed Mr. Al-Attiya to chair and lead the Qatar National Food Security Programme, a cooperative effort virtually unprecedented in Qatar's history. Under Mr. Al-Attiya's leadership, the QNFSP is developing a Master Plan which upon implementation, will become a model for sustainable, environmentally friendly agriculture in arid regions, and represent a unique challenge to the popular conceptions of Food Security being achieved in dry land countries.

Abstract:

Without a doubt, the nations of the Gulf understand the critical role this body of water has played in shaping the history and development of the region. But with increased growth and development, we must examine together the serious responsibility we have to collaboratively manage our shared water resources. In this session, Qatar National Food Security Programme Executive Chairman Fahad Bin Mohammed Al-Attiya will explore the shared opportunities and responsibilities of Gulf states through the lens of long-term sustainable planning, and will challenge audience members to take a serious look at using sustainability to re-define common ambitions such as security and development.

Keynote: Ayman Abu Hadid, ALARI, Ain Shams University, LARI, Egypt, Food Security in the Arid Arab world

Prof. Dr. Ayman F. Abou-Hadid
Professor, Arid Lands Agricultural studies and Research Institute (ALARI)
Faculty of Agriculture, Ain Shams University, Cairo, Egypt

Fields of interest Agricultural and rural Development, Agro climatology environmental stresses, Water/plant/environment relations, Crop water requirements, Irrigation of horticultural crops, Protected cultivation, Soilless culture, Vegetable production, Breeding, Seed production.

Education: (Ph.D.) in Vegetable Crops, Feb. (1984), Faculty of Agriculture, Al-Azhar University, Cairo, Egypt. Research conducted in Botany Dept. UCW, Aberystwyth, UK, through a British Council fellowship.

Employment: Emeritus Professor, Arid Lands Agricultural Studies and Research Institute, Faculty of Agriculture, Ain Shams University, and Cairo, Egypt.

Laureate of the National Award for Agricultural Sciences, 2009.

Abstract:

The Arab world is located in one of the most arid areas on Earth. The water resources in the Arab countries are limited. In the meanwhile, the standard of living in the Arab countries is relatively high and the demand of food in increasing not only in terms of quantity, but also in terms of quality. The imports of food in the Arab countries are high and increasing with time. The concept of food security was reported in several reports released from international organizations. Agriculture is known to be one of the most water consuming activities in the world especially in the countries that depend on irrigated agriculture. The concept of food security should then be linked to the issue of water security. This presentation will shed some lite on the relation between food security and water security in the Arab countries.

Keynote: Khalid Al-Ruwais, King Abdulla Bin Abdulaziz Food Security Chair, Food Crisis and Food Security, Saudi Arabia Experience

Dr. Khalid Alrwis is Professor in the Department of Agricultural Economics at the College of Food and Agriculture Sciences at King Saud University in Riyadh. Dr. Alrwis has published numerous articles on the Saudi agriculture sector and market, with particular emphasis on broiler farms, red meat standards, organic agriculture, and the importation of wheat into the Kingdom. He is a member of the Scientific Group Supervisor for the King Abdullah Initiative for Agriculture Investments Abroad and President for a study group on the analysis of the socio-economic market for agriculture biotechnology products in the Riyadh Region, and Supervisor of King Abdullah Bin Abdul Aziz Food Security Chair.
Dr. Alrwis is also a member of the Agriculture Marketing Committee and food security Committee at the Riyadh Chamber Commerce of Industry. He received his PhD from Oklahoma State University.

ملخص:

تمثل مشكلة نقص الغذاء واحدة من أهم المشاكل المطروحة على الساحة العلمية والسياسية في العالم. حيث أن توزيع الفائض الغذائي في التجارة الدولية لا يتم وفقاً للاعتبارات الاقتصادية أو ينتقل إلى الدول الأكثر حاجة إليه. وإنما ينتقل وفقاً لمجموعة من الاعتبارات السياسية. ومن ثم يقع العاجزون عن إنتاج الغذاء لأنفسهم بالقدر الكافي في دائرتي التبعية الاقتصادية والسياسية.

ويرتبط مفهوم الأمن الغذائي بتحقيق التنمية الزراعية والريفية المستدامة ومحاربة الفقر حيث أن التنمية الزراعية والريفية تؤدي لتوفير فرص العمل وزيادة الدخل لصغار المزارعين والرعاة والصيادين والذين يمثلون الغالبية العظمي من سكان الريف مما يمكنهم من الحصول علي إحتياج أسرهم التغذوية والترقي بنوعية حياتهم. كما أن توفير الغذاء والإرتقاء بالمستوى الغذائي لصغار المزارعين والفئات الفقيرة يؤدي إلى زيادة نشاطهم وإقبالهم على العمل وزيادة إنتاجيتهم وخروجهم من دائرة الفقر. وفي ظل ما هو معروف حالياً عن مشكلة الأمن الغذائي فإن الأمر يتطلب أن تبذل كل الجهود لوضع الخطط والإجراءات الاقتصادية الزراعية مع ما تحويه من برامج ومشروعات بهدف زيادة الإنتاج الزراعي من خلال زيادة الإنتاجية الزراعية حيثما تتوفر الميزات النسبية للإنتاج الزراعي لضمان كفاءة استخدام الموارد الطبيعية والزراعية الشحيحة. كما يتطلب الأمر ايضاً توسيع الطاقة الإنتاجية في الدول ذات الميزة التنافسية والوفره المائية من خلال تشجيع الاستثمار الزراعي الخارجي لدى هذه الدول للتغلب على مخاطر التقلبات في الأسواق العالمية وتكرار الأزمات الدولية المؤثرة علي إمكانات التجارة العالمية للغذاء. كما أضحي توفير الغذاء الآمن والصحي من أهم متطلبات دول الخليج والعالم، وقد إكتسب محور التغذية وسلامة الغذاء وإستقرار توافرة علي إهتمام كبير خلال العقد الأخير كإحد أهم مرتكزات تحقيق الأمن الغذائي. ويمكن القول أن الفجوة الغذائية في كثير من الدول النامية نشأت وتطورت بفعل مجموعة من العوامل تمثلت في:

1- مجموعة من العوامل المرتبطة بالاختلالات الهيكلية القائمة بين الموارد الاقتصادية والإحتياجات الغذائية والنمو السكاني.

2- مجموعة العوامل المرتبطة بالنظام الاقتصادي العالمي.

3- مجموعة العوامل المرتبطة بفشل السياسيات الاقتصادية الزراعية في تخصيص الموارد داخل القطاع الزراعي.

وتعزى أهمية دراسات الأمن الغذائي إلى:

- شبح الجوع الذي يهدد 30 دولة نامية بصورة مباشرة مع ارتفاع عدد المتأثرين بنقص الغذاء إلى نحو 1.02 مليار نسمة عام 2009.
- الارتفاع في أسعار السلع والمواد الغذائية وتقلبها وتزامن ذلك مع انخفاض مخزونات العالم والطلب المتزايد للغذاء مع تغيرات مناخية حادة وزيادة إستخدام الغذاء لإنتاج الوقود الحيوي.
- الأزمات المالية العالمية وزيادة المضاربات التجارية على السلع الزراعية.
- عدم الاستثمار بشكل كافي ولائق في المجال الزراعي في الدول النامية.
- تطبيق بعض المعوقات التجارية لبعض المنتجات الغذائية خاصة في أوقات الأزمات:
  - إيقاف التصدير.
  - فرض حصص تصديرية.
- زيادة عدد سكان العالم .
- تحسن المستوى المعيشي في العديد من دول العالم، مما أدى إلى الطلب الهائل للكيانات القارية في الصين والهند وما اعتراهما من نمو اقتصادي وتغير في النمط الاستهلاكي أحالها لمستوردة للغذاء بالدرجة التي باتت تهدد وضع الغذاء العالمي.
- اتساع فجوة الغذاء بنحو 19 مليار دولار في الوطن العربي الأعوام الأخيرة مع قابليتها للزيادة الكبيرة بفعل ارتفاع الطلب والأسعار مما يجعل قضية الأمن الغذائي العربي على رأس أولويات هذه الدول.
- تزايد اقتناع القيادة السياسية للمملكة وعلي رأسها خادم الحرمين حفظة الله بأهمية تحقيق الأمن الغذائي المحلى والإقليمي والعالمي ودعم جهود التنمية الزراعية المستدامة من خلال دور ريادي عالمي في مجال التعاون الدولي لمحاربة الفقر وتحقيق الأمن الغذائي، كما إنعكس مؤخرا فى إهتمام متزايد بالتنمية المستدامة والمتوازنة فى كافة أنحاء المملكة، وليس ادل على ذلك من تبنى المملكة للإعداد وإقامة مؤتمر القمة العالمي للأمن الغذائي بروما في عام 2009م.

Sustainability of Food Production Systems in Bahrain under the Challenge of Water Scarcity; Food Security and Climate Change

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Abstract:

Due to arid climatic conditions, the Kingdom of Bahrain is characterized by high temperatures, erratic and often scanty rainfall, high evapotranspiration rates and high humidity levels due to the surrounding Gulf waters, as result of which water in Bahrain is inherently scarce. Water scarcity will reduce agricultural production and threaten country food security. Therefore, strategies to optimize water use in agriculture under conditions of scarcity need to be developed to maximize return per unit of water. The aim of this paper is to review the role of local production systems in ensuring food security, with major emphasis on the approaches and actions to be taken towards ensuring food security as well as adaptation strategy in response to water scarcity and climate change in the Kingdom of Bahrain. This paper analyzes government policies on agricultural development and monitoring of water resources, focusing on the depletion of strategic groundwater. Improved water management and sustainability in the agricultural sector will resolve issues of food security and stability in food production. Therefore, the key element towards sustainable solutions fundamentally lies in the way a water resource in the agricultural sector is managed. Effort is being made in the agricultural sector on adoption of sustainable development agricultural policies; to promote improved water use efficiency in agriculture and the utilization of treated sewage effluent (TSE). However, new policies and institutions are needed for implementing a sound agricultural water use development program under these conditions.

Key words: Sustainability; Food Production System; Water scarcity; Food security.

1. Introduction

Scarcity of freshwater resources is expected to be the second most formidable challenge to the world in general and arid countries in particular in the 21st century, as a result of climate change, population growth, pollution, drought and the dissipation of resources. Therefore, the complex connections between water, food security and climate change will create significant negative impact on food production and remains a crucial policy issue.

Due to arid climatic conditions, natural sources of water in Bahrain are limited to groundwater which can be renewed either very slowly or not at all as result of which water in Bahrain is inherently scarce. Groundwater became less accessible and less acceptable environmentally. The deficit between available water and water demand is growing and expected to increase in the near future. The question however is: can we increase water productivity to satisfy the increasing demand for food and at the same time ensure enough water for sustaining the resource base?

In Bahrain, water-related strategies of past years were mainly concerned with increasing supplies of desalinated water and upgrading the efficiency of the water distribution system with a view to restoring a balance between demand for groundwater and supply from underground sources. But the country's water resources were steadily declining, and in 1990 Bahrain adopted a water strategy for the period up to 2010. The demand for water in Bahrain comes from domestic, agricultural and industrial sectors. The water demand in Bahrain is met through groundwater, desalinated water and treated sewage effluent. About 70% of the total water demand is met by the island's groundwater resources. There is a need to review policy on water resources. A critical review must address legal and institutional reforms, economic considerations and water conservation and enforcing of existing laws and regulations, as well as investing in developing desalination technology. Zubari et al. (YR), for example, speaking of water-related issues in Bahrain, considered that the problem is not so much the enactment of legislation as its implementation. These authors argue that there will be no point in devising water resource management strategies until that problem is solved. They also emphasized the importance of Government commitment and political will as the two key factors in ensuring that policies are not merely approved but put into practice, raising public awareness, and securing popular participation in programme planning from the earliest stages. Therefore, sufficient availability and adequate water quality are of crucial importance for sustainable development and protection of the environment.

Bahrain being in an arid to extremely arid climate, as a result of which, natural sources of water are limited to groundwater which can be renewed either very slowly or not at all. The demand for water in Bahrain comes from domestic, agricultural and industrial sectors. The water demand in Bahrain is met through groundwater desalinated water and treated sewage effluent. About 70 percent of the total water demand is met by the island's groundwater resources.

In order to conserve the country's scarce water resources, the government directed its efforts toward developing non-conventional sources of water, by constructing a desalination plant in 1974. Additional plants are being constructed and planned. A sewage treatment plant was also built in the 1980's, to meet agricultural water demands.
Water allocated to the agriculture sector represents more than 80% of the available water resources in the country. Water scarcity will reduce agricultural production and threaten country food security. Therefore, strategies to optimize water use in agriculture under conditions of scarcity need to be developed to maximize return per unit of water. Thus answers to the resolving issues of food security and stability in food production will increasingly come from improved water management and its sustainable use in the agriculture sector.

2. Management of water used in agriculture.

Development efforts in agriculture have included the promotion of intensified farming, increasing food self-sufficiency and conservation, and further development of existing agricultural resources. In order to improve production and raise productivity in the sector, a two-phase plan covering 2004-15 is being implemented by the Ministry of Municipality, in cooperation with the FAO, for sustainable agriculture development. The first phase of the plan (someUS$19.5 million) consists of a treated sewage effluent water and groundwater plant. Phase two (some US$12.4 million) includes a plant protection laboratory; expansion of protected cultivation; flower production; strengthening of the plant tissue culture laboratory; improvement of existing land drainage system; livestock development strategy; and agricultural census.

In order to manage more efficiently water used for agricultural purpose, two guiding principles have been introduced. The first approach has dealt with the issue of reducing groundwater abstraction, while the other has concentrated on finding alternative irrigation water for agriculture and ever-growing landscape projects. A number of actions have been worked on to reach these two aims. These include, enacting and strictly enforcing laws to reduce groundwater abstraction, increasing water use efficiency in agriculture, improving irrigation methods (modern irrigation techniques-(75 percent of agricultural area is under flood irrigation), replacing high- irrigation requirement crops with others of less water demand, introducing tariffs for using groundwater, and using treated sewage effluent.

Water scarcity will reduce agricultural production and threaten country food security. Therefore, strategies to optimize water use in agriculture under conditions of scarcity need be developed to maximize return per unit of water. Effort is being made in the agricultural sector to make water use much more efficient. This includes agriculture in greenhouse which was introduced in 1976 with the aim of increasing production and achieving a higher level of self-sufficiency in various agricultural products, particularly high-quality fresh vegetables crops.

The main greenhouse crops produced are: tomato, cucumber, pepper, squash, eggplant, lettuce, strawberry, bean and cauliflowers. Efforts were not only to apply water to crops more efficiently but also to the utilization of treated sewage effluent (TSE), however, new policies and institutions are needed for implementing a sound water use development program under these conditions.

Food Production and Food Security

Agriculture plays an important role in the livelihoods of Bahraini families however, the biggest challenges Bahrain agriculture is facing are limited agricultural lands and shortage of water resources. The total arable land in Bahrain is estimated to be 64,000 dunam (Ag. Statistics 2010). In other words, it is about 10 percent of the total area which amounts to 622 square km. Two thirds of this arable land is cultivated.

Government provides subsidies in several forms. Agricultural production is supported through provision of subsidies such as 84 percent of the cost of machinery services; 40 percent of the price of modern irrigation equipment; and 50 percent of the price of pesticides; 40 percent of the price of plastic sheet; 50 percent of the price of veterinary drugs and animal vaccines; and 5 percent of the price of local poultry meat. Loans are also provided to farmers intending to launch programmes to protect date palms, and other farming activities. Government of Bahrain to diversify its economy and to increase the level of food production focused on economic incentives for improving crop productivity.

Agriculture in Bahrain depends mainly on groundwater resources with irrigated agriculture being the heaviest water user at 80 percent of groundwater abstraction. One of the major challenges facing the agricultural sector is freshwater supply, which has declined considerably due to the increasing demands associated with the accelerating population growth. Therefore, programmes are being implemented to re-use treated wastewater for irrigation purposes.

Efforts have been made in the agricultural sector to make water use much more efficient. This includes efforts not only to apply water to crops more efficiently but also the utilization of treated sewage effluent (TSE). Agriculture under greenhouse was introduced in 1976 with the aim of increasing production and achieving a higher level of self-sufficiency in various agricultural products, particularly high-quality fresh vegetables crops.

The food security coupled with the water security of the many developing nations is a cause of serious concern. Bahrain, in order to overcome the deficit between food production and imports need to achieve relative food security relying on local production of certain strategic items and to encourage agricultural investment and optimize the role of the private sector in developing the sector. The question however is: can water productivity increased to satisfy the increasing demand for food and at the same time ensure enough water for sustaining the resource base?

Food availability is achieved when sufficient quantity of food is consistently available to all individuals within a country. To ensure food availability Bahrain government has taken a number of actions regarding food subsidy since late seventies of the past century. In 1975, the government established a directorate to control the subsidy through the Amiri Decree No. (7)-1975 to establish the Department of Supply and Price Control within the Ministry of Commerce, Agriculture and Economy, which among other things is responsible for direct provision of food to the merchants and achieved the following:

Monitor implementation of the provisions of the legislative Decree No. 18 – 1975 regarding Price setting, Control, and its implementing decisions and to demonstrate a violation of rules that happen to them.
The Implementation of policy measures to prevent monopoly and to compel merchants to adhere to specific and non-price manipulation.
Control of local markets in terms of prices or quantities and the pursuit and study of developments in world prices in order to propose foundations for determining a fair price and to combat the root of the adjournment unjustified in the country.
To regulate payment of subsidy by differences in prices, the government decided to pay a subvention to the differences in prices, determined by a resolution issued by the Ministry of Commerce, Agriculture and Economy, as well as overseeing the way of sales to achieve justice in the distribution of reduced prices to consumers.

Sustainability of Food Production System in Bahrain

Bahrain's agricultural policy reflects overall economic policy, which emphasizes diversification of the production base. Development efforts in agriculture have included the promotion of intensified farming, increased food self-sufficiency and conservation, and further development of existing agricultural resources. Bahrain aims to maintain its agricultural production base and develop sustainable farming systems to improve crop productivity while providing important environmental goods, integrated pest and weed management, integrated nutrient management, use of cover crops, and aquaculture, among others.

However the productivity and sustainability of the Bahrain food production system, especially under a more severe climate change scenario is a major concern and challenge for the government. Therefore, to ensure sustainable food production system for the future, we need planning and policies that protect agricultural land, water and other resources. Bahrain implemented a 2004-2015 plan for sustainable agricultural development to improve production and raise productivity. As a result, the ministry of agriculture has implemented some important programs that are expected to have a positive impact on the development of the agricultural sector in Bahrain, besides preserving the groundwater. The programs include improving irrigation methods, changing cropping pattern, utilizing recycled wastewater or

treated sewage effluents, and using the sludge by-product from the sewage treatment plant for improving soil fertility and water holding capacity.

An incentive framework aimed at water management strategies to ensure food security.

The kingdom of Bahrain adopted a water strategy which emphasizes better water management for the period up to 2010. The water strategy's objectives for the longer-term future include a comprehensive demand management plan featuring loss reduction, the installation of meters, a tariff schedule featuring progressively higher rates for higher consumption brackets with a view to encouraging water conservation, public awareness campaigns, encouragement for the use of treated wastewater, and the use of desalinated seawater to make up the country's water deficiency.

Sufficient availability and adequate water quality are of crucial importance for sustainable development and protection of the environment. As groundwater has become less accessible and less acceptable environmentally, the demand management approach remains the logical strategic solution. Groundwater strategies should aim toward the sustainable use of groundwater and the preservation of its quality.

Long-term water policy and supply strategy must be set to make water resources more sustainable. Therefore, the demand management approach remains the logical strategic solution. Groundwater strategies should aim toward the sustainable use of groundwater and the preservation of its quality. Long-term water policy and supply strategy must be set to make water resources more sustainable. Therefore, groundwater should be recognized as a natural resource with both economic and ecological value. Sufficient availability and adequate water quality are of crucial importance for sustainable development and protection of the environment.

Despite limited land and water resources and constraints of climatic conditions, the government of Bahrain has been encouraging agricultural development in both public and private sectors by providing various facilities, and strengthening research and extension activities. Development efforts in agriculture have included the promotion of intensified farming and further development of existing agricultural resources. Bahrain is implementing a 2004-15 plan for sustainable agriculture development to improve production and raise productivity. This aims to enhance the productivity and competitiveness of Bahrain's agricultural products in domestic and regional markets. The framework in Figure (1) shows that Bahrain's Agricultural Policy is towards the right direction of creating impact on the local production system embracing diversified production base focusing on strategic option for a sustained growth of productivity and diversification of economies in general. In specific, it significantly emphasizes non-traditional methods of production which in turn spells out a sound strategic option for ensuring sustainable food security in Bahrain.

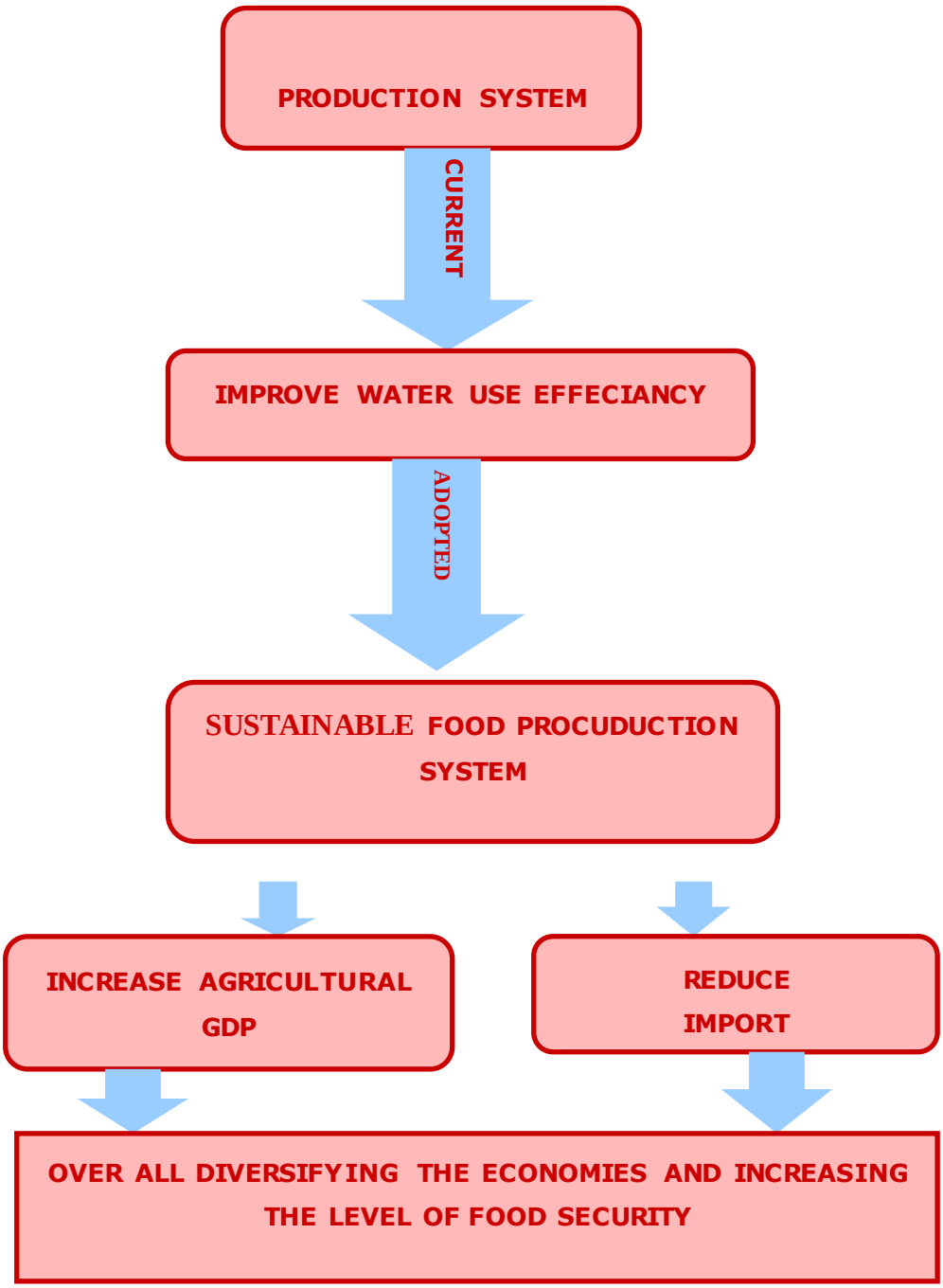

Figure 1: An incentive framework aimed at water management strategies to ensure food security

Conclusions

The biggest challenges Bahrain agriculture is facing are limited agricultural lands and shortage of water resources. Water allocated to the agriculture sector represents approximately 80 percent of the available water resources in the country. As a consequence, agricultural water management will have to improve in order to address the growing demands of an ever-increasing population, combined with the scarcity of natural resources, and with the world facing perfect storm of food scarcity. The key element towards sustainable solutions is fundamentally lying in the way we are using and managing our water resources in the agricultural sector. Therefore, Bahrain require a reallocation of domestic resources in order to increase agricultural production lowering its food imports and boost the contribution of agricultural sector to its Gross Domestic Product. Thus, answers to the resolving issues of food security and stability in food production will increasingly come from improved water management and its sustainable use in the agriculture sector.

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Water scarcity versus agricultural production – a new way for an optimal and sustainable management of resources under arid conditions

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Abstract

Sustainable and optimal strategies for integrated water resources management, with respect to the environmental and socio-economic development, require consideration of contradicting viewpoints of the concerned players together with prediction uncertainty. Considering global change impacts we develop a new integrated Assessment-, Prognoses-, Planning- and Management-tool (APPM) which integrates the complex interactions of the strongly nonlinear meteorological, hydrological and agricultural phenomena, taking into account socio-economic aspects. To achieve a robust and fast operation of the management system, the APPM unites process modelling with artificial intelligence tools and evolutionary optimisation techniques for managing both, water quality and water quantity of coupled groundwater-agriculture systems which are typical for arid environments. We demonstrate our methodology by an application of the south Batinah region in Oman which is affected by saltwater intrusion into the coastal aquifer due to excessive groundwater withdrawal for irrigated agriculture. Results are presented for the estimation of the water resources availability as well as their uncertainties using a 3D density dependent transient groundwater model together with a fuzzy based approach for groundwater recharge estimation and a new developed simulation tool for wadi runoff inclusive infiltration and artificial recharge dam operation. For simulating the behaviour of agricultural farms soil-vegetation-atmosphere-transport (SVAT)-models are used together with a new evolutionary optimisation algorithm for optimal irrigation scheduling and control, which demonstrates the capability of water saving in the agricultural sector. Finally the linking between the agriculture and the water resources is presented using a simulation based water management system for the optimisation and evaluation of different irrigation practices, crop patterns and abstraction scenarios. The results indicate that due to contradicting objectives such as profit-oriented agriculture vs. aquifer sustainability only a multi-objective optimisation can provide

sustainable solutions for the management of the water resources in respect of the environmental and the socio-economic development.

Keywords: integrated water resources management, multicriterial optimisation, density dependent groundwater flow modelling, irrigation, global change

1 Introduction

Due to rapid population growth and increasing industrialisation, the water demand in arid regions is continuously on the increase. More than 80% of the limited water resources are used for irrigated agriculture in this regions but the water use efficiency is quite low. Groundwater aquifers, which represent the predominant natural water resources, are overused. Thereby continuously sinking groundwater levels are often associated with water quality problems occurring e.g. due to marine saltwater intrusion into coastal aquifers or a changing groundwater chemistry in the case of pumping in fossil resources. Especially saline irrigation water causes a destruction of agricultural resources and menaces the economical basis of farmers. Considering the uncertainty of climate and global change development a sustainable solution to the tight water situation can be only achieved by a comprehensive, integrated and highly efficient water management based on innovative approaches.

This paper introduces a new tool for integrated water resources management in arid regions. For ensuring a reliable basis as regards both optimal sustainable water resources management and long-term planning in a changing environment, the proposed APPM (Assessment, Prognosis, Planning and Management Tool) aims at incorporating the relevant complex interactions of the strongly nonlinear meteorological, hydrological and agricultural phenomena, taking into account the socio-economic aspects. The task demands a rethinking of current research strategies: Instead of straightforwardly applying currently available hydrological, hydrogeological, meteorological and socio-economic models and concepts, a fully customised problem specific tool is required which is based upon a comprehensive data analysis and tailor made process models for reliably portraying the nonlinear phenomena and their interdependency in a changing environment. Apart from process modelling, a realistic management tool needs to include the stochastic nature of meteorological data for mimicking the site specific weather pattern as well as the impact of climate change together with a sound, rigorous, multicriterial and multidimensional optimisation.

It is often the case, however, that these highly accurate yet complex and intricate components fully contradict the general needs of potential users i.e. farmers who require a simple, easy to use and robust operation without numerical inconvenience. For this reason, recently developed new approaches serve to overcome this problem: synthesizing process models and artificial intelligence techniques (Bhattacharjya and Datta 2009, Schmitz and Cullmann 2008, Rao et al. 2004) will provide a convenient, easy to use but nevertheless highly reliable, rigorous management tool.

In this paper we present some key issues of the APPM methodology. Thereby we focus in a more detailed way on a new simulation based integrated water management system for

sustainable arid zone water management. It demonstrates how a highly coupled and dynamic agriculture-aquifer system – a land use-water interaction – can be integrated in an optimisation environment for finding optimal management strategies under multiple but mostly contradicting viewpoints and trade offs. By means of an exemplary application of the south Batinah region in the Sultanate of Oman which is affected by saltwater intrusion into the coastal aquifer due to excessive groundwater withdrawal for irrigated agriculture, we illustrate the functionality of the management system for multi-objective decision making.

2 The study area

The study area is situated in the north of the Sultanate of Oman in the Al-Batinah region. Al-Batinah is a roughly 30km broad coastal plain which extends over 250km along the coast of the gulf of Oman north-westward of the capital Muscat. The Hadjar mountain range borders Al-Batinah from the south with peaks up to a height of 3000m. Along with the capital area of Muscat more than 65% of the Omani population lives in the region (Statistical Year Book 2008). Additionally more than 75% of the nation-wide arable soils are located in Al-Batinah (Agricultural Census 2004/05). We focus our investigation on three wadi catchments in the south-eastern part of Al-Batinah which covers an area of about 2640 km² (see Figure 1).

Fresh water resources in the south-eastern Al-Batinah region are scarce. A potential evaporation rate of approx. 2000 mm/a contrasts greatly with rainfall of up to 350mm/a in the Hajar Mountains and about 50mm/a along the coastline. The rainfall variability in time and space is extreme, where relatively wet periods during high rainfall years are followed by extreme dry periods. Convective rainstorms are typical in the region. They cause the well known flash floods, transporting great amounts of freshwater into the sea. In order to minimize the freshwater losses and to enforce an artificial groundwater recharge, several

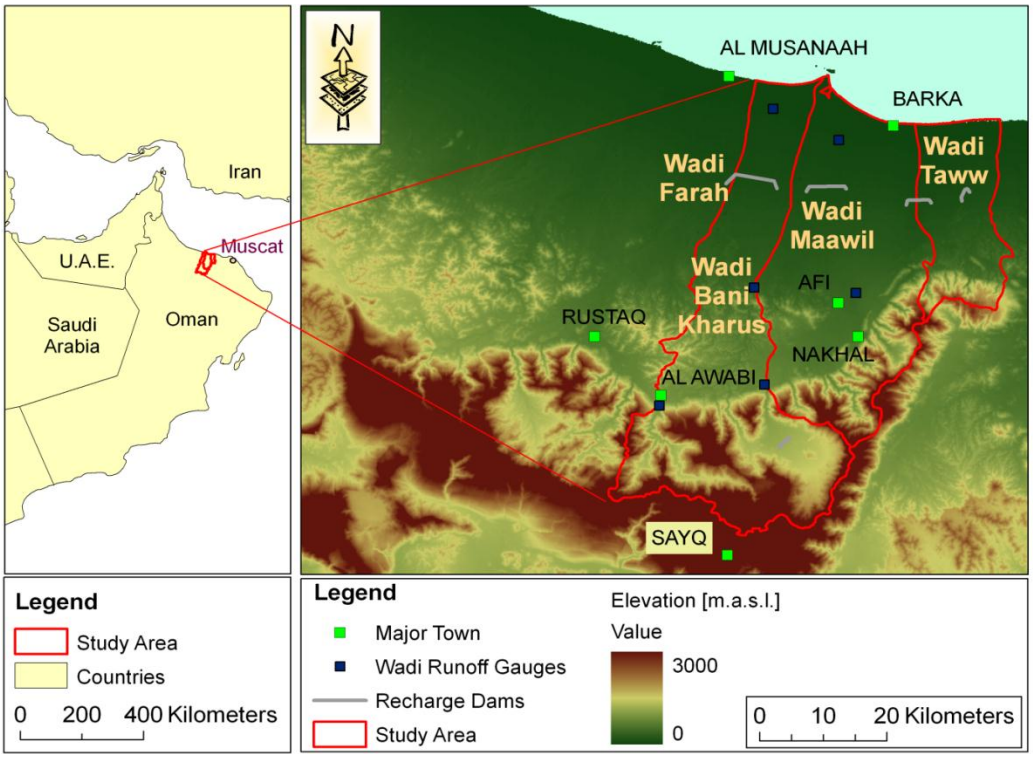

Fig. 1: The study area in the northern Oman

dams have been recently built in the wadi channels, but the groundwater situation still remains severe. This is caused by the high water demands of agriculture which requires more than 90% of the water resources (Al-Hattaly & Al-Kindy 2008). Agriculture plays an important role in the Omani society since one third of the economically active population work in this sector (FAO, 2008). Due to the climate conditions, the majority of Oman's agricultural production requires irrigation; mostly from sprinkler systems, but there is a small but not negligible amount under flood irrigation, a few farms with bubbler and even fewer with drip systems (Agricultural Census 2004/05). Most of the farms are located near the coastline and take their water from the groundwater by numerous decentralized and often uncontrolled wells. As a result, the groundwater levels continue to fall. Ongoing overexploitation of the aquifer has enforced the intrusion of salt water from the sea. As a consequence, some farms near the coast have had to close down due to the increasing salinity of the pumped water and soil salinization when salty water was used for irrigation. There is a small amount of agriculture in the oasis at the foot of the mountains which receives its water from the traditional Omani falaj-system.

3 Methodology

3.1 APPM: an integrated Assessment, Prognosis, Planning and Management Tool

The APPM is designed as an innovative water management and long-term planning tool for arid zone water management. Together with the optimal design of a problem oriented water distribution system, the APPM aims at the prediction, visualisation and evaluation of the consequences of planning options and management decisions including estimations as to the impact of climate change according to latest findings. The GIS-based APPM permits managing and operating the interactions between water resources availability, the demands on water and the technical system of water distribution. Along these lines, it provides optimal solutions for water allocation, groundwater storage and withdrawal including saline water management with alternative, highly beneficial irrigation strategies. For a comprehensive solution to the complex optimisation problem – and for a simple, robust and easy operation – we use hybrids of process models and Artificial Neural Networks (ANN) along with other customised artificial intelligence tools (Schmitz and Cullmann 2008, Schmitz et al. 2007, Schütze et al. 2005)). The APPM incorporates three major steps:

- Analysis and modelling of actual and future water resources availability and demands,
- Evaluation of optimal and sustainable management strategies of water resources and agricultural production considering the demands of other water consumption sectors.
- Operative optimal control of the technical systems of water allocation and distribution depending on given objectives, actual hydrological conditions and future prognosis.

Figure 2 gives an overview as to the general structure of the APPM-tool. The several components are explained in more detail in the later sections.

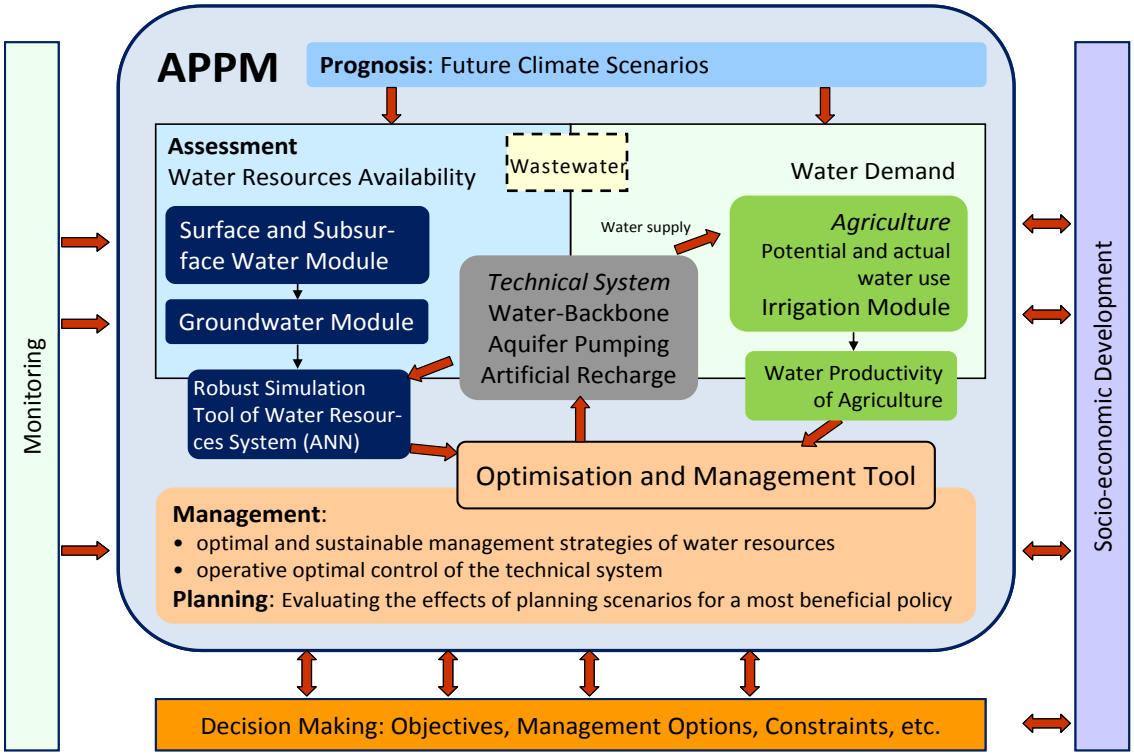

Fig 2: General structure of the APPM-tool.

3.2 The Water Resources Availability (WRA) Module

This GIS-based module deals with the analysis and assessment of the water resources availability. It forms the basis for evaluating the renewable water resources and saltwater intrusion phenomena as well as for managing the groundwater reservoirs in an optimal manner. Including climate change scenarios, results will yield a prognosis of the short and long term water availability. For this purpose, a regional meteorological model for estimating climate development on the basis of the global climate development (IPCC, 2007) will be established.

The modular concept allows for the use of several process models with different, problem-oriented complexity in order to analyse and simulate the most relevant hydrologic surface and subsurface flow processes in the study area (see Figure 3). The problem-oriented model library consists of a new analytical approach for the modelling of the hydraulic phenomena of flash floods, like runoff in initial dry beds and standing wave effects, under consideration of infiltration through the wadi channel (Philipp et al., 2010). The combination of this approach

with a dam simulation model (Philipp and Grundmann, 2012) allows for an evaluation of artificial recharge dam behaviour in terms of operation and control as well as an estimation of evaporation and infiltration losses – as a potential rate of groundwater replenishment – during wadi runoff.

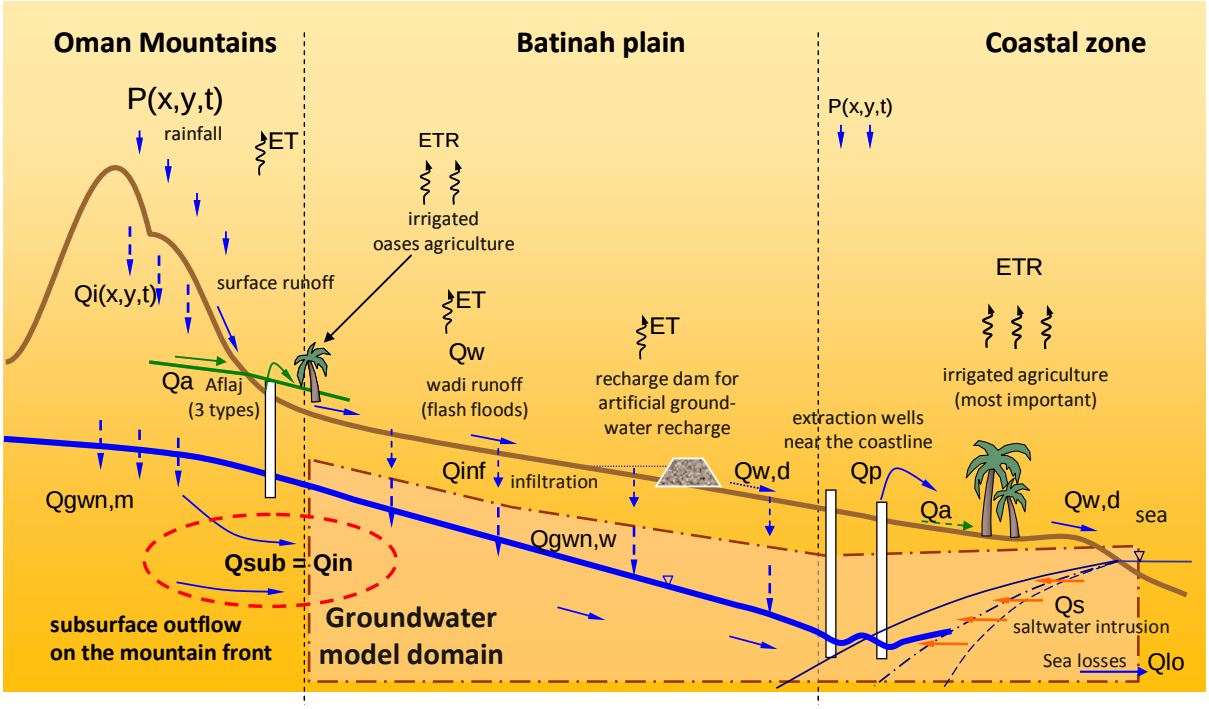

Fig 3: Two-dimensional slice of the most relevant hydrological processes in the study area

For simulating the subsurface outflow on the mountain front (see Figure 3) – the main path for replenishing the coastal aquifer – a GIS-based spatial distributed method was developed which considers the specific morphological and geological conditions as well as different types of the traditional Omani aflaj system within a catchment (Gerner et al., 2011). In fact isotope studies within the study area (Weyhenmeyer 2002) indicate that due to the hydrogeological characteristics of the region the subsurface catchment extend does not fit to the surface catchment border lines. This introduces large uncertainties into the estimation procedure of groundwater recharge as well as the water balance. For describing these uncertainties adequately a fuzzy logic based approach was developed (Gerner and Schmitz, 2012).

Complex physically based modelling is required for a sound description of the groundwater flow phenomena introduced by different geological units (fissure, karst and phreatic aquifers) and water quality problems caused by salt water intrusion. We achieve this task using a 3D groundwater model with density dependent transient flow (Walther et al. 2012) which is built by means of the OpenGeoSys(OGS)-software package (Kolditz et al., 2008). Based on the groundwater model the identification and optimisation of scenarios for a sustainable aquifer

management will be possible which not only includes an adjustment of groundwater pumping rates but also the location of optimal sites for groundwater abstraction. Nevertheless for an application of the physically based groundwater model within an optimisation environment a fast and robust model operation is mandatory. To achieve this we portray the complex groundwater model of the study area by a surrogate model namely a multilayer perceptron artificial neural network (Nabney 2002). Like shown in Figure 4a two steps are required: (i) the generation of a scenario database containing the responses of the numerical density depended groundwater flow model OGS for all realistically feasible abstraction scenarios and configurations, and (ii) the training of the multilayer perceptron artificial neural network (ANN) with a backpropagation learning algorithm (Yan and Minsker 2006). Subsequently, the derived surrogate model, which is referred to ANN-OGS, is used in the simulation based management model for optimising the groundwater abstraction rates according to given objective functions (Figure 4c).

3.3 Irrigation Module

The aim of the irrigation module is to identify the potential of agriculture to produce greater economic revenue whilst, at the same time, using water more sparingly and more efficiently. The module is backed up by the development of operational tools which provide optimal control for both water and fertilizer applications. It also allows for evaluating the risk in yield loss when brackish water is used for irrigation. Besides the optimal operation for full irrigation systems, the module also provides solutions for optimal irrigation scheduling under limited seasonal water supply, thereby maximizing overall water use efficiency. These solutions rely on a highly efficient scheduling algorithm which takes into account the crop response to water stress at different stages throughout the growing season. Furthermore, the irrigation module consists of stochastic planning tools which are able to evaluate the impacts of field, farm and system level improvements in water use efficiency into water resources management at basin scale. On this basis, so-called crop water production functions (CWPF) are estimated which describe the relationship between the applied amount of water and the produced yield for a given combination of crop/soil/climate under the assumption of optimal water application (Figure 4b). Taking into account the local climate variability the OCCASION methodology (Optimal Climate Change Adaption Strategies in Irrigation by Schütze and Schmitz 2010) is used for generating so-called stochastic crop-water production functions (SCWPF). The methodology consists of:

a weather generator for incorporating typical local weather characteristics as well as updated estimations of the regional impacts of climate change (e.g. LARS-WG by Semenov et al. 1998)

a new custom-made evolutionary optimisation algorithm for optimal irrigation scheduling (GET-OPTIS by Schütze et al. 2011a)

adequate process models for simulating water transport and crop growth, together with operational tools for optimal irrigation control (e.g. the soil-crop simulation model APSIM by Keating et al. 2003)

The result - a database of SCWPF for relevant crop/soil combinations - can be used, on the one hand, for evaluating the benefit of different irrigation strategies or cropping patterns by considering the local environmental conditions such as landscape, soil and typical local weather characteristics (rainfall pattern, radiation, wind, potential evaporation etc.). On the other hand, the SCWPF database also provides the basis for assessing the impact of climate variability on the risk for the potential yield. In order to consider salinity stress of the plants, the OCCASION-framework is extended by a second dimension namely the salinity of the irrigation water by means of the salinity tolerance index (Steppuhn et al. 2005). Combining this index with a selected quantile of the SCWPF (e.g. the CWPF with 90% reliability) the resulting 2D-CWPF additionally considers the water quality and allow for an appropriate choice of the crop patterns regarding their salinity tolerance.

3.4 A System of Water Distribution and Management

The technical system for realising the water allocation and distribution consists of a pipeline-system (water backbone) which connects different sources of water and aquifer systems to water consumers. Within the project, backbone technology will be designed for best meeting the requirements for a spatial and temporal compensation of the differences between the local water resources availability and the demands placed on the water.

This task needs a flow-network model for portraying the full hydrodynamic behaviour of the supply system with all elements (pumps, pips, valves, etc. (Rossman, 2000)) for connecting the different sources of water with the users. It includes the traditional Omani aflaj system as well as modern water supply techniques, like wellfields and desalination plants. Together with the above mentioned water resources and irrigation modules an optimisation and management tool (see Figure 2) is designed to evaluate the possibilities and consequences of selected management options.

Considering the long term fluctuations of the natural water resources as well as economic, environmental and social aspects, a multi-year and multi-criterial optimisation is necessary for establishing a sustainable water management. Due to the large amount of farms the number of optimisation variables continues to increase. In order to keep the model computationally feasible we define demand zones which aggregate the crop water demand of different farms. This cluster concept is part of a hierarchical optimisation structure which provides tools for a further water distribution within the zones having regard to the crop

pattern and the crop water demand as well as the water exchange between catchments. In accordance with the design criteria, the technical system will be elaborated on the basis of expected future water yield and demands. The necessary operational control of the technical system is also provided by the optimisation and management tool.

The optimisation framework for a simulation based water management model

The optimisation framework of the simulation based management system, illustrated in Figure 4c, consists of three major modules, (i) a groundwater module for calculating the aquifer response, (ii) an agricultural module for simulating the behaviour of farms and (iii) an optimisation module. The framework connects the agricultural and groundwater module and aims for managing both – water quality and quantity – according to the formulated objective function (Equation 1). For this purpose we use the CMAES global evolutionary optimisation technique (Hansen et al., 1996) in order to estimate the optimal water demands $Q(t_i)$ and cropping pattern $A(t_i)$ for m crops over a certain period T (Equation 2, Figure 4c). The water demands are evaluated by the groundwater module which calculates water $h(t_i)$ and salinity $S(t_i)$ levels at the beginning and end of an extraction period i. Fixed and variable costs for pumping $CP(t_i)$ are considered in the objective function (Equation 1). Furthermore, the salinity of the abstracted irrigation water is provided to the agricultural module (Figure 4c).

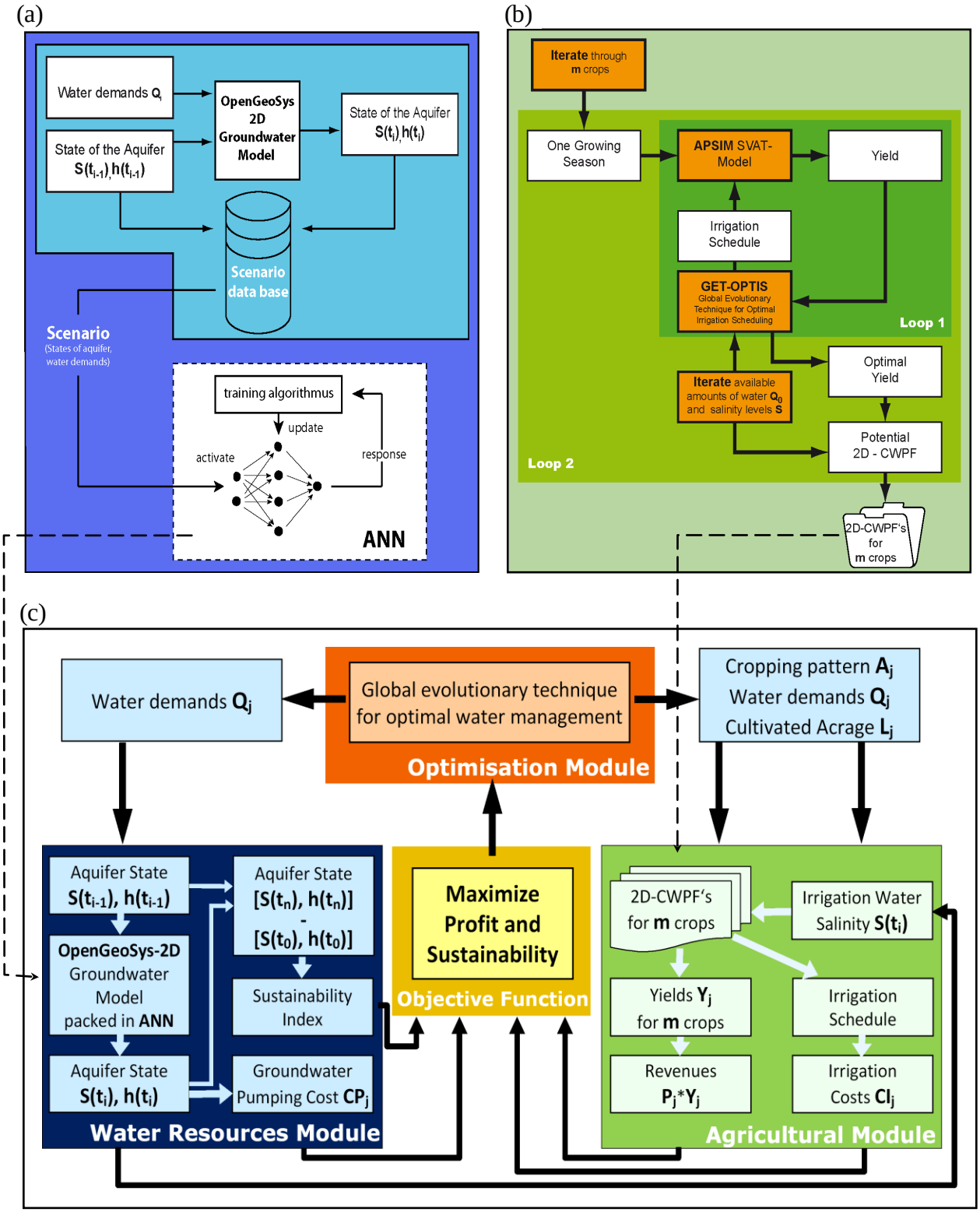

Fig 4: Estimation procedure for the ANN groundwater model (a) the 2D crop water production functions (b) and their linking within the optimisation framework (c)

Together with the cropping pattern and the water demands the salinity values serve as input for estimating the crop yields Y_j by means of the 2D-CWPF database for each crop. Based on

the yields revenues P_j*Y_j are estimated which are part of the objective function as well as the irrigation costs $CI(t_i)$ resulting from the irrigation schedule. Finally we calculate a sustainability index SI which evaluates the change of the aquifer state between the end and the initial state of the simulation period. This index is included in the objective function (Equation 1) which aims for maximising the net profit and the sustainability considering varying weights w between the two contradicting objectives.

$$max(OF) = w_1 \Sigma_{i=1}^{n} \left[\left(\Sigma_{j=1}^{m} P_j Y_j(t_i) - CI_j(t_i) \right) - CP(t_i) \right] + w_2 SI(t_n) \qquad (1)$$

$$\left(A_1(t_1) ... A_1(t_n), A_m(t_1) ... A_m(t_n), Q(t_1) ... Q(t_n) \right) = arg\ max\left(OF\right) \qquad (2)$$

4 EXAMPLary APPLICATION

The functionality of the proposed management system is illustrated by an exemplary application dealing with a typical management problem in coastal arid regions. The example shows the need for, and the effectiveness of, a combined management of the groundwater aquifer and the agricultural water demand for solving water quantity and quality problems.

The management problem deals with one coastal aquifer which provides water for agricultural production. The groundwater aquifer is connected to the sea and the farmers use the pumped freshwater from the aquifer to irrigate their land. Depending on the amount of groundwater abstraction the salt water will begin at some stage to intrude into the aquifer. As a consequence, the water for irrigation becomes more and more brackish. The aim of the management system is now to evaluate several strategies in order to find the best possible and sustainable management practice by considering the contradicting objectives like high profitable agriculture vs. sustainability which both are potentially affected by the water quality. A long term evaluation of the environmental and economical development of a hypothetical farm – located in vicinity of the sea – under different management scenarios is subsequently investigated.

4.1 Application settings

The exemplary application consists of three elementary steps: (i) the assessment of the long term water resources development using the ANN-OGS (see chapter 3.2) (ii) the estimation of crop yields for different levels of irrigation water amount and salinity by means of the 2D-CWPF's (see chapter 3.3) and (iii) the application of the simulation based water management model to optimise the revenues of the farm as well as the sustainability of the aquifer management. We set up the exemplary application according to the characteristics of the wadi Ma'awil catchment located within the study area (see Figure 1). To demonstrate the optimisation framework functionality we build a 2D slice in x-z-direction of the coastal aquifer to model the groundwater flow inclusive saline transport (see Grundmann et al., 2011 for more details). For sake of simplicity 2D-CWPF's are constructed for two different crops, maize – a salt sensitive cash crop – and sorghum – a lower priced but more salt resistant crop – which are grown in two seasons per year (Schütze et al. 2011b). We incorporate fixed and variable costs for installation and operation of pumping and irrigation equipment. Afterwards long term optimisation runs over the next 20 years for three different management scenarios were performed in order to maximise:

scenario 1: the short term profit (only for the next 4 years) with the assumption that the farmers decisions are profit based;

scenario 2: the long term profit over the next 20 years;

scenario 3: the profit together with the aquifer sustainability as a multi-objective analysis by using equal weights within the objective function (Equation 1).

The decision variables are the yearly cultivated acreage, the yearly cropping pattern and the yearly irrigation water demands which results in a number of 60 decision variables for the 20 years period. Exemplarily for scenario 2, the optimisation algorithm needs 1200000 evaluations of the objective function and a computing time of approx. 3 hours on a standard PC for finding an optimal variable set. This relatively short computing time will be possible by the use of the ANN-OGS surrogate model which operates approximately 1000 times faster than the physically based OpenGeoSys model.

4.2 Results

The results for the different scenarios are shown in Figure 5. The lower part illustrates the temporal course of the profit which rises up very quickly in the first two years for the short term profit scenario (Figure 5c). After then the profit is decreasing quite fast due to increasing salinity in the irrigation water, like shown in Figure 5b, which also leads to a change in the cropping pattern from maize to sorghum (Figure 5a). The results for the long term profit scenario shows also a rising and falling course of the profit (Figure 5f). Nevertheless, the peak comes later with a lower peak value in relation to the short term profit scenario. The

crop pattern changes also later (Figure 5d). The salinity of irrigation water (Figure 5e) increases in the last 5 years very quickly and achieves a level at the end of the 20 year period on which the farmer will not get a profit from the agricultural production. The results of the multi-objective scenario show very smooth graphs (Figure 5g-i). Maize is grown all the time but on a lower acreage than on the beginning stages of scenario 1 and 2 (Figure 5g). Therefore the salinity of irrigation water does not raise (Figure 5h) and a profit is made the whole time (Figure 5i).

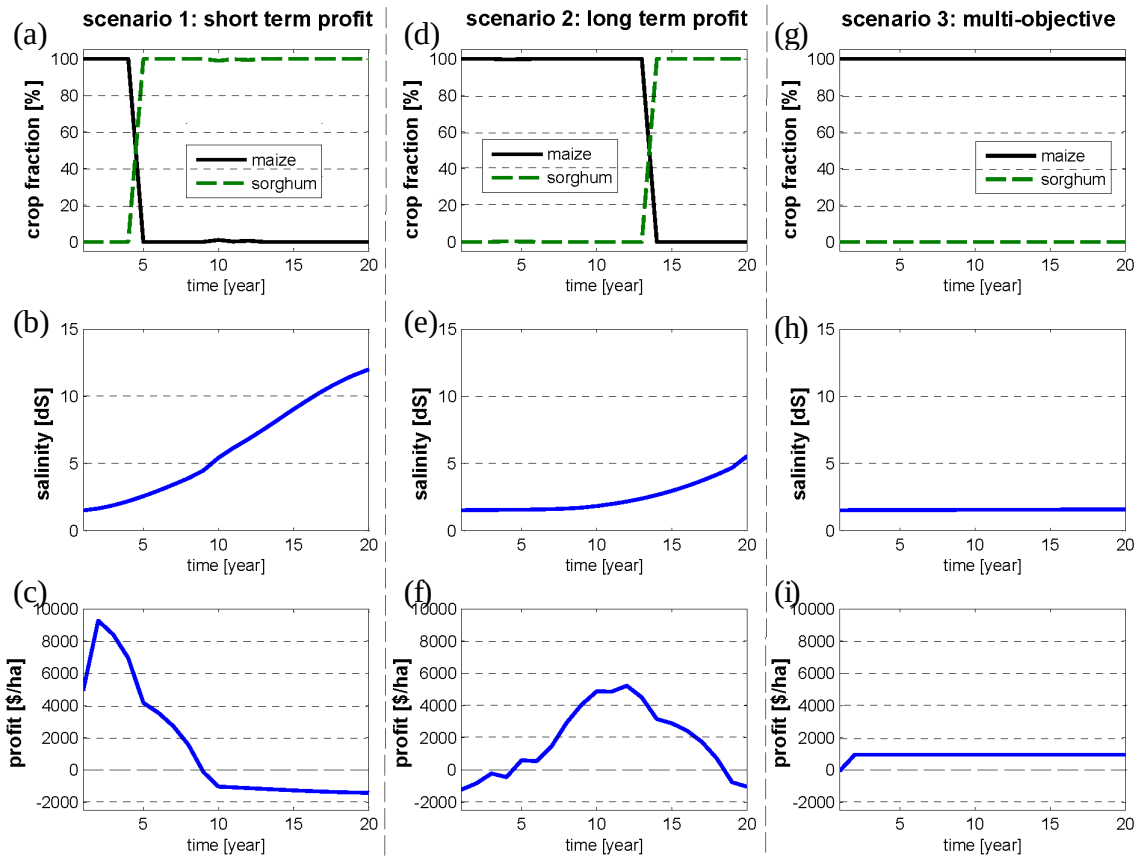

Fig. 5: Results of three optimisation runs illustrated by the percentage of acreage, the salinity and the profit for the short term (5 a-c) and the long term (5 d-f) profit based scenarios and the multi-objective scenario (5 g-i)

Comparing the total return between the three scenarios estimated by the line integral of the profit graphs, then the best return is made in scenario 2. However, at the end of the 20 years the farmer probably has to give up farming like the farmer in the short term profit scenario due to the high salinity levels of the irrigation water. In contrast the farmer in the multi-objective scenario can work additional 20 years and get then a higher return than the farmer in scenario 2 because of a more sustainable aquifer management.

The outlined example helps to illustrate the interplay and feedback mechanisms between a groundwater management and the agricultural production in terms of water quantity and quality. This is only achievable by the use of predictive models for both the groundwater system and the agricultural system. Furthermore a synthesis of these models by artificial intelligence is necessary to allow for an optimisation of an integrated, combined management of both compartments in a reasonable time. Additionally, the exemplary application shows that farm operation focusing exclusively on profit maximization leads sooner or later to further progress of the saltwater front. Therefore the sustainability must be considered as a second optimisation objective. In this context a multi-objective optimisation can provide sustainable solutions both in an environmental and social sense. To tackle this problem a multicriterial optimisation approach along the lines of the principles of pareto optimality (Goldberg, 1989) is necessary. Comprehensive extensions of the presented example such as sustainable water management for multiple demand zones, multiple crops and complex abstraction schemes will be possible by employing a 3D groundwater model together with a SCWPF-database containing all the relevant crop/soil relationships for a considered region.

5. Summary and outlook

Tackling the challenges of global change, the need for a tailor made approach for a most efficient and sustainable management of the scarce water resources in arid zones is highlighted. As a solution, we introduce an integrated Assessment, Prognosis, Planning and Management Tool (APPM) on the basis of innovative approaches like synthesizing process models and artificial intelligence techniques as well as sound rigorous multicriterial and multidimensional optimisation under consideration of the stochastic nature of future climate conditions. The APPM unites optimal solutions for water allocation, groundwater storage and withdrawal including saline water management with alternative, highly beneficial irrigation strategies.

The presented prototype of a simulation based water management model allows for the management of both water quality and quantity of a coupled, dynamic agriculture-groundwater system. Thereby the modelling of the density driven groundwater flow is mandatory for calculating crop yield damages due to aquifer overpumping and irrigation with salty water. The exemplary application shows that farm operation focusing exclusively on profit maximization leads sooner or later to further progress of the saltwater front. Therefore the sustainability must be considered as a second optimisation objective. In this context a multi-objective optimisation can provide sustainable solutions both in an environmental and social sense. To achieve this task in a reasonable time a rigorous application of artificial intelligence methods is necessary in order to speed the process models up.

Our ongoing research aims to facilitate and ensure a continuously improving, more reliable and comprehensive assessment of the water resources availability and the agricultural water demand. On this basis, the integrated water management tool will be further developed and will include scenario analysis together with local Omani experts.

Acknowledgement

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SESSION 2:
SUSTAINABLE WATER RESOURCES PLANNING AND MANGEMENT

Keynote: Ghaith Fariz, UNDP, The Arab Water Governance Report.

Dr. Ghaith Fariz has a Ph. D. in Planning from the University of Michigan, USA He is the Director/Coordinator of the Arab Water Report- And of the Arab Knowledge Report.

He has coordinated and authored several publications and papers as well as regional and international level developmental reports. He was the coordinator of the Arab Human Development Reports for 2004 and 2005 and he tangibly participated in writing AHDRs of 2002 and 2003. He is the author of the first Arab Millennium Development Report 2003 and he supervised, and tangibly contributed to the formulation of several other developmental reports all over the Arab region. He is also the author of several publications in socioeconomic development and population-environment dynamics. In addition, he is an expert in gaming and simulation.

التقرير العربي الأول للمياه

نحو الأمن المائي في المنطقة العربية: قضايا الحوكمة وفعالية التكاليف

تواجه المنطقة العربية أزمة مياه حادة حيث تم تصنيف ثلاثة عشر دولة عربية من بين الدول التسع عشرة الأكثر فقرا مائيا في العالم. وتعتبر أزمة المياه بالدول العربية هيكلية وذات أبعاد اقتصادية، وبيئية، واجتماعية، وتقنية متباينة المدى والأثر من دولة إلى أخرى، وذلك لتداخل العديد من العوامل النابعة من الحقائق الجغرافية والاقتصادية والسياسية والإستراتيجية. بيد أنه، وعلى الرغم من تضافر الجهود المحلية والإقليمة والدولية الرامية لإيجاد حلول لأزمة المياه، يبقى هناك نقص حاد في الحلول المتعلقة بحساب التكاليف المباشرة وغير المباشرة للسياسات المائية والتي من المفترض أن تضمن الكفاءة الاقتصادية، والاستدامة البيئية، والعدالة الاجتماعية على المدى الطويل. ولقد بات من المهم وضع أسس أفضل لفهم سبل الوصول إلى سياسة فعالة ومستدامة للمياه بأقل تكلفة اقتصادية وبيئية واجتماعية وسياسية. وستكون هذه الأسس بمثابة حلول عملية شاملة وخلاَّقة لمواجهة مشكلة العجز في الموارد المائية وأزمة الأمن الغذائي المرتبطتان إرتباطا وثيقا بالتّطور العمراني والسكاني والاقتصادي المطّرد مما يعيق تحقيق التنمية المستدامة للمنطقة العربية.

وفي هذا الصدد ارتئ برنامج الأمم المتحدة الإنمائي إصدار التقرير العربي تحت عنوان " **نحو الأمن المائي في المنطقة العربية : قضايا الحوكمة وفعالية التكاليف** ". ويتناول هذا التقرير الأزمة المائية بالوطن العربي من خلال منظور الحوكمة ومنهج الخيار الأمثل بأقل كلفة. وسيقوم نخبة من الخبراء العرب المتميزين من ذوي التخصصات المتنوعة بكتابة التقرير الذي يستعرض وبشكل تحليلي : الواقع الحالي للموارد المائية و التحديات ومدى تأثرها بالتغيرات ذات العلاقة بما في ذلك العوامل المناخية، وفعالية أنظمة توزيع شبكات المياه، ومعضلة الارتكاز الكلي على الطاقة الغير متجددة، ومؤشرات الحوكمة كمؤشر الشفافية والتواصل والمساءلة، وأيضا مسألة بناء القدرات في مجال الإدارة المتكاملة للموارد المائية.

ويتفرد التقرير بتقديمه توضيحات عن كيفية قياس التكاليف الرئيسية للتدخلات المحتملة وأيضا حساب كلفة التراخي وأثارها على المجتمع والبيئة بشكل خاص. وأخيرا، يهدف التقرير لمساعدة صناع القرار على المستوى المحلي والوطني والاقليمي والعالمي في إحداث تغيير في السياسات المائية الحالية وفي ممارسات المستخدمين للموارد المائية من خلال المشروعات التجريبية الناجحة والتحليلات المشتركة البناءة، والتي ستكون بمثابة حجر الأساس لحوار تشاركي وفعال يشمل كل الفاعلين بقطاع المياه لتدارس السبل المثلى لحوكمة المياه وتحقيق الأمن المائي باعتبارهما قضايا مشتركة آنية ومن رهانات مستقبل المنطقة العربية.

Keynote: Ahmed Khater, NWRC, Egypt, Integrated water resources Planning in the Arab countries.

Dr. Ahmed R. Khater is currently Professor Emeritus of Water Resources Management at the National Water Research Center, Egypt. He has held various national senior positions including Vice-President of the National Water Research Center, Director of the Research Institute for Groundwater and Director of the Water Resources Research Institute. He received his M.Sc. degree in Irrigation Engineering and Ph.D. degree in Water Resources management from the University of Southampton, England. He has over 35 years of research experience in the areas of water resources development and management. Khater's profile of expertise includes development and application of modelling techniques to water resources management problems, management of shared aquifer systems, teaching water resources planning and management, and supervision of M.Sc. and Ph.D. research students. He has also been actively involved in expert meetings on various water resources aspects and served as a consultant for several regional and international agencies. He has served as the regional coordinator for the UNESCO IHP-Network on Groundwater Protection in the Arab Region (2000-2010). He has previously served (2000-2008) as elected Vice-President of the International Association of Hydrogeologists (IAH) for the MENA Region. Prof. Khater has over 60 publications of peer reviewed articles, proceedings and book chapters.

Abstract:

Past traditional approaches of water resources management are mostly sectoral, top-down and supply oriented. These approaches have had questionable effectiveness and lead to fragmented and uncoordinated development of water resources. Given such shortcomings with traditional approaches, Integrated Water Resources Management (IWRM) has emerged as a means of addressing the global water problems and working toward a sustainable future for water management. IWRM was developed as a philosophical framework to look at the way in which water resources are developed and managed, with the essence that in water management there are many different functions to be managed simultaneously. The philosophy of IWRM, as globally formulated, yielded numerous interpretations emphasizing that the social, environmental and economic aspects should be all developed concurrently in a sustainable manner. IWRM is a sound philosophy which is hard to disagree with. However, converting a philosophy into practice is a challenge. A significant philosophical water management controversy exists over the balance between economics, social equity and environmental protection in IWRM. Making such transition and significant shift from current paradigms is proving to be difficult. One major constraint is the gap between the well-defined philosophy and the fuzzy definition of operational indicators for the achievement of management goals and the performance of strategies. Reported IWRM experiences in the Arab region present a case in point. At the operational level, implementation challenges in the Arab region are identified to demonstrate the gap that exists between theoretical and practical applications of IWRM. This paper provides an analytical overview of the perceived

difficulties and conceptual shortcomings regarded as inhibiting implementation of IWRM in the region, emphasizing major issues of concern pertinent to manage water resources in an IWRM compatible manner.

دراسة تحليلية للإحتياجات والإمدادات المائية في المملكة العربية السعودية

د. عبدالعزيز بن سليمان الطرباق
د. عبدالعزيز بن عبدالله العثمان
قسم الهندسة المدنية – كلية الهندسة – جامعة الملك سعود

ملخص:

الأمن المائي والأمن الغذائي قضيتان عالميتان تعاني منهما أو على الأقل من إحداهما، كثير من دول العالم الثالث وذلك أن كثيراً منها تقع في المنطقة المناخية الجافة (Arid Zone) أو شبه الجافة (Semi Arid Zone)، مما يجعل أغلبها يعاني من مشكلة ندرة المياه وبالتالي من أزمة في الغذاء، وخاصة عندما تشح الأمطار في هذا الجزء من العالم ويصاب بالجفاف. وقد قامت المملكة بتطوير مصادر مياهها المتاحة، بما في ذلك تحلية مياه البحر وحفر الآلاف من الآبار العميقة. إلا أنها بمرور الزمن أصبحت تخشى من عدم استدامة المياه نتيجة لتزايد الإستهلاك، لدرجة لا تستطيع معها تعويض المياه التي استخدمت، كما تخشى من تزايد تكاليف تحلية المياه وتوزيعها عبر مساحتها الكبيرة ، كما أن الأمن الغذائي الذي يعتمد أساساً على الإنتاج المحلي، يزيد من تفاقم أزمة الأمن المائي، خاصة وأن قطاع الزراعة هو الأكثر استخداماً للمياه. تهدف هذه الورقة إلى استعراض نتائج دراسة قام بها الباحثان لتقدير كميات المياه المتاحة من المياه السطحية والجوفية ومياه التحلية ومياه الصرف الصحي المعالجة حتى عام 2025م وكذلك تقدير الاحتياجات المائية الحالية والمستقبلية لكل الأغراض الزراعية والبلدية والصناعية ، قد تم ذلك بتقدير الإستهلاك المتوقع لهذه الاستخدامات بافتراض عدة سيناريوهات مبنية على تقدير الإستهلاك الزراعي في المستقبل حسب تركيبة محصولية مقترحة وعلى ضوء افتراضات متوقعة للزيادة السكانية والاحتياجات المائية الأخرى ، وفي الجزء الأخير من الدراسة قورنت كميات المياه المتاحة مستقبلاً مع الاستهلاك المتوقع حسب الافتراضات المختلفة ومن هذه المقارنات اتضحت مشكلة نقص المياه المتوقعة مستقبلاً وقدمت ونوقشت الحلول اللازمة لتلافي العجز المتوقع في مختلف القطاعات.

مقدمة:

تقع المملكة، في منطقة صحراوية جافة المناخ، ولا توجد بها أنهار جارية سوى بعض الوديان الموسمية التي تحاول جاهدة الاستفادة من مياهها بإنشاء السدود والمملكة وإن كانت لا تمتلك مصادر مياه غير الوديان والآبار الجوفية، فقد أفاء الله عليها بمصادر مالية تراكمت لديها من فوائض إيرادات النفط، لذا فقد قامت بتطوير مصادر مياهها المتاحة، بما في ذلك تحلية مياه البحر. إلا أنها بمرور الزمن، أصبحت تخشى من عدم استدامة مياه الآبار والوديان نتيجة لتزايد الإستهلاك. ومن الجانب الآخر، فإن الأمن الغذائي الذي يعتمد أساساً على الزراعة المحلية، يزيد من تفاقم أزمة الأمن المائي، خاصة وأن الزراعة تستهلك ما يقارب 90% من إجمالي استهلاك المياه في المملكة. ولذا عمدت السياسات الزراعية الجديدة في المملكة وأهمها قرار مجلس الوزراء رقم 335 وتاريخ 1428/11/9هـ إلى محاولة تحقيق التنمية المستدامة وهذا يتطلب الإدارة الأمثل لاستخدام الموارد الطبيعية غير المتجددة أو القابلة للنضوب مثل المياه الجوفية وبطريقة تلبي احتياجات الجيل الحاضر دون الإخلال بحق الأجيال المستقبلية في تلك الموارد. ويتم إدارة جانبي العرض والطلب للمورد الطبيعي بطريقة تعمل على ترشيد استخدامه وصيانته وتنميته في وقت واحد.

وخلال المسيرة التنموية التي شهدتها المملكة خلال الأربعة عقود الماضية مر قطاع المياه بثلاث مراحل مميزة وهي كالتالي:-

- المرحلة الأولى " الاكتفاء والوفرة" : (1)
وتغطي هذه المرحلة خطتي التنمية الأولى والثانية ما بين (1390هـ حتى 1400هـ). كانت السياسة المائية المتبعة في هذه المرحلة تهدف بشكل رئيسي إلى توفير المياه الصالحة للشرب لجميع مدن وقرى المملكة كما اهتمت السياسة المائية خلال تلك الفترة على تحلية المياه كمصدر جديد إضافة إلى الموارد المائية الطبيعية مع إجراء الدراسات الهادفة إلى تنمية الموارد وتحسين أساليب المحافظة عليها.

- المرحلة الثانية: "مرحلة ظهور العجز": (2)
وهي الفترة الممتدة ما بين عام (1401- 1420هـ) وتغطي أربع خطط تنمية متتابعة من خطة التنمية الثالثة حتى نهاية خطة التنمية السادسة حيث تم خلال هذه الفترة ازدياد استهلاك المياه لجميع الأغراض بصورة مطردة تفوق قدرة الموارد المائية المتاحة وفي ظل ازدياد معدلات الطلب ووصول الاستهلاك كمياً إلى مستويات حرجة.

- المرحلة الثالثة: "مواجهة العجز"(3)
وتبدأ هذا المرحلة منذ بداية خطة التنمية السابعة عام (1420هـ) ومستمرة حتى الوقت الحاضر حيث تم خلال تلك المرحلة مواجهة العجز في محاولة للحد من تفاقم مشكلة نقص المياه وإيجاد البدائل الاقتصادية الآمنة التي تساعد على مواجهة العجز.

وفي العام 1422هـ حدث تطور كبير بالنسبة لهيكلة قطاع المياه حيث صدر قرار من مجلس الوزراء بتأسيس وزارة المياه وبعدها بعام ضم إليها قطاع الكهرباء لتصبح وزارة المياه والكهرباء.

الدراسات السابقة

أجرى الطرباق (4) دراسة استهدفت التعرف على الوضع الراهن والمرتقب للموارد المائية في المملكة العربية السعودية. وتبين منها أن قطاع المياه يواجه عدة معوقات أهمها: (1) محدودية الموارد المائية المتجددة في المملكة واستنزاف المخزون المائي الإستراتيجي، (2) عدم وجود إستراتيجية واضحة لاستخدامات المياه في مختلف القطاعات، (3) يستهلك القطاع الزراعي أكثر من 90% من استخدامات المياه بدون مبرر اقتصادي، كما أن استمرار هذا الوضع على ما هو عليه الآن سيعرض المخزون المائي الإستراتيجي للنفاد، (4) ضعف برامج ترشيد استخدامات المياه في القطاع الزراعي. وأخيراً، أوصت هذه الدراسة بضرورة وضع إستراتيجية واضحة لاستخدامات المياه في مختلف الأغراض، بالإضافة إلى تقليل ما يستهلكه القطاع الزراعي من المياه، مع ضرورة استخدامها بفاعلية وكفاءة عالية. كما بينت دراسة للطرباق والضويلع (5) أهمية معالجة مياه الصرف الصحي ودورها في حل مشكلة نقص المياه في المملكة والمساهمة في التنمية الزراعية والصناعية عن طريق توفير مصدر مائي جديد يساهم في تلبية هذه الإحتياجات لهذه القطاعات خاصة في ظل شح المياه. وقام غانم والرويس (6) بدراسة استهدفت التوصل إلى التركيب المحصولي الأمثل المقترح في ضوء اعتبارات الأمن المائي في المملكة، وتبين من هذه الدراسة أن القطاع الزراعي يعتمد على المياه الجوفية غير المتجددة بنسبة 66.5%، في حين يعتمد على المياه الجوفية المتجددة بنسبة 33.5%. ويقدر إجمالي العائد النقدي لكمية المياه المستخدمة في التركيبة المحصولية المقترحة بنحو 35.5 مليار ريال، بينما بلغ نظيره في التركيبة المحصولية الراهنة نحو 10 مليارات ريال، وبالتالي يمكن زيادة إجمالي العائد النقدي لكمية المياه المستخدمة في الأغراض الزراعية بمعدل 255% وذلك من خلال تنفيذ تلك التركيبة المحصولية.

الموارد المائية الحالية والمستقبلية

يمكن تقسيم موارد المياه في المملكة إلى قسمين أساسيين:
1- موارد تقليدية (وتشمل المياه السطحية- والمياه الجوفية المتجددة وغير المتجددة).
2- موارد غير تقليدية (وتشمل مياه البحر المحلاة- ومياه الصرف الصحي المعالجة).

المياه السطحية

وهي المياه الناتجة من سقوط الأمطار سواءً كانت مياهاً سطحية جارية تتجمع في الأدوية أو خلف السدود. وهي توجد بشكل رئيس في المنطقتين الجنوبية الغربية والغربية، وبشكل أقل في المناطق الأخرى من المملكة. وتمتاز المياه السطحية بأنها مياه متجددة لأنها تتغذى بهطول الأمطار، وتبلغ كمية هذه المياه كمصدر سنوي حوالي 2000مليون متر مكعب. ونظرا لضرورة استغلال المياه السطحية كمورد متجدد، ركزت المملكة على تطوير شبكة واسعة من السدود لغرض التحكم في جريان مياه الأمطار والسيول المفاجئة درءاً لخطر الفيضانات على الأرواح والممتلكات، ولحجز المياه للاستعمال المباشر سواءً أكان لأغراض الشرب والري، أو لتغذية الطبقات الحاملة للمياه، وبلغت عدد السدود بالمملكة حتى عام 1428هـ (230) سداً.

المياه الجوفية

وهي المياه الموجودة تحت سطح الأرض، وتعتبر أهم مورد طبيعي للمياه في المملكة، وتنقسم من حيث العمر الزمني لها وعمقها إلى قسمين:

1- المياه الجوفية المتجددة
وهي المياه التي تتأثر إيجابا بعد هطول الأمطار نتيجة لتغذيتها بمياه السيول، وتوجد في الرواسب الوديانية والصخور المتشققة أسفل هذه الرواسب، ويتراوح عمقها بين بضعة أمتار إلى نحو 100 متر، ويكثر وجود هذه المياه في مناطق الدرع العربي التي تشغل الثلث الغربي من المملكة، وتختزن فيه المياه مباشرة بعد سقوط الأمطار ولذلك تسمى بالمياه المتجددة ، كما توجد هذه المياه في الأجزاء غير المحصورة من الطبقات المائية الرسوبية التي تتأثر أيضاً بعد هطول الأمطار وتعتبر مياهها متجددة . وتقدر كميات المياه التي تغذي هذه الطبقات بحوالي 940 مليون متر مكعب في السنة.

2- المياه الجوفية العميقة
وهذه المياه قد اختزنت في باطن الأرض منذ آلاف السنين على أعماق بعيدة قد تصل إلى آلاف الأمتار، وتتواجد في طبقات جيولوجية متعاقبة، ولها امتداد أفقي واسع وتشغل أكثر من ثلثي مساحة المملكة، وهناك متكونات رئيسة تحتوي على كميات جيدة من المياه، وثانوية تحتوي على كميات أقل. هذه المتكونات تمثل أهم مصادر إمدادات المياه لجميع الأغراض، وتغذية هذه الطبقات العميقة من الأمطار المباشرة محدودة، وتقل كثيراً عن معدلات السحب السنوية، حيث تقدر تغذيتها السنوية بحوالي 2000 مليون متر مكعب، وقد تكون هناك تغذية جانبية من طبقات أخرى نتيجة لتغير التراكيب الجيولوجية تحت السطح كالصدوع والطيات وغيرها. وأهم المتكونات الرئيسية الحاملة للمياه في المملكة هي: الساق، الوجيد، المنجور، البياض، الوسيع، أم الرضمة، الدمام والنيوجين.

وهناك تقديرات مختلفة لهذا المورد الرئيس للمياه الجوفية، إلا أن العودة إلى التقديرات الأساسية التي عملت في أول محاولة لتقدير كميات المياه المخزونة، والتي يمكن استغلالها من هذه المتكونات تبين أن مجموع الاحتياطي المحتمل للتكوينات الرئيسة هو 565 بليون متر مكعب، وإذا أضيف لذلك الطبقات الثانوية والتي سبق تقديرها بحوالي 162.5 بليون متر مكعب فيكون الاحتياطي الإجمالي المحتمل هو 727.5 بليون متر مكعب. وهذا يمثل تقديرا معقولا لكميات المياه الممكن استغلالها من المخزون عام 1980م. وقد قامت وزارة المياه والكهرباء خلال السنوات القليلة الماضية بتحديث لعرض الدراسات السابقة وهناك خطة للقيام بدراسات تحديثية أخرى على الطبقات الأخرى وقد تغير هذه الدراسات من تقديرات المخزون (7) وبغض النظر عن كميات المياه غير المتجددة المتوفرة فإن تحقيق هدف التنمية المستدامة يتطلب سرعة تخفيض الاعتماد على تلك الموارد والاحتفاظ بها كاحتياطي إستراتيجي لأغراض الشرب في المقام الأول.

مياه البحر المحلاة

تعتبر مياه البحر المحلاة مورداً مهماً ومسانداً للموارد التقليدية وليس بديلاً عنها، إلا أنه أصبح مورداً لا يمكن إهماله في ظل الظروف الصعبة. كما تحتل المملكة المركز الأول عالمياً من حيث استخدامها لتقنية تحلية المياه المالحة، حيث بلغ العدد الإجمالي للمحطات (30) محطة موزعة على الساحلين الشرقي

والغربي من المملكة، منها (6) محطات على ساحل الخليج العربي و (24) محطة على ساحل البحر الأحمر. كما يجري حالياً إنشاء أربع محطات رئيسة جديدة هي: الشقيق والشعيبة ورأس الزور والجبيل.

مياه الصرف الصحي المعالجة

تعتبر مياه الصرف الصحي المعالجة مورداً إضافياً مهماً للمياه في المناطق الجافة وشبه الجافة، وذلك لسد احتياجات قطاعات مهمة مثل الزراعة والصناعة والأغراض الترفيهية وغيرها، كما تهدف إلى تخفيف السحب من المياه الجوفية. وتتزايد أهمية مياه الصرف الصحي في استغلالها اقتصادياً خاصة في ظل الزيادة السكانية المطردة ومحدودية مصادر المياه، وارتفاع تكاليف تحلية المياه وتوصيلها إلى مراكز التجمعات السكانية والمدن الكبرى، لذا فقد تم التركيز في السنوات الأخيرة على ضرورة إعادة استخدام مياه الصرف الصحي المعالجة للأغراض الزراعية. ويقدر مجموع كميات مياه الصرف الصحي المعالجة بنحو 714 مليون متر مكعب عام 1430هـ. وتقوم الجهات ذات العلاقة برفع كفاءة درجة معالجة هذه النوعية من المياه إلى الدرجة الثلاثية، وذلك وفق برنامج زمني محدد من أجل تعظيم الفائدة من هذه المياه باعتبارها مصدرا جديدا يتوفر بالمناطق المزدحمة بالسكان.

تقدير الموارد المائية المستقبلية

المياه السطحية
من المتوقع أن يرتفع حجم المياه السطحية المستخدم إلى (1500) مليون متر مكعب في عام 1445هـ، وذلك نتيجة تشييد السدود المتتالية في مختلف أرجاء المملكة. وهناك العديد من السدود تحت التنفيذ حالياً بمختلف مناطق المملكة وسدود أخرى كثيرة تحت الدراسة.

المياه الجوفية
تقدر الكمية الإجمالية من المياه الجوفية المتجددة الممكن استغلالها بالمملكة العربية السعودية كحد أقصى بحوالي (2940) مليون متر مكعب، ويمكن احتساب هذه الكمية ضمن الموارد المتجددة، ويمكن اعتبار هذا الحد الأقصى رقماً ثابتاً طوال الفترة من عام 1430هـ. إلى 1445هـ وتوجد هذه المياه بشكل كبير في مناطق تهامة والدرع العربي ومناطق الوديان بشكل عام.

مياه التحلية
قدر إنتاج محطات التحلية بحوالي (1082) مليون متر مكعب عام 1430هـ. وطبقا لما أشارت إليه المؤسسة العامة لتحلية المياه المالحة من المشاريع المستقبلية التي سوف تنفذها حتى عام 1445هـ ببناء المحطات الجديدة لرفع الطاقة الإنتاجية وذلك لمقابلة الاستهلاك في المدن، وإيصال المياه إلى بقية المدن في المملكة، ويبين الجدول (1) كمية إنتاج مياه التحلية المتوقعة حتى عام 1445هـ، وسوف تخصص هذه الكمية لأغراض الاستخدام المنزلي فقط.

جدول (1): كميات إنتاج مياه التحلية المتوقعة حتى عام 1445هـ (8)

السنة	كمية المياه المنتجة (مليون م3/السنة)
1430هـ	1082
1435هـ	1579
1440هـ	2070
1445هـ	2144

مياه الصرف الصحي المعالجة

بناء على المعلومات المتوفرة عن مياه الشرب والصرف الصحي، وافتراض أنه بحلول عام 1445 هـ ستكون شبكة الصرف الصحي تغطي كامل مدن المملكة، وبافتراض أن كميات مياه الصرف الصحي ستصل للحد الأعلى وهو 75٪ من مياه الشرب، يوضح جدول(2) كميات مياه الصرف الصحي المتوقعة والكميات الممكن استخدامها مستقبلا حتى عام 1445 هـ.

جدول (2): كميات مياه الصرف الصحي المتوقعة والتي يمكن استخدامها حتى عام 1445 هـ

السنة	كميات مياه الصرف الصحي المتوقعة "مليون متر مكعب"	كميات مياه الصرف الصحي المتاحة للاستخدام "مليون متر مكعب"
1430هـ	1038	714
1435هـ	1334	952
1440هـ	1647	1176
1445هـ	1972	1408

كميات المياه المتاحة من المصادر للأغراض المختلفة

يمكن تقدير كميات المياه المتوقع الحصول عليها من الموارد التقليدية وغير التقليدية للأغراض الزراعية والبلدية والصناعية، و يوضح الجدول(3) تقدير الموارد المائية المستقبلية في المملكة حتى عام 1445هـ.

جدول (3): تقدير الموارد المائية المستقبلية في المملكة (مليون متر مكعب/سنة).

السنة	مياه سطحية	مياه جوفية متجددة	مياه التحلية	مياه الصرف الصحي المعالجة
1430 هـ	950	2940	1082	714
1435 هـ	1130	2940	1579	952
1440 هـ	1310	2940	2070	1176
1445 هـ	1500	2940	2144	1408

أما المياه الجوفية غير المتجددة فستكون بمثابة مصدر يؤخذ منه لكل استخدام لا تغطي فيه المياه المتجددة حاجة ذلك الغرض. فمثلا المياه المستخدمة للشرب ستغطى من مياه التحلية (كل إنتاج التحلية)، والفرق يؤخذ بشكل أساسي من المياه الجوفية غير المتجددة عن طريق حقول آبار مياه الشرب الموجودة في مختلف أنحاء المملكة. أما الاستهلاك الزراعي وهو الأكبر من بين الاستخدامات فيستهلك معظم المياه السطحية وجزءً كبيراً من مياه الصرف الصحي المعالجة والمياه الجوفية المتجددة، ويغطي الفرق من المياه الجوفية غير المتجددة وهكذا. وسيتم تفصيل ذلك بعد عرض استهلاك المياه الحالي والمستقبلي.

استهلاك المياه الحالي والمستقبلي لكافة القطاعات

الاستهلاك الحالي للقطاع الزراعي من المياه

في ضوء الاحتياجات المائية للوحدة الأرضية (الهكتار) ومتوسط المساحة المزروعة قدرت كمية الموارد المائية المستخدمة بنحو 17018.64 مليون م^3، خصص منها نحو 6118.1 مليون م^3 بنسبة تبلغ 35.95% لمحاصيل الحبوب، تليها محاصيل الفاكهة (وتشمل النخيل) بنسبة تبلغ 33.49%، ثم الأعلاف بنسبة تبلغ 25.4%، والخضروات بنسبة 5.16% وقد أُقترح في دراسة سابقة (6) تركيبة محصولية للزراعة في المملكة على مدى الخمسة عشر سنة القادمة.

وفقاً للتركيبة المحصولية المقترحة عام 1436هـ (2015م) يتبين ما يلي :

تحتل الفاكهة المرتبة الأولى في هيكل التركيبة المحصولية بالمملكة، إذ تبلغ مساحة الفاكهة نحو 171.44 ألف هكتار، تمثل 31.65% من المساحة المحصولية البالغة 541.73 ألف هكتار عام1435هـ (2015م)، في حين تحتل الخضروات المرتبة الثانية، بنسبة بلغت 28.98%، تليها الحبوب بنسبة بلغت 20.23%، والأعلاف بنسبة 19.14%.

احتل محصول التمور أهمية اقتصادية بالغة في هيكل التركيبة المحصولية على مستوى المملكة، إذ تبلغ مساحة التمور 149.82 ألف هكتار، تمثل 27.66% من جملة المساحة المحصولية عام 1436هـ (2015م)، يليه في ذلك الذرة الرفيعة بنسبة تبلغ 15.27%، ثم البرسيم بنسبة 12.13%، ثم الكوسا بنسبة 3.51%، ثم الخيار والبطيخ والبطاطس بنسب بلغت 3.44%، 3.24%، 3.15% على التوالي.

أما في ضوء التركيب المحصولي المقترح لعام 1446هـ (2025م) يتضح ما يلي:

تحتل الفاكهة المرتبة الأولى في هيكل التركيبة المحصولية بالمملكة، إذ تبلغ مساحة الفاكهة نحو 167.86 ألف هكتار، تمثل 40.01% من المساحة المحصولية البالغة 419.57 ألف هكتار عام 1446هـ (2025م)، في حين تحتل الخضروات المرتبة الثانية، بنسبة بلغت 36.26%، تليها الحبوب بنسبة بلغت 16.06%، والأعلاف بنسبة 7.67%.

احتل أيضاً محصول التمور أهمية اقتصادية بالغة في هيكل التركيب المحصولي على مستوى المملكة، إذ تبلغ مساحة التمور 149.82 ألف هكتار، تمثل 35.71% من جملة المساحة المحصولية عام 1446هـ (2025م)، يليه في ذلك الذرة الرفيعة، بنسبة تبلغ 12.48%، ثم الطماطم بنسبة 5.29%، ثم الخيار بنسبة تبلغ 4.94%، والكوسا بنسبة 3.99%.

باستعراض نتائج التركيبة المحصولية المقترحة للزراعة في المملكة لعامي 1436هـ، 1446هـ، يتضح من البيانات الواردة بجدول (4) أنه وفقاً للتركيبة المحصولية المثلى عام 1436هـ (2015م) تبلغ كمية الموارد المائية المستخدمة 10.15 مليار م^3.

أما في ضوء التركيبة المحصولية المقترحة عام 1446هـ (2025م) فتبلغ كمية الموارد المائية المستخدمة 7.46 مليار م^3.

جدول (4): مقدار الموارد المائية المستخدمة في التركيبة المحصولية المثلى للزراعة في المملكة عامي 1436هـ، 1446هـ.

المجموعة السلعية	عام 1436هـ(2015م)		عام 1446هـ (2025م)	
	الموارد المائية بالمليون م^3	الأهمية النسبية %	الموارد المائية بالمليون م^3	الأهمية النسبية %
الحبوب	1587.19	15.64	954.78	12.80
الخضروات	1129.96	11.13	1077.64	14.44
الأعلاف	2785.83	27.44	864.57	11.59
الفاكهة	4648.17	45.79	4563.38	61.17
الإجمالي	10151.15	100	7460.37	100

ومما سبق يتضح أن التركيب المحصولي المقترح عامي 1436هـ، 1446هـ يحقق التوازن بين الأمن المائي والأمن الغذائي النسبي، حيث من خلال تطبيق التركيب المحصولي المقترح يمكن تقليل كمية المياه المستخدمة في القطاع الزراعي من 17.02 مليار م^3 حسب استهلاك التركيبة المحصولية الحالية إلى ما يقرب من 7.46 مليار م^3 عام 1446هـ. كما أن تطبيق التركيب المحصولي المقترح يحقق الأمن الغذائي النسبي لمحاصيل الخضروات والتمور، أما بقية المحاصيل ذات المقننات المائية العالية وأهمها محاصيل الحبوب والأعلاف فسيتم تحقيق الأمن الغذائي النسبي لها من خلال الاستيراد المباشر من الخارج أو من خلال الاستثمار الزراعي الخارجي وفقاً لمبادرة الملك عبد الله. حيث تهدف هذه المبادرة إلى الإستثمار الزراعي السعودي في الخارج إلى المساهمة في تحقيق الأمن الغذائي الوطني ، وبناء شراكات تكاملية مع عدد من الدول في مختلف أنحاء العالم ذات مقومات وإمكانات زراعية عالية لتنمية وإدارة الاستثمارات الزراعية في عدد من المحاصيل الزراعية الإستراتيجية بكميات كافية وأسعار مستقرة، إضافة إلى ضمان استدامتها.

الاستهلاك الحالي والمستقبلي للأغراض البلدية والصناعية

استهلاك المياه للأغراض البلدية

أدى التطور العمراني الذي تعيشه المملكة منذ بداية السبعينيات من القرن الميلادي الماضي في جميع المرافق وكذلك زيادة السكان الملحوظة، وتحسن مستوى المعيشة والوعي الصحي في جميع القرى والمدن، وتوفر المرافق البلدية وكفاءتها، وكذلك انخفاض التعرفة للمياه، والدعم الحكومي لقطاع المياه وازدياد المسطحات الخضراء في المدن، كل هذا أدى إلى ارتفاع ملحوظ في الاستهلاك والاحتياج المتزايد إلى المياه، وخاصة في المدن الكبيرة ذات التجمعات السكنية الكبيرة مثل الرياض وجدة والدمام وغيرها.

ويوضح الجدول (5) والذي يبين الاستهلاك الفعلي للمياه للأغراض البلدية في المملكة خلال الفترة (1415-1430هـ) بالاعتماد على عدد السكان وإمدادات الشبكات.

جدول (5): استهلاك المياه للأغراض البلدية خلال الفترة 1415- 1430هـ.

العام	تعداد السكان	متر مكعب/يوم	مليون متر مكعب /سنة	لتر/فرد/يوم
1415هـ	17.902.580	3.919.880	1388	219
1420هـ	20.288.060	5.120.160	1813	252
1425هـ	22.673.538	6.189.500	2191	273
1430هـ	25.653.027	7.002.825	2479	273

استهلاك المياه للأغراض الصناعية

لقد أصبح القطاع الصناعي عنصراً مهماً من عناصر الاحتياجات المائية خلال خطتي التنمية الرابعة والخامسة وما تلا ذلك من الخطط بسبب زيادة عدد المصانع الخاصة والتوسع في المناطق الصناعية الضخمة وخاصة الجبيل وينبع حيث بلغ 400 مليون متر مكعب عام 1415هـ.

ويوضح الجدول (6) الاستهلاك للأغراض الصناعية حسب ما ذكر في خطط التنمية.

جدول (6): استهلاك المياه بالمملكة للأغراض الصناعية (خطط التنمية)

السنة	الاستهلاك (مليون متر مكعب)
1405هـ	300
1410هـ	350
1415هـ	400
1420هـ	450
1425هـ	640
1430هـ	800

ويوضح الجدول (7) التقدير النهائي لإجمالي الطلب على المياه لجميع الأغراض، والذي سيكون أساساً للتقديرات المستقبلية.

جدول (7): التقدير النهائي لإجمالي الطلب على المياه عام 1430هـ

الغرض	الاستهلاك (مليون متر مكعب)
الأغراض البلدية	2479
الأغراض الصناعية	800
الأغراض الزراعية	15302
إجمالي الطلب	18581

التقدير المستقبلي لاستهلاك المياه للأغراض البلدية

تم تقدير استهلاك المياه للأغراض البلدية بناءً على عدد السكان ونسبة النمو السنوية وحصة الفرد من المياه، وقد تم حساب عدد سكان المملكة بناءً على عددهم عام 1425هـ الصادر من مصلحة الإحصاءات العامة، وتم احتساب نسبة نمو سنوية تبلغ 2.5%، والجدول (9) يوضح استهلاك المياه للأغراض البلدية حتى عام 1445هـ.

جدول (8): استهلاك المياه للأغراض البلدية حتى عام 1445هـ

السنـة	عدد السكان	لتر / فرد / يوم	كمية الاستهلاك (مليون متر مكعب/سنة)
1430هـ	25.653.027	273	2479
1435هـ	29.024.045	273	2805
1440هـ	32.838.043	273	3174
1445هـ	37.153.232	273	3591

الاحتياجات المائية المستقبلية للقطاع الصناعي

تم تقدير الاحتياج المائي المستقبلي في الصناعة على أساس معرفة مدى التوسع الصناعي، ومدى استعمال التدوير داخل المصانع، كما ينبغي معرفة مدى الاستهلاك المائي لكل نوع من أنواع الصناعات. وكما ذكر من قبل فقد كانت نسبة النمو في القطاع الصناعي تتراوح مابين 2.5-3.5%. وقد تم تقدير استهلاك المياه للأغراض الصناعية وذلك بالاعتماد على كمية الاستهلاك في عام 1430 والذي يقدر بـ 800 مليون متر مكعب، وبنسبة نمو سنوية تساوي 4%، والجدول (9) يوضح تقدير استهلاك المياه للأغراض الصناعية حتى عام 1445هـ.

جدول (9): تقدير الطلب المستقبلي للأغراض الصناعية

السنة	كمية الاستهلاك (مليون متر مكعب)
1430هـ	800
1435هـ	960
1440هـ	1120
1445هـ	1280

تقديرات إجمالي استهلاك المياه للأغراض المختلفة

من الجداول السابقة تم تقدير الاحتياجات المائية المتوقعة لجميع الأغراض خلال الفترة 1430- 1445هـ. ويوضح الجدول (10) التقدير النهائي للطلب الإجمالي على المياه حتى عام 1445هـ لجميع الأغراض.

جدول (10): التقدير النهائي للطلب الإجمالي على المياه حتى عام 1445هـ (مليون متر مكعب) والنسب المئوية لكل غرض من الأغراض

الأغراض	1430هـ	1435هـ	1440هـ	1445هـ
الأغراض الزراعية	15302 (82.4)	11010 (74.5)	9075 (67.9)	7729 (61.3)
الأغراض البلدية	2479 (13.3)	2805 (19.0)	3174 (23.7)	3591 (28.5)
الأغراض الصناعية	800 (4.3)	960 (6.5)	1120 (8.4)	1280 (10.2)
الإجمالي	18581	14775	13369	12600

مقارنة العرض والطلب على المياه

تحديد الموارد المائية المستخدمة للأغراض الزراعية والبلدية والصناعية
لمعرفة الفجوة المستقبلية الممكن حدوثها مستقبلاً فإنه لا بد من تحليل الطلب لكل استخدام من الاستخدامات الرئيسة الثلاثة (أي من أين سيلبى الطلب)، وكمتطلب لهذا فإنه لا بد من تحديد النسب من الموارد المائية المستخدمة لكل غرض من الأغراض، فمثلاً المياه السطحية وبمراجعة السعات التخزينية والأغراض المختلفة التي أنشئت من أجلها السدود، يتضح أن 75 مليون متر مكعب من مياه السدود تستخدم للشرب، وحوالي 590 مليون متر مكعب تستخدم للزراعة إما بطريقة مباشرة (سدود للري) أو بطريقة غير مباشرة (تغذية المياه الجوفية) وذلك عام 1430هـ. وبدراسة السدود التي ستنشأ خلال الأعوام الخمسة عشر القادمة يتبين أن كمية المياه التي ستكون للشرب مباشرة من المياه السطحية سترتفع إلى 300 مليون متر مكعب سنوياً، والمياه المستخدمة للري ستزيد إلى 750 مليون متر مكعب عام 1445هـ ، أما بالنسبة للمياه الجوفية المتجددة وهي 2940 مليون متر مكعب في السنة فيمكن توزيع هذا المورد عام 1430هـ على النحو التالي: 10% لمشاريع مياه الشرب الصغيرة والمتناثرة في بعض المدن والقرى في شتى أنحاء المملكة، و 15% تستغل للمزارع الصغيرة والاستراحات، أما الباقي 75% من هذا المورد فيستخدم مباشرة في الزراعة وخاصة في مناطق الدرع العربي. ومن المتوقع أن تصبح هذه النسب عام 1445هـ 15%، 20%، 65% للاستخدامات المشار إليها على التوالي. وكمورد مهم للأغراض البلدية سوف تستمر مياه التحلية في تغطية جزء مهم من هذا الاستخدام وتقتصر عليه حالياً ومستقبلاً أي أن 100% من إنتاج التحلية سيكون للاستخدامات البلدية (مياه الشرب) فقط.

يتضح أيضاً في المستقبل أهمية مياه الصرف الصحي المعالجة كمورد مهم يمكن استخدامه لأغراض عديدة مما يخفف الضغط على استخدامات الموارد المائية الأخرى. وتقدر نسبة استخدام هذا المورد عام 1430هـ للأغراض الزراعية بحوالي 80%، و10% للاستخدامات الصناعية والباقي لاستخدامات مختلفة. ومن المتوقع أن تزيد نسبة الاستخدامات في المجالات الصناعية إلى 20% من هذا المورد عام 1445هـ، مع بقاء الاستخدامات الأخرى عند 10%، و 70% للأغراض الزراعية.

تحليل العرض والطلب على المياه وتحديد الفجوة المائية مستقبلاً

تحليل الطلب على المياه للأغراض الزراعية
يوضح الجدول (11) كميات المياه اللازم توفيرها للقطاع الزراعي من الموارد المائية المختلفة. وحسب النسب المحددة من الموارد المائية المتجددة بشتى أنواعها (مياه سطحية – مياه جوفية متجددة – مياه صرف معالجة) وتقدير الباقي واللازم سحبه من المياه الجوفية العميقة (غير المتجددة) لتلبية الطلب للاستخدامات الزراعية.

جدول (11): توزيع الطلب للقطاع الزراعي على الموارد (مليون متر مكعب)

السنة	الطلب الكلي	الموارد المائية المتجددة			الكميات اللازم سحبها من المخزون لتلبية الطلب
		مياه سطحية	مياه جوفيه	مياه صرف معالجة	
1430هـ	15302	590	2205	571	11936
1435هـ	11010	643	2107	709	7551
1440هـ	9075	696	2009	847	5523
1445هـ	7729	750	1911	986	4802

ويتضح من هذا الجدول أن ما سيتم سحبه من المياه الجوفية العميقة للاستهلاك الزراعي سيتناقص من 11936 مليون متر مكعب عام 1430هـ إلى 4802 مليون متر مكعب عام 1445هـ، بشرط إتباع التركيبة المحصولية المقترحة وتبني سياسات توفر المياه للقطاع الزراعي من الموارد المتجددة حسب ما ورد في جدول (11)، وقد تم حساب كميات المياه اللازم سحبها خلال فترة الدراسة وكانت النتيجة أنه يلزم سحب 107.2 مليار متر مكعب من المخزون الإستراتيجي للمياه الجوفية حتى مع اتباع التركيبة المحصولية المقترحة.

تحليل الطلب على المياه للأغراض البلدية

من خلال تقديرات الطلب على المياه للأغراض البلدية الموضحة في الجدول (8) يتبين أن هذه ستزيد من 2479 مليون متر مكعب عام 1430هـ إلى 3591 مليون متر مكعب عام 1445هـ، وذلك بسبب الزيادة في السكان وتوسع المدن وارتفاع مستوى المعيشة في المملكة. وبحسب النسب المفترضة من الموارد فإنه يمكن تقدير كميات المياه المتوقعة لتلبية الطلب للاحتياجات البلدية من الموارد المختلفة حسب ما هو مبين في الجدول (12).

جدول (12): توزيع الطلب على الموارد المائية المختلفة للأغراض البلدية (مليون متر مكعب)

السنة	تقديرات الطلب	الموارد المختلفة (مياه متجددة)			الكميات اللازم توفيرها من المياه الجوفية غير المتجددة
		مياه التحلية	مياه سطحية (سدود)	مياه جوفية متجددة	
1430هـ	2479	1082	75	294	1028
1435هـ	2805	1579	150	360	716
1440هـ	3174	2070	225	426	453
1445هـ	3591	2144	300	492	655

ويتضح من هذا الجدول أن كميات المياه اللازم سحبها من المياه الجوفية العميقة لتلبية باقي الطلب المتبقي للاستخدامات البلدية ستتغير في خلال الأعوام الخمسة عشر القادمة حسب ما هو متوفر من الموارد الأخرى وخاصة مياه التحلية. ومن العمود الأخير في جدول (12) يمكن تقدير هذه الكميات بحوالي 9800 مليون متر مكعب, وهذه الكمية هي مجموع المياه الجوفية اللازم سحبها من المخزون (المياه الجوفية العميقة) لتلبية الطلب للاستخدامات البلدية خلال الفترة 1430هـ - 1445هـ.

تحليل الطلب على المياه في قطاع الصناعة

لتلبية الحاجة المتزايدة للمياه خاصة مع تشغيل المدن الصناعية الجديدة في بعض مناطق المملكة. واستناداً للنسب المفترضة من الموارد المستخدمة لتلبية الاحتياجات الصناعية فإنه يمكن تقدير كميات المياه المتوقعة لتلبية هذا الطلب من الموارد المختلفة حسب ما هو موضح في الجدول (13).

جدول (13): مقابلة الطلب على المياه للقطاع الصناعي للموارد المائية المختلفة(مليون متر مكعب)

السنة	تقديرات الطلب	مياه صرف صحي معالجة	الكميات اللازم توفيرها من المياه الجوفية غير المتجددة
1430هـ	800	71	729
1435هـ	960	141	819
1440هـ	1120	212	908
1445هـ	1280	282	998

ويتضح من جدول (13) أن ماسيتم سحبه من المياه الجوفية العميقة للاستخدامات الصناعية سيتزايد من 729 مليون متر مكعب سنوياً عام 1430هـ إلى 998 مليون متر مكعب سنوياً عام 1445هـ، وتقدر مجموع الكميات الكلية اللازم ضخها من المياه الجوفية العميقة لتلبية متطلبات القطاع الصناعي فقط خلال فترة الدراسة بحوالي 13مليار متر مكعب.

الفجوة المائية المستقبلية

لتحقيق التنمية المستدامة وبشكل كامل فإنه لا بد من اقتصار استخدامات المياه مستقبلاً على الموارد المائية المتجددة، ولصعوبة ذلك في المناطق الجافة وشبه الجافة فإنه يلزم سحب مياه جوفية عميقة (أو غير المتجددة) من المخزون الإستراتيجي للمياه الجوفية، وهذا ما يعرف بالفجوة المائية أو الفرق اللازم تغطيته لمقابلة الطلب المتزايد. ويلاحظ في هذا الصدد أن الكميات التي تم سحبها حتى الآن (1430هـ) من المياه الجوفية العميقة كبير جداً، إلا أن السياسات الجديدة التي بدأت تطبق قد تقلل بشكل واضح من الضخ المتزايد. وبمراجعة ما تم حسابه للاستخدامات الرئيسة التي نوقشت في هذا الفصل يتبين أن ما يلزم ضخه خلال السنوات الخمس عشرة القادمة هو 130 مليار متر مكعب (107.2 مليار متر مكعب للقطاع الزراعي، 13 مليار متر مكعب للقطاع الصناعي و 9.8 مليار متر مكعب لمقابلة جزء من الطلب لمياه الشرب)، وبالرغم من أن هذا الرقم قد يبدو كبيراً نوعاً ما إلا أنه أصغر بشكل واضح كمتوسط سنوي مما كان يضخ في الماضي، ويمكن زيادة التوجه لاستخدامات الموارد غير التقليدية والمتجددة للأغراض المختلفة للتقليل مستقبلاً من هذه الفجوة المائية.

التوصيات

لقد تبين من هذه الدراسة **أن** الموارد المائية تلبي احتياجات القطاعات الزراعية والصناعية والبلدية خلال الخمسة عشر سنة القادمة (1430 – 1445 هـ) إذا تم إتباع التركيب المحصولي المقترح للقطاع الزراعي. وبالرغم من ذلك سيكون هناك فجوة مائية (سحب من المياه الجوفية غير المتجددة) خلال الفترة المشار إليها، لكن المعدل السنوي للسحب من المخزون الإستراتيجي سيتناقص بشكل واضح. ولضمان الوصول لنوع من التوازن بين الموارد المائية والاستهلاك، فإنه لابد من إتباع السياسات التالية:

- **تنمية الموارد المائية المتجددة وزيادة فعاليتها**
- **تكثيف أساليب ترشيد المياه لكافة الاستخدامات**
- **إصدار التشريعات والأنظمة الخاصة بقطاع المياه**
- **إتباع التركيب المحصولي المقترح للقطاع الزراعي**
- **تنفيذ البدائل الاستثمارية في المناطق الزراعية خارج المملكة وداخلها**
- **إعادة هيكلة صناعة الأعلاف لتنمية الثروة الحيوانية**

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Water Resources And Water Consumption Pattern In Saudi Arabia

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Abstract

Rapid growth of population, limited water reserves, insufficient recharge and extensive agricultural and landscaping activities have increased pressure on the water resources in Saudi Arabia. Understanding of water resources and trends of water consumptions is important to offer sustainable water resources management strategy. In this research, water resources and trends of water consumptions in Saudi Arabia were investigated. The non-renewable ground water reserves were estimated to be 259.1–760.6 billion cubic meters (BCM) with an effective annual recharge of 886 million cubic meters (MCM). The total internal renewable water was estimated to be 2.4 BCM/year. Approximately 1.4 BCM/year of runoff is stored by 302 dams across Saudi Arabia, from which 992.7 MCM is recharged to the shallow aquifers, 303.5 MCM is used for drinking and 51.5 MCM is for agriculture. The country produces approximately 1.06 BCM desalinated water annually, which is blended with groundwater for domestic water supplies. The wastewater treatment plants treat approximately 0.58 BCM/year domestic wastewater from which 0.33 BCM is recycled. The total water demand in 2009 was 18.51 BCM in which 83.5% were used for agriculture. From 2004 to 2009, agricultural water demand was decreased by 2.5%/year (17530 MCM to 15464 MCM), while the domestic and industrial water demands were increased by 2.1%/year and 2.2%/year, respectively. Between 1999 and 2008, domestic water subscribers were increased by 22.7%, while the annual domestic water consumption was increased from 1391 (609–2164) to 3818 (1687–7404) m^3/subscriber (274%). The industrial water demands were increased from 56 MCM/year in 1980 to 713 MCM/year in 2009. Following characterization, nonlinear equations were developed to predict the domestic, industrial and agricultural water demands. The predicted water demands were within 1-10% of the historically reported values. The findings of this study might be useful in understanding the water sources, water demands and identifying new sources for sustainable water resources management.

Keywords: Water resources, water availability, water consumption, water management, Saudi Arabia.

Introduction

The Kingdom of Saudi Arabia is located in an arid region, which have relatively low average annual rainfall (114 mm/year) [1]. The Kingdom has an oil based economy, covering approximately 90% of foreign export earnings, which has accelerated a comprehensive development coupled with population growth and living standards [2-3]. The population has increased from 6.9 million to 26 million in 39 years (1972 to 2011), resulting in significant increase of water use [4]. The total water consumptions in 1990, 1992, 1997, 2000, 2004 and 2009 were reported to be approximately 27000, 31500, 18500, 20500, 20200 and 18500 million cubic meter (MCM), respectively [5-7]. The high water demands in the early 1990s were due to extensive agricultural activities during these periods; the agricultural water demands represented 83%, 90%, 83%, 89%, 86% and 83% of the total water demands in these years, respectively. To address the water issue, Saudi Arabia has adopted a strategy to reduce agricultural water demands by reducing agricultural productions and/or by introducing advanced irrigation techniques, which has resulted in 2.5%/year reduction in irrigation water demands in the period 2004 and 2009 [7]. Conversely, the domestic and industrial water demands were increased by 2.1% and 2.2%/year, respectively, during this period [7].

The water demands in the Kingdom are satisfied by the non-renewable groundwater sources, renewable surface and groundwater sources, desalinated water and treated wastewater, in which the non-renewable groundwater sources supply the most, followed by the renewable surface and groundwater sources, desalinated water and treated wastewater [7]. The source specific data show that the supplies from renewable surface and groundwater sources were increased from 5410 MCM in 2004 to 5541 MCM in 2009 (0.5%/year increase). The non-renewable groundwater supplied approximately 13500 MCM and 11550 MCM water in 2004 and 2009, respectively (3.1% decrease/year). The desalinated water supplied approximately 1070 MCM and 1048 MCM water in 2004 and 2009, respectively (0.4% decrease/year). Use of treated wastewater was increased from 260 MCM to 325 MCM during this period [7].

The available water sources are limited in Saudi Arabia, which can be further affected by the impacts of climatic change [8]; a recent study has indicated that the reference evapotranspiration could increase from 0.245 m/year to 0.368 m/year from 2011 to 2050. The loss of soil moisture was estimated to be 0.181 m/year (0.042 m/year–0.236 m/year) during this period. Increase in temperature was estimated to be 1.8°C–4.1°C during this period, which could raise agricultural water demands by 5%–15% to maintain the current level of agricultural productions.

To develop a sustainable water resources management strategy, it is important that the available water sources are characterized, trends of water uses are identified and possible new sources of water are investigated. In this research, available water sources, current water demands and trends of water uses are investigated, and predictive equations were developed to assess future water demands. Possibility of developing new sources for water has been investigated. Finally, an approach to obtain sustainability in water resources has been outlined.

Resource Characterization

Non-renewable ground water sources

In Saudi Arabia, the shallow alluvial and deep rock aquifers are the two major sources of groundwater. The deep rock aquifers are sedimentary in origin, usually sandstone and limestone, extending over thousands of square kilometers with poor natural recharge through upland and foothill zones where the rocks have surface outcrops. These aquifers include the major formations of Saq, Tabuk, Wajid, Minjur-Dhurma, Biyadh-Wasia, Umm er Radhuma and Dammam, which are known as the principal aquifers [9-10]. The groundwater in these aquifers is non-renewable or 'fossil' water, which was formed approximately 10 to 32 thousand years ago [11]. This fossil groundwater is confined in sand and limestone formations of a thickness of about 300 m and are located at a depth of 150–1500 m. Most of the fossil groundwater in Saudi Arabia is stored in the principal aquifers in the eastern and central parts of the country (Figure 1). Past studies have reported variable amounts of fossil water reserves in Saudi Arabia. The Food and Agriculture Organization (FAO) reported that the groundwater reserves were 253.2 BCM as the proven resource, while the probable and possible reserves were estimated to be 405 BCM and 705 BCM, respectively [1]. Abderrahman [5] reported groundwater reserves of 2185 BCM to a depth of 300 m from the ground surface. The Ministry of Planning reported that the groundwater reserves were approximately 338 BCM with a probable reserves reaching to 500 BCM (noted in [1]). The natural recharge to these aquifers is approximately 1.28 BCM per year [9], while approximately 394 MCM/year of water drains out from Saudi Arabia to Jordan (180 MCM), Bahrain (112 MCM), Iraq (80 MCM), Kuwait (20 MCM) and Qatar (2 MCM). Using the data from the Water Atlas and Ministry of Planning [9-10,12], the proven, probable and possible groundwater storage are presented in Table 1. The proven, probable and possible groundwater water reserves in the major aquifers are 259.1, 415.6 and 760.6 BCM, respectively [10-12]. The estimated reserves were based on the data from 1984 [9]. However, a previous study indicated that approximately 141.1 BCM groundwater was used from the principal aquifers between 1984 and 1996 [10].

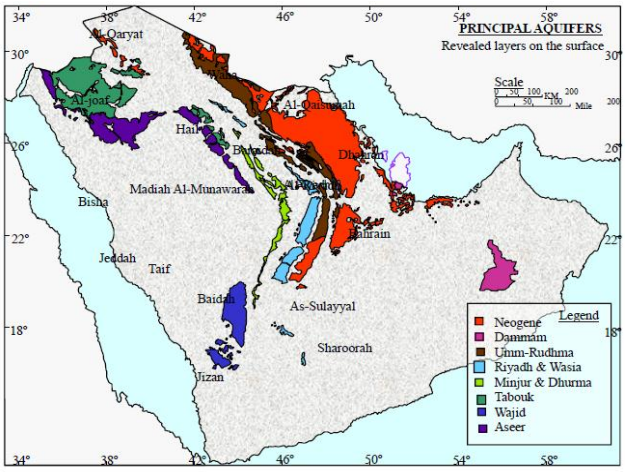

Figure 1. Principal aquifers for groundwater in Saudi Arabia

Table 1. Fossil groundwater in Saudi Arabia (a: proven; b: probable; c: possible) [10,12]

Aquifer	Depth	Water Quality	Reserve (BCM)		
			a	b	c
Saq	Thickness: 400–800 m	Moderately mineralized: TDS <1000 ppm	65	100	200
Wajid	Thickness 200–400 m	TDS < 1000 ppm	30	50	100
Tabuk	Thickness: ~1070 m	TDS: 500–600 ppm (Tabuk); 600–3500 ppm (E); 2500–4000 ppm (N)	5.6	5.6	5.6
Minjur/ Dhurma	Depth: 1200–1500 m Thickness: Minjur: 310-400 m; Dhurma: 100–110 m	Salinity increases with depth: TDS: 1200–15000 ppm	17.5	35	85
Wasia-Biyadh	Biyadh: 100–400 m thick. Wasia: 50–550 m thick.	Dissolved solids: ~ 150,000 ppm	120	180	290
Umm er Radhuma	Depth: 240–700 m	Heavily mineralized	16	40	75
Dammam-Neogene	Depth: 20–80 m	Dissolved solids: < 1000 ppm	5	5	5

Some aquifers showed significant drops in their water levels. For example, the piezometric level in Minjur aquifer reduced from 45 m to 170 m below surface between 1956 and 1980 [13]. The water level in the Wasia aquifer declined at well M1-1-W from +131 m above the land surface in 1978 to +125 m above land surface in 1982, a net decline of 6 m in water level during four years [11]. During the past 15 years (1996 to 2011), it is likely that significant amount of groundwater from the remaining reserves have been extracted and/or drained out from the Saudi Arabian aquifers [1]. The data in the Ninth Development Plan show that the withdrawals of groundwater from the non-renewable sources were 13.5 BCM and 11.6 BCM in the year 2004 and 2009, respectively [7]. Abdurrahman [5-6] reported that groundwater withdrawals were 24.5, 28.6 and 15.4 BCM in 1990, 1992 and 1997, respectively. At these rates of extraction, the available reserves may not last for a long time. It is important that the currently available economically viable reserves in these aquifers and their yields be better understood.

Renewable surface and groundwater sources

The source of surface water in Saudi Arabia is the seasonal precipitation. The largest quantity of runoff occurs in the western region, which represents approximately 60% of the total runoff although it covers only 10% of the total area of the country [1]. The remaining 40% of the runoff occurs in the far south of the western coast (Tahama), which covers 2% of the total area [1]. The total runoff in Saudi Arabia has been estimated to be 2.2 BCM/year [5], most of which infiltrates to recharge the shallow alluvial aquifers located along the river valleys and beneath the alluvial fans and plains in various areas. These aquifers are generally unconfined, small in area and have water tables that respond rapidly to local precipitation conditions. Some of the shallow aquifers are Khuf, Tuwail, Aruma, Jauf, Sakaka and Jilh in basalt and alluvial areas. The shallow aquifers have been tapped for years. In most of the shallow aquifers, water is being used at a much faster rate than these can be replenished [10]. An example of these shallow aquifers is the Jubaylah aquifer in Riyadh, which is about 100-150 m thick, where many water wells (e.g., city wells) were suspended due to falling water levels [10].

To facilitate the storage and recharge of surface runoff, a total of 302 dams in the country where build. These store about 1.4 BCM of surface runoff annually [7]. Among these, 275 dams are used for groundwater recharge and control, which recharge about 992.7 MCM/year water (Table 2). A total of 25 dams stores 303.5 MCM water annually for drinking purposes,

while 2 dams are used to store 51.5 MCM water annually for agricultural purposes (Table 2). Some of the major dams are King Fahd dam in the Asir (capacity: 325 MCM), Wadi Abha in the Asir (capacity: 213 MCM), Rabigh dam in Makkah (capacity: 220.4 MCM) and Bish dam in Jizan (capacity: 193.6 MCM). Details on the dams are available in literature [14]. The total internal renewable water resources are estimated at about 2.4 BCM/year [1]. The Kingdom has low average annual rainfall [5,8]. In the north, annual rainfall varies between <100–200 mm. However, in the south, 500 mm/year rainfall is not uncommon [1]. The long term average of rainfall across the country was estimated to be about 114 mm/year [1]. The country has an area of 2,149,690 km^2, which results in approximately 245 BCM rainfalls annually [1]. However, most of the rainfall occurs in the west, south and south-western parts, which cover less than 13% of the total area [1]. Currently (year??), the total freshwater requirement in Saudi Arabia is approximately 20 BCM/year [7,15]. The rainfall in the west, south and south-westerns parts can provide an opportunity to harvest rainwater, leading to substantial support toward achieving sustainability in water resources.

Table 2. Summary of the dams and their storage across Saudi Arabia (MCM/year) [14-15,17]

	Storage		Control		Drinking		Irrigation	
Province	Dams	Capacity	Dams	Capacity	Dams	Capacity	Dams	Capacity
Riyadh	48	72.87	19	19.12				
Makkah	27	58.60	7	234.75	2	42.80		
Madina	14	20.70	6	64.45				
Asir	43	358.81	17	16.59	17	35.99		
Jazan	1	0.25	1	0.15	4	194.17	1	51.00
Najran	8	2.98	4	87.08				
Baha	25	9.62	3	0.14	2	30.50	1	0.50
Qassim	8	5.16	1	1.30				
Tabuk	8	6.63						
Hail	22	11.05	3	1.76				
Northern borders	6	20.65						
Jouf			4					
Column Total	210	567.32	65	425.34	25	303.46	2	51.50

Desalinated water

Desalination of sea water has been practiced in many countries. Saudi Arabia produced 7.65 MCM desalinated water in 1980 [16]. In 31 years (1980–2011), the Kingdom has 30 desalination plants in operation along the coasts of the Red Sea and the Arabian Gulf, producing the largest amount of desalinated waters in the world [7].

The Ninth Development Plan of the Ministry of Economy and Planning (MOEP) reported that the Kingdom produced approximately 1070 and 1048 MCM of desalinated water in 2004 and 2009, respectively [7]. This reflects a 0.4%/year decrease in desalinated water. The annual report of the Ministry of Water and Electricity (MOWE) shows that the desalinated water supply was 1141.7 MCM/year for the year ?2008? [15]. The plant specific production, desalination approaches, commissioning dates and design lives are presented in Table 3 [16]. The total production of desalinated water was 1055.1 MCM in 2009 [16]. Table 3 shows that the design lives of thirteen plants have already been expired. For example, the Jubail 2 plant, which produces the largest amount of desalinated water (297.5 MCM/year), was commissioned in 1983 with a design life of 25 years (Table 3). To produce more desalinated

water, two new plants are being constructed in Jeddah and Ras Al-Zor, and there is a plan to construct more plants in the near future [16]. The plants use different approaches for desalination: First Stage, Second Stage, Third Stage, Reverse Osmosis (RO) and Multi-effect (MED) respectively [16]. These plants also produce approximately 3355 MW electricity/year (Table 3). Desalinated waters are mainly used for domestic purposes in the major cities (Riyadh, Madina, Mecca, Jeddah, etc.). Among these cities, Riyadh, Makkah, Madina and Eastern province consume approximately 90% of the desalinated water. The desalinated water is generally blended with the groundwater prior to supply to the consumers. Overall, desalinated water supplies approximately 50% of the domestic water needs in the country (~1000 MCM/year), while remaining demands are satisfied from the non-renewable groundwater sources [15].

Table 3. Summary of desalination plants in Saudi Arabia [16]

Plant	Supply (MCM) /yr	Plant total (MCM)/yr	Service Area	Commission date	End of life	Elec. (MW)	Stage	
Jubail 1	43.23	369.31	Riyadh, Jubail, Jubail Naval base and Royal Commission in Jubail	1982	2007	238	1st	*
Jubail 2	297.54			1983	2008	762	2nd	*
Jubail RO	28.54		Riyadh, Qassim, Sudair	2000	2025		RO	
Khobar 2	70	157.89	Khobar, Dammam, Qatif, Dhahran airport, Saihat, R. Tanura, Hofuf	1983	2008	500	2nd	*
Khobar 3	87.89			2000	2025	311	3rd	
Khafji	7.18	7.18	Res Al-Khafji	1986	2011		2nd	*
Jeddah 3	27.74	132.95	Jeddah	1979	2004	200	3rd	*
Jeddah 4	69.55			1982	2007	500	4th	*
Jeddah RO1	17.83			1989	2014		RO	
Jeddah RO2	17.83			1994	2019		RO	
Shoaiba 1	70	212.68	Makkah and Taif	1989	2014	157	1st	
Shoaiba 2	142.68		Makkah, Jeddah and Taif	2001	2026	340	2nd	
Yanbu 1	34.54	117.4	Yanbu, Medina and nearby villages	1981	2006	250	1st	*
Yanbu 2	43.84			1998	2023	35	2nd	
Yanbu RO	39.02			1998	2023		RO	
Shoqaia	30.45	30.45	Abha / Khais Mushait, Rafidah, military city, nearby villages	1989	2014	62	1st	
Haql RO	1.38	1.38	Field and nearby villages	1990	2015		2nd	
Duba RO	1.38	1.38	Duba and nearby villages	1989	2014		3rd	
AlWajih	3.29	3.29	Face and nearby villages	2009	2034		3rd, MED	+
Umlujj RO	1.38	1.38	Trowel	1986	2011		RO	*
Umlujj 3	3.29	3.29	Trowel and its villages	2009	2034		3rd, MED	
Rabigh 1	0.44	0.44	Rabigh and nearby villages	1982	2007		1st	*
Rabigh Trns.1	0.28	0.28	Rabigh and nearby villages	1979	2004		RD	*
Rabigh 2	6.57	6.57	Rabigh, covert, Thule	2009	2034		2nd, MED	
Alazizia	1.41	1.41	Island Azizia	1987	2012		1st	
Albirk RO	0.71	0.71	Ponds and nearby villages	1983	2008		1st, RO	*
Farasan1	0.16	0.16	Knights Island	1979	2004		1st	*
Farasan Trns.1	0.39	0.39	Knights Island	1978	2003		RD	*
Laith	3.29	3.29	Laith	2009	2034		1st, MED	
Al-Qunfutha	3.29	3.29	Qunfudah, Al-Quoz-Costume	2008	2033		1st, MED	

(*) Design life expired; RO: Reverse Osmosis; MED: Multi-effect; RD: Redeployed

Treated wastewater

Application of treated wastewater is in practice in many countries [1]. Treated wastewater (TWW) is generally used for agriculture, landscaping and industries. Saudi Arabia has been using a fraction of TWW in agriculture and industries. Wastewater is treated in sewage

treatment plants (STP) distributed across the country. Following treatment, a fraction of the TWW is recycled for reuse while the remaining is discharged into water bodies (e.g., Arabian Gulf or Red Sea) or into empty wadies. Previous studies [5] reported that TWW effluents were 110, 185 and 185 MCM in 1990, 1992 and 1997, respectively. Elhadj [3] reported that about 475 MCM/year of wastewater was treated in Saudi Arabia. The FAO data showed that about 547.5 MCM wastewater was treated in 2002 [1]. Generation of wastewater was higher than the TWW. For example, the generation of wastewater in 2000 was reported to be 730 MCM [1].

The plant specific TWW volume, the treatment types and disposal methods for some major STP are summarized in Table 4. The data shows that the annual wastewater treatment capacity of these plants is approximately 601.8 MCM/year, while these plants treated approximately 567.1 MCM/year. Among these plants, two plants in Riyadh (Riyadh North and South) treated approximately 146 MCM/year [3]. Table 4 shows that significant fractions of the TWW from many STP are discharged into the Wadi, lagoons, the Red Sea and the Arabian Gulf. The FAO data shows that about 166 MCM of TWW was reused in 2006 [1]. However, the Ninth Development Plan of the MOEP reported that the total reclaimed TWW (including agricultural wastewater) were 300 and 347 MCM in 2004 and 2009, respectively, which represented an increase of 3.1%/year [7].

The MOWE reported that the per capita domestic water consumption is approximately 226 L/day [15]. The total population in Saudi Arabia is 26 millions [4], requiring approximately 2144.7 MCM/year of domestic water. Assuming the coefficient for wastewater generation of 0.7, then approximately 1500 MCM/year of domestic wastewater is likely to be generated [15]. This indicates that approximately 37.8% of the wastewater is collected for treatment by the STP. Significant fraction of the remaining wastewater is likely to be discharged into the natural system without or with minimal treatment. Consequently, there is a risk of contamination of the groundwater aquifers, which can be reduced by reducing the discharges of wastewater. On the other hand, reuse of TWW must satisfy certain regulatory criteria to prevent microbial infections [18-19]. Human exposure to contaminants from TWW can occur through direct and indirect pathways [20-21]. To minimize such risks, wastewaters are treated to secondary and/or tertiary levels prior to reuse. In the secondary treatment, TWW typically have 30-100 MPN (most probable number) fecal Coliform/100 ml water, while the tertiary treatment produces effluent of 1-7 MPN fecal Coliform/100 ml [22]. Saudi Arabia follows stringent regulation that requires tertiary treatment to reuse wastewater effluent.

Table 4. Summary of major wastewater treatment plants in Saudi Arabia

Sl.	City	Plant Name	Design (m^3/day)	Treatment Scheme	Actual (m^3/day)	Disposal
1	Buraidah	Buraidah	11000	FP+MP	13000	To sand dunes
2	Unaizah	Unaizah	7080	AL	9900	To Wadi
3	Al-Kharj	Al-Kharj	21000	AL+SF	21600	To Wadi
4	Qatif	Sanabis	8340	2 stage FP	22195	Gulf
5	Qatif	Gesh	8990	2 stage FP	15930	Gulf
6	Qatif	Awamia	9260	2 stage FP	13430	Gulf
7	Qatif	Qatif	210000	OD	35000	Gulf + L.I.
8	Al-Hasaa	Oyoon	6310	2 stage FP	17100	To Lagoon
9	Al-Hasaa	Emran	13320	2 stage FP	22100	To Lagoon
10	Al-Hasaa	Hufuf-Mubarraz	29500	2 stage FP	136780	To Lagoon

11	Khafji	Khafji	25000	2 stage FP	5190	Gulf
12	Jeddah	Al-Khomra	36000	TF (stone)	66000	Red Sea
13	Jeddah	Plant C	40000	PCS	63000	L.I. + Lagoon
14	Jeddah	Plant A	32000	PCS	55000	L.I. + Red Sea
15	Jeddah	Bani Malik	8000	PCS	6500	L.I. mostly
16	Jeddah	Al-Jamia	8000	PCS	7000	Red Sea + L.I.
17	Jeddah	Tertiary (Al-Khomra)	30000	TF+O+C+SF+RO	20000	Red Sea L.I.
18	Jeddah	Al-Iskan	3000	AS	3,500	
18	Makkah	Old plant	24000	TF (stone)	65000	Wadi +A.I.
19	Makkah	New	50,000	PF+AC+NDN		
20	Riyadh	Al-Hayer old (South)	200,000	TF + PL+ASD	200,000	Wadi + A.I.+Ref.
21	Riyadh	Al-Hayer new (North)	200000	AS + NDN+F	200000	Wadi + A.I.+Ref.
22	Riyadh	Refinery	20000	C+F+RO+IE	13500	
23	KSU	KSU Plant	8000	Settling, TF	8000	L.S. + power plant
24	Riyadh	Diplomatic Quarter	9300	Screening, AS	9500	L.I.
25	Dammam	Dammam	208000	OD	140000	Gulf + L.I.
26	Al-Khobar	Al-Khobar	133000	OD	100000	Gulf
27	Madinah	New	120000	AS	100000	Wadi + L.I. + A.I.
28	Safwa	Safwa	7570	CM	8600	Gulf
29	Khamis-Mushait	Al-Dhoba	7500	OD	10,000	Wadi + L.I. + A.I.
30	Abha	Abha	9000	Aeration	11500	Wadi
31	Taif	Taif	67000	AS+NDN+F+ACF	34000	L.I. + A.I.
32	Jubail	Jubail Industrial city	12500	Tertiary	38630	A.I.
33	Saihat	Saihat		Secondary	15717	
34	Aramco 9 plants	Saudi Aramco	66000	Variable	66000	A.I. + Sea

L.I.: Landscape irrigation; A.I.: Agricultural irrigation; Ref: Refinery; FP: Facultative ponds; MP: Maturation ponds; AS: Activated sludge; TF: Trickling filters; SF: Sand filters; RO: Reverse osmosis; IE: Ion exchange; OD: Oxidation ditch; PCS: Package contact stabilization; AL: Aerated lagoons; O: Ozonation; C: Clarification; NDN: Nitrification-Denitrification; PL: Polishing lagoons; ASD: Anaerobic sludge digestion; F: Filtration; CM: Completely mixed; ACF: Activated carbon filters: PF: Plug flow

Trends of Water Consumption

Domestic water demand

Saudi Arabia has a relatively high population growth rate [4,23]. The population has increased from 6.9 million to 26 million from 1972 to 2011 [4,24]. The population increase coupled with improved lifestyle has increased the domestic water demands significantly. The MOEP reported that the domestic water demands in 2004 and 2009 were 2100 and 2330 MCM, respectively, reflecting an average increase of 2.1%/year [7]. The FAO reported that the domestic water demand in 2006 was 2130 MCM [1]. The Saudi Statistical Year Book (SSYB) presented the water demands based on the total number of subscribers in different regions [2]. The total number of subscribers to the municipal water systems increased from 687813 to 844243 (22.7% increase) between 1999 and 2008 [2]. Using data from the SSYB, the growth of subscribers for the entire country can be approximated as:

$$Log_{10}(Y_s) = C_o + K(X+1) \quad (1)$$

Where, Y_s = number of subscribers at X years from 1999; C_o = coefficient of Equation 1 (e.g., 5.817 for Saudi Arabia); K = slope of Equation 1 (0.01101 for Saudi Arabia); X = no. of years after 1999. The R^2 of Equation 1 was 0.89.

In 1999, average water consumption per subscriber was 1391 m^3 (609–2028 m^3)/year. In 2008, average water consumption per subscriber was increased to 3818.1 m^3 (1687.2–7404 m^3)/year. To predict the per capita consumption in 1999 and 2008, the subscribers were compared with the populations. In 1999 and 2008, total populations in Saudi Arabia were estimated to be 21.38 and 28.17 million, respectively [4,23-24]. The persons per subscriber was 31.08 in 1999, which was increased to 33.34 in 2008 (0.7%/year) [2,23]. The increase in persons/subscriber can be approximated as:

$$P_X = P_o(1+rX) \tag{2}$$

Where, P_X = persons per subscriber at X years from 1999; P_o = persons per subscriber in 1999 (e.g., 31.08 persons/subscriber for Saudi Arabia); r = rate of increase per year (e.g., 0.007/year for Saudi Arabia); X = number of years after 1999. The R^2 value for Equation 2 was 0.76.

Equations (1) and (2) represent the generalized forms of predicting subscribers and persons per subscriber for the entire country. The parameters for Equations (1) and (2) to predict the domestic water demands on regional basis are presented in Table 5. Following the predictions of subscribers and persons/subscriber, water demands can be predicted as:

$$WD_{DOM} = W_{USE} \times P_X \times Y_s \tag{3}$$

Where, WD_{DOM} = domestic water demands (m^3/year); W_{USE} = water demands per person per year (m^3); P_X = number of persons/subscriber in year X after 1999; Y_s = number of subscribers for that year.

To estimate W_{USE}, historical rate of domestic water use has been considered. Elhadj [3] reported that the per capita water use was approximately 250 liter per capita per day (LPCD). The MOWE reported that the average use of domestic water in 2009 was 226 LPCD [15]. The SSYB presented the consumption of municipal water per subscriber as 1391.1 m^3 and 3818.1 m^3 in 1999 and 2008, respectively [2]. These data showed that the use of municipal water was approximately 122.6 and 313.8 LPCD in 1999 and 2008, respectively. The overall average use of municipal water between 1999 and 2008 was estimated to be 219.1 LPCD, while the averages for different regions varied in the range of 119-378 LPCD [2]. The minimum use of domestic water was 590.6 m^3/subscriber (50.2 LPCD) in Taif in 2001 and the maximum use of domestic water was 7826.7 m^3 per subscriber (629.5 LPCD) in Dammam in 2007 [2]. Using Equations (1-3) and the per capita water use of 219 LPCD (W_{USE}), domestic water demands were predicted from 2012 through 2020. The results are presented in Figure 2.

Table 5. Equations for predicting domestic water demands

Equations	State/Country	Parameter values	R^2
$Log_{10}(Y_s) = C_o + KX$ $P_X = P_o(1 + rX)$	Saudi Arabia	[C_o = 5.817; K = 0.01101]; [P_o = 31.08; r = 0.007]	0.89; 0.76
	Qasim	[C_o = 4.654; K = 0.020]; [P_o = 28.02; r = 0.005]	0.98;0.66
	Asir	[C_o = 4.172; K = 0.012]; [P_o = 34.7; r = 0.004]	0.94;0.67
	Al-Khobar	[C_o = 4.384; K = 0.016]; [P_o = 27.34; r = 0.009]	0.69;0.62
	Dammam	[C_o = 4.57; K = 0.014]; [P_o = 28.06; r = 0.006]	0.98;0.81
	Taif	[C_o = 4.569; K = 0.008]; [P_o = 33.2; r = 0.006]	0.96;0.73
	Makkah*	[C_o = 4.773; K = 0.007]; [P_o = 30.3; r = 0.015]	0.96*;0.72
	Yanbu	[C_o = 3.899; K = 0.016]; [P_o = 34.7; r = 0.009]	0.86;0.66
	Madinah	[C_o = 4.699; K = 0.008]; [P_o = 29.08; r = 0.011]	0.63;0.62
	Jeddah	[C_o = 5.133; K = 0.008]; [P_o = 30.3; r = 0.012]	0.81;0.57
	Riyadh	[C_o = 5.384; K = 0.013]; [P_o = 29.8; r = 0.009]	0.89;0.74

*X should be replaced by (X-1)

Equations (1-3) have predicted the domestic water demands for 2004 and 2009 as 1966 and 2307 MCM, respectively (Figure 2). In these years, actual water demands were 2100 and 2330 MCM, respectively [7]. The predicted demands are fairly consistent with the actual demands (1%–6.4% variation). Furthermore, the MOEP estimated the domestic demands as 2583 MCM in 2014 [7]. Equations (1-3) have predicted the domestic water demands in 2014 as 2704 MCM, which is 4.5% more than the MOEP estimates (Figure 2) [7]. For the year 2020, the domestic water demand was predicted to be 3268 MCM (Figure 2). At this year, total number of subscribers is predicted to be 1.146 million for the entire country (Figure 2) and persons/subscriber is estimated to be 35.65. To predict the domestic water demands for different provinces, Equations (1-3) and the coefficients in Table 5 can be used.

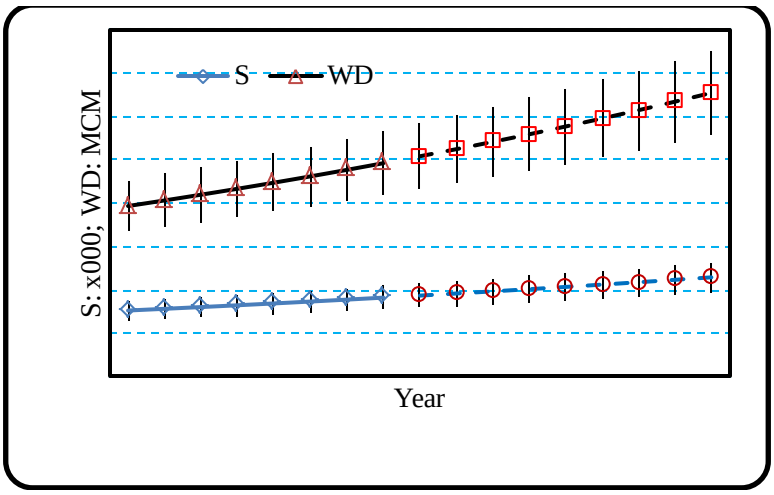

Figure 2. Domestic water demands in Saudi Arabia (error bars show the Std. Dev; S: Subscribers in thousands; WD: Water demands in MCM; dotted lines for future forecast)

Industrial water demand

The industrial water demands in Saudi Arabia are less than half of the domestic water demands [7]. The industrial demands were 56 MCM/year in 1980 [6]. The FAO reported that the industrial demand was approximately 710 MCM in 2006 [1]. In 2009, this demand was reported to be 713 MCM/year [7]. The MOEP reported that the industrial demand increased

by 2.2%/year between 2004 and 2009. However, for the period 2009-2014, the growth in industrial water demand was estimated to be 5.5%/year, leading to probable industrial water demands of 930 MCM/year in 2014 [7]. Using the long term industrial water consumption data (1980-2009), the trend of water use has been characterized using the power law equations as:

$$WD_{IND} = a \times (Y+1)^b \quad (4)$$

Where, WD_{IND} = water demands for industrial purpose (MCM/year); a = 235.06 (range: 207.29–262.83 as the 95 percentile C.I. value); b = 0.43 (range: 0.399–0.455 as the 95 percentile C.I. value); Y = year after 1992.

Equation (4) was applied to predict the industrial water demands. The predicted demands were compared with the reported demands. These are shown in Figure 3. The predicted demands are in agreement with the actual demands (Figure 3). For example, actual industrial water demand in 2000 was 550 MCM/year [6], while the predicted water demand was 604.6 (498.1–714.3) MCM/year (9.9% inflated). In 2006, the reported industrial demand was 710 MCM/ year [1], while the predicted water demand was 753.2 (610.7–901.1) MCM/year (6.0% inflated). For 2014, industrial demand was forecasted to be 930 MCM/ year by the MOEP [7], while the forecast by Equation (4) was 905.2 (724.3–1094.6) MCM/year (2.7% lower). This study predicts the industrial water demand as 1000 MCM/year (range: 794.5–1216.4) in 2020.

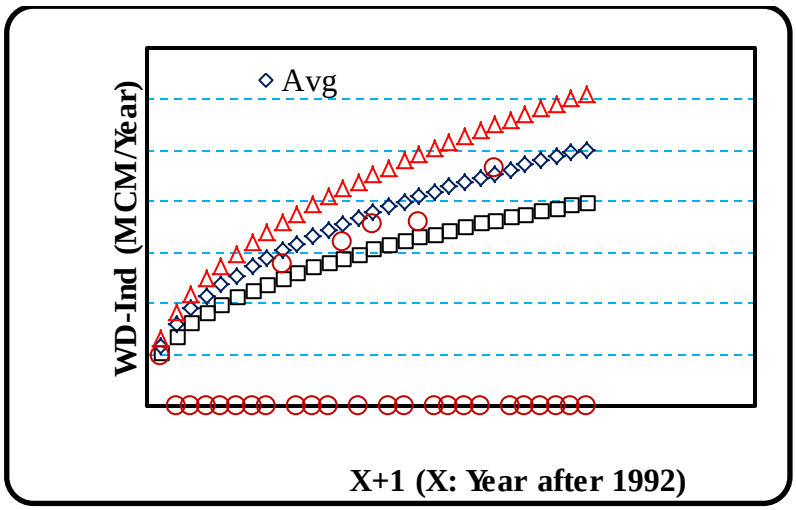

Figure 3. Industrial water demands in Saudi Arabia (Avg: Mean demands; Min: Minimum demands; Max: Maximum demands; Actual: The historical water demands)

Agricultural water demand

The agricultural water demands depend on the extent of agriculture, crops and type of irrigations. In Saudi Arabia, the cultivable land was estimated to be 52.7 million hectares (Mha) [1]. In 1971, total cultivated land was less than 0.4 Mha [25]. In 1992, the cultivated land was expanded to about 1.62 Mha [25]. The SSYB reported that the total cultivated lands

were 1.11, 1.07 and 1.07 Mha in 2005, 2006 and 2007, respectively [2]. Most of these lands were used for wheat, fodder crops, fruits, dates and vegetables productions [2]. For example, 0.489, 0.468 and 0.450 Mha land area was used for wheat productions in 2005, 2006 and 2007, respectively [2]. Different types of crops (wheat, fodder crops, barley, dates, vegetables, fruits, etc.) are produced through various irrigation practices [1]. Water demands are significantly different among various crops and types of irrigations [10]. For example, 1 ha land for wheat production requires about 13713 m^3 water, while the same area for dates production requires about 9100 m^3 water [10]. Generally, the water demands vary in the range of 9,100–39,000 m^3 per ha [10].

The agriculture sector is the largest consumer of water in Saudi Arabia, consuming more than 80% of the total water demands [5,7]. The historical data showed that agricultural water demand was 1850 MCM/year in 1980 [5]. In 1992, agricultural water demand reached 29826 MCM/year [5]. Since then, a policy has been taken to conserve water in the agricultural sector, which was reflected in reduction in water use in the following years. For example, the SSYB reported that the agricultural water demand was 17530 and 15464 MCM/year in 2004 and 2009, respectively, reflecting a decrease of 2.5%/year [7]. The MOEP has undertaken a plan to reduce the agricultural water demands to 12794 MCM/year in 2014, which will reduce the agricultural water by 3.7%/year [7]. Using past data, trend of agricultural water use has been characterized by the exponential relationship as:

$$WD_{AGR} = a \times e^{b(Z+1)} \tag{5}$$

Where, WD_{AGR} = water demands for agriculture (MCM/year); a = 18287.5 (range: 18018.3–18558.5 as the 95 percentile C.I. value); b = 0.033 (range: 0.029–0.039 as the 95 percentile C.I. value); Z = year after 2004.

Equation (5) was applied to predict agricultural water demands. The differences between the MOEP [7] and predicted demands were between 1-6%. It is to be noted that the agricultural water demands can be significantly affected by the climatic change [26-27]. Studies have predicted the overall increase in temperature in the range of 1.8°C–4.1°C from 2011 to 2050, while an overall increase in the reference evapotranspiration was predicted to be 10.3%–27.4% [8]. A recent study showed that an increase in the temperature by 1°C may increase agricultural water demands by 2%–4% in Saudi Arabia [26]. Another study reported possible increase in agricultural water demands by 5%–15% by 2050. This implies that to maintain the current level of agriculture, water demands will be increased from X MCM/year to 1.05X–1.15X MCM/year [8]. In developing long term predictive models for agricultural water demands, it is essential that implications from various factors be adequately understood, including: i) policy on reducing agricultural crop productions in future; ii) implications of climatic change on agricultural water demands; iii) types of crops, effective area and crop specific water demands; and iv) irrigation practices.

Sustainable Water Resources Management

The data on water availability and water consumptions show that Saudi Arabia needs to act on sustainable water resources management. The available non-renewable and renewable water sources, desalinated water and treated wastewater may not be enough to satisfy the

domestic, industrial and agricultural water demands in future. It is imperative that alternative resources be discovered. The options may include extensive desalination and importing water through channeling from other countries. However, feasibility of these options needs to be evaluated in context to regional political stability, cost, bilateral relationships and environmental impacts. In Saudi Arabia, a total of 30 desalination plants are already in operation, producing approximately 1 BCM of water annually [16]. It is important to know the number of new plants along with their capacities those can be supported in the coasts of the Red Sea and the Arabian Gulf. Further, increasing the capacities of the existing plants is another option. However, the costs and environmental implications need to be evaluated in extensive expansion of desalination plants.

Recently, Libya and China have started projects for water transportation from one region to another region within the country through channeling [28]. However, this option needs adequate water reserves and significant cost, which might not be feasible in Saudi Arabia. Any option using the locally available resources may be the most dependable one. Zuhair *et al.* [29] demonstrated that rainwater harvesting (RWH) can provide significant amount of freshwater in the Arabian Gulf States. Chowdhury and Al-Zahrani [8] showed that the averages of rainfall in the northern and southern parts of Saudi Arabia were 70.1 and 264.6 mm/year, respectively, with the countrywide average of 125 mm/year [8]. The western and south-western regions of the country often have intense rainfall [1,8]. This may provide an opportunity to collect and store substantial amount of freshwater, which can be transported through channeling and/or pipelines [28]. In addition to the surface runoff, direct harvesting can be done through the employment of the residential rooftop collection systems. However, comprehensive investigation is warranted in context to water demands in various sectors, rainfall intensity and patterns, effective runoff, rooftop collection area and cost of water transportation and treatment prior to selecting this approach for sustainable water resources management.

Conclusion and Recommendations

This study characterized the water sources and water demands in various sectors in Saudi Arabia. The domestic and industrial water demands have been increasing, while the agricultural water demand has been decreasing. However, decrease in the agricultural water demands might be due to the policy of the country and/or advanced irrigation practices. If adequate water reserves can be ensured, this policy might be changed. Trends of water demands were investigated. Nonlinear equations were developed to predict water demands in various sectors. The equations predicted the water demands with reasonable accuracy. The available water resources and trends of water uses show that the country must act on sustainable water resources management through developing additional sources of water supplies. Among the few possibilities, rainwater harvesting can be the promising one. There is an immediate need to understand the overall water resources through comprehensive studies. Further, preventing water loss through the leakage in the water distribution networks can save significant amount of water. Understanding these factors is essential to achieve sustainable water resources management.

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DAY TWO
Monday, 23 April, 2012

SESSION 3A:
CONVENTIONAL WATER RESOURCES MANAGEMENT

Keynote: Abdin Salih, UNESCO-IHP, Sustainable Management of Natural Water Resources

Prof. Abdin SALIH

Abdin Mohamed Ali Salih, Professor Civil Engineering Department, Faculty of Engineering, University of Khartoum; Education includes degree in Civil Engineering from University of Khartoum; and DIC and PhD from Imperial College London, in 1973. Various academic positions at many universities in Africa, Middle East, Europe and USA, with full professorship since 1982 at the University of Khartoum. Deputy Vice-Chancellor of the UoK 1990-92. Worked for UNESCO, 1993-2008, as Regional Hydrologist in Cairo, Deputy Secretary of the International Hydrological Programme (IHP) of UNESCO in Paris; and Director of UNESCO Regional Offices in Cairo and Tehran. Following retirement from UNESCO in 2008 he was elected as the President of the Intergovernmental Council of the IHP of UNESCO until 5 July 2010. He is a member of the Bureau of the IHP and Member of the Governing Board of the UNESCO-IHE Institute for Water Education.

Abstract:

Sustainable water resources management has been recognized as an integral element of national, regional and international peace and security. In addition to the challenge posed by climate change, which is expected to adversely affect the availability of fresh water resources in the Arab Region, challenges such as population growth and increased development pose additional stresses on water resources. The challenge is even more pronounced in the GCC countries, where the climatic conditions are among the harshest in the world and water resources are the most scarce compared with any region in the world. The world Bank's "*Water Sector Assessment Report on the Countries of the Cooperation Council of the Arab States of the Gulf"* (WB 2004) emphasized that by 2030, the per / capita freshwater resources in the region will reach about 94 cubic meters (WB 2004) without further development of additional resources through other means such as water harvesting.

The unique economic conditions of the GCC countries provide opportunities for alternative strategies to develop fresh water resources. Water desalination is increasingly becoming a primary source of fresh water in the region and wastewater re-use could be another promising potential. At the same time, the high cost and of the energy intensive desalination process necessitate a fully integrated conservation strategy that addresses the increasing demand for water, manages and reduces losses, mitigate the potential unforeseen impacts and, maintains a sustainable development of fresh water resources.

This presentation will provide an overview of the deepening crisis facing water resources in the Arab region and some of the potential solutions that focus on alternative and non-conventional sources (water harvesting, desalination, virtual water) with conservation being one of these sources. The presentation will also discuss some of the potential problems associated with non-conventional sources. The potential contributions of UNESCO's

International Hydrological Programme, during its upcoming eighth phase (IHP-VIII 2014-2021) to the improved sustainable management of water resources will also be discussed, with issues relevant to GCC countries and the Arab region being highlighted.

Keynote: Iyad Hussain, Jordan, Development of Risk Assessment Indicators for the mega scale shared water projects

Development of Risk Assessment Indicators for the mega scale shared water projects in the Arab World ; the case of Red-Dead Sea Canal, Peace Pipeline, Unity Dam and Disi Groundwater projects

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Abstract:

The level of risk acceptability depends on the need and anticipated responses. Usually decision-making process under risk is a big challenge for the decision maker and taker, especially when the subject is related to water resources. In the Arab World, where water is a precious and vital public commodity that will not sustain high risk in its delivery at the right time to the right place with the right quantity and quality within affordable price.

Many mega scale shared water projects were implemented, designed or planned in the Arab world among the riparian countries. These shared water projects have certain level of risk depends on the economical, political and financial aspects among the riparian countries. Five mega scale projects have been selected to be the domain for making the exercise of developing a risk assessment indicators for these projects. The aim of this paper is to develop a scale of evaluation for the decision makers based on the risk assessment techniques that will consider five sides of evaluation technical financial, economical, political and environmental.

The five selected mega scale projects are: Red – Dead Sea Canal between Jordan, Israel and Occupied Palestinian territories, Peace Pipeline form Turkey to Gulf and some other Arab Countries, Unity Dam between Jordan and Syria and last the Disi Groundwater development between Jordan and Saudi Arabia. The Governments had to overcome the "high risk" decisions by adopting "hydro-diplomatic" dialogue and "mutual benefits" agreements with the potential riparian. In other similar cases, where politics is the valued component in the process of high-risk decision-making, more coordination, collaboration and communication will be necessary to manage the risk consequences.

Groundwater Vulnerability Map For Northeast Missan Governorate, Southern Iraq

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Abstract

Nowadays, aquifer vulnerability assessments are carried out in almost all developed countries in areas where water resources are under stresses originating from urbanization, industrial and agricultural activities. The vulnerability studies can provide valuable information for stakeholder working on preventing further deterioration of the environment. Assessment of aquifer vulnerability is based on using GIS-DRASTIC model. Preparation of DRASTIC factors was achieved through gathering data from different sources including field survey; geological and meteorological data, a digital elevation model DEM of the study area, archival database, and published research. The DRASTIC parameters include; Depth to groundwater level (D), net recharge (N), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I), and hydraulic conductivity (C). The obtained results related to the vulnerability to general contaminants showed that the study area is characterized by three vulnerability zones: very low, low, and moderate. The DRASTIC index ranges between 69 and 128, and (85%) of the study area has a very low class of groundwater vulnerability to contamination, whereas a total of (15%) of the study area has low vulnerability. Only (1%) of the study area falls within the moderate class and there are no areas in the high and very high classes. A very large area (99%) in very low and low vulnerability classes may be attributed to the impact of vadose zone and the low values of hydraulic conductivity of the aquifer.
The pesticides DRASTIC index map showed that study area is characterized by three zones of vulnerability too: low, moderate, and high. The Pesticides DRASTIC index ranges between 91 and 171, which is higher than the standard DRASTIC index. The resulted map of this version of DRASTIC clearly shows that significant parts of the study area (southwestern) has high vulnerability to contamination, and most parts of the study area have low vulnerability to pollution (about 64%). The moderate vulnerability area distributes unevenly through the area from south to north and occupies only (16%) of the study area. This pattern may relate to the variation on the impact of vadose zone from south to north and low values of hydraulic conductivity and net recharge.

Keywords: Vulnerability map, Vulnerability index, DRASTIC, Sensitivity analysis.

1. INTRODUCTION

The term "**vulnerability**" is used to describe the degree to which human or environmental systems are likely to experience harm due to perturbation or stress, and can be identified for a specified system, hazard, or group of hazards [1] .Aquifer vulnerability studies are useful in the evaluation of the economic impacts of the waste disposal in highly vulnerable areas. Moreover, they are providing preliminary information and criteria for decision making in such areas as designation of land use controls, delineation of monitoring networks, and management of water resources in the context of regional planning as related to protection of groundwater quality. Yet internationally, vulnerability maps were becoming an essential part of groundwater protection schemes and a valuable tool in environmental management.
The National Research Council [2] outlined three 'laws' of groundwater vulnerability that should be spelled out explicitly with every vulnerability assessment:

- All groundwater is to some degree vulnerable.
- Uncertainty is inherent in all vulnerability assessments.
- In the more complex systems of vulnerability assessment, there is a risk that the obvious may be obscured and the subtle may become indistinguishable.

The first attempt to the concept of groundwater vulnerability to contamination was applied by Margat (1968) in France. Then there were several approaches for developing aquifer vulnerability assessment maps, such as DRASTIC [3], GOD [4], AVI [5], SINTACS [6], etc. A thorough overview of existing methods is given in Vrba and Zaporozec [7] and in Gogu and Dassargues [8]. These methods have been mainly applied to groundwater protection in porous aquifers, except the EPIK [9], PI and COP [10] methods which were specifically developed for the assessment of vulnerability in karstic area.

2.METHODOLOGY

The best known and probably the most widely applied scheme of vulnerability assessment was developed by the US Environmental Protection Agency (USEPA) and is known as the DRASTIC methodology applied later in several regions by different researchers where they modified this system to meet a wide range of application such as land use index, lineaments, aquifer thickness and impact of contaminant. Thirumalaivasan et al (2003) developed a software package AHP-DRASTIC to derive rating and weights for modified DRASTIC model parameters [11].

A DRASTIC method was derived from rating and weights associated with the seven parameters. These are: Depth to groundwater (D), Net recharge (R), Aquifer media (A), Soil media (S), Topography (T), Impact of the vadose zone (I) and Hydraulic conductivity (C) . Each parameter is subdivided into ranges and is assigned different ratings in a scale of **1** least contaminant potential to **10** highest contaminations potential.

The DRASTIC numerical ranking system contains three major parts: Weights, Ranges, and Ratings. The final vulnerability index is the weighted sum of the seven factors and can be computed using the following formula :

$$\text{Vulnerability index} = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw \quad \ldots\ldots\ldots (1)$$

where D, R, A, S, T, I, and C are the seven factors of the DRASTIC method, w the weight of the factor, and r the rating associated. Values of DRASTIC index vary from 26 to 256 in the case of the DRASTIC pesticides and from 23 to 226 in the case of the DRASTIC standard version. Aller et al. (1987) did not propose any classification for their drastic results, so the vulnerability ranges of the DRASTIC index used in this study correspond to the most commonly used references in the literature [12] &[13] (Table 1).

Table 1 Criteria of the evaluation of the degrees of vulnerability (Civita and De Regibus, 1995; Corniello et al., 1997)

Degree of vulnerability	DRASTIC index
< 80	Very low
80 – 120	Low
120 – 160	Moderate
160 – 200	High
> 200	Very High

2.1 Description of DRASTIC factors in the study area: The DRASTIC parameters include the following features:

2.1.1 Depth to Groundwater levels (D):

The groundwater depth for main aquifer in the study area was classified into four classes using classification command in spatial analyst with regard to DRASTIC rating system (Figure1 and Table 2). The depth to groundwater was classified from one (least effect on vulnerability) to 9 (most effect on vulnerability).

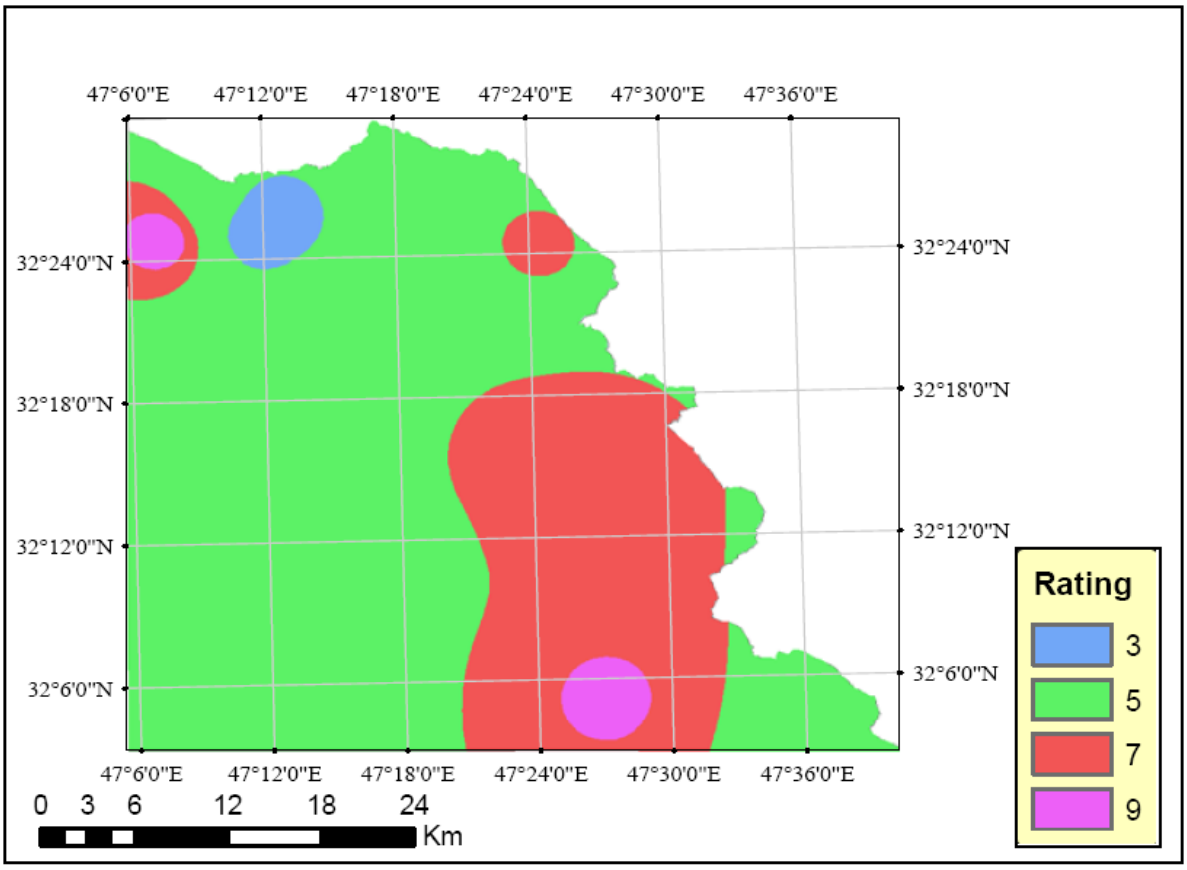

Figure 1 Depth to groundwater level rating

Table 2: DRASTIC rating and weight values for the study area.

DRASTIC Factors	Range	Rating	Weight		Total weight (rating × weight)	
			standard	pesticides	standard	pesticides
Groundwater Depth (m)	1.5 – 4.5	9	5	5	45	45
	4.5 – 9	7			35	35
	9 – 15	5			25	25
	15 – 22	1			15	15
Net Recharge (mm)	< 50	1	4	4	4	4
Aquifer Media	Sand and gravel	8	3	3	24	24
Soil media	Group A	10	5	2	50	20
	Group B	8			40	16
	Group C	6			30	12
	Group D	4			20	8
Topography (Slope %)	0 – 2	10	3	1	30	10
	2 – 6	9			27	9
	6 – 12	5			15	5
Impact of vadose zone	Sand – gravel	8	3	5	24	40
	Silt - Clay	3			6	15
Hydraulic conductivity (m/d)	0 – 4	1	2	3	2	3
	4 – 8	2			4	6

2.1.2 Net Recharge (R)

The amount of annual net recharge calculated by mass chloride balance method for the main aquifer in the study area is less than 50 mm. An absolute value of 1 is assigned to rating value of this factor because of lack of information concerning the spatial distribution of this factor over the study area and the nature of confining conditions of main aquifer which overly partly by a confining unit.

2.1.3 Aquifer media

The main constituents of main aquifer in the study area are mixture of gravel and sand with significant amount of silt and clay, therefore the rating value of this media is 8.

2.1.4 Soil media

The hydrological soil groups of study area (Figure 2) represent the soil capabilities to infiltrate water applied where the infiltration capacity of soil decreases from group A to D. according to this fact, the soil media rating map were prepared (Figure 3). These groups were assigned scores of 10, 8, 6, 4 to reflect the ability of these groups to infiltrate water and other constituents such as contaminants.

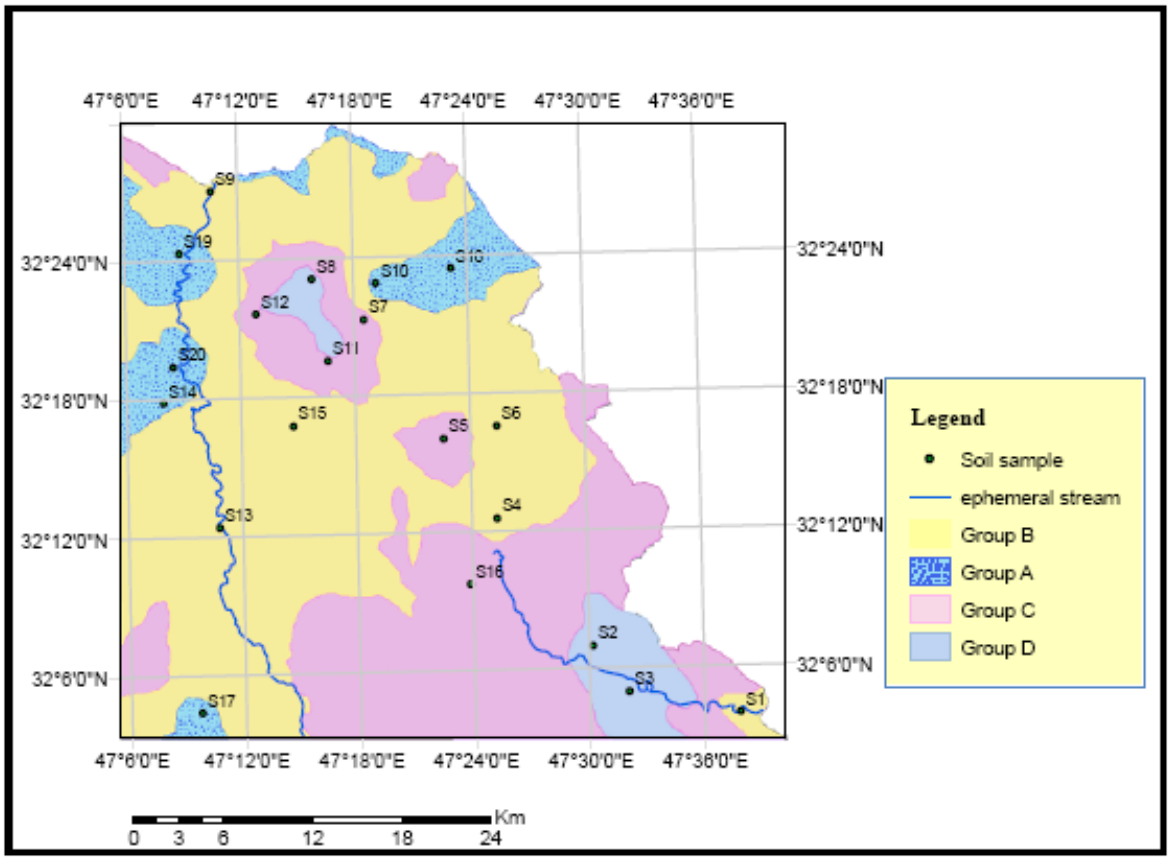

Figure 2 Hydrological soil group map.

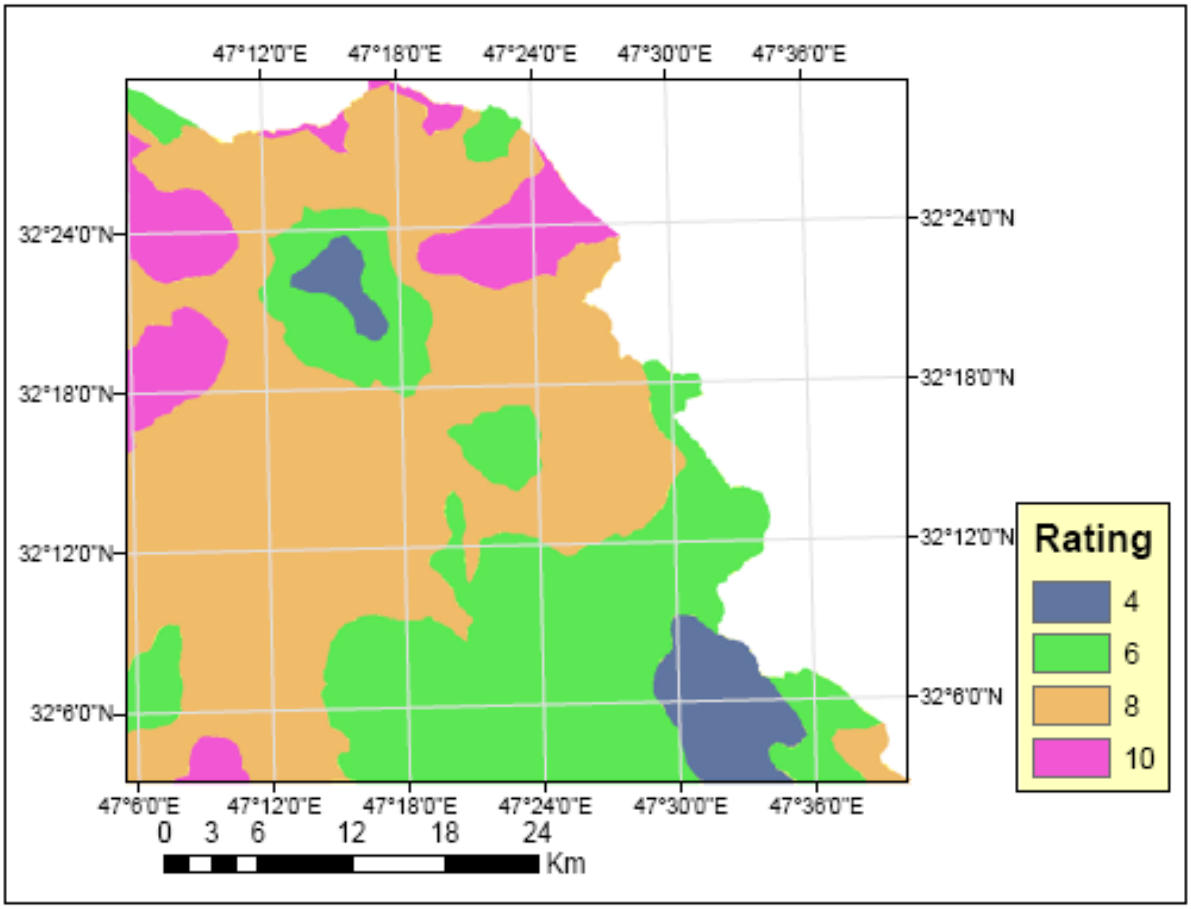

Figure 3 Soil Media Rating

2.1.5 Topography (slope)

The topography of the study area was obtained from the DEM covering the study area. Slope values (%) were calculated from this map using the spatial analyst tools in Arc GIS 9.3, (Figure 4). It is clear from this map that most of the study area is flat where slope does not exceed 1.2%. The slope values are rated based on the criteria of DRASTIC model (Table 3) with 10 being the lowest slop (Figure 5). Generally, slope in the study area is low and therefore increases the groundwater vulnerability.

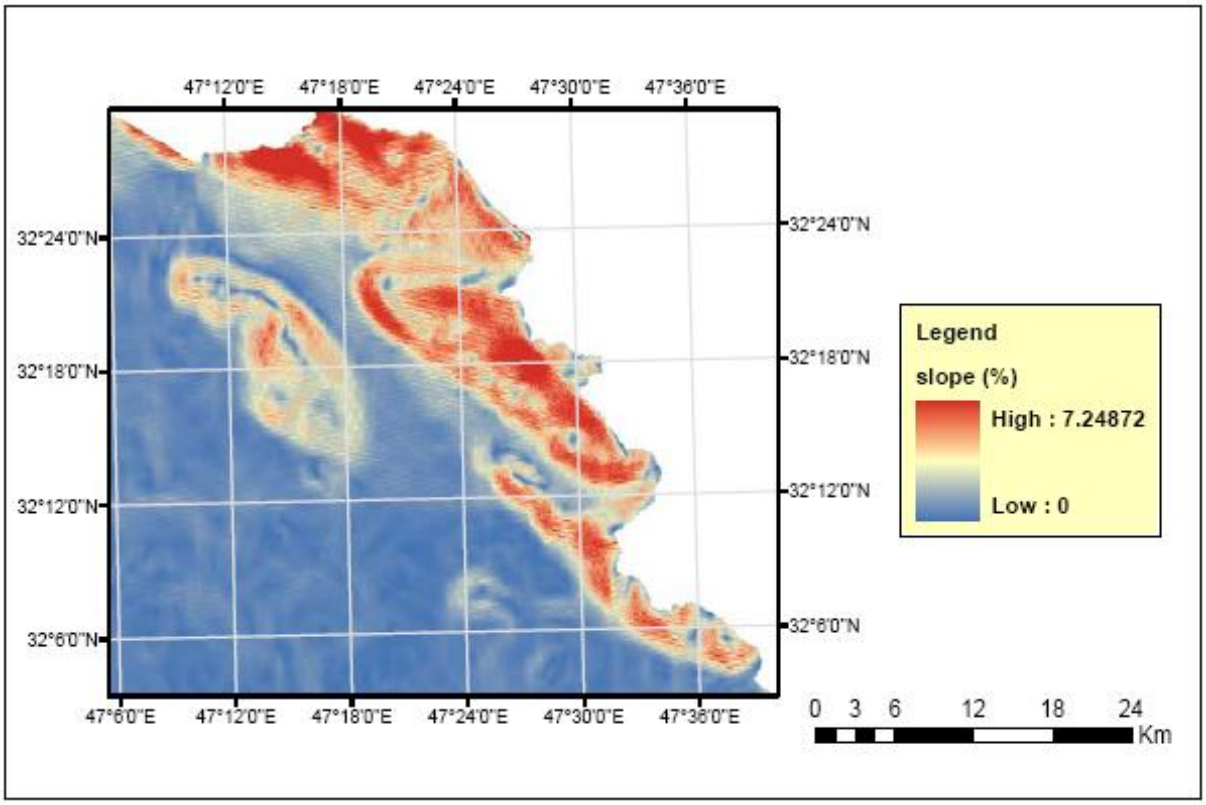

Figure 4 Slope (%) of the study area derived from DEM

Table 3 Ranges and ratings for topography (slope %)

Soil surface slope (%)	Rating T_r
0 – 2	10
2 – 6	9
6 – 12	5
12 – 18	3
> 18	1

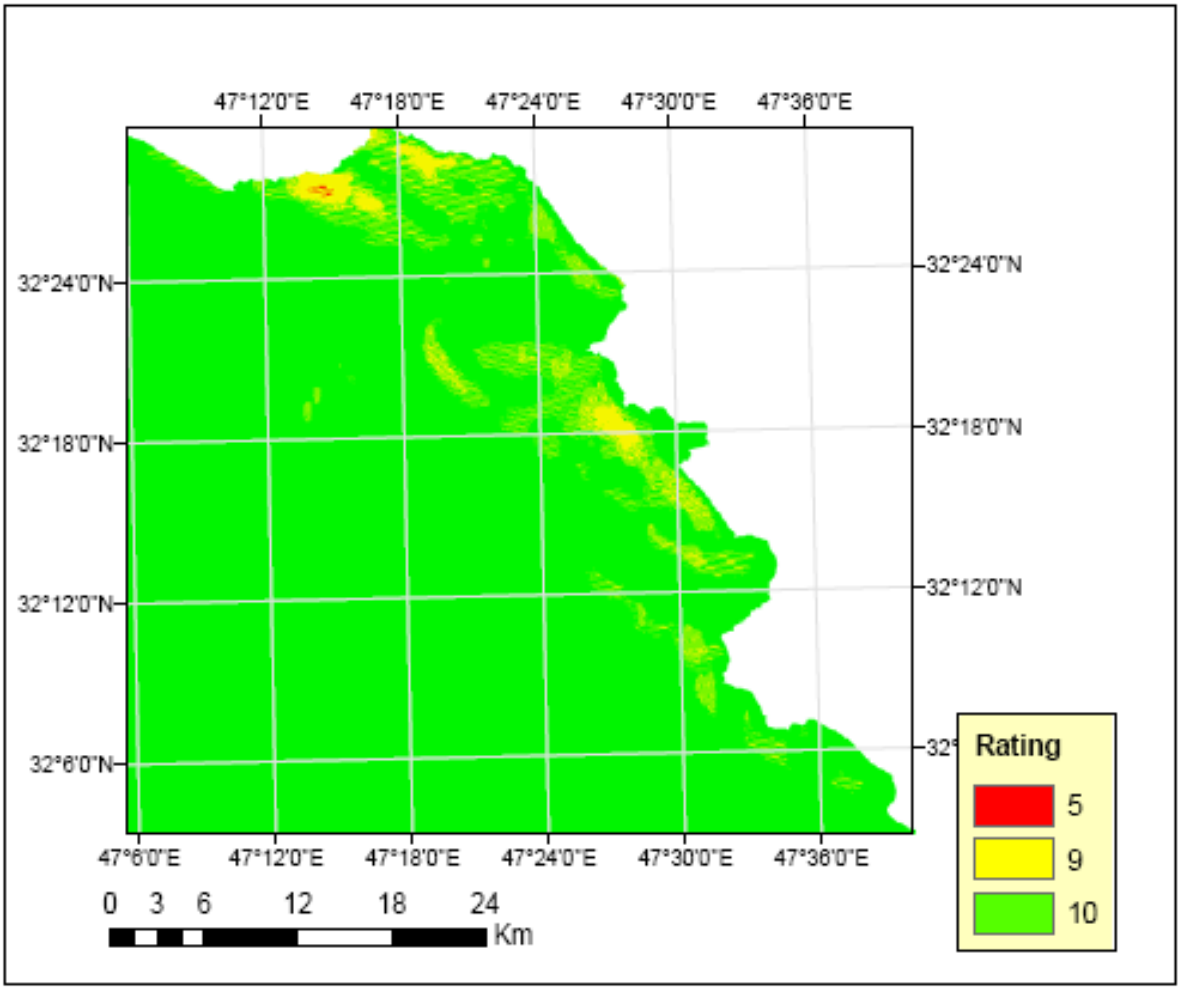

Figure 5 Slope rating

2.1.6 Impact of vadose zone (I)

The main aquifer in the study area is semi-confined aquifer where the confined part occupies about 72% from the study area and the remaining for the unconfined part. The unsaturated zone in the confined part mainly consists of silt and clay, while the main constituents of vadose zone of the unconfined part are sand and gravel. Therefore the vadose zone of the confined and unconfined parts was rated 8 and 3 depending on the criteria of DRASTIC model (Table 4) and (Figure 6).

Table 4 Ranges and ratings for vadose zone

Media types	Rating range I_r	Typical range I_g
Confining layer	1	1
Silt/ clay	2 – 6	3
Shale	2 – 5	3
Limestone	4 – 7	6
Sandstone	4 – 8	6
Bedded sandstone, limestone, and shale sequences	4 – 8	6
Sand and gravel with significant silt and clay	4 – 8	6
Metamorphic/ igneous	2 – 8	4
Sand and gravel	6 – 9	8
Basalt	2 – 10	9
Karst limestone	8 – 10	10

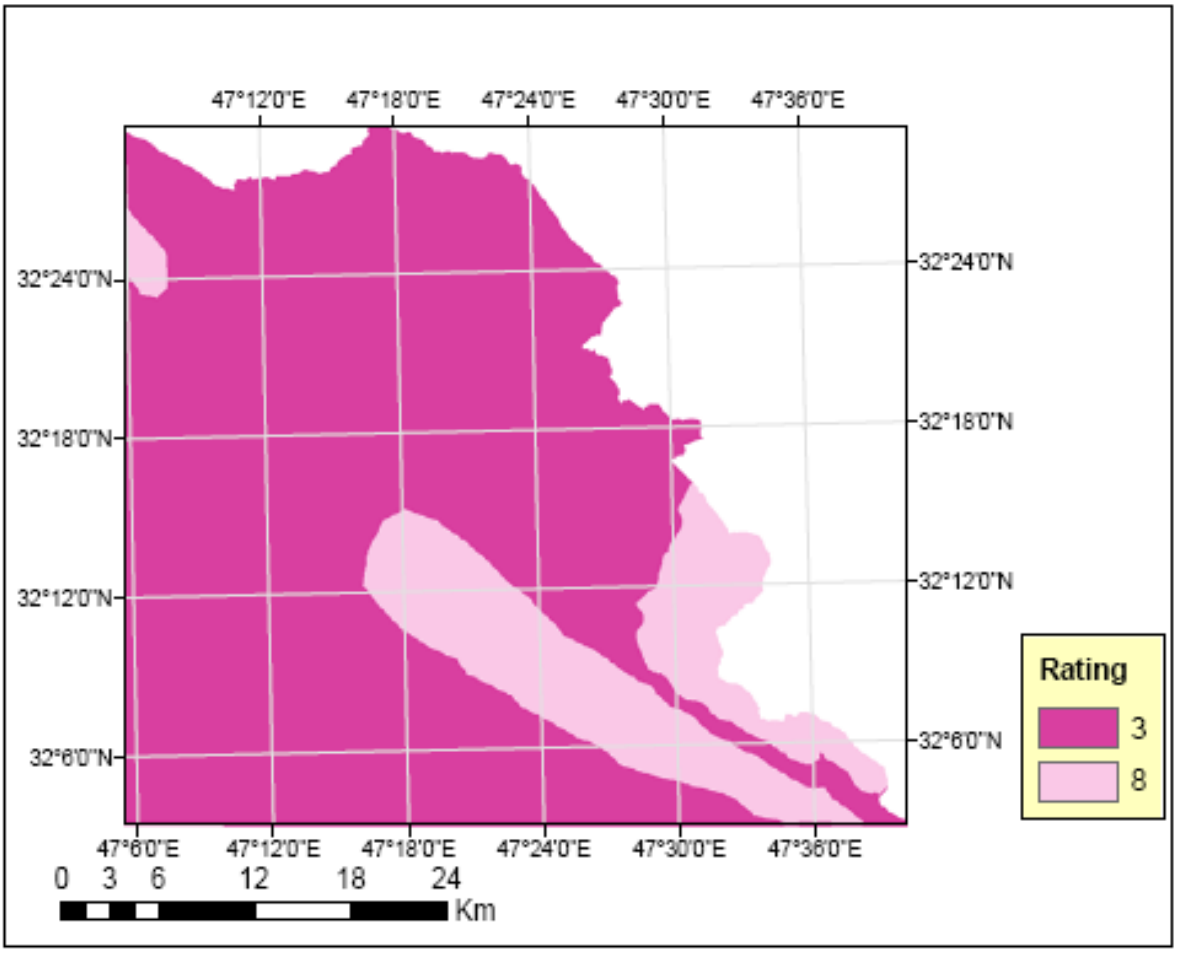

Figure 6 Impact of vadose zone rating

2.1.7 Hydraulic Conductivity (C)

The hydraulic conductivity map of the main aquifer was reclassified according to the criteria of DRASTIC model (Table 1), using reclassify tool in spatial analyst extension of Arc GIS environment (Figure 7) which shows that the southern parts of the study area have hydraulic conductivity values from 0.5 to 4 (m/d) with rating value of 2. In the northern parts of the study area and small parts of southeast, the hydraulic conductivity of more than 4 (m/d) had rating value of 1 according to the criteria of DRASTIC model.

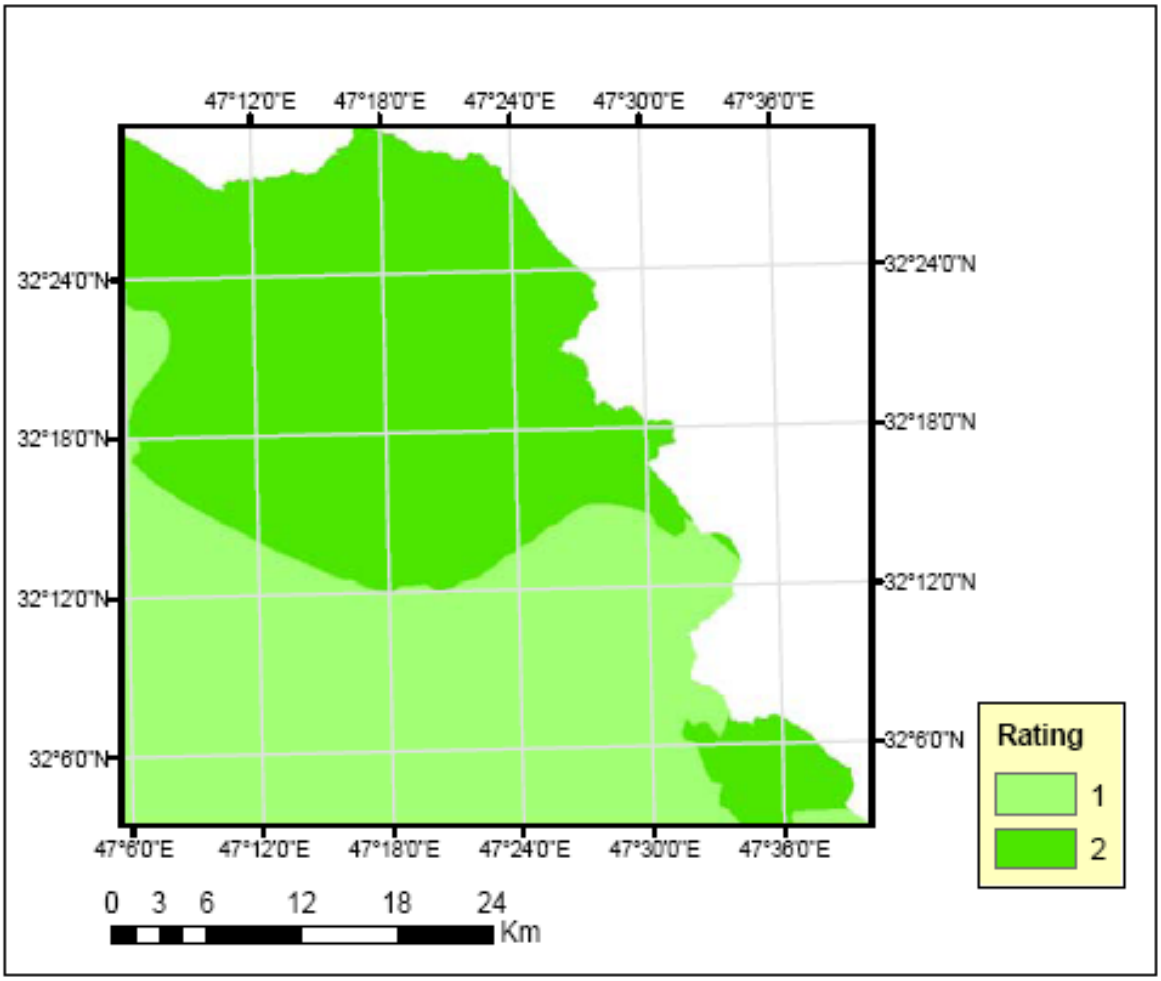

Figure 7 Hydraulic conductivity rating

3. CONCLUSIONS

3.1 DRASTIC Calculation and Analysis

The final vulnerability maps (standard and pesticides DRASTIC versions) of the study area were calculated using raster calculator in spatial analyst tool. The DRASTIC rating from each input layer was multiplied by the weight for that layer and summed to determine the DRASTIC index. The resulted indexes were classified according to Table (5) for deriving the classes of vulnerability. Figure (8) reveals the vulnerability classes for standard and pesticides DRASTIC, respectively. Table (6) shows the area occupy by each of these classes for standard and pesticides versions of DRASTIC model.

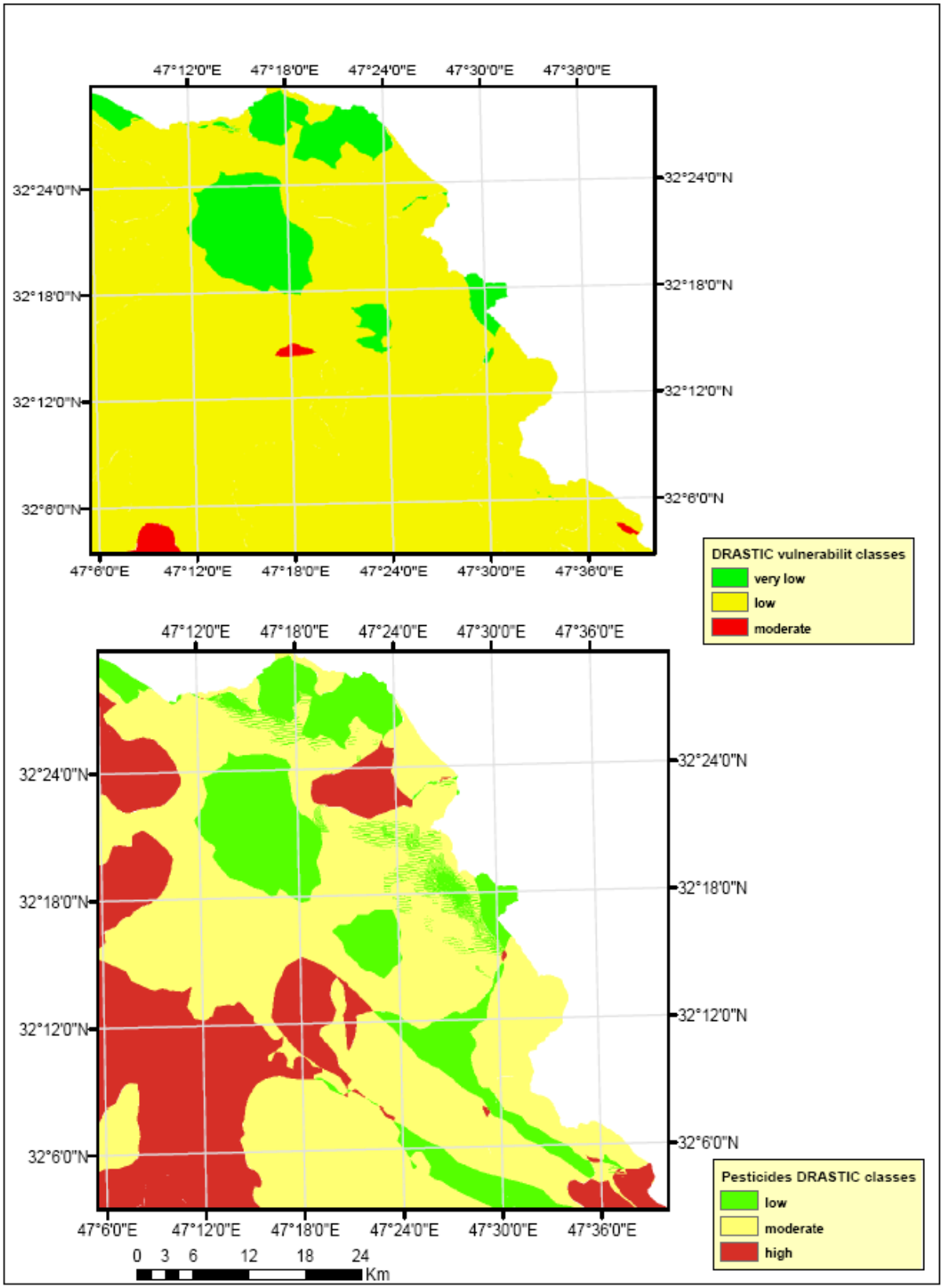

Figure 8 Aquifer vulnerability classes for the study area

Table 5 Criteria of the evaluation of the degrees of vulnerability (Civita and De Regibus, 1995; Corniello et al., 1997)

Degree of vulnerability	DRASTIC index
< 80	Very low
80 – 120	Low
120 – 160	Moderate
160 – 200	High
> 200	Very High

Table 6 The vulnerability classes for the study area

DRASTIC version	Vulnerability classes	Area occupied	
		Km^2	%
Standard	Very low	280	15
	Low	1563	84
	Moderate	13	1
Pesticides	Low	1189	64
	Moderate	289	16
	High	378	20

The obtained results related to the vulnerability to general contaminants showed that the study area is characterized by three vulnerability zones: very low, low, and moderate. The DRASTIC index ranges between 69 and 128. Table (6) showed that (85%) of the study area has a very low class of groundwater vulnerability to contamination, whereas a total of (15%) of the study area has low vulnerability. Only (1%) of the study area falls within the moderate class and there are no areas in the high and very high classes. A very large area (99%) in very low and low vulnerability classes may be attributed to the impact of vadose zone and the low values of hydraulic conductivity of the aquifer.

The pesticides DRASTIC index map showed that study area is characterized by three zones of vulnerability too: low, moderate, and high. The Pesticides DRASTIC index ranges between 91 and 171, which is higher than the standard DRASTIC index. The resulted map of this version of DRASTIC clearly shows that significant parts of the study area (southwestern) has high vulnerability to contamination, and most parts of the study area have low vulnerability to pollution (about 64%). The moderate vulnerability area distributes unevenly through the area from south to north and occupies only (16%) of the study area. This pattern may relate to the variation on the impact of vadose zone from south to north and low values of hydraulic conductivity and net recharge.

3.2 Sensitivity analysis

Aquifer vulnerability assessment requires validation to reduce subjectivity in the selection of rating ranges and weight and to increase reliability. Sensitivity analysis provides helpful information on the influence of rating and weighting values assigned to each parameter and helps hydrogeologist to judge the significance of subjectivity elements.

Table (7) reports the statistical summary of the seven factors maps used to compute the DRASTIC index. The high risk of groundwater contamination in the study area originates from the impact of vadose zone, hydraulic conductivity, Soil media, and depth to groundwater level factors (mean values are 9.9, 9.61, 8, and 7.3). The other factors imply low risks of contamination. Soil media, impact of vadose zone, hydraulic conductivity, and depth to groundwater levels are highly variable, while recharge, aquifer media, and topography are low variable. The low variability of the factor implies smaller contribution to the variation of the vulnerability index across the study area.

Table 7 A summary of the DRASTIC factor maps

Factor	Min	Max	Mean	Standard deviation	Coefficient of variation (C_v)
D	3	9	9.61	1.09	**11.34**
R	1	1	1	0	0
A	8	8	8	0	0
S	4	10	7.31	1.44	**19.69**
T	5	10	9.9	0.09	0.91
I	3	9	3.86	1.89	**48.96**
C	1	2	1.52	0.49	**32.24**

3.3 Recommendations for mitigation of contamination risk

The following recommendations should be taken into consideration for mitigation the contamination risk in the moderate and high vulnerability zones:

- Prevent the use of pesticides in these areas and use other safe methods for controlling pests and weeds such as biological methods.
- Monitor the industrial and agricultural contaminants in these areas to define the status of contamination and make corrective measures.

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Groundwater Management Optimization by ALL_WATER_gw: New problem formulation and additional functionalities.

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Abstract:

ALL_WATER_gw is a tool developed to optimize groundwater abstraction rates to satisfy demands with consideration of salinity, drawdown and cost. It was an enhancement of the existing WEAP-MODFLOW Decision Support System (DSS) to allow user to find in short computation time a set of optimal solutions designed in a PARETO front. The main objectives of the present contribution are to increase the flexibility of the developed tool, in term of problem formulation and data acquisition, and to evaluate its efficiency. Three objectives are considered in the developed problem formulation: i) the demand satisfaction, ii) the minimization of the unit cost of water supplied over a planning period and iii) the minimization of the maximal drawdown. Water salinity is considered a constraint in demand sites. The hydraulic constraints taken into account are the transmission links flow capacities as well as the maximal drawdowns and abstraction rates at the wells. Thus, to handle the formulated problem, a Multi-Objective Genetic Algorithm (MOGA) and the PARETO optimality concept are used. Two main fitness functions need to be defined by user using the weighted sum of the considered objective functions and constraints. The developed tool is tested on a real case study in the Easter South of Tunisia: Zeuss Koutine aquifer. Results demonstrated that optimal solutions are applicable and offers large water management improvement in term of cost and aquifer protection, in comparison with the reference scenario. It is also showed the valuable help offered to managers with the representation of the relationship between conflicting objectives on a PARETO front.

Key words: Groundwater Management; ALL_WATER_gw; Optimization; Satisfaction; Cost; Salinity.

1 Introduction

Groundwater management constitutes a difficult task due to the complexity of the natural and the Man-made hydraulic systems, generally characterized by higher number of sources, demand sites and transfer and supply links. The length and the time step of the management period and the variability of the management priorities over time and space increase the problem complexity.

To address the multiple criteria aspect and the higher dimensionality of the groundwater management problems, researchers had developed specialized optimization tools. Khare *et al.* (2007) proposed a simple economic-engineering optimization model to explore the potential of conjunctive use of surface and groundwater resources. Van Cauwenbergh *et al.* (2008) developed a DSS to rank different sustainable planning and management alternatives according to their socio-economic and environment performances as fulfilling water demand, water price, technical and economical efficiency, social and environment impacts. Ayvaz (2009) studied the groundwater management problem to develop sustainable strategies. Liu *et al.* (2010) addressed the IWRM using an optimization-based approach. Sedki and Ouazar (2011) explored the optimal pumping schemes that meet the current and the future water demands while minimizing the risks of several adverse environmental impacts, such as saltwater intrusion prevention, avoiding excessive drawdown, as well as controlling water logging and salinity problems. Gaivoronski *et al.* (2011) addressed the water management problem to obtain a "robust" decision policy.

The main objectives considered by the cited works are the demand satisfaction (Van Cauwenbergh *et al.*, 2008; Sedki and Ouazar, 2011) and the maximization of the net benefit of water use (Khare *et al.*, 2007). Liu *et al.* (2010) used the minimization of the capital and operating costs as single objective. Gaivoronski *et al.* (2011) proposed a cost-risk coupled objective function to minimize

the risk of wrong management decision. The socio-economic and environment aspects have been considered in the works of Prato and Van Cauwenbergh *et al.* (2008), Ayvaz (2009) and Sedki and Ouazar (2011).

To resolve their formulated problems, authors used mathematic optimization methods, such as linear programming (Khare *et al.*, 2007) and mixed integer linear programming (Liu et al.; 2011). Ayvaz (2009) used the Harmony search (HS) optimization algorithm. The sum of weighted objective functions is usually used to transform the multi-objective problems on single objective ones. The difficulty to compare the objectives importance's and to choose values of their weights, need to be addressed.

The goal of this work is modify to existing optimization tool for groundwater management optimization "***ALL_WATER_gw***" (Nouiri, 2010) in order to increase its flexibility in terms of problem formulation and data acquisition. To evaluate its efficiency, the new version of

"***ALL_WATER_gw***" is used to optimize the groundwater management for a real case study in the Eastern South of Tunisia: Zeuss Koutine aquifer to demonstrate its computation efficiency and its usefulness for managers and DM.

2. Methodology

2.1 General Conceptual model

Groundwater sources "se" with different locations and salinity are used to satisfy the water requirements in demands sites. Each of the "ND_{max}" demand sites needs to be supplied by at least one water source through supply link to satisfy its water demand pattern "D(d, t)" and its maximal acceptable water salinity over time "Q_{max}(d, t)" (figure 1). Each of the supply links from source "se" to demand site "d" is characterized by its maximal supply capacity "$F_{max}D(se,d)$" and its specific supply cost: "C_{UD}(se, d, t)".

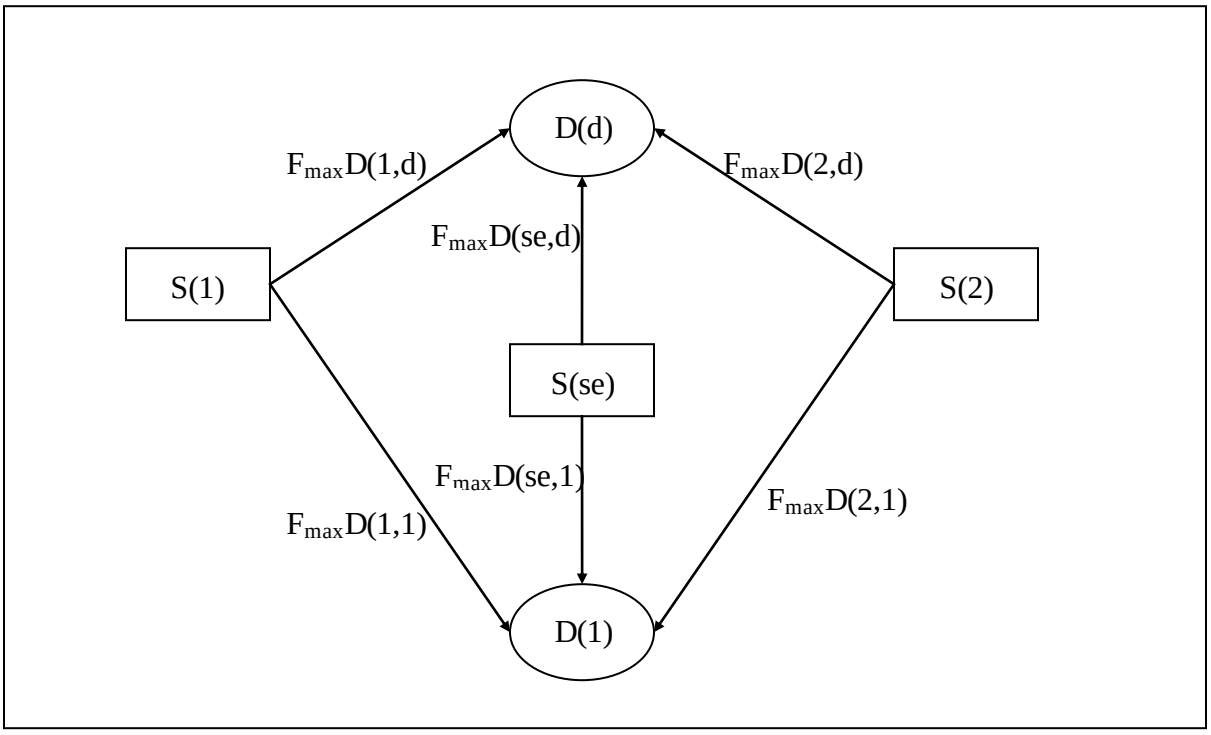

Figure 1: Groundwater sources and demand sites connectivity in planning area.

The decision variables to be identified by the proposed tool, and constitute the outputs are the water supplied by each groundwater source "se" to each demand site "d" at any time steps "t": "F_D(se, d, t)", over an optimization period "P_{opt}" between a starting and end moments, "T_{start}" and "T_{end}" respectively.

2.2 Problem formulation

The groundwater management problem is formulated as a constrained multi-objective problem. While in the first version of ***ALL_WATER_gw*** the water salinity satisfaction is considered as objective function, it is chosen in the present work to consider the salinity as a constraint, to be in harmony with the WEAP approach. The objective functions and the constraints characterizing the second version of ***ALL_WATER_gw*** are presented in next paragraphs.

2.2.1 Objective functions

The first optimization objective is to satisfy the water demand of the demand site "d" at every time step "t", over the optimization period. This objective can be expressed by the minimization of the function "f_{DS}" presented in equation (1):

$$f_{DS} = Max\left[\left(\left| \sum_{se=1}^{NSE_{max}} FD(se,d,t) - D(d,t)) / D(d,t) \right| \right] \right] \qquad d=1,\ldots, ND_{max} \text{ and } t = T_{start},\ldots, T_{end} \qquad (1)$$

The drawdown objective function evaluates the relative drawdown and the violation of the maximal acceptable drawdown "VMaxDD(w)" of the water head in each of the active wells cell "w" over the optimization period as presented in next equation:

$$f_{DD} = Max\left(\frac{DWDW(w) \times VMaxDD(w)}{(Hi(w) - BOTM(w)) * I(w)}\right) \qquad w= 1, \ldots, N_{aw} \qquad (2)$$

Where DWDW(w) is the water drawdown in the well cell "w"; VMaxDD(w) is the maximal violation of the acceptable drawdown observed in the well cell "w", computed using equation (3); Hi(w) is the initial head in the well cell "w"; BOTM(w) is the bottom of the well cell "w"; I(w) is the importance of the well cell "w" and N_{aw} is the number of the active wells.

$$VMaxDD(w) = Max\left(\frac{DWDW(w)}{DD_{max}(w)}\right) \qquad w= 1, \ldots, N_{aw} \text{ and } t = T_{start},\ldots, T_{end} \qquad (3)$$

Where "DD_{max}(w)" is its maximal acceptable drawdown in well cell "w".

The cost objective function "f_C" (Equation 4) represents the average unit cost of water supplied by sources to demand sites over the optimization period.

$$f_C = \frac{\sum_{t=T_{start}}^{T_{endx}} \left[\left(\sum_{se=1}^{NSE_{\max}} \sum_{d=1}^{ND_{\max}} F_D(se,d,t) \times CUD(se,d,t) \right) \right]}{\sum_{t=T_{start}}^{T_{endx}} \left(\sum_{se=1}^{NSE_{\max}} \sum_{d=1}^{ND_{\max}} F_D(se,d,t) \right)} \quad (4)$$

2.2.2 Constraints

The maximal supply capacity from groundwater source "se" to demand sites "d" is considered hydraulic constraints, expressed by equations (5):

$$F_D(se,d,t) \le F_{\max} D(se,d) \quad \forall\, se, \forall\, d \text{ and } \forall\, t \quad (5)$$

The maximal water abstractions from well constitutes the second hydraulic constraint.

$$Q(w,t) \le Q_{\max}(w) \quad (6)$$

Where "Q(w, t)" is the abstraction from well cell "w" at time step "t" and "Q_{max}(w)" is the maximal acceptable abstraction from the well cell "w".

The maximal acceptable drawdown in each of the used wells is other constraints that have to be respected by optimal solutions.

$$DD(w,t) \le DD_{\max}(w) \quad (7)$$

Where "DD(w, t)" is the drawdown in well cell "w" at time step "t".

In order to meet the requirements for water salinity in demand sites at each time step of the optimization period, equation (8) need to be verified:

$$Q(d,t) \le Q_{\max}(d,t) \quad \forall\, d \text{ and } \forall\, \mathrm{t} \quad (8)$$

Where "Q(d, t)" is water salinity at demand site "d" at time step "t", due to the mixture of inflow water from different sources. In order to simplify the problem, it is assumed that water mixes completely and instantaneously in demand sites. Equation (9) is used to compute the resulting water salinity in each demand site "d" at any time step "t":

$$Q(d,t) = \frac{\sum_{se=1}^{NSE_{\max}} F_D(se,d,t) \times Q(se,t)}{\sum_{se=1}^{NSE_{\max}} F_D(se,d,t)} \quad (9)$$

2.3 Problem resolution

This section presents the methodology proposed to resolve the formulated groundwater management problem.

Genetic Algorithms (GA) are global search heuristics, frequently used to solve complex problems, difficult to solve using conventional techniques such as linear and non-linear programming (Goldberg, 1991; Hrstka et Kucerova, 2004). In GA, problem solutions are represented as chromosomes formed by a set of genes. Each gene represents a bit that must be filled by a decision variable value, in its definition interval. For multi-objective optimization, Goldberg (1991) recommended the use of the PARETO optimality concept to compare solutions.

2.3.1 Multi-objective genetic algorithm (MOGA) for groundwater optimization

To resolve the formulated problem, it is developed a Multi-Sexual Genetic Algorithm (MSGA). This algorithm is elitist and characterized by weak parameters number and by good distribution of the optimal solutions on the PARETO front. The main computation steps of the developed MSGA are described below:

Create randomly an initial population of "T_{pop}" solutions "s". The MSGA assigns a randomly sex to each solution. The sex number is equal to the number of objectives. With the present formulation there are 2 sexes as detailed in next step. For the present problem, it is used a real coded solutions.

Evaluate solutions "s" by computing the objective functions "$f_{DS}(s)$", "f_{DD}(s)" and "$f_C(s)$" and the constraints verification. Each solution is evaluated by the "*fitness*" functions "*Fitness 1*" (Eq. 10), computed as the weighted sum of two objective functions and the associated constraints penalties and "*Fitness 2*" (Eq. 13):

$$Fitness\ 1 = \frac{p_1 \times f_{DS} \times (1 + MaxEQty) + p_2 \times f_{DD} \times (1 + MaxEQag)}{p_1 + p_2} \qquad (10)$$

Where "MaxEQag" is the maximal violation of the acceptable abstraction from wells, computed using the equation (11):

$$MaxEQag = Max(0, \frac{Qag(w,t)}{Q_{\max}(w) \times I(w)}) \qquad w = 1, \ldots, N_{aw} \text{ and } t = T_{start}, \ldots, T_{end} \quad (11)$$

"MaxEQty" is the maximal violation of the acceptable salinity computed by equation (12)

$$MaxEQty = Max(0, \frac{Q(d,t) - Q_{\max}(d,t)}{Q_{\max}(d,t)}) \qquad (12)$$

"p_1" and "p_2" are the weights of the demand satisfaction and the drawdown objectives, respectively. The weights values allow the manager and/or the decision maker to attribute different importance to the objectives and to choose the optimization priorities.

$$Fitness\ 2 = f_c \qquad (13)$$

Identify non-dominated solutions by the PARETO optimally concept,

Create a set of non-dominated solutions identified: Archive of size "T_{arch}".

Evolution: New population is created using the solutions of the previous population.

Elitism: "P_e" percent of the "T_{pop}" solutions of the new population are copied from the archive of non-dominated solutions.

Selection: Two solutions are selected from the previous population, according to their fitness functions, to participate to the crossover.

Crossover: The selected solutions participate on an arithmetic crossover to produce two new solutions, with a probability "P_c".

Mutation: Some "bits" of each created solution can be randomly changed, in the research space, with a probability "P_m".

Evaluate created solutions, as in step (2).

Identify non-dominated solutions in the current population, as in step (3).

Insert non-dominated solutions of the current population in the archive.

Update the archive by the PARETO optimality concept.

If "T_{arch}" is not reached then return to step 5.

If iteration number is less than the maximum one "G_{max}", **then** repeat steps from 5 **to** 11.

The exposed resolution methodology is coded using the Visual Basic 6 programming language. A multi-objective optimization tool is build with friendly user interface. The developed tool is called "***ALL_WATER_gw***".

2.3.2 *ALL_WATER_gw* presentation

ALL_WATER_gw is developed with the support of the technical cooperation project between the Federal Institute for Geosciences and Natural Resources (BGR) and the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD).

Figure 2: The welcome screen of ***ALL_WATER_gw***.

To re-constitute the hydraulic system from WEAP-MODFLOW DSS framework, the version 1.1.1 of ***ALL_WATER_gw*** performs three steps using the screen "ALL_WATER_gw – WEAP and MODFLOW Inputs". In the first, it reads the variable values of all the demand sites, the groundwater sources and the transmission links from the WEAP Area. The second step is to read the linkage between demand sites and the active well cells from the linkage shape file. The third step allows the reading of the main characteristics of the MODFLOW model.

The version 1.2.1. of ***ALL_WATER_gw*** allows also the read of input data without the need to connect to the WEAP-MODFLOW framework. In such case, user needs to prepare a set of input text files, detailed in the user guide.

The third screen (ALL_WATER_gw – Optimization) allows the definition of the objectives and their weights, the constraints, the genetic algorithm parameters and the parameters of the convergence criteria.

This screen offers a dynamic displaying of the objective functions and the convergence criteria values over iterations. This allow user to follow the optimization progress. In the same screen, it is displayed in parallel the optimal solutions founded in a PARETO front As output, ***ALL_WATER_gw*** displays statistics (ALL_WATER_gw – Overview screen) of the identified optimal solutions and creates "csv-files" required by WEAP to simulate the optimized scenario (see the user guide).

This screen is designed to display optimal solutions characteristics and to simulate each of them. A simplified PARETO front is offered to simplify the decision making task. The available user manual of ***ALL_WATER_gw*** presents in detail the required steps to use the tool and to perform an optimization run.

In case when ***ALL_WATER_gw*** is used with WEAP-MODFLOW framework, the new version allows an automatic build of new WEAP scenario in the Area when the user chooses to evaluate a specific optimal solution by WEAP-MODFLOW DSS.

3 Results and discussion

3.1 Case study presentation

In Eastern South of Tunisia, groundwater is the mainly resource used for drinking water to supply the cities of Medenine, Jerba, Zarzis, Benguerdene and a part of Tataouine city. The supplied population in the study area is about 500,000 in 2004, according to the last official report of the National Institute of Statistics (INS, 2004). In addition, the cities of Jerba and Zarzis represent one of the most important touristic regions of Tunisia. They represent 21 % of the national capacity (Chapoutot, 2008). The agricultural activity still based on not irrigated olive trees. Starting from 1990, irrigated areas are created around wells drilled in the

Zeuss Koutine aquifer. The total irrigated surface is estimated to 530 ha in 2010. The expected higher evolution of the population in the region and the important socio-economic development, especially the tourism, will apply a large pressure on the Zeuss Koutine groundwater in the future. The sea water intrusion constitutes other problem facing the managers of the water resources in the studied region.

The strategic importance of the Zeuss Koutine aquifer has encouraged the development of research and development activities to preserve the resource by improving its management. Most of the previous works leads to the development of annual MODFLOW models. The last one is developed by INAT (Hadded, 2008). Based on this model, the collaboration between INAT, BGR, ACSAD and GTZ, by training and technical workshops, permitted the development of a yearly management model for the Zeuss Koutine aquifer, using the WEAP software. It is now improved to a monthly model for the period from 1982 to 2015. The precious contribution of the regional administrations of Agriculture and the Drinking Water Utility of Medenine governorate has been fundamental to understand and to model the water resources and the hydraulic system as close as possible to the reality.

The elaborated MODFLOW model and the future water projects in the study pilot are considered to build the WEAP schematic as shown in the next figure:

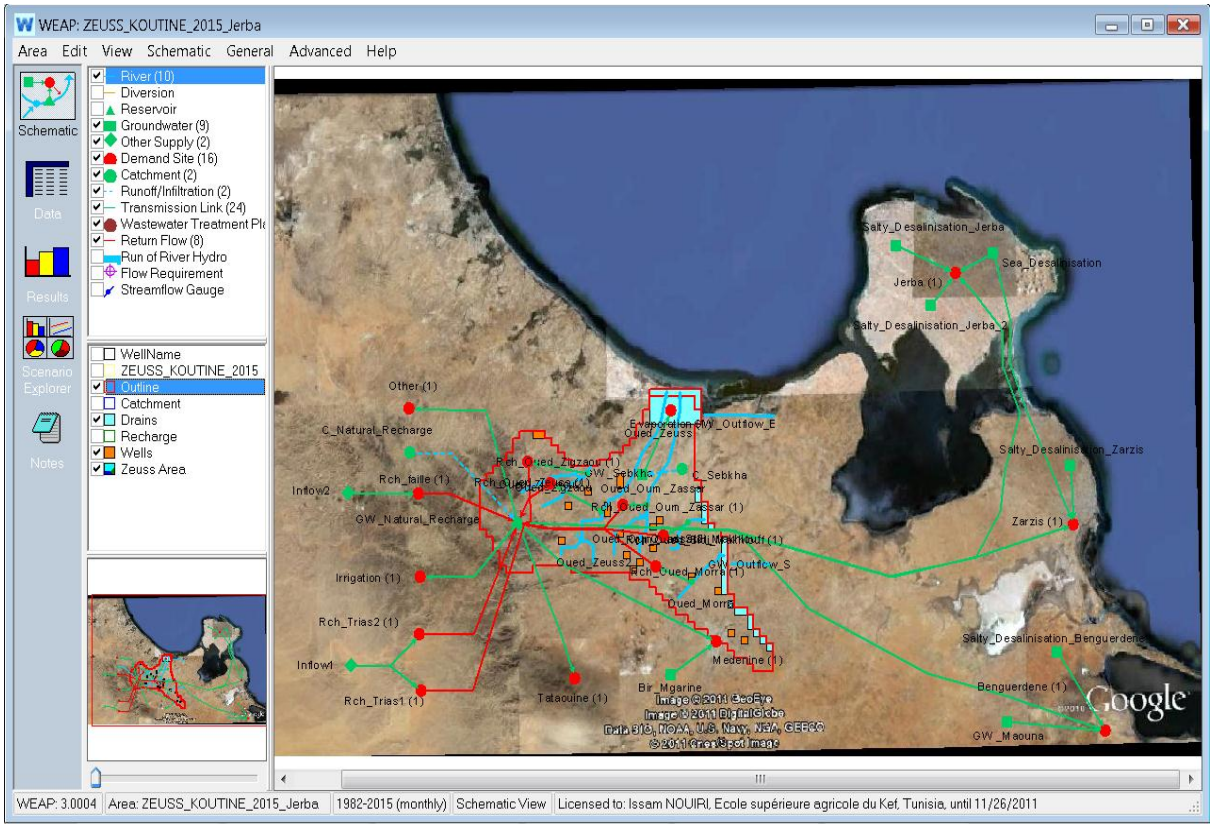

Figure 3. ***WEAP schematic of the Zeuss Koutine study area.***

The proposed WEAP schematic contains sixteen demand site nodes. The groundwater sources and the desalinization plants are represented in the present WEAP schematic by groundwater nodes. The schematic enclose nine groundwater nodes. Twenty-four transmission links are used to supply the demand site nodes.

3.2 Use of *ALL_WATER_gw* to optimize the management of the Zeuss Koutine aquifer

The management of the Zeuss Koutine aquifer is optimized for the period 2013-2015. The demand satisfaction, the drawdown minimization and the cost reduction objectives are considered having the same importance. The hydraulic and quality constraints are considered. By choosing a maximal iteration number of 1500, a population size of 30 and a percentage of elitism of 30%, ***ALL_WATER_gw*** have been able to identify a set of optimal solutions drawing a Pareto front.

By the new functionalities of ***ALL_WATER_gw***, a new scenario is created in WEAP automatically, under the 'Reference' scenario. The simulated optimal solution demonstrates that the new problem formulation allows an easier understanding of the relationships between the management cost and the head drawdown in well cells, while satisfying the water demands and quality requirements.

The compromised solution is chosen for simulation in WEAP to evaluate the income of the optimization in groundwater management. The comparison of the demands satisfaction, heads in well cells, flows in transmission links and unit water costs between the 'Reference' and the 'Optimized' scenarios demonstrate that '***ALL_WATER_gw***' succeeded to identify better management solution.

While the optimization using the new formulation does not lead to a strong difference in comparison with the one proposed in the first version of the tool, for the Zeuss Koutine pilot study, the new problem formulation and functionalities can be considered a simplification step in the advantage of users. Indeed, there is no need to manage the WEAP scenarios or to eliminate the salinity quality parameter to be able to simulate an optimal solution on the WEAP Area.

The version 1.2.1 of ALL_WATER_gw can be requested from the author by mail (inouiri@yahoo.fr).

4 Conclusion

This paper has presented the enhancement and the test of the existing ***ALL_WATER_gw*** software, designed for groundwater management optimization. The modified multi-objective formulation of the problem integrates the demand satisfaction, the reduction of the unit cost of water and the drawdown minimization objectives. In addition the hydraulic and water

quality constraints have been considered. As the first version of the tool, multi-objective genetic algorithm and the PARETO optimality concept were used to resolve the formulated problem.

The test of the version 1.2.1 of ***ALL_WATER_gw*** to optimize the management of a real pilot area in Tunisia, demonstrate that the new functionalities and problem formulation make easier the understanding and the use of the optimization results. In comparison with the first version results, there is no strong improvement in term of optimal solutions performances.

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Actually Assistant Professor at National Institute of Agronomy of Tunisia, involved in teaching, research and extension. His fields of expertise:
Water resources management,
Optimization with single and multi-objective genetic algorithms (MOGA),
Drinking water demand forecasting using Neural Networks (NN),
He is author of many optimization tools; the last one is ***ALL_WATER_gw***, for groundwater management optimization.
He is Auditor for Pressurized Water Network and WEAP trainer.
He contributes on national and international Research and development projects as principal investigator and as partner.

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Groundwater contamination in Wafra Agricultural Area by the Produced Water of the Evaporative Pond

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Abstract

For more than three decades the produced water from the Wafra Oil Field was disposed of in an evaporative pond. This disposed produced water maybe a source of contamination for the groundwater in the Wafra agricultural area, and contaminated the groundwater. The Total Dissolved Solids (TDS) of the groundwater sampled from the monitoring wells in the Wafra area was used as an indicator of groundwater contamination by the produced water. Hydrogeological data were collected from conventional monitoring and multi-level wells in the Wafra agricultural area. A maximum TDS of 58000 mg/l of a different origin than the groundwater of the Kuwait Group aquifer was detected in the area separating the oil field from the agricultural area. The source of this high TDS in the groundwater is the evaporative pond located in the Wafra Oil Field, which imposes a direct threat of contaminating the natural source of water for irrigation in the area. More studies are needed to define the exact distribution of the plume, and to suggest the suitable preventive measures and solutions of this environmental problem.

Key words: Produced water, Wafra, salinity, Piper diagram, Kuwait Group.

Introduction

The Wafra agricultural area and the active Wafra Oil Field are located on the southern border of Kuwait with the Kingdom of Saudi Arabia. The oil field became operational in 1954. Over years to keep up the oil well pressurized, water injection technique was introduced in Wafra oil. The produced water is disposed at a massive evaporative pond in the Wafra oil Field. This evaporative pond is situated about 2.5 km from the nearest farms in the western side of the Wafra agricultural area Fig. (1). The volumes and the chemical characteristics of the produced water in the oil field is unknown. However, El-Sayed et al., (2008), reported that produced water from the southern oil fields in Kuwait have maximum TDS of about 331000 mg/l, and maximum oil content of about 8.4 mg/l. There is likelihood that the evaporative pond is leaking into Kuwait Group Aquifer. There are more than 2500 pumping wells taping the Kuwait Group Aquifer in Wafra area (Al-Murad et al., 2010). In Kuwait recently the subsurface injection of steamed produced water was selected for permanent disposal/secondary recover (Al-Hubail and El-Dash, 2005, Mahdi, 2010). This paper aims to use the TDS of the groundwater as an indicator of the groundwater contamination due to the produced water in the Wafra Oil Field.

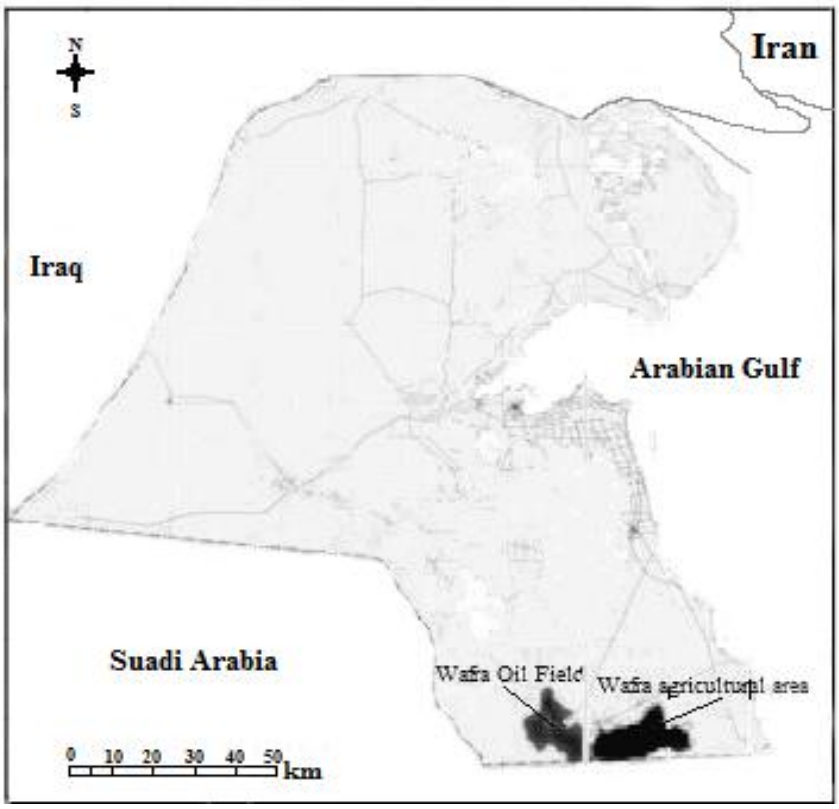

Fig. 1. Location map of the Wafra agricultural and oil field.

Methodology

The Public Authority of Agriculture Affairs and Fish Resources (PAAAFR) conducted a project to assess the causes and impacts of the water table rise in the Wafra agricultural area (Al-Murad et al., 2010). In the project fourteen conventional monitoring wells were constructed penetrating the Upper Kuwait aquifer. In addition, a multi-level well was constructed in the area separating the oil field from the Wafra agricultural area. This multi-level well penetrated the Upper and Lower Kuwait Group Aquifer. Fig. 2, represents the spatial distribution of the monitoring wells in the Wafra agricultural area.

Before the collection of groundwater samples from the conventional monitoring wells, the wells were purged for three volumes of well water and/or constant pH, electrical conductivity (EC), temperature, dissolved oxygen (DO), and oxidation-reduction potential (ORP) were attained. After the completion of well purging, groundwater samples were collected in laboratory-cleaned, sterilized glass containers. The collected samples were transported on ice to the laboratory the same day. Samples from the multichannel monitoring well were collected, directly after the development of intake zones in laboratory-cleaned, sterilized glass bottles. Duplicate, and in some cases triplicate samples have been taken for quality control and quality assurance (QC-QA) purposes. Blank samples were also analyzed to ascertain the instrument's accuracy and rule out any laboratory contamination. The pump used for sample collection was decontaminated in laboratory using Decon 90, followed by cleaning with tap water. The same step was repeated after sampling was completed, for the subsequent use of the pump. The TDS values were mapped geostatically by GS^{+} version 7.0, using kriging technique.

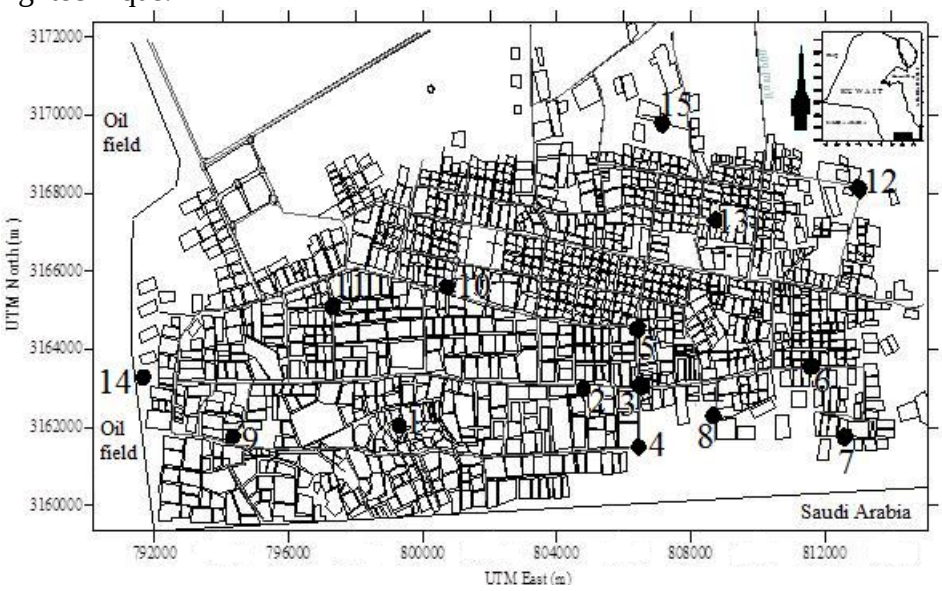

Fig. 2. Locations of the monitoring wells in the Wafra area (Modified after Al-Murad et al., 2010).

Results and Discussion

The available satellite images from KISR archive, for the year 1985 shows the presence of an evaporative pond in the well field in addition to two other small ponds (Plate 1A). This pond is divided into several compartments, where the black colored compartment indicates the presence of oil, and the green color indicates the presence water. The size of the ponds increased in later years to be about 3.5 km^2 (3.0 x 1.2 km). Plate (1B), represents the same ponds obtained from Google Earth on the early of 2010, where the ponds became smaller in size.

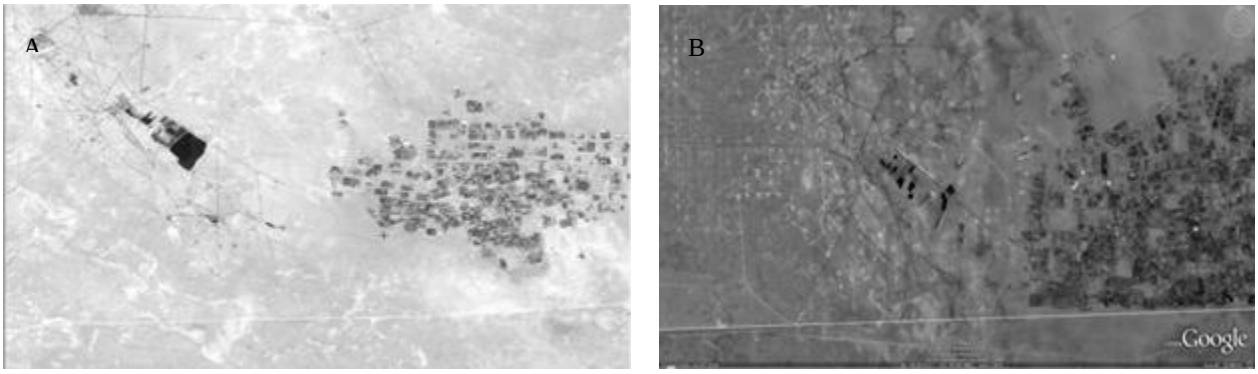

Plate1. (A, B) The evaporative ponds in Al-wafra oil field in 13th January 1985 (from KISR archive (A), and Google Earth (B)).

Table 1. shows the vertical pH, EC and TDS of the groundwater in the multi-level well PAAAFR Well No.14, which is located between the evaporative pond and the eastern side of the Wafra agricultural area (Fig.1). The table shows a stratified TDS in the location of the well. The TDS ranged from 15000 mg/l to 58000 mg/l, where the maximum TDS 58100 mg/l is located at depth 31-m below the ground surface, which suggest that the center of the plume is at this depth in the area of the well. The pH in the multi-level well are less than 7.0, and as the TDS increases the pH decreases.

Table. 1. vertical distribution of pH, EC and TDS in Well No. PAAFR-14 (Al-Murad et al., 2010).

Depth below ground surface (m)	pH	EC (µS/cm)	TDS mg/l
27.0	6.88	27100	15280
28.0	6.71	51800	36831
29.0	6.59	65300	49707
30.0	6.52	71100	54791
31.0	6.46	75500	58175

40.0	6.54	73600	56664
45.0	6.69	73100	56183

Fig. 2, represents the kriged TDS of the groundwater in the Wafra agricultural area. The TDS values of the upper 30 m of the multi-level well were averaged and used as a value representing the Upper Kuwait Group aquifer. The groundwater is saline in the west part of the agricultural area, where the average TDS is more than 23000 mg/l. The salinity decreases towards the central part of the area, where the groundwater become brackish. The reported TDS values in the Wafra area for the Kuwait Group aquifer range between 4400 to10,000 mg/l, where the TDS increases from the SW to NE direction. It is also, reported that the TDS of the Dammam aquifer below the Kuwait Group aquifer range between 4700 to 8700 (Omar et al., 1981, Saleh, et al., 1999, Al-Awadi et al., 2003). The TDS of the groundwater of the Kuwait Group aquifer had changed severely in the western side of the area, which make the groundwater useless for irrigation in the Wafra agricultural area. It is highly possible that the source of this high TDS is the percolated produced water from the evaporative pond in the oil field, where the separating distance is about 2.5 km. This short distance with the presence of more than 2500 pumping wells constructed in the Kuwait Group may force the contaminated groundwater to migrate towards the Wafra area.

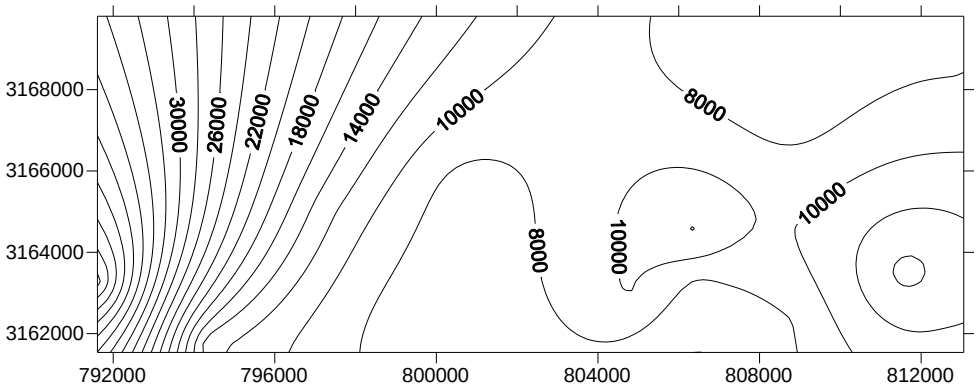

Fig. 2. Spatial distribution of TDS in the Wafra area.

The Piper trilinear diagram (Fig. 3) was used to illustrate the major ion compositions of the groundwater in Wafra area. The major ions cluster in the area of sodium and potassium indicating their dominance in the quality of the groundwater. The major anions cluster in the area of chloride, indicating the dominant influence of chloride on the quality of the groundwater. One exception is the plot of the major anion content of the groundwater sample collected from the multi-level Well No. PAAFR-14, in which chloride is seen to be relatively more dominant than it is in the groundwater from the other monitoring wells. From the plot, two types of groundwater can be identified: mixed Na-Cl and Ca(Mg)-Cl, and Na-Cl. The groundwater in the study area at the locations of all of the monitoring wells except Well No.

PAAFR-14 appears to be of the mixed type, whereas that of Well No. PAAFR-14 appears to be of the Na-Cl type.

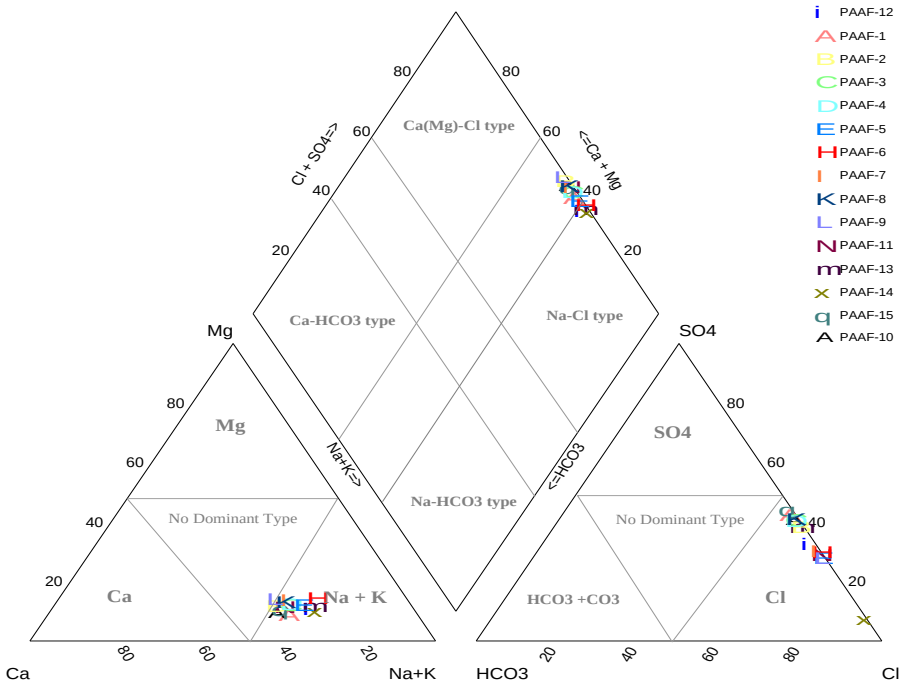

Fig. 3. Piper Diagram of the groundwater samples from the Wafra area.

Conclusions

The primary objective of this work was to use the TDS as an indicator of groundwater contamination by the produced water. The field data clearly indicated the presence of a stratified salinity in a multi-level well. In Wafra agricultural area the initial TDS of the groundwater of the Kuwait Group aquifer was ranging between 4400 to10,000 mg/l, and the TDS of the Dammam aquifer is less than that of the Kuwait Group. The change in the TDS at the west side of the Wafra agricultural is highly due to the migration of the produced water from the evaporative pond toward the agricultural area. It is recommended to conduct more studies using different chemical parameters to define the distribution of the contamination plume in the Wafra agricultural area and its adjacent areas. Defining the spatial distribution of the plume will help the decision makers in planning the appropriate remediation plan in Wafra Oil field and the agricultural area.

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استخدام المحكاة الرياضية للتنبوء بسلوك خزان الدمام الجوفي في مملكة البحرين

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ملخص

تقع مملكة البحرين في منطقة تعتبر من أكثر مناطق العالم جفافاً وأشدها ندرة للمياه، وتمثل المياه الجوفية المصدر الطبيعي الوحيد للمياه العذبة نسبياً فيها. تعتمد مملكة البحرين في تلبية احتياجاتها من المياه الجوفية على خزانين رئيسيين، هما خزان الدمام (والمتكون من طبقتين هما العلاة (أ) والخبر (ب))، وخزان الرس-أم الرضمه (ج). في العقود الأربعة الماضية أدى الاستخدام العشوائي والمكثف لمياه خزان الدمام في المنطقة، بسبب معدلات النمو السكاني والتنمية المتسارعين فيها، إلى هبوط مستوياته المائية وتدني نوعية مياهه بشكل مستمر، مما يستوجب إدارته والتخطيط لاستخداماته بعناية وباستخدام أحدث التقنيات المساعدة على اتخاذ القرار، ومن أهمها نماذج المحاكاة الرياضية.

ولذا، هدف البحث إلى توفير نموذج رياضي لخزان الدمام الجوفي في مملكة البحرين لكي يستخدم في فهم سلوكه في الفترة الماضية وإدارته في الفترة المستقبلية، والتنبؤ بتأثير الخطط المستقبلية في كل من مملكة البحرين والساحل السعودي عليه. وقد تم اختيار نموذج رياضي إقليمي ثلاثي الأبعاد من دراسة نمذجة سابقة غطت الفترة 1925-1983. حيث تم إعادة بناء النموذج وتطويره ومن ثم تحديثه وإعادة معايرته باستخدام بيانات السحب والمراقبة للفترة (1984-2006). وبعد الحصول على نموذج رياضي يحاكي ويمثل الظروف الطبيعية للمياه الجوفية بمنطقة الدراسة إلى أقرب الحدود وبدرجة مرضية من الاطمئنان، تم استخدامه في التنبوء بسلوك الخزان تحت ثلاثة سيناريوهات سحب رئيسية محتملة بناء على دراسات أعدت لصالح الإدارات المائية في البحرين والمملكة العربية السعودية. وهي أن يستمر نمط نمو السحب الحالي في الساحل السعودي بنمو سنوي قدره 1.5%، أو أن يتناقص هذا النمو ليصبح 0.5%، أو أن يتزايد ويكون 2.5%. ويقابل هذه السيناريوهات في الساحل الشرقي السعودي سيناريو واحد في البحرين تثبت فيه كميات الاستخدام الزراعي وتتناقص باقي الاحتياجات من مستوياتها الحالية إلى الصفر في عام 2025، نتيجة لمساهمة الموارد المائية غير التقليدية في تلبيتها. بالإضافة لذلك، تم استخدام النموذج لتقدير تأثير ارتفاع سطح البحر الناتج من ظاهرة تغير المناخ العالمي على معدلات غزو مياه البحر للمياه الجوفية في البحرين.

ولقد بينت نتائج تشغيل النموذج وجود انعكاس للممال الهيدروليكي بين الطبقة (ب) والطبقة (ج) لصالح الأولى بدءاً من العام 2006، وسيترتب على ذلك خسارة كميات من المياه شبه العذبة من الطبقة (ب) إلى الطبقة (ج) المائلة للملوحة. تضمنت نتائج النموذج في جميع السيناريوهات المتوقعة أن يستمر تأثير انعكاس الممال الهيدروليكي بين هاتين الطبقتين حتى عام 2025، وأظهرت المحاكاة المستقبلية أن خزان الدمام في مملكة البحرين سيتأثر بالسحب في الساحل الشرقي السعودي بشكل كبير على الرغم من تخفيض السحب في البحرين، . وسيتجاوز خط الصفر للسطح البيزومتري، الذي يمثل بشكل تقريبي الجبهة المالحة، البحرين في اتجاه الساحل السعودي، وسيكون ذلك مؤشراً سلبياً يدل على مدى تغلغل مياه البحر في الخزان. كما اتضح من نتائج النموذج أن ارتفاع سطح البحر الناتج عن ظاهرة تغير المناخ يتسبب في زيادة كميات مياه البحر الداخلة للخزان مع مرور الوقت، تم تقديرها بحوالي 5% من إجمالي

المياه الداخلة للخزان في عام 2025 في كل السيناريوهات، مما سيؤدي إلى تفاقم وضع المياه الجوفية في البحرين.

يوصي البحث بضرورة التنبه للتغيرات المهمة التي طرأت في طبيعة حركة المياه في نظام المياه الجوفية في البحرين، والمتمثلة في انعكاس الممال الهيدروليكي لصالح الطبقة (ب) وخسارة هذه الطبقة لمياهها شبه العذبة للطبقة (ج)، وأخذها في الاعتبار في عملية إدارة الموارد المائية في البحرين والخطط المستقبلية لإدارة خزان الدمام. كما يُوصى بإعادة التعاون مع الإدارة المائية في الساحل السعودي لتبادل البيانات ورسم السياسات المائية التي تكفل للبلدين الاستفادة القصوى من الخزان، واتخاذ التدابير اللازمة للمحافظة عليه وعلى استدامته في خدمة أهداف التنمية في البلدين. وأخيراً، يُوصى بتطوير النموذج الرياضي الذي تم بناءه ليمثل كامل طبقات الخزان الجوفي بشكل نشط (تحديداً الطبقة (ج))، وأن يضاف للنموذج تمثيل حركة الأملاح ليوفر متطلبات الإدارة المائية، التي تستلزم معرفة التغيرات في المستويات المائية والملحية معاً، في ظل تغير أدوار الطبقات المائية وتداخل مياه البحر التي أصبحت واقعاً مؤثراً في اتخاذ القرارات والتخطيط المائي.

مقدمة

مملكة البحرين عبارة عن أرخبيل من الجزر تقع في خليج سلوى في الخليج العربي، في المنطقة الواقعة بين مدار السرطان وخط الاستواء، وتوصف هذه المنطقة وفق المعايير العالمية بأنها ضمن المناطق الجافة التي تتسم بندرة الأمطار، حيث يبلغ المتوسط السنوي لهطول الأمطار في البحرين حوالي 74 مم، وتسقط خلال الفترة من أكتوبر إلى مايو، وهي أمطار غير منتظمة زمنيا أو مكانياً، ويرتفع معدل التبخر فيها إذ يتراوح بين 1650-2050 مم/سنة (النعيمي، 1999) مما يؤدي إلى استحالة وجود مياه سطحية في المملكة.

أن الموقع الجغرافي ومناخ مملكة البحرين جعل من الخزان الجوفي مصدر ومورد المياه الطبيعي الوحيد لها. وقد أكدت الدراسات أن مملكة البحرين تعتمد في تلبية احتياجاتها من المياه الجوفية على خزانين رئيسيين، هما خزان الدمام (والمتكون من طبقتين هما العلاة (أ) والخبر (ب))، والخزان الثاني خزان الرس - أم الرضمه (ج)، وهو على شكل عدسه محدبة، تنكشف قمتها في منتصف جزيرة البحرين. يعتبر خزان الدمام (الخزان الجوفي الرئيسي) جزءاً صغيراً من الخزان الجوفي الواسع الامتداد والمسمى بالخزان العربي الشرقي الذي يمتد من صحراء الدهناء إلى المنطقة الشرقية في المملكة العربية السعودية، مكوناً في مملكة البحرين نهاية الدورة الهيدروجيولوجية ومنطقة التصريف، ويتم تغذية خزان الدمام بشكل رئيسي من خلال التدفق الأفقي من خارج الحدود الإقليمية لمملكة البحرين والقادمة من المملكة العربية السعودية، قُدرت تلك التغذية بحوالي 90 م م3 سنويا (GDC, 1979).

وقد أجمعت معظم الدراسات السابقة بأن الخزان كان في حالة شبه استقرار واتزان طبيعي في الفترة التي سبقت عام 1924، وبسبب ارتفاع معدلات السحب عن معدلات التغذية الطبيعية، دخل الخزان مرحلة عدم الاستقرار منذ مطلع الستينات في القرن الماضي، مما تسبب في هبوط مستوياته البيزومترية وتملحه بسبب غزو مياه البحر ومياه الطبقة (ج). في منتصف السبعينات توجهت الإدارة المائية لتحلية مياه البحر لتلبية احتياجات القطاع البلدي، ثم تلى ذلك الدراسات المتواصلة لخزان الرس – أم الرضمه لتحلية مياهه، ورافق ذلك عمل نماذج رياضية تمثله لبحث الاستفادة منه بالشكل الأمثل لتحقيق هدفين، هما إيجاد مصدر لمياه الشرب في حالة تلوث مياه البحر بانسكاب نفطي وتوقف محطات التحلية، والحد من تملح خزان الدمام بواسطة انتقال مياه الرس- أم الرضمه إليه. ورافق هذه الخطوات معالجة مياه الصرف الصحي ومشروع إعادة استخدامه. وقد شكل ذلك في مجمله دعم لخزان الدمام وتخفيف الضغوط عليه، إلا أن توقفت الدراسات المتعلقة بإدارة ونمذجة خزان الدمام بعد عام 1989، قد حال دون فهم المتغيرات الهامة التي جدت على الخزان طوال العشرين عام الماضية، وبالتالي إعاقة القيام بالتخطيط المتكامل للموارد المائيه المتاحة.

تحديد المشكلة

حاليا لا يتوفر في البحرين نموذج رياضي يحاكي الخزان الجوفي الرئيسي فيها (الدمام) يمكن استخدامه كأداة مساندة لاتخاذ القرار في عملية إدارة وتخطيط المياه الجوفية من قبل الجهات المسؤلة. وبالرغم من بناء نماذج رياضية للخزان الجوفي أكثر من مرة من عدة جهات (شركات استشارية وباحثين)، إلا أنه لم يتم إعادة تحديث تلك النماذج بالبيانات الضرورية، مما يتعذر معه عمل تلك النماذج بالشكل المطلوب.

أهمية البحث

وجود نموذج رياضي حديث هو أداة ضرورية في عملية إدارة المياه الجوفية وتخطيطها في مملكة البحرين، وهذه الدراسة ستكون بمثابة ربط بين البيانات التي تم الحصول عليها من ناتج أعمال 60 عام (1924- 1983) لكل الدراسات والقياسات التي أجريت حتى عام 2006، بما في ذلك البيانات التي قيست

في شرق البر السعودي، والخروج بنموذج رياضي يعتمد على قاعدة بيانات عريضة وحديثة، ليستخدم للتنبؤ بردود أفعال الخزان على السيناريوهات التنموية المتوقعة. ويتم من خلاله إلقاء الضوء على المتغيرات التي جدت على هذا الخزان طوال العشرين عام الماضية خصوصاً وان آخر دراسة له كانت عام 1989.

أهداف البحث

يهدف البحث إلى تطوير نموذج رياضي رقمي ثلاثي الأبعاد، إقليمي وحديث يشمل الخزان الجوفي في مملكة البحرين، مع جزء من الساحل الشرقي للملكة العربية السعودية، بحيث يمكن استخدامه لفحص سلوك الخزان نتيجة التطورات التي قد تحدث مستقبلا، وذلك بتطبيق السيناريوهات المتوقعة من الإدارات المائية، سواء في مملكة البحرين أو المملكة العربية السعودية.

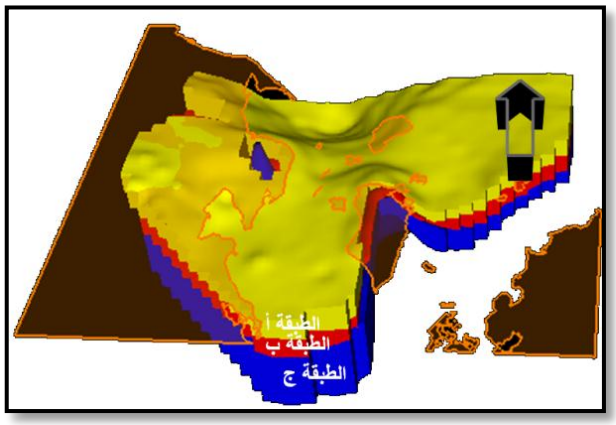
اختيار النموذج

من خلال الاطلاع على الدراسات السابقة، أتضح أنه تم تمثيل خزان الدمام الجوفي- بشكل شامل لمملكة البحرين والساحل الشرقي للملكة العربية السعودية- في دراستين، وهما:
دراسة GDC (1979) بني بطريقة خاصه تحول دون تغيير حدودة ومكوناته.
دراسة Zubari (1987) وهو النموذج الذي تم اختيارة.

إعادة بناء النموذج وتطويره

تم إعادة بناء هذا النموذج باستخدام بيانات النموذج الأصلي المتوفرة ورقياً، وجرى إعادة تشغيله للتأكد من الحصول على نفس النتائج التي توصل لها النموذج في فترة الاستقرار وهي قبل 1924، وعدم الاستقرار للفترة 1924-1983.

جرى التطوير باضافة ابعاد الطبقات، بجمع البيانات ومعالجتها ومن ثم إدخالها في النموذج الرياضي، والبيانات في هذه الحالة عبارة عن خرائط تم تحويلها إلى بيانات يمكن إدخالها في النموذج الرياضي، وذلك باستخدام برامج نظم المعلومات الجغرافية وتم الحصول على شكل وتراتب طبقات الخزان كما يتضح من الشكل (1).

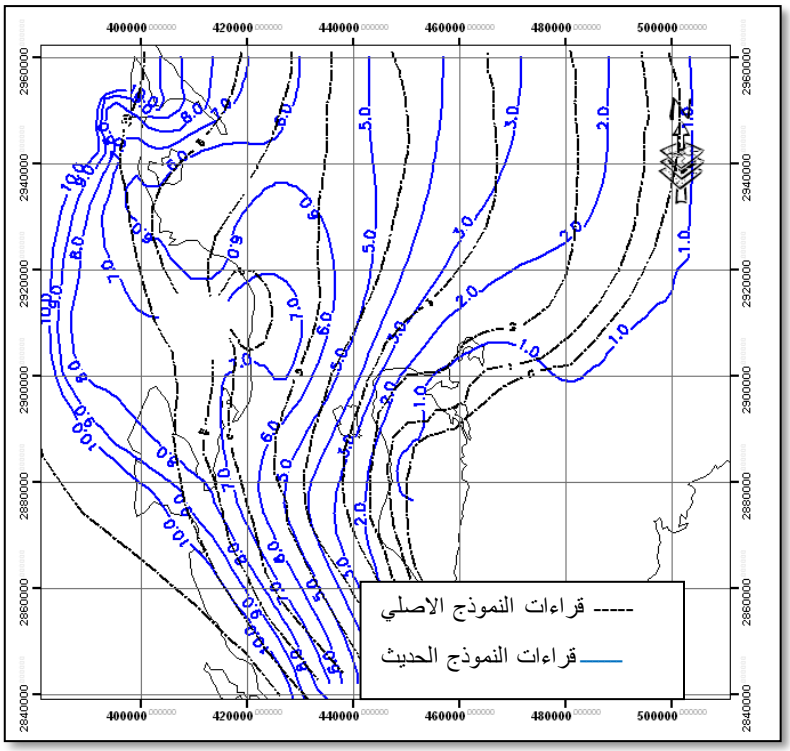


شكل (1) الطبقات بعد اضافة ابعادها (النموذج الجيولوجي).

تم تقسيم كل خلية إلى أربع خلايا، لتصبح الشبكة ممثلة بخلايا مربعه، طول ضلع الخلية 2 كم، ويصبح عدد الخلايا(61 عمود X69صف)، وذلك لتحقيق أحد أهداف البحث، وهو استخدامه في إدارة الخزان الجوفي لمملكة البحرين، وتم تصحيح أماكن تصريف العيون والشروط الحدودية ومواقعها في النموذج.

معايرة النتائج مع نتائج النموذج القديم

بعد الانتهاء من عمل خطوات تطوير النموذج تم تشغيل النموذج للتأكد من الحصول على النتائج الأصلية ومعايرة النموذج المطور عليها، ويوضح الشكل (2) مدى تقارب النتائج في حساب المستويات البيزومترية في عام 1983 في الطبقة (ب) في النموذجين القديم والحديث.



شكل 0(2) المستويات البيزو مترية في الطبقة (ب) عام 1983 في النموذج القديم والنموذج الحديث.

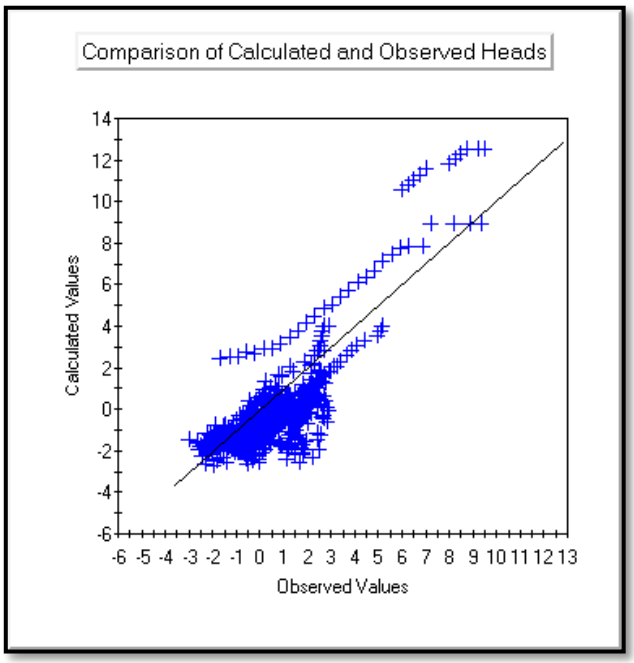
تحديث بيانات ومُدخلات النموذج

عادة تتم عملية تحديث النماذج، من خلال إدخال البيانات الجديدة للسحب، وقراءات آبار المراقبة المتزامنة معها، وذلك للتثبت من تقارب القراءات المحسوبة من النموذج مع تلك المقاسه من الواقع (السباعي وآخرون، 2003). وقد تم استخدام هذه المنهجية، حيث تم جمع بيانات الضخ وتوزيعها مكانياً وزمنياً في خلايا النموذج، مع إدخال بيانات المراقبة.

معايرة النموذج

تمت معايرة النموذج حتى الوصول إلى أقرب درجة ممكنة من التطابق بين مخرجات النموذج والنظام الطبيعي في الطبقة (ب) في مملكة البحرين، ويوضح الشكل (3) مقدار التباين variance بين القراءات

المحسوبة والقراءات المقاسة ميدانياً لكامل منطقة ألدراسة بما فيها بيانات الساحل ألسعودي ويساوي(0.9).



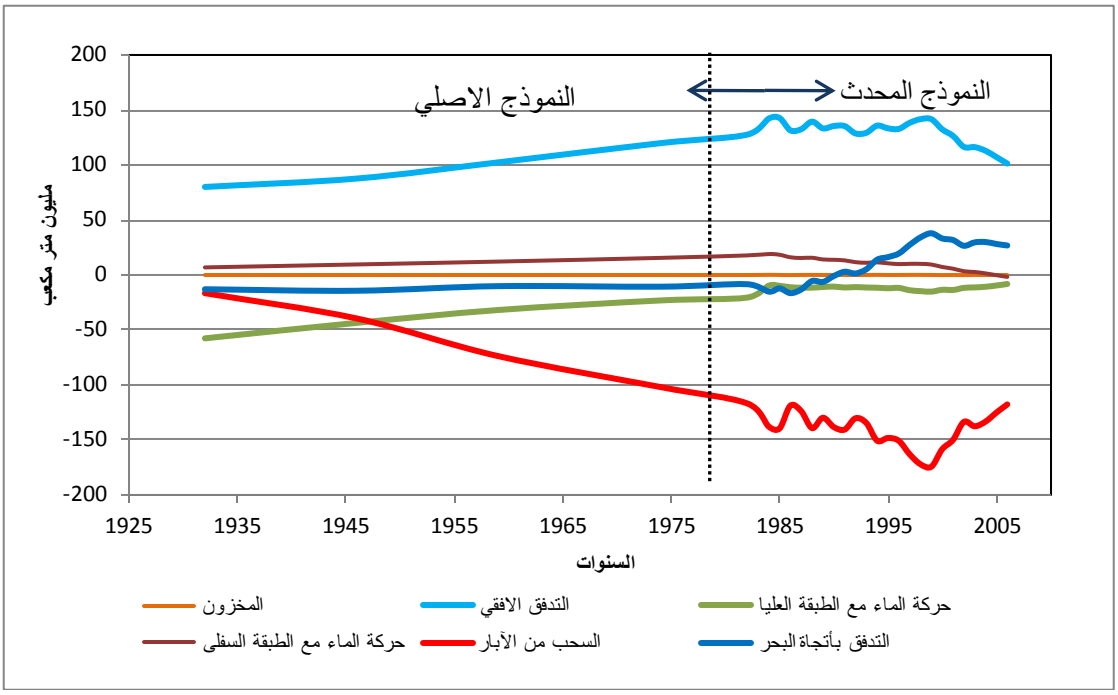
شكل (3) معدل تباين القراءات المحسوبة مع المقاسة.

الميزانية المائية

بعد الانتهاء من معايرة النموذج، تم حساب الميزانية المائية للطبقة (ب) في مملكة البحرين، لحساب كميات المياه الداخلة والخارجة من هذه المنطقة وفي هذه الطبقة تحديداً باعتبارها الخزان ألرئيسي وبطول المدة الزمنية من عام 1984-2006.يوضح الشكل البياني (4) مكونات الموازنة المائية، ويبين الشكل أن حركة التدفق الأفقي للمياه الداخلة للمنطقة المحددة من المملكة العربية السعودية إلى الطبقة (ب) يرتفع من حوالي 75 م م3 سنوياً في فترة الاستقرار ويتزايد ليصل لذروة الارتفاع عند حوالي 142 م م3 في عام 1999. ويمكن ملاحظة أن هذا المصدر حتى مع تزايد كميات السحب من الطبقة (ب) في السنوات اللاحقة وارتفاعه من 140 م م3 سنوياً إلى 170 م م3 كانت تتزايد كميات التدفق الجانبي بشكل أقل نوعاً ما من السابق، ليكون جزء من التعويض من الحدود الشرقية (مياه البحر)، وذلك بعد تشكل ميل هيدروليكي من جهة البحر يرجح دخول مياهه للتعويض عن كميات السحب.

كما يوضح الشكل مساهمة متدنية جداً من مخزون الطبقة، وقد كانت ذلك محل تدقيق، وتم حسابه حتى خارج النموذج الرياضي، وكانت النتائج متقاربة، وهذا لا يعكس عدم تأثر الخزان، إنما هو عائد لطبيعة الخزانات المحصورة وتدني كفاءتها التخزينه (Storage Coefficient) وهي مقدرة في النموذج الرياضي بـ 0.0001. كما أن تدخل مياه البحر على امتداد الجهة الشرقية تجعل من جزء كبير من الخزان في حالة اتزان مع مياه البحر، مما يلغي جزء كبير من التأثير على المخزون. ويمكن ملاحظة تشكل عامل ضغط جديد على هذه الطبقة، وهو تكون ممال هيدروليكي في اتجاه الطبقة (ج)، وهذا تحديدا ما أشارت له دراسة زباري (1994)، "اتضح من مخرجات النموذج أن الحدود الزمنية لاستغلال الخزان (ج) لأغراض التحلية هي بحلول العام 2007، والذي يبدأ بعده الهبوط في الضغوط البيزومترية بتعدي الحد المسموح به، الأمر الذي يترتب عليه فقدان المياه من خزان الدمام إلى خزان الرس-أم

الرضمه."، ويمكن ملاحظة ذلك في منحنى حركة الماء في الطبقة السفلى (ج)، التي بدئت تستلم الماء من الطبقة (ب) من العام 2006، وهو العام الذي بدأ فيه الانعكاس الهيدروليكي.

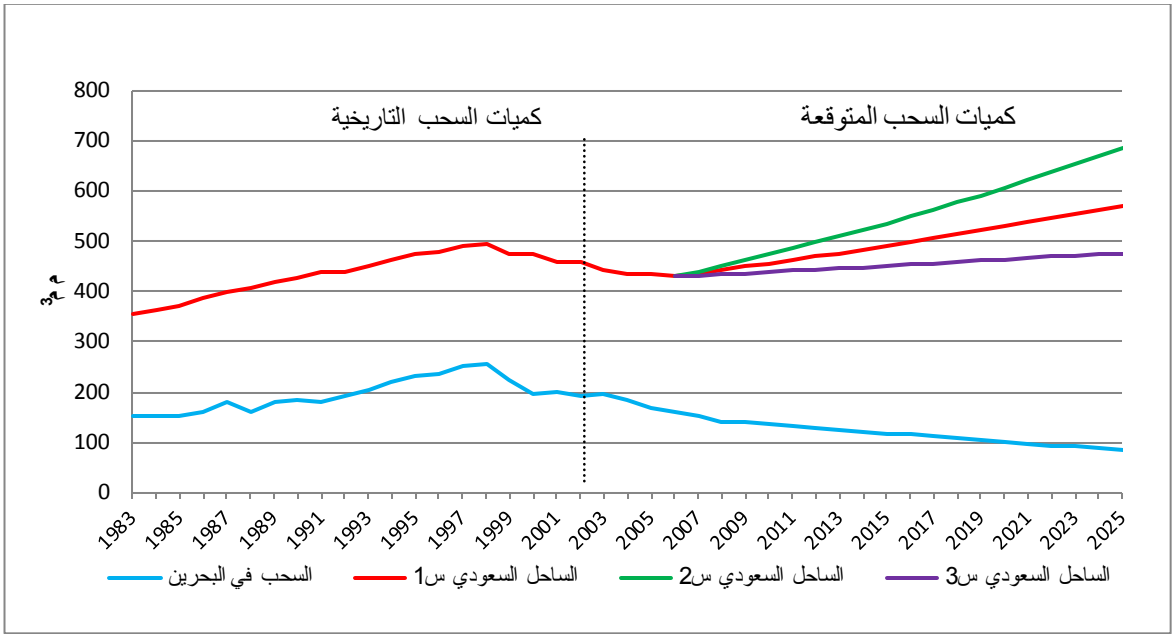


شكل (4) حركة الماء من وإلى الطبقة (ب) في البحرين في الفترة (1924-2006).

نمذجة السيناريوهات

من خلال الدراسات التي أعدت للتوقعات المستقبلية لاستخدامات المياه الجوفية في البحرين، يتضح أن الوضع بالنسبة لخزان الدمام سيأخذ اتجاه واحد، حيث يثبت الضخ للاستخدام الزراعي عند 76.4 م م^3 في العام، وتناقص كميات الشرب من 48 م م^3 عام 2006 إلى أن تصل الصفر عام 2025(المصري، 2010). أما الوضع في الساحل السعودي فمن المتوقع أن يأخذ السحب من الدمام واحد من ثلاث سيناريوهات، الاول استمرار تنامي السحب بمعدله الطبيعي البالغ 1.5% (سيناريو مرجعي)،الثاني ينخفض معدل النمو السنوي للسحب ليكون 0.55% (سيناريو ايجابي)، والثالث يزداد معدل النمو للضخ في الساحل الشرقي ليصبح 2.5% (سيناريو سلبي)، ويوضح الرسم البياني (5) هذه السيناريوهات.

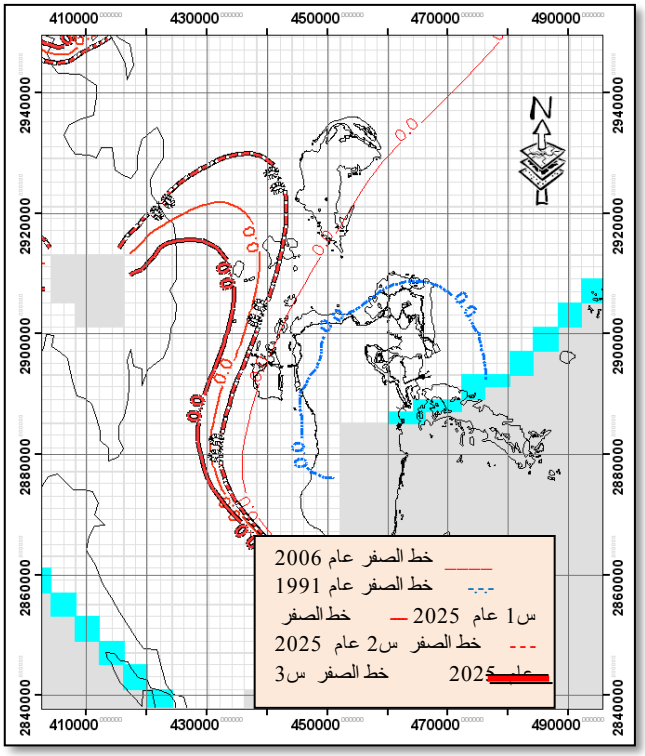
أما بالنسبة لطبقة الرس-أم الرضمه يتضح أن هناك ثلاثة سيناريوهات متوقعة لها في الساحل السعودي تبعا للسحب المتوقع منها، وسيناريو واحد في البحرين، وهذه الدراسة أخذت بافتراض تشابه الانخفاض مع البحرين، لأن كميات السحب والمراقبة في الساحل السعودي ينقصها كثير من الدقة، وبالتالي فأن البناء على هذه البيانات يعطي توقعات بمستوى ثقة متدنية. ولأن النموذج هو لإدارة خزان الدمام في البحرين، وبهدف إلغاء أي تأثير لتقديرات لا تحمل مقدار مناسب من الثقة، فقد كان من المناسب مواصلة تمثيل الرس_أم الرضمه في الساحل السعودي على نفس الاتجاه السابق ومتماشي مع الوضع في البحرين.



شكل (5) كميات الضخ الماضية والمستقبلية من البحرين والساحل السعودي من خزان الدمام.

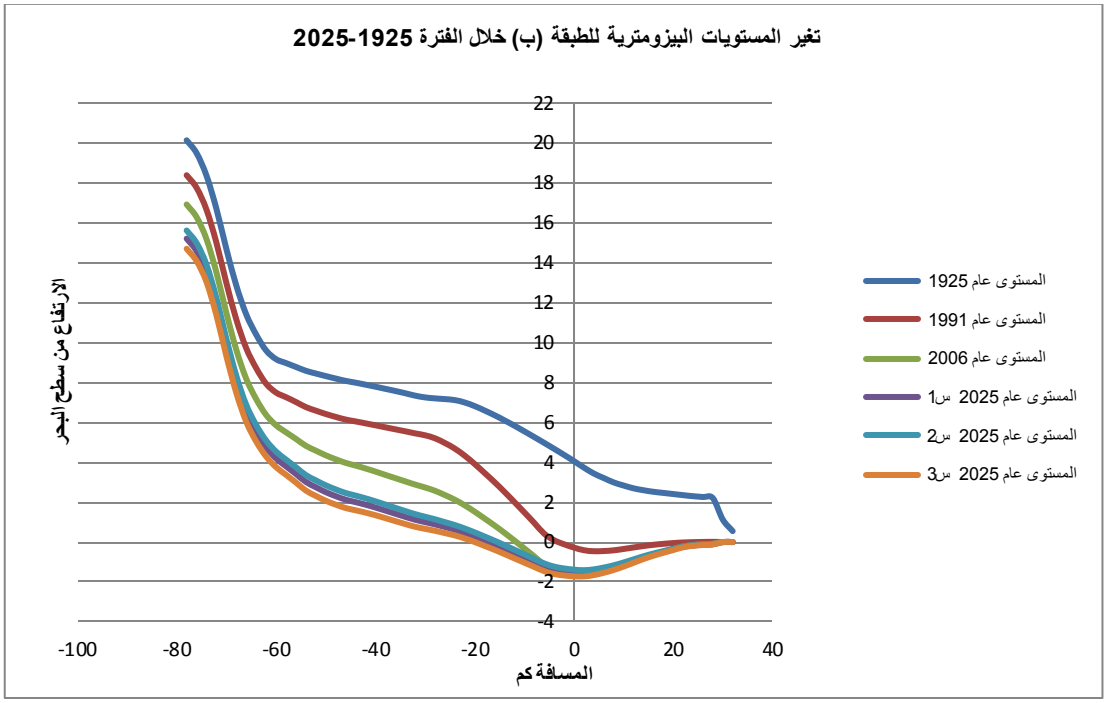
النتائج والمناقشة

جرى إعادة تشغيل النموذج في السيناريوهات الثلاثة المتوقعة، لدراسة تأثيرها على الطبقة (ب)، من حيث الهبوط المصاحب لكل سيناريو، ومقدار تداخل مياه البحر والطبقة (ج) معها. ويوضح الشكل (6) مقارنة لموقع مستوى الصفر للثلاثة سيناريوهات المستقبلية وكذلك للعامين 1991و 2006. ويتضح من شكل جميع الخطوط زيادة تأثير السحب في الساحل السعودي على المستويات البيزومترية للخزان الجوفي، على عكس الوضع السابق حيث يكون التأثير الرئيسي ناتج عن السحب في جزيرة البحرين.



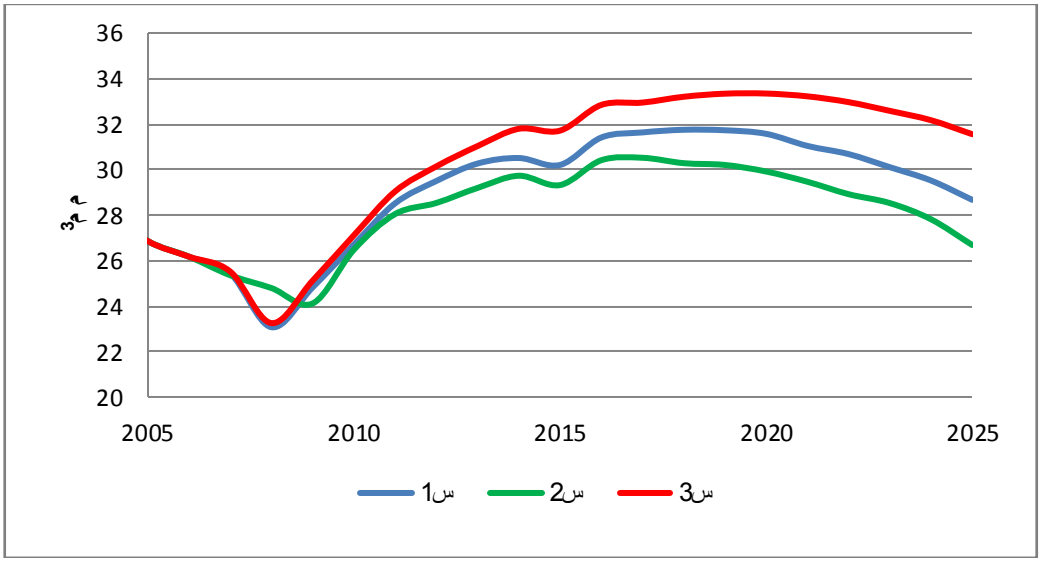
شكلل (6) تحرك مستويات الصفر من العام 1991 حتى 2006 والمتوقع مع السيناريوهات المستقبلية في 2025.

ويوضح الرسم (7) مقطع للمستويات البيزومترية للخزان في عام 1991، التي اختفت فيها جبهة الصد الموالية للبحر، وتكون تقعر للمستويات البيزومترية قاعه تحت سطح البحر بحوالي-0,5 م، وهو العام سجل النموذج أول قراءات تبيّن تداخل مياه البحر في المنطقة التي يمثلها النوذج. ويفسر الرسم تفاقم الوضع في الخمسة عشر عام التالية حتى عام 2006، إذ تحرك قاع الهبوط في اتجاه الشرق ليترك المجال لتداخل مياه البحر، ورافق ذلك انخفاض في المستويات البيزومترية من اتجاه الساحل السعودي، مما تسبب في انخفاض الممال الهيدروليكي وبالتالي انخفاض قدرة المياه العذبة في تعويض الهبوط. وكذلك يفسر الرسم الوضع المستقبلي وسبب التحرك السلبي المتوقع، لمستوى سطح البحر في اتجاه الشرق حتى مع انخفاض السحب في البحرين، بأنه عائد لتحرك قاع الهبوط في اتجاه الشرق، مما سيتسبب في زيادة دخول كميات مياه البحر وتناقص كميات التدفق الأفقي للمياه العذبة من الغرب.



شكل (7) المستويات البزومترية للطبقة (ب) في المقطع العرضي خلال عدة فترات.

وبشكل عام فأن الموازنة المائية ناتج النموذج الرياضي في السيناريوهات الثلاثة للطبقة (ب) في مملكة البحرين، اوضحت أن السيناريو الايجابي للضخ من الساحل الشرقي سيكون له أقل الآثار بالنسبة للسيناريوهات الأخرى، حيث يصاحبه أعلى تدفق من الحد الغربي (مياه عذبة)، وأقل سيناريو يتسبب في تدفق مياه البحر من الشرق كما يتضح من الشكل (8)، حيث أن أعلى الكميات الداخلة للخزان من مياه البحر تصاحب السيناريو السلبي ثم السيناريو الواقعي، كما يوضح التأثر الشديد لتلك الكميات في الفترة 2005-2008 التي تم فيها تخفيض كميات الضخ البلدي من 49.8 م م3 إلى 28.5م م3. وعلى الرغم من أن تلك الكميات واصلت التناقص، إلا إن الكميات الداخلة من البحر سرعان ما عادت للارتفاع مرة أخرى، وهذا ناتج عن الهبوط في المستويات المائية في الطبقة السفلية (ج)، حيث يلاحظ سرعة تناقص معدل تلك الكميات في كل السيناريوهات في نهاية فترة النمذجة، وهي الفترة التي تصل فيها الطبقة السفلى للاستقرار، مما يؤكد ارتباط الطبقتين وتأثير كل منها على الأخرى .



شكل (8) كميات المياه الداخلة للخزان من مياه البحر في كل سيناريو.

التأثيرات المتوقعة لظاهرة تغير المناخ

من المتوقع أن يكون لظاهرة تغير المناخ العالمية تأثيرات عديدة على المياه الجوفية. وقد تكون هذه التأثيرات مباشرة مثل زيادة التبخير، أو التأثير السلبي على تغذيتها بطول فترات الجفاف، أو إيجابياً بالعواصف المطرية الشديدة. وقد تكون هذه التأثيرات غير مباشرة مثل زيادة الاحتياجات المائية (للإنسان والنبات)، وما يترتب عليه من زيادة لكميات ضخ المياه الجوفية. ومن أهم أشكال تأثير هذه الظاهرة بشكل مباشر على المياه الجوفية هو أرتفاع مستوى سطح البحر بسبب ارتفاع درجات الحرارة وذوبان الجليد في أقطاب الكرة الأرضية. وهذا الارتفاع بدوره يسبب غزو مياه البحر المالحة للخزانات الجوفية الساحلية وتملحها، وهذا مشابه للخزان الجوفي محل هذه الدراسة. وقد تم استخدام النموذج في دراسة جزئية ارتفاع سطح البحر وتأثيرها على الطبقة (ب) من الخزان الجوفي في مملكة البحرين.

نمذجة ارتفاع سطح البحر

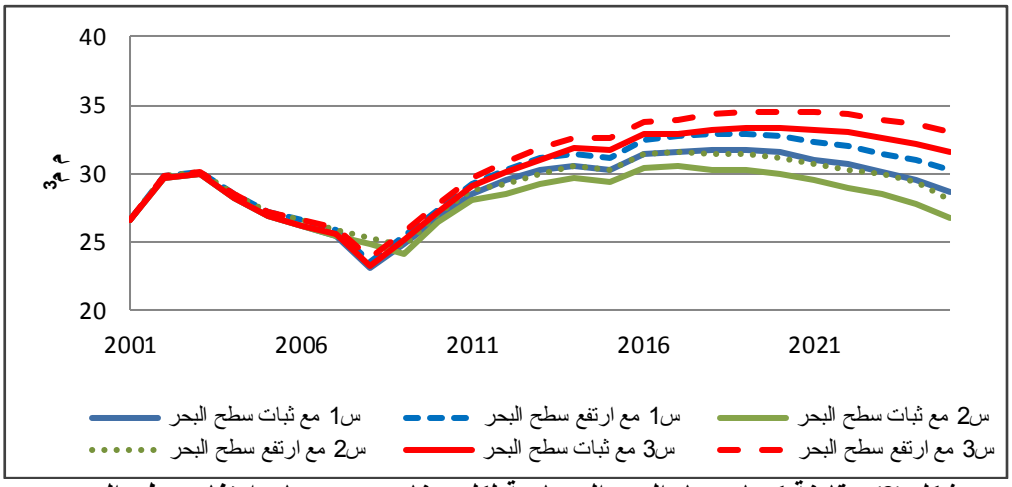
تقدر الدراسات التي تناولت معدل ارتفاع سطح البحر، بأن سطح البحر يرتفع بمقدار يتراوح بين 0.28 م و 0.59 م خلال 100 عام (IPCC, 2007). وعليه تم افتراض أن التغير سيكون عند الحد الأعلى وبدايته من عام 2001، وعليه فأن الحد الشرقي الذي يمثل سطح البحر في النموذج يرتفع خلال العام الواحد 0.0059 م، ويصل إجمالي ارتفاعه في نهاية فترات النمذجة عام 2025 إلى 0.1475 م، وتم إضافة هذا الافتراض في جميع السيناريوهات، لقياس تأثيره في كل سيناريو.

قياس تأثير ارتفاع سطح البحر

اتضح أن التغير الوحيد الذي يمكن الاعتماد عليه لتحديد حجم التغييرات الناتجة من ارتفاع منسوب البحر على الخزان الجوفي، هو مقدار ما يدخل للنموذج من الجانب الشرقي الممثل لمياه البحر. ولذلك تم اعتماد نفس التقسيم الذي عمل للميزانية بهدف عزل الحد الغربي عن الحد الشرقي، للتمييز بين مياه البحر والمياه العذبة الداخلة للنموذج، وبذلك تكون كمية المياه الداخلة للمنطقة المحددة ومصدرها الحد المشروط هي من مياه البحر وتحسب من خلال خيارات الموازنة المائية.

مقارنة تأثير ارتفاع سطح البحر في السيناريوهات المتوقعة

بعد الحصول على كمية التدفق من البحر باتجاه الطبقة (ب) في كل سيناريو في حالتين (بدون حساب ارتفاع سطح البحر ومع حساب ارتفاع سطح البحر)، اتضح أن كميات تداخل مياه البحر تزيد في كل مرة تضاف إلى أي سيناريو، كما يوضحه الشكل (9)، وهذا منطقي إذ إن الزيادة في ارتفاع سطح البحر هو زيادة في الممال الهيدروليكي ويترتب علية ترجيح مياه البحر للدخول إلى الخزان الجوفي. ويظهر الشكل كذلك تزايد تأثير ارتفاع سطح البحر مع الوقت بنسبة تتزايد مع مرور الوقت ليتسبب بـ 5% إضافية من إجمالي الكمية الداخلة للخزان من مياه البحر بحلول العام 2025، إلا أنه يعود إلى التناقص في آخر خمس سنوات من زمن النمذجة، والسبب يعود إلى تباطؤ الهبوط في الطبقة (ج) مع تناقص السحب من الطبقة (ب).



شكل (9) مقارنة كميات مياه البحر المصاحبة لكل سيناريو مع حساب ارتفاع سطح البحر.

الاستنتاجات والتوصيات

في هذا البحث تم اختيار نموذج رياضي من دراسة سابقة تم بناءه بالاعتماد على بيانات تمثل المرحلة الزمنية 1925-1983، وجرى تحديث بياناته بإدخال بيانات الفترة الزمنية 1984-2006، وقد رافق هذا التحديث تعديل وتطوير بعض الخواص والحدود الهيدروليكية، مع معايرة نتائجه بالمقارنة مع النتائج الميدانية. وتم الحصول على نموذج يحاكي خزان الدمام الجوفي إلى أقرب الحدود، استخدم في التنبؤ بسلوك الخزان الجوفي في المستقبل تحت تأثير انخفاض الضخ من خزان الدمام في البحرين، الناتج من تنامي كميات المياه من المصادر غير التقليدية، في ظل وجود ثلاثة سيناريوهات محتملة في الساحل الشرقي السعودي.

الاستنتاجات

اتضح من خلال العمل على تحديث النموذج أن الخزان الجوفي للبحرين قد طرأت عليه تغيرات مهمة ومؤثرة وخصوصاً في الطبقة (ج)، مما استلزم تمثيلها بطريقة خاصة لمحاكاة اتجاهات النشاط الذي طرأ عليها، حيث تم تمثيلها على هيئة طبقة ذات ضغط ثابت يتغير مع الوقت، وبينت نتائج النموذج انعكاس الممال الهيدروليكي بين الطبقة (ب) والطبقة (ج) لصالح الأولى بدءاً من العام 2006، مما سيترتب علية خسارة كميات من المياه شبة العذبة من الطبقة (ب) إلى الطبقة (ج) المائلة للملوحة. وأوضحت النتائج المستقبلية في النموذج أن كل كمية يتم سحبها من الطبقة (ج) سيقابلها في نهاية المطاف خسارة نفس الكمية من الطبقة (ب)، وسيؤدي هذا الانعكاس إلى دخول كميات من مياه البحر أعلى بـ50% من تلك التي كانت تدخل لها من المياه المائلة للملوحة، مما يعني أن الطبقة (ب) ستتضرر بزيادة دخول كميات مياه بملوحة أعلى. وهذا يناقض أهم أهداف الإدارة المائية في البحرين التي بنت عليها قرار استخراج الماء من الطبقة (ج)، والمتمثلة في تخفيف الطلب من خزان الدمام وتقليل تملحه من الطبقة السفلية.

لقد أظهرت قراءات النموذج المستقبلية تأثر خزان الدمام في مملكة البحرين بالضخ في الساحل الشرقي السعودي بشكل كبير حتى في حالة اتخاذ مملكة البحرين خطوات إدارية لتخفيض السحب من الخزان، حيث سيؤدي إلى هبوط في مستويات الطبقة (ب) بين المنطقتين، ليقلل مقدار الممال الهيدروليكي بينهما ويخفض معدل التغذية الجانبي، مما يتيح المجال لتداخل مياه البحر مع الخزان من جهة الشرق. كما بين النموذج أهمية الأخذ في الأعتبار التغير في ارتفاع مستوى سطح البحر، وأن هذا التغير له تأثير ملموس على كمية مياه البحر الداخلة للخزان مع مرور الزمن، حيث ارتفع هذا التأثير من الصفر عام 2001 ليصبح مسبباً لزيادة قدرها 5% في عام 2025.

التوصيات

أكدت نتائج هذا البحث وجود تغيرات مهمة في طبيعة حركة الماء بين طبقات الخزان الجوفي، ناتجة عن عمليات السحب من الطبقة (ج) الذي سبب انعكاس في الممال الهيدروليكي بينها، مما يؤدي إلى خسارة مستمرة للمياه شبه العذبة من الطبقة (ب) بتسربها إلى الطبقة (ج) المائلة لملوحة، وستستمر خسارة تلك الكميات بصورة متزايدة مع مرور الوقت، مما يستلزم أخذ ذلك بالاعتبار عند إدارة المياه الجوفية.

أوضحت نتائج النموذج المستقبلية أن السحب من الساحل الشرقي السعودي سيؤثر على معدلات التغذية الأفقية للخزان الجوفي للمملكة البحرين بشكل كبير حتى في حالة اتخاذ مملكة البحرين خطوات إدارية لتخفيض السحب من الخزان، مما يستلزم إعادة التنسيق مع الإدارة المائية في الساحل السعودي لتبادل البيانات، ورسم السياسات المائية التي تكفل الاستفادة القصوى من الخزان الجوفي للجانبين واستغلاله بعناية، باعتباره المورد المائي الطبيعي الوحيد المتوفر لكلا البلدين .

مع مرور الوقت أصبحت طبيعة التفاعل بين طبقات الخزان الجوفي أكثر تعقيداً، مما يستلزم إدارة هذا الخزان بواسطة نموذج رياضي متطور، ولذا يوصى باستخدام النموذج الرياضي الذي تم بناءه في هذه الدراسة وتطويره ليمثل جميع طبقات الخزان بشكل نشط وتحديثه مع الوقت، وكذلك إضافة نمذجة حركة الأملاح فيه لتمثيل الخزان الجوفي بشكل أكثر دقة للمساعدة في اتخاذ القرارات الإدارية التي تعتمد على كلاً من كمية المياه ونوعيتها. كما يوُصى بالاستفادة من النموذج الحالي في تطبيقات متعددة مثل تقييم التغذية الصناعية للخزان، والنظر في امكانية استخدامه في النمذجة الاحتمالية مستقبلاً لتجاوز حالة عدم الاطمئنان في بعض البيانات التي أدخلت في بناء هذا النموذج.

لقد أصبحت ظاهرة التغير المناخي أمراً واقعاً، وقد أوضحت نتائج النموذج الرياضي في هذا البحث أن تأثيرها على الخزان الجوفي في مملكة البحرين سيتزايد مع مرور الوقت مما يستلزم التخطيط للتكيف معها وتلافي تأثيرها المستقبلي.

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المياه الجوفية بدولة قطر

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ملخص

تقع دولة قطر كسائر دول الخليج العربية في المنطقة الجافة من العالم ، وتبلغ المساحة الكلية 11606.8 كيلو متر مربع ولا يوجد بها أي مصادر للمياه السطحية ، تعتبر المياه الجوفية المختزنة في باطن الأرض على مر السنين و المغذاة بمياه الأمطار الشحيحة المصدر التقليدي الوحيد للمياه في دولة قطر مع العلم بأن المتوسط السنوي للأمطار الساقطة 77.8 ملم خلال الفترة من 1972/71 إلى 2010/2009 وتتباين معدلات مجموع سقوط الأمطار من سنة لأخرى. **خصائص الخزانات الجوفية**:يمتد الخزان الجوفي قليل العمق على إجمالي مساحة الدولة ويتكون من صخور كارستية على درجة عالية من عدم التجانس يُعزا إلى التشققات والفراغات الكارستية. ولذا فانه من الصعب التنبؤ بالخواص الهيدروليكية للخزان على مسافات مختلفة لهذه النوعية من الصخور. على سبيل المثال، بئران للمياه على مسافة أقل من ١٠٠ متر قد ينطويا على خواص صخرية وهيدروليكية شديدة التباين . **ملوحة المياه الجوفية**:التوزيع الحالي للمياه العذبة والمياه قليلة الملوحة والمياه المالحة على امتداد الدولة، فقد وجد إن منطقة تواجد المياه العذبة في شمال وسط الدولة قد تناقصت من حوالي ١٥٪ من مساحة البلاد في العام ١٩٧١ إلى مجرد ٢٪ من مساحة البلاد في العام ٢٠٠٩. تمثل منطقة تواجد المياه العذبة حاليا ١١٪ تقريبا مما كانت عليه في العام ١٩٧١. بناء علي مخرجات مشروع لدراسة التغذية الطبيعية والاصطناعية لمخزون المياه الجوفية في دولة قطر2010

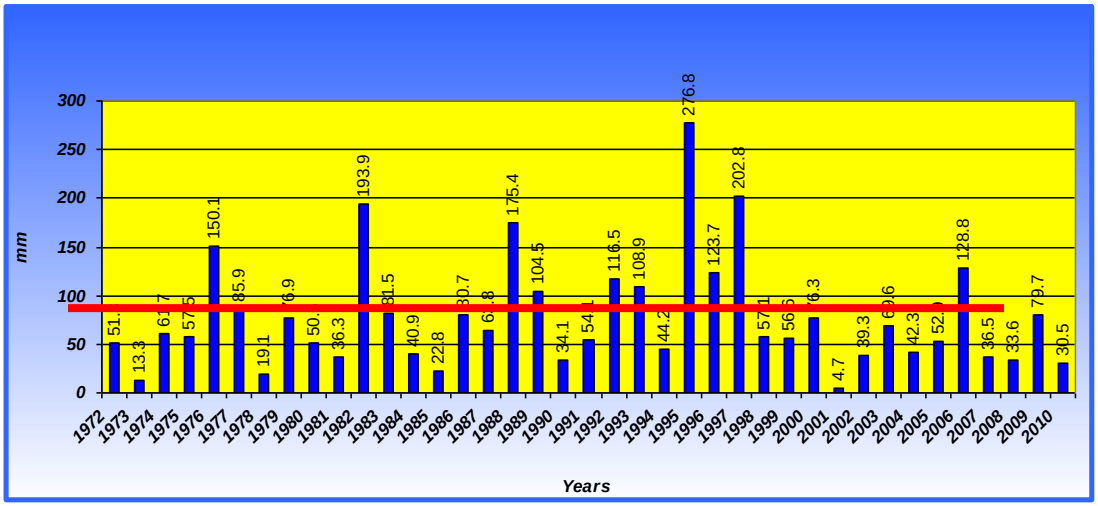
Abstract

Qatar is, like the other Gulf Arab states in the arid region of the world, the total area of 11,606.8 square kilometers and has no any sources of surface water, Groundwater is stored in the ground over the years and fed by rain water scarce the only traditional source of water in the State of Qatar. The average annual rainfall of 77.8 mm falling during the period from 71/1972 to 2009/2010 and rates vary the total rainfall from year to year. *Aquifer Characteristics*: the shallow groundwater system that underlies Qatar is a highly heterogeneous karstic system. The heterogeneities are likely largely due to fractures and karstic voids. Variations in hydraulic properties are not expected to be predictable in spatial terms; one well could be drilled less than 100 meters away from another well and have dramatically different hydraulic properties, *Groundwater Salinity*: most critically, the

current distribution of freshwater, brackish water and saline water has been well defined throughout the country. The freshwater lens that is located in the north-central part of Qatar has declined in area such that in 1971 it underlay approximate 15% of the country, and today only underlies approximately 2% of the country. The freshwater lens is now approximately 11% of the size it was in 1971 according *Studying and Developing the Natural and Artificial Recharge of the Groundwater Aquifer in the State of Qatar* .

المقدمة:

تقع دولة قطر كسائر دول الخليج العربية في المنطقة الجافة من العالم ، وتبلغ المساحة الكلية 11606.8 كيلومتر مربع تقريباً ولا يوجد بها أي مصدر للمياه السطحية ، و تعتبر المياه الجوفية المختزنة في باطن الأرض على مر السنين والمغذاة بمياه الأمطار الشحيحة المصدر التقليدي الوحيد للمياه في دولة قطر ولذا يعتبر المحافظة علي هذا المخزون الجوفي يحقق الحد الأدنى من الأمان المائي لدولة قطر ويساهم في أقامة تنمية بالدولة ، مع العلم بأن المتوسط السنوي للأمطار الساقطة 77.8 ملم خلال الفترة من 1972/71 إلى 2010/2009 [1] ، وتتباين معدلات مجموع سقوط الأمطار من سنة لأخرى كما يشير إلية الشكل رقم (1) .



شكل رقم (1) متوسط مجموع الإمطار لعام 1972 إلى 2010

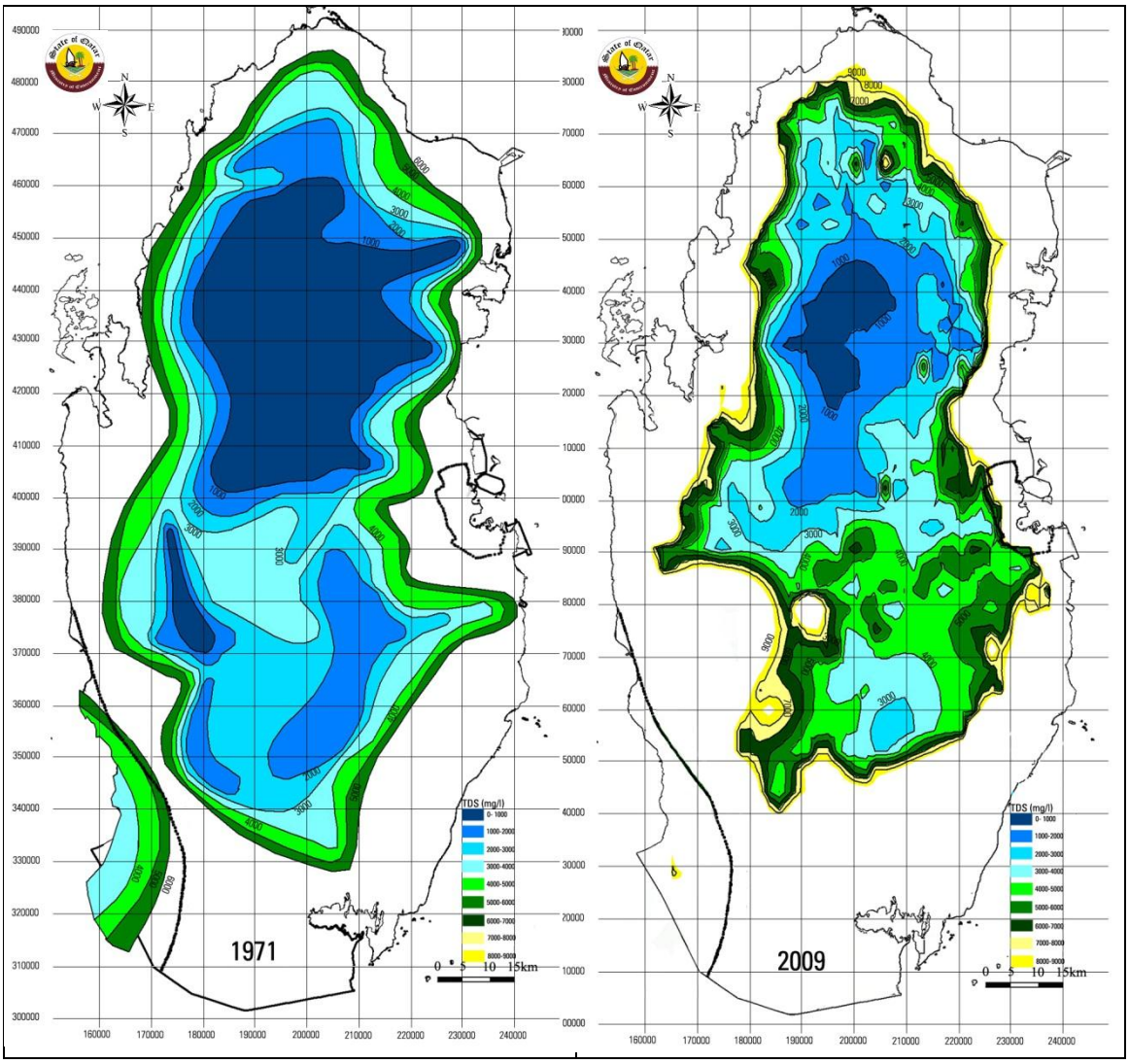
الهيدروجيولوجيا:

تتكون الطبقات الحاملة للمياه الجوفية بقطر من عدد طبقتين رئيستين والتي يتم استغلالها وهي طبقة الرس العصر الأيوسني و طبقة أم الرضمة العصرباليوسين ، و تنقسم الخزانات الجوفية في دولة قطر على حسب امتداد الطبقات المياه الجوفية إلى قطاعين هيدرولوجية رئيسية وهي حوض المياه الجوفي الشمالي والحوض الجنوبي ، و تعتمد إلى حد كبير هذه الأحواض على درجة تركيز الأملاح ، حيث توجد المياه الجوفية قليلة الملوحة نسبياً في القطاع الشمالي و التي تعكس إلى حد كبير كتأثير المنطقة إلى مياه الأمطار التي تتساقط بكثرة بها ، أما القطاع الجنوبي فإن تركيز الأملاح أعلا من الشمالي ، بالإضافة أن توجد أحواض اصغر للمياه الجوفية في أبوسمرة ، الدوحة [2] .

ملوحة المياه الجوفية:

التوزيع الحالي للمياه العذبة والمياه قليلة الملوحة و المياه المالحة على امتداد الدولة ، فقد وجد أن منطقة تواجد المياه العذبة في شمال ووسط الدولة قد تناقص من حوالي 15% من مساحة الدولة في العام 1971 إلى مجرد 2% من مساحة الدولة في العام 2009 ،وتمثل منطقة تواجد المياه العذبة حالياً 11% تقريباً

مما كانت عليه في العام 1971 [3] حيث يمثل الاضمحلال الكمي والنوعي بتواجد المياه الجوفية بدولة قطر،وعلي الرغم من أن المياه الجوفية الجيدة نسبياً إجمالا بمعزل عن البحر إلي أن هناك عدد عوامل تأثر عليها ومنها تأثير تداخل المياه البحر من المناطق المجاورة للبحر وتصاعد المياه الملحة من الطبقات السفلي .



شكل رقم (٢):خريطتا نسبة ملوحة المياه الجوفية لعامي ٢٠٠٩ و ١٩٧١ [3]

خصائص الخزان الجوفي:

يعتبر الخزان الجوفي قليل العمق ممتد على إجمالي مساحة الدولة و يتكون من صخور كارستية على درجة عالية من عدم التجانس ، يعزا ذلك إلى كثرة التشققات و الفراغات كارستية ولهذا فمن الصعب التنبؤ بالخواص الهيدروليكية للخزان على مسافات مختلفة لهذه النوعية من الصخور ، وعلى سبيل

المثال بئرين للمياه على مسافة اقل من 100متر قد ينطوي على خواص صخرية و هيدروليكية شديدة التباين.

وقد بلغ عدد الآبار بدولة قطر أكثر من 8509 بئر [3] وتم توزيع هذه الآبار على حسب الاستخدام حيث اتضح أن معظم تلك الآبار تقع مـن ضمن المزارع كم يتبين مـن الجدول رقم (1) ، كما يوضح الشكل رقم (3) توزيع هذه الآبار وفق الأحواض الجوفية .

جدول رقم (1) عدد الآبار على حسب الاستخدام [3]

الاستخدام	المزارع	صناعي	المنازل	البلدي(الحكومي)	المجموع
العدد	6299	280	665	1265	8509
النسبة	74	8	3	15	%100

شكل (3) توزيع الآبار والأحواض الجوفية في دولة قطر

كما تم تصنيف الآبار بدولة قطر وفقاً لأحواض المياه الجوفية ونسب تواجدها ، وهي كالتالي :

- الشمالي 70%
- الجنوب 28%
- أبوسمرة 1%
- الدوحة 1%

ومن هذه النسب نرى إن الغالبية العظمى من الآبار تتركز في القطاعيين الرئيسيين الشمالي والجنوبي .

جدول رقم (2) يمثل نسب الآبار موزعة علي الأحواض الجوفية [3]

الحوض الجوفي	الطبقة الحاملة للمياه	النسبة
أبوسمرة	العلات	88.6%
	العرمة	11.4%
الدوحة	الرس	100.0%
الشمالي	العرمة	0%
	الرس	64.6%
	الرس + ام الرضمة	35.3%
	ام الرضمة	0.1%
الجنوب	العرمة	1.5%
	الرس	77.7%
	الرس + ام الرضمة	18.9%
	ام الرضمة	1.9%

يتضح من الجدول رقم (2) أن طبقة العلات فقط متواجدة ويتم استغلالها في الحوض الجوفي أبو سمرة في حين الحوض الجوفي بالدوحة هو بالكامل في طبقة الرس إلي أن الحوض الجوفي الشمالي والحوض الجنوبي فان الطبقة المستغلة بها هي ايضاً طبقة الرس في معظمها مع استغلال بسيط جداً لطبقة العرمة الم يكن معدوم خصوص في الحوض الشمالي مع اختلاط في استغلال الطبقات الحاملة للمياه الجوفية الرس وام الرضمة في الحوض الشمالي والحوض الجنوبي .

أما عن حالة تواجد بدولة قطر فان هذه الآبار في الغالب منها هي آبار عاملة ضخ حيث تقدر 4205 بئر حيث تشكل نسبة 49.4% في حين إن الآبار الغير عاملة هي 2625 بئر بنسبة 30.8% ، أما الآبار الملغاة فهي 808 بئر وتشكل ما نسبته 9.5% ، والآبار الجافة 534 بئر بنسبة 63% ، أما آبار التغذية الطبيعية فهي 313 بئر بنسبة 3.7% ، والآبار العميقة 24 بئر بنسبة 0.3% [3].

جدول رقم (3) نسبة الضخ من الآبار بدولة قطر على حسب الاستخدام [3]

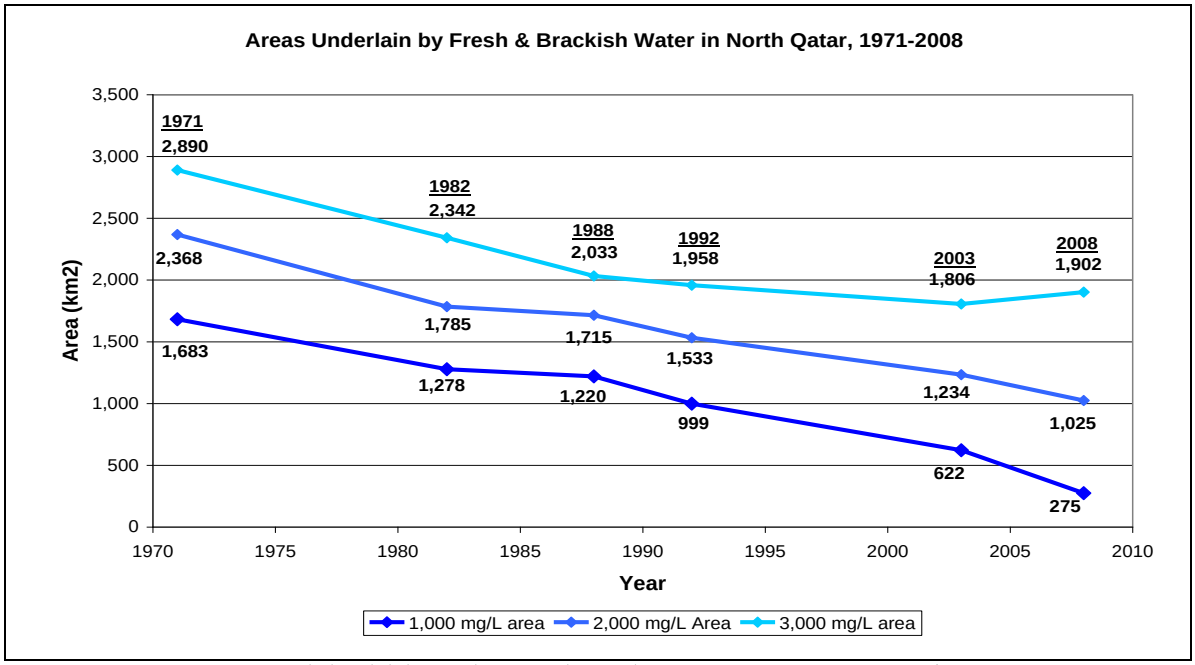
نوع الاستخدام	الضخ مليون متر مكعب/سنة	النسبة المئوية
مزارع	226.0	90.9%
المنازل	9.9	4.0%
البلدي (الحكومي)	9.3	3.7%
صناعي	3.4	4%
المجموع	248.7	100%

جدول رقم (4) نسبة الضخ بين الآبار على حسب الأحواض [3]

الأحواض	الضخ مليون متر مكعب/سنة	النسبة المئوية
الشمال	198.6	79.9%
الجنوب	47.1	19.0%
أبوسمرة	2.2	0.9%
الدوحة	0.7	0.3%
المجموع	248.7	100%

كما يوضحان الجدولين رقم (3) و(4) نسبة الضخ الآبار علي حسب الاستخدام والأحواض الجوفية ان النسبة الغالبة لمستهلك المياه الجوفية هو القطاع الزراعي وبنسبه تشكل أكثر من 90% من ضخ المياه وتقدر 226 مليون متر مكعب في السنة ومعظمها مركز في الحوض الشمالي وبنسبة 80 % تقريباً الذي يعتبر المخزون الاستراتيجي للمياه بالدولة .

كم يوضح الشكل (4) ترجمة للمنحى الذي اتخذته الثروة المائية بين العامين ١٩٧١ و ٢٠٠٩ ويظهر المناطق المائية التي تبلغ نسبة الملوحة فيها ١٠٠٠ جزء/المليون و ٢٠٠٠ جزء بالمليون و ٣٠٠٠ جزء بالمليون. يشير الرسم إلى تدني مناطق المياه العذبة والمياه القليلة الملوحة الملائمة للريّ. تعتبر المياه التي تتراوح نسبة الملوحة فيها بين ١٥٠٠ و ٣٥٠٠ جزء بالمليون صالحة للريّ لكن من المستحسن عدم استعمالها. أما المياه التي تفوق فيها نسبة الملوحة ٣٥٠٠ جزء بالمليون فتعتبر عادة غير صالحة للريّ [3].



شكل (4) :مساحة مناطق المياه العذبة والمياه القليلة الملوحة [3]

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[3] مشروع لدراسة التغذية الطبيعية والاصطناعية لمخزون المياه الجوفية في دولة قطر وزارة البيئة 2010

SESSION 3B:
CONVENTIONAL WATER RESOURCES MANAGEMENT

Keynote: Ralf Klingbeil, UN-ESCWA, Managed Aquifer Recharge in West Asia

Ralf Klingbeil is the Regional Adviser Environment and Water at the United Nations Economic and Social Commission for Western Asia (UN ESCWA), Beirut, Lebanon. Mr. Klingbeil is a principal adviser for water and environmental with extensive experience in policy advice and resources management in Middle East and Africa. Initially trained as hydro geologist, geophysicist and geoscientist, he acquired more than 18 years of professional experience in universities, private consultancies, public institutions, advisory services for UN agencies and German Federal Ministries. He has worked as groundwater specialist and adviser for water and land resources management in Africa, Europe and Middle East.

Abstract:

Water scarcity is one of the prevailing regional characteristics; challenging water and environmental management as well as the overall sustainable development at national and regional levels. Today, in many places, the available, traditional renewable water resources from surface and groundwater are already not enough to sustain the livelihoods and lifestyles of the peoples in the Middle East. Hence technical approaches such as desalination have often become one of the backbones of urban water supplies, esp. in Gulf countries. Beside existing challenges to water management under scarcity, impacts of climate change on the availability and seasonality of fresh water resources and the overall environmental habitat contribute additional challenges.

Much attention has been given to improving access to water by focusing on water governance, institutional settings and technical solutions in the water sector. At least in the water scarce Middle East it has become obvious that efforts in institutional arrangements and water demand management are in many places not enough in the face of physical limitations to the availability of water resources.

Leakage control in urban water supply systems, more efficient irrigation technologies, water saving devices at household level, industrial water recycling, more drought-resistant crop patterns, etc. … are all important to reduce the overall demand for fresh water. However, all these important achievements are continuously challenged by the ever increasing demands of growing populations, changing diets and highly water consuming urban lifestyles. The region needs to mobilize more financial and human resources to develop “new water” and to recycle otherwise wasted water in the safest ways possible.

Among the various options to cope with increased seasonal variability of renewable fresh water resources, surplus from desalination plants and treated sewage effluent is the approach to intermediately store water in underground reservoirs for later usage: Managed Aquifer Recharge (MAR). MAR can be understood as human enhanced and managed groundwater

recharge with the purpose of later abstraction or use either as a fresh groundwater resource or as hydraulic barrier against other threats such as seawater or saline water intrusion.

Enhancing recharge or actively injecting water in subsurface reservoirs requires not only sound technical and scientific understanding of the hydrogeological circumstances at a given location, it also requires a preventive caretaking by the respective government authorities to ensure that any "new water" introduced to existing groundwater resources is actually to the long term sustainable benefit of all and does not cause any damages to the groundwater nor to the reservoir rock itself. Similarly to the requirements for national regulations to groundwater abstractions, national laws and regulations will have to address the needs for regulating managed aquifer recharge.

The presentation intends to offer an overview of different technical approaches to MAR, examples of experiences with MAR in various countries of the region and proposals for future attention and focus to address technical, scientific and governmental / regulatory challenges.

ESCWA supports its member countries to develop capacities related to socio-economic development, among others in the fields of water resources, environment and sustainable development. ESCWA, based on intergovernmental ministerial session resolutions, coordinates and cooperates with its member countries in the implementation of biannual work plans through intergovernmental committees, works in close cooperation with relevant regional institutions and other UN agencies and responds through technical cooperation and regional advisory services to specific requests from member countries. Together with partners and funded by the Swedish SIDA, ESCWA is leading a regional cooperation for an "Assessment of the impact of climate change on water resources and socio-economic vulnerability in the Arab region". Upon request of the Arab Ministerial Water Council (AMWC), ESCWA is engaged as one cooperation partner in preparing a draft legal framework for shared waters in the Arab region. Jointly with the German BGR, ESCWA is preparing an inventory of shared surface and groundwater in West Asia. At the request of AMWC, ESCWA has established region-specific indicators to more accurately monitor the quality and reliability of water supply and sanitation services in the region. The implementation of this MDG+ initiative is financially supported by SIDA.

Assessment of Groundwater Recharge in an Arid Zone Using Several Approaches

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Abstract

The study area is located in the Najd region in south-west Oman. The Najd area mainly consists of marine limestone of Tertiary age. These deposits are classified hydrogeologically to four aquifers A to D following the order from ground level, downwards. Aquifer A is located in the Rus formation above deposits, whereas the aquifers from B to D are restricted with the Umm Er Radhuma formation (UER). Aquifer D is the dominant in Najd whereas the other aquifers are appearing in different parts due to geological structural influences. It has the potential to collect recharge from the Dhofar mountains in the south during cyclone events and monsoon, and conducts the water through faults and fissures to the overlying aquifers farther north.

Our investigations of groundwater in the Najd region have shown that the recharge should occur by different mechanisms. By monitoring of water levels in boreholes during periodical floods, cyclone events seem to be a significant source of recharge to Najd groundwater. Based on water quality investigations, it can be concluded that groundwater mineralization in all aquifers increases towards northeast direction. The type of water is changing from earth alkaline-sulphate type to alkaline (Na) chloride type along this general flow direction.

The stable water isotopes reveal enrichment of ^{2}H and ^{18}O due to monsoon origin close to the mountain range. Along the flow direction the ^{2}H and ^{18}O content of groundwater decreases due to the recharge and admixing of different water bodies. ^{14}C data and model age calculations point to the distribution of fossil groundwater, but also to the problematic of groundwater age dating. Processes of recharge are discussed in the light of the multi-component approach.

Keywords: carbon-13, carbon-14, groundwater; groundwater age, Najd aquifers, recharge

Introduction & hydro-geological structure of the Najd area

Study area and its geology

The study area is located in south of Oman at Najd area and is considered as one of the most important groundwater reservoirs, especially for agricultural irrigation purposes. The Najd area is covers about 88000 km^2 and is mainly formed of flat area penetrated by several wadis dipping north to northeast ward (Fig 1).

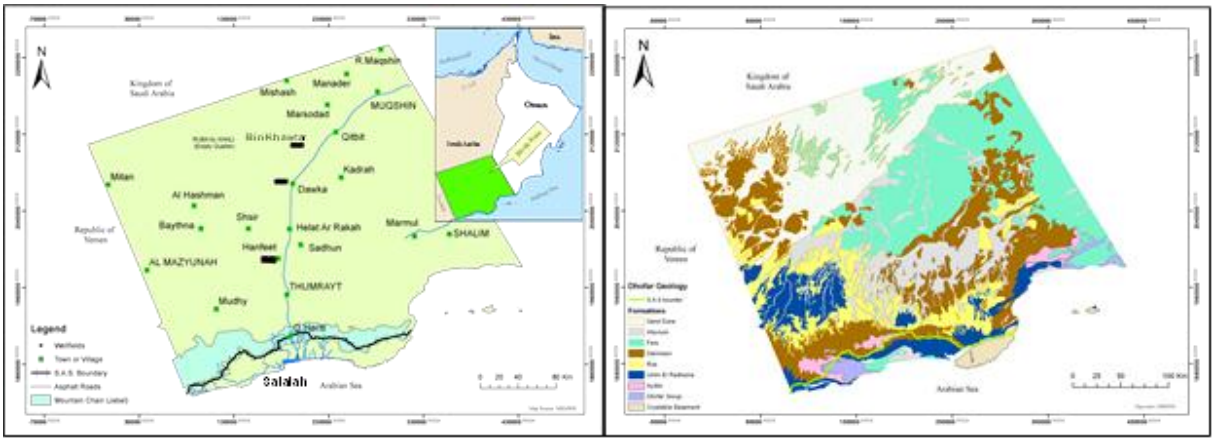

Figure 1 Location of the Study Area in Dhofar with the proposed agriculture sites (*bold black*) and the main geological units (after Al-Mashaikhi, 2011)

Geologically, two groups are present in Najd; Fars group and Hadhramaut group (MMI, 1991). The Hadhramaut group is distributed over all the study area and consists of three formations ranking in the order from top to bottom as follows: Dammam, Rus, Umm Er Radhuma (UER) (Fig. 1). They are the main aquifers. Hydrogeologicaly, Najd is classified into four aquifers following the order from ground level downward A to D (Hydrotechnica, 1985).

Hydrogeology

Aquifer A occupies the upper two formations Dammam / Rus strata and is concentrated in central Najd. The aquifer is semi-confined to confined and significant in Shsir, Hanfeet, Helat Ar Rakah and west to southwest of Qitbit village. The aquifer thins or completely disappears towards the east. Its thickness reported is highly variable from being absent to over 110m within the northern area.The discharge in this aquifer varies from 0.7 L.sec^{-1} to more than 200 L.sec^{-1}, however the highest discharge was found close to northeast corner of the study area. Aquifer B is confined and occurs in Upper Umm Er Rhadhuma (U. UER) strata with small saturated thickness ranging from 1 m up to 43m occasionally. This aquifer is concentrated in central and west of Najd, mostly significant around and southeast to west of Shsir. The discharge in this aquifer ranges from less than 1 L.sec^{-1} to more than 100 L.sec^{-1}. Aquifer C is confined and occurs in the upper part of lower UER (U.L UER).This aquifer appears around Thumrait at about 80 km offshore and is consistently identified as the primary zone of groundwater northward. The groundwater outflow whilst drilling in aquifer C was found in the range from less than 1 L.sec^{-1} to more than 100 L.sec^{-1}. Aquifer D is confined and restricted to the base of UER with thickness range between 133m to more than 350m. The discharge reported is between 2-43 L.sec^{-1}. It is the dominant aquifer and has the potential to collect rainfall or flood water near the recharge area (Jabal Chain) in the south, and to

dewatering the above aquifers C to A. These processes occur further north (80 km offshore) due to high pressure and via faults and fissures. (Al Mashaikhi, 2011).
The study area is characterized by several faults which affect groundwater movement. These faults vary in length and sometimes extend for more than 60 km and generally in the direction south and southwest to north and northeastward. This geological structure seems to control the groundwater flow direction. The groundwater flow direction often is from the south and southwest to the north and northeastward.

Characteristic of groundwater recharge using several approaches

Approach 1: Recharge behavior based on water level signatures
The groundwater level is affected by two components: abstraction for agricultural purposes and a few artesian boreholes which still flow to the ground since over 30 years. The abstraction was concentrated in the area and forms the triangle (Helat Ar Rakah, Shsir and Hanfeet) with approximate dimensions of 50x50x40 km. This area controls approximately 85% of the total water consumption in Najd. Therefore the majority in decline of water level is observed in these areas and the circle of decline radius increases specifically around Helat Ar Rakah. The circle radius is not less than 60 km, based on the latest water level data which expands annually.

Generally, the water level is declining in aquifers A to D. This decline is concentrated more in aquifer C than A, B or D. The groundwater in Najd seems to be in a steady state condition pre 1994; followed by intensive abstraction caused by drawdown varying from one aquifer to the other. On the other hand, water levels in aquifers B and D are still decreasing even though they are not being used intensively. As a result, these aquifers are feeding each other through some faults or fractures depending on the pressure and the permeability existing between them. The aquifers from A to D decline at a rate of 0.33m, 0.12m, 2.05m and 0.42m annually. Two examples from aquifer A and C may represent the water level behavior.

Aquifer A
Two selected wells with a historical record of water level were used as representatives for aquifer A (Fig 2). These wells are HRB-19 (210/902) and HRB-21 (210/850) located in Helat Ar Rakah have a very intensive consumption.

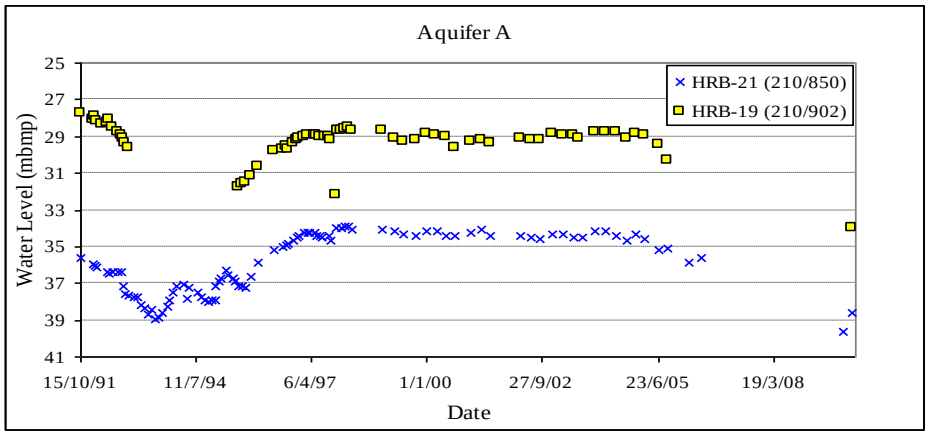

Figure 2 Water level variations in Helat Ar Rakah (aquifer A) for the period (1991-2009)

The monitoring data shows steep decreases from 1991 to 1994 followed by recovery in 1995 and reflected the direct response to agriculture activities. This recovery became close to the initial level in 1997. The water level remained stabilized afterwards until 2005, then decreased again.

Aquifer C

The most intensive abstraction is concentrated in aquifer C represented by the concentration of all Grasses farms as a main source of water supply. JICA in 1988, 1989 concluded that water levels in central Najd (Hanfeet and HelatArRakah) declined in the range of 0.15 to 0.3m.yr^{-1} in aquifer C.

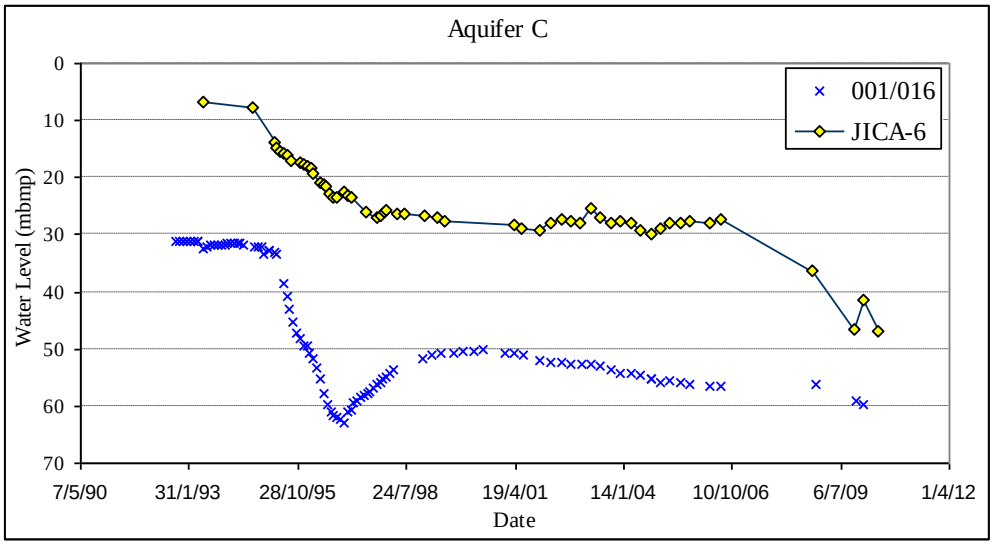

Figure 3 Water level variations in HelatArRakah (JICA-6) and Hanfeet (001/016) in aquifer C for the period (1990-2009) (after Al-Mashaikhi, 2011)

Two monitored boreholes represent the historical trend of the water level in high depleted areas (Fig 3):(1) AF825206AA (JICA-6) from Helat Ar Rakah, and (2) ZV193045AA (001/016) from Hanfeet. Data analyses show that water levels are declining at the rate of 2.05 (JICA-6) and 1.59 m.yr^{-1}(001/016), respectively. Further affects were recorded 35 km east of MRMWR (Helat Ar Rakah camp) in the new borehole DEP-18 drilled in 2008 which dropped in water levels of 1.67m after one year. In general, both boreholes hydrographs had steady state conditions in the water level before 1994, dropped until 1997, and declined again until 2006. After 2006 to February 2010, JICA-6 water levels dropped more than 13m, however 001/016 is also decreasing at a low rate (3.2m).

A decline in aquifer B (location Hanfeet) could be related to the abstraction in Hanfeet and Helat Ar Rakah from aquifer C which was recorded as a steep drawdown from 1995 to 1996 with more than 29m.

The water level in aquifer D is affected as well as with other aquifers in Najd. The historical record detected from borehole BE094486AA (RBK-D) located east of Hanfeet shows a gentle declining since 1992 up to January 2010. The water level record for RBK-D shows annual decline in aquifer D at the rate of 0.42m. On other hand, continuous drawdown in this area reflects regional effect of all aquifers by each other. Therefore the visible source of this

declining seems to be high abstraction at Helat Ar Rakah, even though it is 30 km far away with the flow direction.

Approach 2: Recharge behavior based on hydrochemistry

A clustering of the hydrochemical signature was detected in the aquifers C and D, but also in B. This process seems to shift the water type in aquifer D to a sodium chloride dominated system in northern part of aquifer D. This obvious mixing and/or separation behavior is clearly expressed in the log-plot of major ion ratios (Fig 4). For example, the log-plot of ionic ratios of $(Ca^{2+} + Mg^{2+})/(Na^{+} + K^{+})$ versus (Cl^{-} / SO_4^{-2}) shows an increasing dominance of chloride and sodium along the C and D aquifer flow.

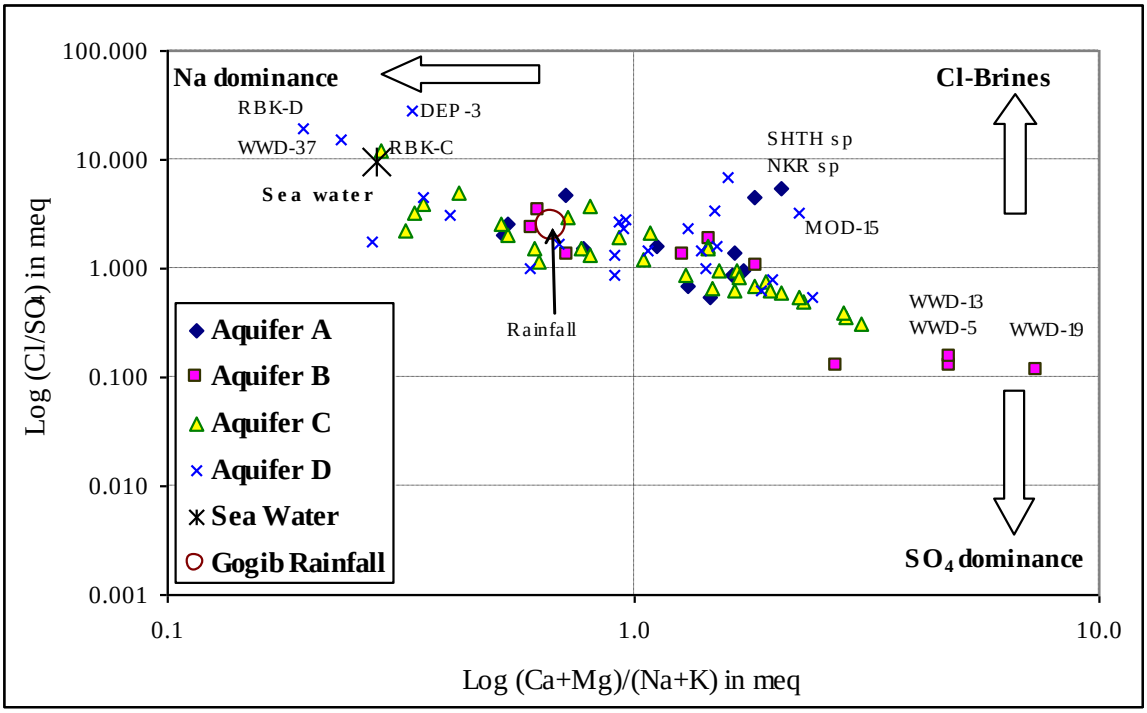

Figure 4 The earth's alkaline-alkaline ratio relative to the salt forming (Cl^{-}/SO_4 ratio in the Najd aquifers

Because of the presence of gypsum in the formation matrices and the dissolution of gypsum common in the upper UER, sulphate-dominant groundwater reduces consequently the ionic ratio (Cl^{-}/SO_4^{-2}) in aquifer B. The increase of groundwater salinity and dominance of chloride and sodium as observed at well WWD-37 in the northeast of the study area tends to support the observation of gypsum dissolution in the different parts of the UER matrix.

Approach 3: Recharge behavior based on isotope evidences

Stable isotopes (^{2}H, ^{18}O) of water

The stable water isotopes reveal enrichment of ^{2}H and ^{18}O due to monsoon origin in or at least close to the Dhofar mountains (Fig 5).

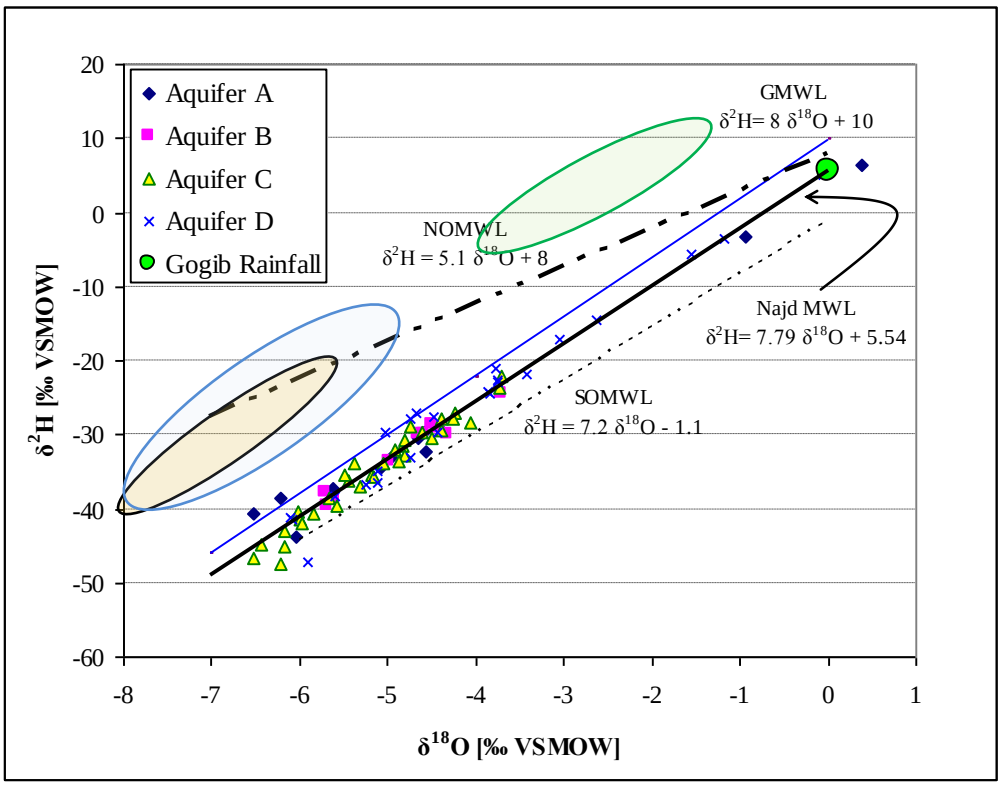

Figure 5 Variations of the stable water isotopes shown in the δ^2H-$\delta^{18}O$ diagram of groundwater, spring water, and precipitation from the Dhofar region (after Al-Mashaikhi et al., Env. Earth Sci 2011). Legend: green: modern water – monsoon recharge; blue: modern water – cyclones; fossil water – precipitation under humid conditions.

This enrichment is still observed in two wells at Thumrait (about 50 km north of Jabal chain) and Hanfeet (about 80 km farther north) along the recharge direction. Farther north, ^2H and ^{18}O becomes depleted by mixing of monsoon and recharged cyclonic water along the groundwater flow direction in aquifer D (Al Mashaikhi, EES,2011).

Mixing of younger groundwater with fossil water should occur within aquifers C and D. The H/O isotope signatures appear in the same range.

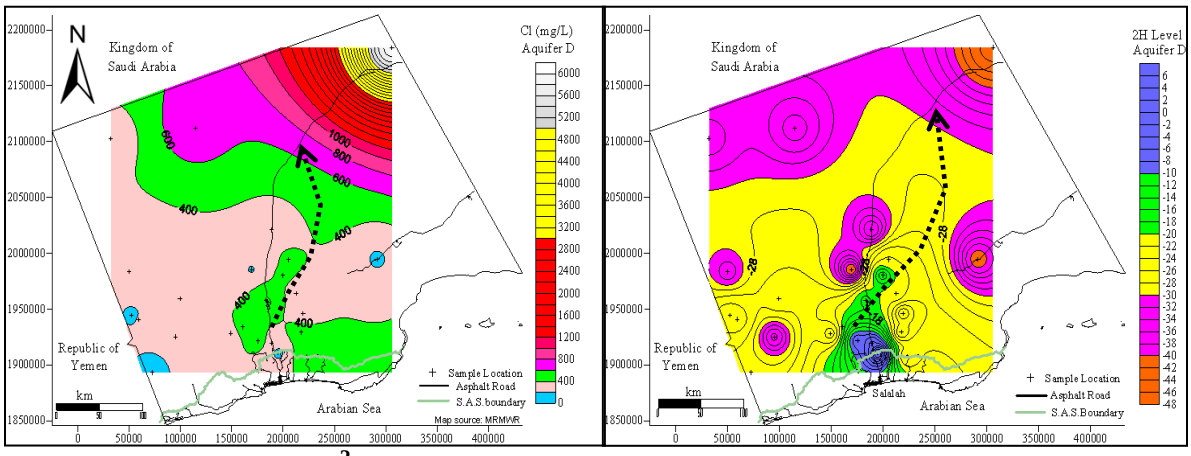

Figure 6 Chlorideand δ^2H (‰) distribution in aquifer Dalong flow direction (dot lines)

Chloride increases towards NE along the groundwater flow direction changing the water quality to a high saline sodium-chloride groundwater (see Figs 4&6). ^{2}H shows decrease of monsoon influence along the flow line; high depletion of ^{2}H could also point to strong pumping activities because of fossils water with isotopically depleted groundwater.

Radiocarbon and stable isotopes of carbon and water

The problematic of radiocarbon age dating of the Najd groundwater is closely connected with the different sources of carbon affecting the groundwater, the origin of water and hydrochemical processes, and the heterogeneity of the aquifer structure and flow processes.

Influence of carbon compounds on the ^{14}C model age calculation – the carbon pools

The data plot for ^{13}C versus ^{14}C (Fig 7) is mainly categorized into three groups. The first group belongs to soil organic carbon by C3 plants and consists of samples which are enriched in ^{14}C pmC and depleted in ^{13}C. The $\delta^{13}C$ of DIC of around -15‰ to -20‰ refers usually to the dissolution of soil CO_2 indicating influence of soil organic carbon (Gonfiantini and Zuppi, 2003). $\delta^{13}C$ of soil containing CO_2 collected from the study area agrees with this range and was found with a valued range between -14‰ to -20‰. Furthermore, boreholes of the first group belong to aquifer B and C. Two were they highlighted with high ^{14}C values (in pmC) which reflected influences of modern water by cyclone events. In the second group, groundwater is associated with both moderate and high ^{14}C >30 pmC values and $\delta^{13}C$ values close to that of the atmosphere (-7 to -8‰), which may reflect rapid infiltration during the recharge process. This group comprises groundwater from aquifers A, B and D. All these boreholes are expected to be influenced by the mixing of recent recharge due to their locations close to the recharge area (SHTH-spring) or as an effect of faults and fissures. The third group consists of ^{14}C values <20 pmC and enriched ^{13}C contents as reported for $\delta^{13}C$ around 0‰ to +2‰ in the limestone (Gonfiantini and Zuppi, 2003). The lithological samples collected from several boreholes in Najd aquifers show $\delta^{13}C$ values from -7.1‰ to +3.5‰caused by carbonate influences. With the exception of DEP-19, all boreholes from aquifer C fall within this group.

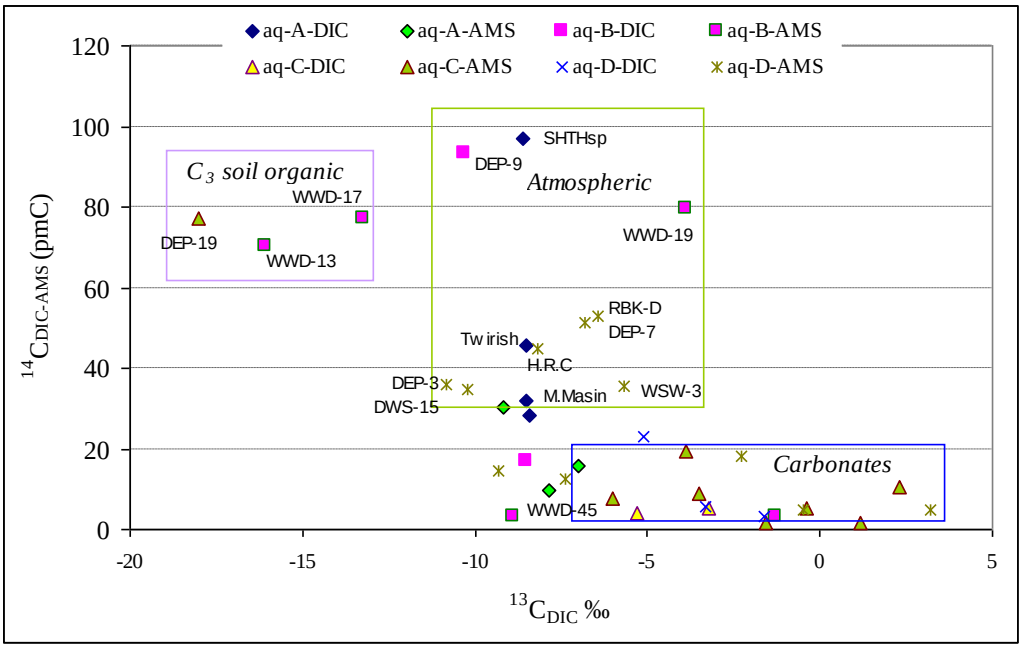

Figure 7 Correlation between $\delta^{13}C$ and ^{14}C showing three types of carbon influence (^{14}C values were estimated by DIC procedure and beta-scintillation as well AMS) (after Al-Mashaikhi, 2011)

Influence of recharge processes on ^{14}C of groundwater

The plot of $\delta^{18}O$ vs. ^{14}C (Fig8) shows that most of groundwater is related to the cyclonic group by $\delta^{18}O$ connected to other groups by mixing processes. As already stated, the ^{14}C content is either affected by sediment, soil organic or atmospheric carbon.

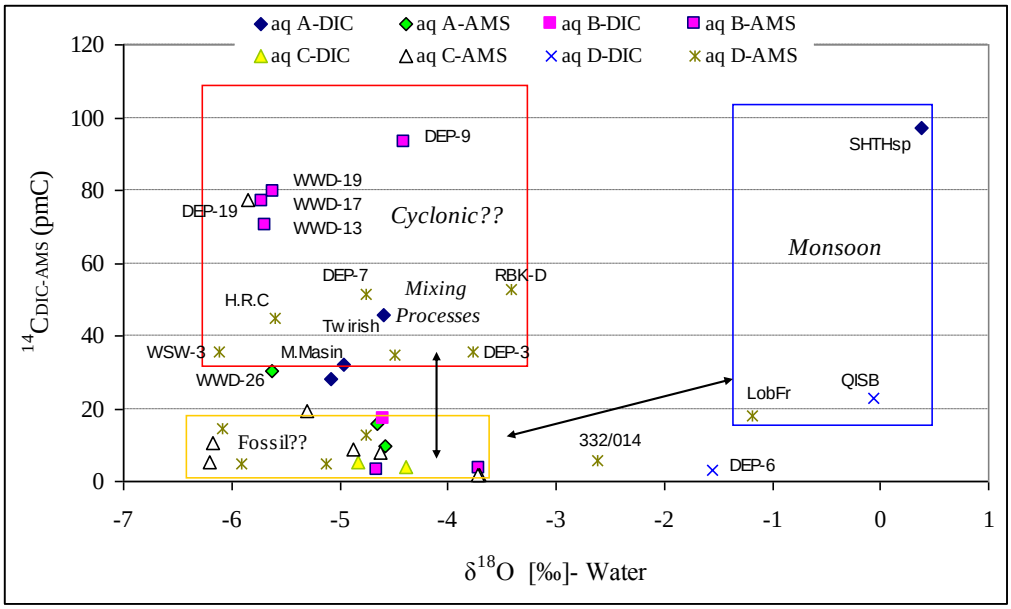

Figure 8 ^{18}O of water versus ^{14}C classified the source of groundwater in Najd to three groups (^{14}C values were estimated by DIC procedure and beta-scintillation as well AMS) (after Al-Mashaikhi, 2011)

Only two boreholes and one spring located in/or close to the recharge area show enrichments in ^{18}O must be related to the monsoon source. The group of fossil groundwater containing $\delta^{18}O$ between -6‰ to -4‰ and low ^{14}C pmC values belongs to aquifer C and sparsely from other aquifers. Despite these classifications, mixing processes are assumed between the aquifers and recharge areas.

Generally, the ^{14}C data and model age calculations (Al-Mashaikhi, 2011) show that the groundwater age in Najd aquifers varies between modern and up to >22,000 years. However, the majority of groundwater belongs to the Holocene period (<10,000 yr).

Conclusion

The different approaches for characterizing the groundwater recharge in the Najd can be concluded to the concept that three main recharge processes should be taken into account for the investigation area: (i) modern water by monsoon events, (ii) runoff and recharge by cyclonic events, and (iii) interactions between the aquifers by hydraulic exchange, as shown in Fig 9.

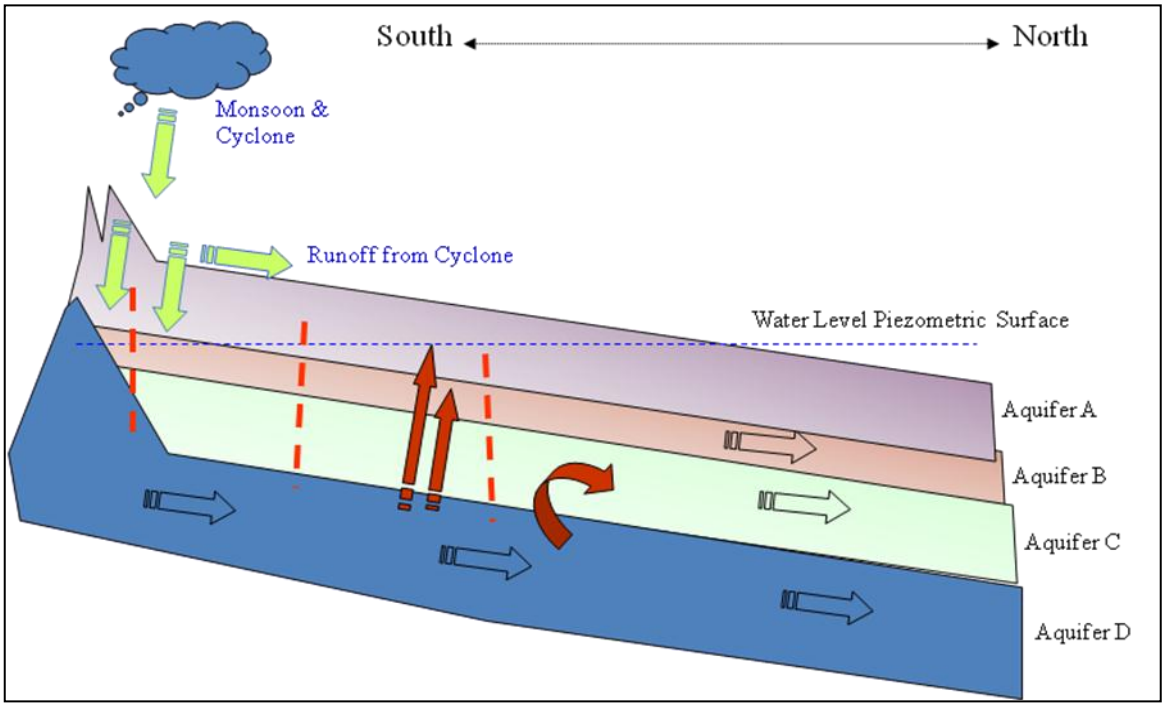

Figure 9 Simplified scheme for recharge processes in Najd aquifers

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استخدامات مياه الصرف الصحي ودورها في حماية المياه الجوفية من تداخل مياه البحر في سلطنة عمان (مدينة صلالة نموذجا)

م / محمود بن محمد بن سليمان العزري نائب مدير دائرة الأفلاج

م / عبدالله بن سالم بن عبدالله الناعبي أخصائي شؤون موارد المياه أول

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المقدمة :

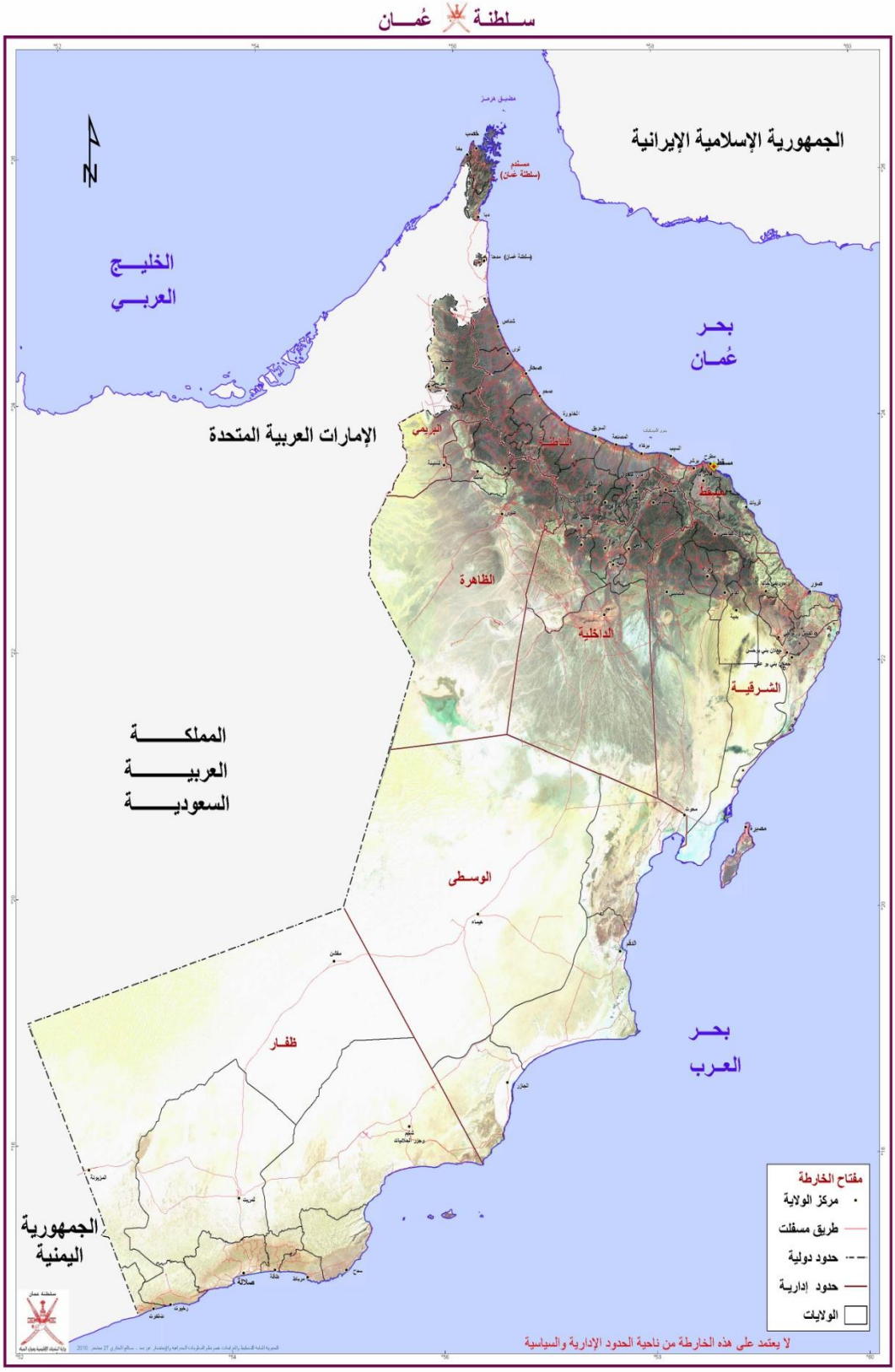
تصنف سلطنة عمان من الدول الجافة أو شبه الجافة حسب التصنيف العالمي نظرا لقلة الأمطار السنوية وعدم انتظامها الأمر الذي يترتب عليه محدودية المياه الجوفية لكون الأمطار المصدر الرئيسي لها وعدم قدرة المخزون الجوفي تلبية الاحتياجات المائية المراد تغطيتها للقطاعات المختلفة في وقت ازدهرت فيه هذه القطاعات ونمت نموا سريعا وزاد الطلب على المياه فمن هذا المنطلق اتجهت الحكومة في البحث عن موارد مائية جديدة أبرزها تحليه مياه البحر واستغلال مياه الصرف الصحي المعالجة وعمدت في سن القوانين والتشريعات المائية الهادفة إلى حماية هذا المخزون من التلوث بأنواعه وإصدار تشريعات تحدد مناطق الحماية للمياه الجوفية وبالذات تلك المغذية لأبار الشرب منعا من تلوثها والتقنيين في استخدام المتوفر من المياه وفق قوانين ومعايير تنظم وتعنى بالمتابعة المستمرة من صناع القرار إضافة الى التركيز على أهمية الترشيد في المياه وبث الوعي المائي لدى المواطن والمقيم مع الاستعانة بوسائل الأعلام في ذلك المقروءة والمسموعة بأهمية الحفاظ على هذا المورد الحيوي نظرا لمحدوديته وبالتالي فإن هذه الورقة ستلقي الضوء على أحد الحلول التي طبقتها السلطنة لحماية المياه الجوفيه من تداخل مياه البحر

الموقع الجغرافي للسلطنة :

تقع سلطنة عمان في أقصى الجنوب الشرقي لشبه الجزيرة العربية وتمتد سواحلها على طول الخليج العربي وخليج عمان وبحر العرب وتعتبر ضمن حزام المناطق الجافة وشبه الجافة مناخ حار و جاف **ويقدر** المعدل السنوي لهطول الامطار 100 ملم.

وفي الجبال يبلغ 350 مم وفي الصحراء يقل عن 50 مم في السنة وإذ تقدر الموارد المائية المتجددة سنويا بحوالي 13 مليون متر مكعب بينما يبلغ نصيب الفرد من المياه المتجددة حوالي 500 متر مكعب/السنة .

ويقدر العجز في الموارد المائية ب 378 مليون م3 مؤديا بذلك اختلال في الميزان المائي نتيجة حدوث جفاف لفترات أكثر من خمسة أعوام .


سلطنة عُمان
الجمهورية الإسلامية الإيرانية
الخليج العربي
بحر عُمان
الإمارات العربية المتحدة
المملكة العربية السعودية
الجمهورية اليمنية
بحر العرب
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ظفار
مفتاح الخارطة
مركز الولاية
طريق مسفلت
حدود دولية
حدود إدارية
الولايات
لا يعتمد على هذه الخارطة من ناحية الحدود الإدارية والسياسية

مصادر المياه في سلطنة عمان :

* المصادر الطبيعية الناتجة عن هطول الأمطار (المياه الجوفية) .
* التحلية (مياه البحر أو المياه الضاربة للملوحة) .
* المياه الافتراضية المستوردة .
* مياه الصرف الصحي المعالجة .

هذا ويعد قطاع الزراعه أكبر مستهلك للموارد المياه المتوفرة حيث يستهلك 90% منها ومن المتوقع أن يزداد الطلب على المياه الاستخدامات المنزلية والتجارية والصناعية بما يزيد عن 50 %خلال عشرين السنة القادمة , كنتيجة حتمية لزيادة عدد سكان السلطنة والتنمية المصاحبة .

بيانات الميزان المائي للسلطنة :

1 - الموارد المائية المتاحة 1276 مليون م3/السنة .

2 – الإحتياجات المائية 1645 مليون م3/السنة .

3 – العـــــــــــــــجز 378 مليون م3/السنة .

أهمية المياه الجوفية في السلطنة :

تقدر تغذية الخزانات الجوفية المتجددة على مستوى السلطنة بحوالي 1300 مليون م3/السنة وتتغذى تلك الخزانات عن طريق تسرب المياه السطحية 70 % والباقي من مياه الأمطار هذا وفي حالة معدلات السحب فاقت معدلات التغذية وخاصة في المناطق الساحلية ستتداخل المياه المالحة بالمياه العذبة (تملح الخزنات الجوفيه) .

* تنشأ تدفقات المياه الجوفيه الرئيسية في عمان من جبال الحجر الغربي وجبال ظفار وفي كلا المنطقتين الجبليتين تكون الرسوبيات في قيعان الأودية خزانات جوفية ممتازة تحتوي على موارد مائية متجددة وذات نوعية جيدة بسبب التغذية أما التدفقات المتجهه نحو البحر تغذي الخزانات الجوفية الواسعة الممتدة تحت السهول الساحلية كما أن التدفقات المتجهه نحو المناطق الداخلية تعمل على تغذية محلية مماثلة للخزانات الجوفيه الضحلة ثم تلتقي في المناطق المنخفضة مثل أم السميم حيث يجري تصريف المياه الجوفيه في طريق التبخر المباشر كما تحظى السلطنة بوجود إحتياطات من الموارد المائية غير المتجددة لوجود تكوينات كربونية عائدة إلى الحقب الثالث يتجاوز سمكها مئات الأمتار تختزن كميات

كبيرة من المياه غالبا ما تكون ضاربة الملوحة فتتدهور نوعيتها في المناطق البعيدة عن مصادر التغذية وتعتمد جميع مناطق السلطنة على الآبار في ضخ المياه الجوفيه من هذه الطبقات وعادةً ما تكون المياه في هذه الطبقات جيدة وصالحة لشرب ماعدا في بعض المناطق التي تعاني من تداخل الملوحة والمناطق الواقعه جنوب المنطقة الداخلية في عمان .

ويتم إستغلال المياه الجوفيه عن طريق :

1 -الآبار والبالغ عددها 127000 والمتواجدة في حوالي 128 مستجمعا مائيا .

2 – الأفلاج ويقدر عددها 4300 فلج (غيلي ، داوودي ، عيني) منتشرة بالسلطنة والمعني بالمياه الجوفيه هي الأفلاج العينيه والداوديه .

<u>المصادر الثانوية للمياه للحد من العجز المائي ودورهما في حماية المياه الجوفيه من التلوث :</u>

1 – تحليه مياه البحر .

2- إعادة استخدام مياه الصرف الصحي المعالجة لري أشجار الزينة والحدائق .

ما أشير أعلاه سوف يساهم في الحفاظ على مخزون المياه الجوفي وحمايته من التلوث وذلك من حيث الاحتفاظ به وتوجيه استخدامه لما يخدم الخطط التنموية والمشاريع الأخرى.

<u>السلطنة حالها حال بقية الدول تتأثر بتلوث المياه الجوفية وتبحث في وضع الحلول والبدائل المناسبة للحد منها والبحث في مسببات التلوث مثل :</u>

<u>1</u>- الأنشط التنموية المدنية والتجارية و الصناعه .

2- تصريف النفايات السائلة والصلبة .

3 – خزانات حفظ الوقود الموجودة على السطح أو في باطن الأرض

4 – مرادم النفايات .

5 – مياه المجاري وتصريفها .

6 – ابار النفط والآبار الاستكشافية وأنابيب نقل البترول .

7 – الزراعه

8 – أنشطة المعادن والمحاجر .

9 – خزانات التحليل اللاهوائي (البواليع)

حماية الخزان الجوفي لمدينة صلالة من التملح (دراسة تداخل المياه المالحة بالخزانات الجوفية الساحلية) :

تصدر الوزارة تقارير دورية عن تداخل المياه المالحة بالمياه العذبة خصوصاً في ساحل الباطنة وسهل صلالة وذلك من خلال مراقبة 2600 بئر في منطقة الباطنة و 600 بئر في سهل صلالة.

وقد أوضحت التقارير أن هناك زيادة مطردة في ملوحة المياه الجوفية وصلت في بعض ولايات جنوب الباطنة إلى معدلات مرتفعة تتراوح ما بين (16000 – 30000 ميكروموز/سم).

مشروع حقن المياه المعالجة للخزان الجوفي بصلالة :

بيانات عن منطقة المشروع : المدينة صلالة

* الموقع: تقع مدينة صلالة في الجزء الجنوبي من سلطنة عمان.
* المناخ: تتمتع مدينة صلالة بطقس معتدل طوال العام لا تتعدى حرارته 35 درجة مئوية.
* السكان: يبلغ عدد السكان الحالي بالمدينه حوالي 140 ألف نسمة .

أهداف المشروع :

* التصحيح البيئي للمدينة .
* معالجة تدهور نوعية وكمية المياه .
* تحسين الوضع الصحي العام بالمدينة .
* التصحيح البيئي للمدينة .
* معالجة تدهور نوعية وكمية المياه .

جهة الإدارة والتشغيل :

* شركة صلاله لخدمات الصرف الصحي.
* تأسست الشركه في منتصف عام 97 بموجب قرار مجلس الوزراء الموقر رقم 97/20 .
* منحت حق الامتياز بخدمات الصرف الصحي لمدينه صلاله بموجب المرسوم السلطاني رقم 2004/16.
* شركة عمانية مساهمه مقفلة مملوكة بالكامل لحكومة سلطنة عمان.

الوضع الصحي والبيئي والاقتصادي قبل المشروع :

* انتشار بعض الأمراض ذات العلاقة بالمياه.
* انتشار الكثير من الحشرات والقوارض.
* تدني جودة المياه.
* ارتفاع تكاليف المبيدات الحشرية.
* تشوهات في المنظر العام نتيجة البرك المائية المتسربة من خزانات الصرف الصحي التقليديه.
* نمو نبتات مشوهه للطرق والأحياء السكنية.

موارد المياه بالمدينة :

يشكل الخزان الجوفي المورد الأساسي للمياه العذبة الذي يمد مدينة صلالة بحاجتها من المياه .

تعتبر الامطار (خصوصا في فصل الخريف) المصدر الرئيسي لتغذية الخزان الجوفي

تقدر كمية التغذية السنوية في المتوسط حوالي 32,4 مليون متر مكعب.

تقدر كمية السحب السنوي بأكثر من 40 مليون متر مكعب

يبلغ العجز السنوي للمياه حوالي 7,6 مليون متر مكعب.

الوضع المائى بالمدينة :

أظهرت دراسة المخطط الرئيسي للمياه ومخلفات المياه لصلالة فبراير **1992** م **(** وجود عجز كبير في الميزان المائي يتراوح بين (8 – 20) مليون متر مكعب في الفترة بين عامي**2020-1990)** م (نتيجة السحب غير المرّشد للمياه الجوفية للري والاستخدامات الأخرى مما أسفر عن انخفاض تدريجي في منسوب المياه الجوفيه العذبة صاحبه ظاهرة تملح الموارد المائية نتيجة لتداخل مياه البحر مع المياه العذبة .

مكونات نظام الصرف الصحي بصلالة :

- محطة معالجة لمياه الصرف الصحي بسعة استيعابية تبلغ 20 ألف متر مكعب يوميا.
- شبكة التجميع والنقل لمياه الصرف الصحي .
- نظام التغذية الجوفية وخطوط نقل المياه المعالجة البالغه 18 ألف متر مكعب يوميا.

شبكة التجميع و النقل:

أكثر من 14,000 وصلة منزلية.

309 مضخة طاحنة (**grinder pumps**).

27 محطة فرعية.

3 محطات رئيسيه.

محطة المعالجة :

* محطة معالجة لمياه الصرف الصحي ذات معالجة ثلاثية بسعة 20,000 متر مكعب يوميا .

تتكون المحطة من الوحدات المعالجية التالية :

* معالجة إبتدائية * معالجة ثانوية * معالجة ثلاثية * تطهير المياه بالكلور * معالجة المواد الصلبة (الحمأة) * حوض التجميع والتوازن للمياه المعالجة.

نظام حقن المياه يتكون من :

*** آبار التغذية * آبار المراقبة * آبار الملاحظة * الخط الناقل للمياه المعالجة**

تصميم الآبار :

* قطر انبوب التغليف : 9 بوصات .
* العمق الكلي للبئر : 48 م.
* الطاقة الاستيعابية لكل بئر : 20-40 لتر/ ث.
* الطاقة الاستيعابية لكل الآبار : 14000-20000 م3/اليوم.
* يتم حقن ما يقارب 18الف متر مكب يوميا .
* بلغت الكميات التي تم حقنها في مجمل الآبار منذ بداية الحقن في أواخر عام 2002 م والى الآن حوالي 208233 متر مكعب تقريبا .

أهداف الحقن الجوفي للمياه :

1 - حماية الخزان الجوفي من تداخل وزحف مياه البحر المالحة , وذلك بخلق حاجز مائي جوفي هيدروستاتيكي من المياه المعالجة موازيا للخط الساحلي يمنع زحف مياه البحر المالحة نحو خزانات المياه الجوفية بالمنطقة .

2- ايقاف أو خفض الهبوط المتزايد لمنسوب المياه الجوفية .

3- الحفاض على ثروة قومية كبيرة متمثلة في انتاج مايقرب من20 مليون متر مكعب سنويا من المياه المعالجة بأحدث الطرق , وذلك بتخزينها في باطن الارض .

4- الحفاظ على المياه الجوفية كمصدر اقتصادي سليم دون أن يتعرض للتدهور الكمي والكيفي .

الإستخدامات الأخرى للمياه المعالجة :

الاستخدام الصناعي اليومي لمصنع الإسمنت بريسوت 1500متر مكعب/اليوم. والاستخدام الزراعي التجريبي 450 متر مكعب / يوميا.

نتائج تقييم فاعلية المشروع :

* انخفاض واضح في انتشار الحشرات والقوارض بالمدينة .
* تحسن نوعية المياه الجوفيه .
* انخفاض الحالات المرضية للأمراض المرتبطة بالمياه .
* انخفاض استهلاك المبيدات الحشرية .
* توفير كمية المياه المطلوبة لمصنع الإسمنت من المياه المعالجة .

نتائج تقييم المشروع :

*** الجانب المائي:**

- تلاحظ تحسن مناسيب المياه الجوفية نتيجة للتغذية من المياه المعالجة وانخفاض معدلات ضخ المياه للأنشطة الصناعية.

- إيقاف التدهور الكبير في جودة المياه بسبب التلوث الذي كان يتعرض له المخزون الجوفي من تسرب مياه الصرف الى الخزان الجوفي .

*** الجانب الصحي :**

التحسن الملحوظ الذي طرأ على الجانب الصحي والمتمثل في انحسار معدلات الإصـــابة بالأمراض المعـــوية ذات العلاقة بالمياه **water born diseases** بنسب مختلفة كالآتي:

* حمى التايفوئد **Typhoid Fever** (%50)
* الإلتهاب الكبدي الفيروسي **Hepatiti Viral** (%63)
* الدوسنتاريا **Dysenery Bacillary** (%70)
* داء الأميبا **Amoebiasis**(%35)
* نزلة معوية حادة وإسهال

Acute Gastro-Enteritis & Diarrhoea (%11)

المراقبة النوعية والكمية للمياه الجوفية :

* تقوم الجهات المختصة في السلطنة بمراقبة المياه الجوفية في 2110 بئرا ، موزع على أنحاء السلطنة المختلفة تقاس شهريا منا 1703 بئرا تقاس كل ثلاثة أشهر وهناك برنامج خاص لقياسات ملوحة المياه في السهول الساحلية لمراقبة تغلغل مياه البحر وذلك من خلال 3000 بئر تمسح مسحا شاملا للملوحة كل عامين ويبلغ إجمالي العينات التي تفحص سنويا لهذا الغرض 934 عينه مياه .

*** تستخدم شبكة المراقبة أيضا في تغطية أنواع مختلفة من أعمال المراقبة اعتمادا على الأهداف وهي كالآتي :**

1 – الحصول على سجل متكامل لجودة المياه الجوفية لإظهار الاختلافات الإقليمية في جودة المياه .

2 – تحديد جودة المياه الجوفية لمعرفة ما إذا كانت الجوده تتدهور أم لا .

3 - التحقق من مدى اتساع انتشار المياه الملوثة واقترابها من مياه مصادر الشرب.

4 – مراقبة جودة المياه بالقرب من مصدر معين ذات تأثير مباشر على المياه .

5- مراقبة مصادر التلوث يسمح بالاكتشاف المبكر لتلوث المياه الجوفية ويساعد في وضع الحلول السريعة .

أهمية حماية المياه الجوفية :

إن الحاجة لإنشاء مناطق حماية حقول الآبار لكافة أنحاء السلطنة أصبحت أكثر إلحاحا في ظل النمو المتسارع لمختلف جوانب تنمية في البلاد إن هذه المناطق توفر الضوابط الخاصة بحماية الحقول من الآثار السلبية لأي مشاريع لاحقة تقع بالقرب من مناطق حماية حقوق الآبار تعتبر حماية المياه الجوفية من التأثير المتوقع من الأنشطة البشرية **من أهم الأولويات بالنسبة للمعنيين بتخطيط إستخدام الأراضي وإدارة الموارد المائية وذلك للأسباب التالية :**

1 – تعتبر المياه الجوفية من المصادر الأساسية لإمدادات المياه .

2 – نسبة لحركه المياه الجوفية فإن التأثيرات الناجمة من الأنشطة البشرية تدوم لفترة طويلة .

3 – من الصعب علاج تلوث المياه الجوفية حتى بعد إزالة مصدر التلوث .

4 – بخلاف ما يحدث في المياه السطحية التي تجري في قنوات محددة فإن المياه الجوفية تتحرك في اتجاهات مختلفة .

5 - تشكل الأنشطة البشرية الغير مخطط لها مخاطر متزايدة على جودة المياه الجوفية .

6 – تقضي اللوائح بضرورة الوقاية من التلوث في إطار الإدارة المستمرة لمراقبة نوعيه المياه الجوفية .

إن أكثر الطرق العلمية فعالة في حماية المياه الجوفية ومن التلوث من خلال تفعيل أساليب الوقاية من تلوث المياه الجوفية من خلال تخطيط وتنفيذ مشاريع حماية المياه الجوفية .

الخلاصة :

نظرا لكون السلطنة من الدول الجافة أو شبه الجافة حسب التصنيف العالمي لقلة الأمطار السنوية وعدم انتظامها الأمر الذي يترتب عليه محدودية المياه الجوفيه حيث أن الأمطار المصدر الرئيسي لها وعدم قدرة المخزون الجوفي تلبية الاحتياجات المائية المراد تغطيتها للقطاعات المختلفة في وقت ازدهرت فيه هذه القطاعات ونمت نموا سريعا وزاد الطلب على المياه فمن هذا المنطلق اتجهت الحكومة في البحث عن موارد مائية جديدة أبرزها تحليه مياه البحر واستغلال مياه الصرف الصحي المعالجة وعمدت في سن القوانين والتشريعات المائية الهادفة الى حماية هذا المخزون من التلوث بأنواعه وإصدار تشريعات تحدد مناطق الحماية للمياه الجوفية وبالذات تلك المغذية لأبار الشرب منعا من تلوثها والتقنيين في استخدام المتوفر من المياه وفق قوانين ومعايير تنظم وتعنى بالمتابعة المستمرة من صناع القرار إضافة الى التركيز على أهمية الترشيد في المياه وبث الوعي المائي لدى المواطن والمقيم مع الاستعانة بوسائل الأعلام بأهمية الحفاظ على هذا المورد الحيوي نظرا لمحدوديته .

إن الفوائد العديدة التى تحققت وراء المشروع الذي تم ذكره خلال فترة قصيرة فاقت الآثار السلبية كنتيجة للدراسات والتقييم وإذ تقوم الجهات المختصة دائما بمتابعة ومعالجة أوجه النقص والآثار السلبية وبالتالي ثبوت جدوى هذا المشروع في المحافظة على المياه الجوفية والتقليل من تلوثها بالحد من تداخل مياه البحر معها .

المراجـــــــــع :

* المخطط الرئيســـــي لتســـــهيلات مياه الشرب والصـــــرف الصحي لصلالة (فبراير 1992م) ديمس ومور العالمية وكامب دريسر وميكي العالمية .

* دراسة الأثر البيئي لمشروع الصرف الصحي لصلالة (أغسطس1993م).

*بيانات بالأمراض ذات العلاقة بالتغذية والمياه خلال الفترة (2000-2003) بمحافظة ظفار- المديرية العامة للخدمات الصحية بمحافظة ظفـــــار (مارس2004م).

بيانات بمعدلات اســـــتهلاك المبيدات الحشرية بمدينة صـــــلالة خلال الفترة (2001-2002) بلدية صلالة دائرة الشؤون الصحية – قسم مكافحة الحشرات (مارس 2004م).

* بيان بكميات مياه الصرف الصحي الواردة يوميا إلى محطة المعالجة الرئيسية بريسوت للفترة من (يوليو 2002 إلى فبراير 2004م).- شركة صلالة لخدمات الصرف الصحي (مارس 2004م).

* بيان بكميات مياه الصرف الصحي الواردة يوميا إلى محطة البرك المهواه بريسوت للأعوام (2002-2004م) دائرة الصرف الصحي – بلدية ظفار(مارس 2004م).

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Water Resources Management Protection Department December, 1997*

Development Activities on Ground Water Quality of Wadi Adai, Al-Kha -*

Feasibility and Health Risk Assessment of Groundwater Recharge by TSE in the Kingdom of Bahrain

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Abstract

The Dammam aquifer represents the only natural source of relatively freshwater in the Kingdom of Bahrain. Since the late 1970s, groundwater abstraction has increased significantly due to the rapid increase in population and development activities leading to its over-exploitation manifested by lowering its water levels and salinization. To meet the country's increasing demands, the government has developed non-conventional water resources, desalination (since 1975) and treated municipal wastewater (since 1984), to provide additional water supplies for municipal and agricultural uses, respectively, and to alleviate the pressure on the groundwater resources. In recent years, the use of unused municipal tertiary treated wastewater in groundwater recharge has received increasing attention in Bahrain to augment and enhance groundwater quantity and quality due to the presence of surplus tertiary treated wastewater being discharged to the sea. This study investigated the possibility of storage enhancement of the Dammam aquifer by artificial recharge using tertiary treated municipal wastewater as one of the proposed options of water resources management in Bahrain. The following methodology was adopted: 1) Site-selection by GIS and criteria matrix; 2) Simulation modeling and analysis of selected sites to investigate hydraulic advantage; and 3) Risk assessment of selected sites. Analysis of the criteria matrix resulted in the selection of two reservoirs locations at western Bahrain; Dumistan and Malikiya. Flow and solute transport numerical simulation, using computer codes MODFLOW and MT3DMS, was made to predict the hydraulic response of the aquifer system and salinity changes in response to six developed scenarios for artificial recharge. The simulation results indicated, in general, that there is an increase in the water levels and salinity changes at all sites, and it is expected that aquifer water levels and salinity changes would increase with the continuation of artificial recharge. Then, the main health risk concerns of aquifer recharge and abstraction for drinking water were investigated under these six scenarios. The injected water should remain within the aquifer for a sufficiently long period of time so that chemical, physical, and biological processes eliminate any associated

chemicals and microorganisms hazards. Two locations of concern were identified: 1) Hamala domestic water wellfield, which the Electricity and Water Authority is utilizing its water for household supply after blending with desalinated water; and 2) Irrigation water wells which farmers use directly for irrigation, and could be used for drinking. Based on data availability, two contaminants were selected for the risk assessment process and site-selection, pathogens and Nitrate. The pathogens health risk of the recharge scenarios schemes were evaluated by using the advective transport model PMPATH. The evaluation was based on that the minimum residence time for the recharged water should not be less than 200 days, which represent a 99% decline rate by natural groundwater attenuation for pathogens. The results of the assessment indicated that health risks exist in all recharge scenarios. However, if farmers do not use their wells for drinking, the risk would be limited to Hamala wellfield only. Nitrate transport was simulated, using MT3DMS transport model, in order to assess the Nitrate health risk under the pathogens-least risk scenario for a five-year period (2010 to 2014). The simulation results indicated that Nitrate does not pose any health risk, even if the recharged water is used for drinking purposes, provided that the current Nitrate concentrations persist. The study main recommendations is to conduct a field pilot study at Malikiya location involving all concerned authorities in Bahrain to further evaluate the process of artificial recharge of the tertiary treated wastewater in the Dammam aquifer and validate the model results.

Keywords: artificial recharge, treated wastewater, feasibility, health risk assessment, Bahrain.

Introduction

Bahrain is an arid country with acute water shortage problems. Rapid population growth, extensive economic and social developments, improved standards of living, and rapidly increasing urbanization in the last four decades have substantially increased the demand for water, causing over-exploitation of the already scarce groundwater resources well in excess of their safe yield. This has led to a significant decline in groundwater levels, a drastic storage depletion, and serious deterioration in groundwater quality. In response to this acute water situation, the government has embarked on a major water supply augmentation program through the development of non-conventional water resources, mainly desalination and reuse of treated municipal wastewater, to provide additional water supplies for municipal and agricultural uses, and to alleviate the pressures exerted on the available groundwater resources. Supply augmentation policies have also been considered through the implementation of some artificial groundwater recharge projects using storm water (**AI-Noaimi, 2005**).

In recent years, the use of non-conventional water resources, such as recycled municipal wastewater (Treated Sewage Effluent, TSE), in groundwater recharge has received increasing attention in the GCC countries and is being practiced in some countries (**Shamas, 2007; Al-Aiban *et al*, 2003; Akber *et al*., 2003; Viswanathan and Al-Otaibi, 2002;; Ghamdi, 1999**). The primary reasons for considering the use of recycled water in groundwater recharge are that recycled wastewater is available for reuse at a relatively low cost and that it provides a dependable source of water in drought years/dry seasons; as municipal water consumption increases, the amount of wastewater generated and treated increase.

This study investigates the possibility of storage enhancement of the Dammam aquifer, the principal aquifer in Bahrain, by artificial recharge using tertiary treated municipal wastewater as one of the proposed options for water resources management in Bahrain. The study focused on site-selection optimization for groundwater artificial recharge by tertiary treated wastewater to maximize the hydrogeological benefits (i.e., water levels enhancement and salinity modification), and investigating and assessing the environmental and health risks associated with such process. The objective is to define a proper site(s) to conduct a pilot field project in Bahrain for reusing surplus tertiary treated municipal wastewater for groundwater recharge as one of the proposed water resources management interventions in Bahrain.

Feasibility of Managed Aquifer Recharge (MAR) in Bahrain

Managed aquifer recharge (MAR) involves building infrastructure and/or modifying the landscape to intentionally enhance groundwater recharge. MAR is increasingly being considered as an option for improving the security of water supplies in areas where they are scarce (**Gale, 2005**). Moreover, MAR is considered as among the most significant adaptation opportunities for developing countries seeking to reduce vulnerability to climate change and hydrological variability. It has several potential benefits, including: storing water for future use, stabilizing or recovering groundwater levels in over-exploited aquifers, managing saline intrusion, and enabling reuse of treated wastewater or storm water.

Implementation of MAR requires suitable groundwater storage opportunities, such as falling water levels, which is the case in Bahrain aquifers. However, MAR potential should be determined before activities commence. Aquifer conditions must be appropriate and suitable water sources (e.g., excess wet season surface water flows or treated wastewater) are required. Detailed planning and assessment are required to determine whether MAR is a viable option at the country/basin level, considering: water availability, hydrogeological suitability, effectiveness in modifying current groundwater conditions in terms of quantity and quality, enhancing groundwater storage, economics of the process, health and environmental risk assessment in the case of using impaired quality water in recharge, and many other country-specific factors.

As indicated earlier, the Dammam aquifer represents the only natural source of relatively freshwater for Bahrain. Since the late 1970s, groundwater abstraction has increased significantly due to the rapid increase in population and development activities leading to its over-exploitation manifested by lowering its water levels and salinization. To meet the country's increasing demands, the government has developed non-conventional water resources, desalination (since 1975) and treated municipal wastewater (since 1984), to provide additional water supplies for municipal and agricultural uses, respectively, and to alleviate the pressure on the available groundwater resources.

In recent years, the use of Treated Sewage Effluent (TSE) in groundwater recharge has received increasing attention by the water authorities in Bahrain to augment and enhance groundwater quantity and quality due to the presence of surplus tertiary treated wastewater being discharged to the sea. Additional reasons for considering the use of TSE in groundwater recharge in Bahrain are in that TSE is available for reuse at a relatively low cost and provides a dependable source of water even in the summer dry season, where domestic water consumption reaches its peak, and as domestic water consumption increases with time due to population growth, the amount of wastewater generated and treated would increase. Furthermore, as domestic water consumption is expected to increase by climate change (i.e., due to temperature increase), the increased fraction due to this phenomena would be reflected on the generated domestic wastewater. Moreover, based on the average unit cost of tertiary treated wastewater, about BD 0.045/m^3 for the anticipated output level for the year 2010 (**AI-**

Noaimi, 2005), the annual monetary value of the tertiary treated wastewater currently discharged to the sea without utilization (16,055 m³/day) is about BD264,000 (US$ 660,000).

Therefore, with the current groundwater deterioration and the presence of surplus tertiary treated wastewater in Bahrain, there is a need to evaluate the hydrogeological and environmental feasibility of using the surplus of tertiary treated wastewater in the artificial recharge of groundwater to enhance its storage, modify its water levels and/or store these amounts for later use (i.e. Aquifer Storage and Recovery ASR). However, although artificial recharge of groundwater in Bahrain using surplus tertiary treated wastewater represents a promising option in the management of water resources, health and environmental risks associated with this process need to be assessed thoroughly before the implementation of such a scheme.

Methodology

The following methodology was adopted (**Figure 1**):

1. **Site selection by GIS and criteria matrix**
   - Collect available relevant geospatial data (aquifer geometry, transmissivity, quality of groundwater, water supply wells location, TSE distribution network and main reservoirs with possible surplus).
   - Design a criteria matrix and apply a methodology to identify potential artificial recharge sites with relevant set of criteria.
2. **Simulation modeling and analysis of selected sites**
   - Develop a groundwater mathematical model for the area of the selected sites.
   - Simulate the artificial recharge of the aquifer by tertiary treated wastewater using several recharge sceneries and evaluate the results in terms of hydraulic efficiency and benefits.
   - Identify the most suitable artificial recharge sites.
3. **Health risk assessment of using tertiary treated wastewater in the artificial recharge the Dammam aquifer**
   - Use groundwater mathematical modeling to assess the environmental and health risks of artificial recharge of the aquifer by tertiary treated wastewater under different injection rates and constant hydraulic parameters at the selected sites.

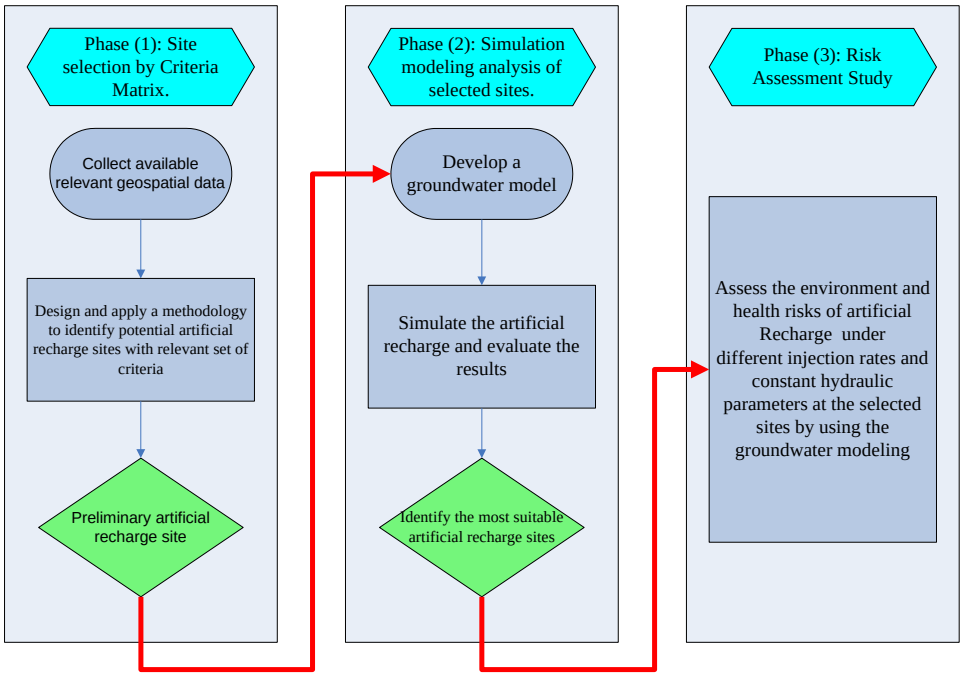

Figure 1. Study methodology.

Results

a. Site-selection

The methodology for optimum site selection for artificial recharge was based on a criteria matrix method developed for the specific case of Bahrain and was implemented using a developed Geographic Information System (GIS). The criteria consisted of 6 essential parameters: 1) location and capacity of tertiary treated wastewater reservoirs tanks; 2) availability of emergency wells for groundwater abstraction/recharge; 3) aquifer hydraulic transmission property (Transmissivity); 4) aquifer salinity in comparison to tertiary treated water salinity; 5) proximity of agricultural areas for indirect reuse in irrigation; and 6) proximity of domestic water supply wellfields for causing health risks.

The first stage of the locations screening process consisted of using the criteria of "*reservoirs tanks capacity*", "*availability of emergency wells*", and "*proximity of agricultural areas*", which are more related to the physical operation of the artificial recharge, as favorable criteria for the location of artificial recharge. **Figure (2a, b, and c)** illustrate the spatial distribution of these three criteria, respectively. The "*aquifer salinity*" criteria (**Figure 2d**) was found suitable in all locations in Bahrain since the salinity of the tertiary treated wastewater (currently 3,500 mg/L and would be improving with time with the projected increase of desalination input in the domestic water supply distribution network) is better than groundwater salinity in the targeted 'B' aquifer zone in Bahrain. The "*aquifer*

transmissivity" criteria, which is relatively high in the fractured 'B' aquifer zone, was found favorable for the operation of the artificial recharge process on one hand, while on the other, it would increase the health risks in the rapid transmission of pollutants in case they existed. Therefore, this criteria, like the "*proximity of domestic water supply wellfields*" was deferred to the next stages of the site selection, where it was embedded in the groundwater modeling results for the selected sites.

Analysis of the criteria matrix, which included 15 tertiary treated wastewater reservoirs in Bahrain (**Table 1**), resulted in identifying two suitable reservoirs locations that ranked high for the artificial recharge of tertiary treated wastewater in the Dammam aquifer. These are the reservoirs of "Dumistan" and "Malikiya" (both scored 80%), both located in the western region of Bahrain, where tertiary treated wastewater is currently supplied to farmers for irrigation. A third reservoir, closer to these two, Hamad Town reservoir scored 75%, but was eliminated from the selection process as it is a controller reservoir transmitting the tertiary treated wastewater received from the main treatment plant (Tubli Wastewater Treatment Plant) to all the western region reservoirs.

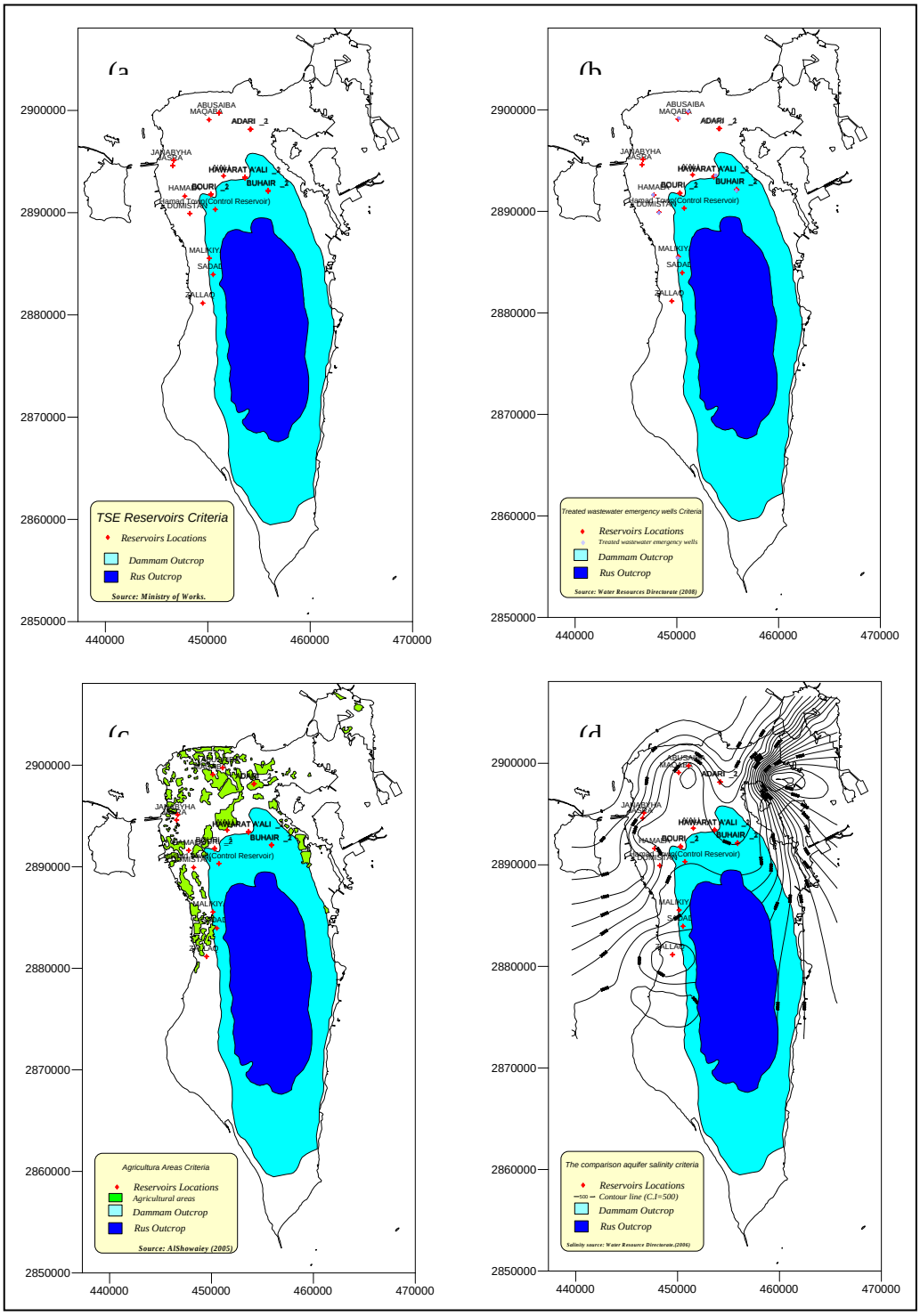

Figure 2. Spatial distribution of site-selection criteria parameters: a) location and capacity of tertiary treated wastewater reservoirs tanks; b) availability of emergency wells for groundwater abstraction/recharge; c) proximity of agricultural areas for indirect reuse in irrigation; and d) aquifer salinity.

Table 1. Treated wastewater reservoirs locations and capacity.

No	Location	Coordinates		Capacity (m^3)
		E	N	
1	HAMALA TSE Pumping Station	447755.6766	2891612.3155	8500
2	DUMISTAN TSE Pumping Station	448251.2252	2889919.5066	12200
3	JASRA TSE Pumping Station	446574.9527	2894598.6001	5500
4	MALIKIYA TSE Pumping Station	450152.3701	2885539.9695	14250
5	SADAD TSE Pumping Station	450526.6283	2883947.1810	12200
6	ZALLAQ TSE Pumping Station	449506.6421	2881151.6592	8500
7	MAQABA TSE Pumping Station	450116.3490	2899090.5824	8620
8	A'ALI TSE Pumping Station	451544.8563	2893597.0707	1350
9	ABUSAIBA TSE Pumping Station	451090.6575	2899738.9432	6100
10	ADARI TSE Pumping Station_2	454129.3009	2898141.6735	2500
	ADARI TSE Pumping Station_1	454206.0136	2898164.1788	4000
11	JANABYHA TSE Pumping Station	446681.0232	2895106.2038	8300
12	BOURI TSE Pumping Station_1	450299.4207	2891834.6091	4000
	BOURI TSE Pumping Station_2	450296.7067	2891745.0208	4000
13	HAWARAT A'ALI TSE Pumping Station_1	453636.7007	2893479.3508	4000
	HAWARAT A'ALI TSE Pumping Station_2	453635.0327	2893388.5814	2500
14	BUHAIR TSE Pumping Station_1	455880.4377	2892183.4137	4000
	BUHAIR TSE Pumping Station_2	455894.9904	2892094.2311	1350
15	Hamad Town (Control Reservoir)	450727.0658	2890315.1701	20715

b. Simulation modeling of selected sites

The second stage consisted of the development of a numerical groundwater flow (MODFLOW; McDonald and Harbaugh, 1993) model and a solute transport (MT3DMS; Zheng and Bennett, 1995) model for the 'B' aquifer zone for the western region of Bahrain, where the two selected sites are located (**Figure 3**). The developed model is used to investigate the hydraulic response of the aquifer system and salinity changes in response to the proposed future plans of utilization at the two selected sites. The Dammam aquifer consists of two groundwater zones, the Alat zone (termed 'A' aquifer) and the Khobar zone (termed 'B' aquifer). The 'B' aquifer zone is developed in highly fractured limestones and dolomites and is the principal aquifer in Bahrain, where it provides most of groundwater abstraction. The 'A' aquifer zone has limited hydraulic properties and due to its salinization is being used at a very local scale by farmers. The Dammam aquifer system in Bahrain represents a small part of an extensive regional aquifer, termed the Eastern Arabian aquifer, that extends from central Saudi Arabia, where the aquifer crops out and its main recharge area is located, to the Arabian Gulf waters, including Bahrain. The Dammam aquifer in

Bahrain receives its water mainly by underflow from this regional aquifer. in this study, the 'B' aquifer zone, as a potential zone for artificial recharge is considered in the modeling study.

Based on its transmissive properties, the 'B' aquifer zone is subdivided in the modeling study into two zones: the upper Khobar, about 10 m thick highly fractured limestone and dolomite, and the lower Khobar which has a thickness that increases gradually from the east to the west (20 – 29 m) in the Western region of Bahrain. The representation of the vertical heterogeneity of the aquifer transmissivity is considered crucial to accurately simulating the fate of the injected water in the aquifer. The western boundary of the model was simulated as a constant head to represent water inflow from eastern Saudi Arabia.

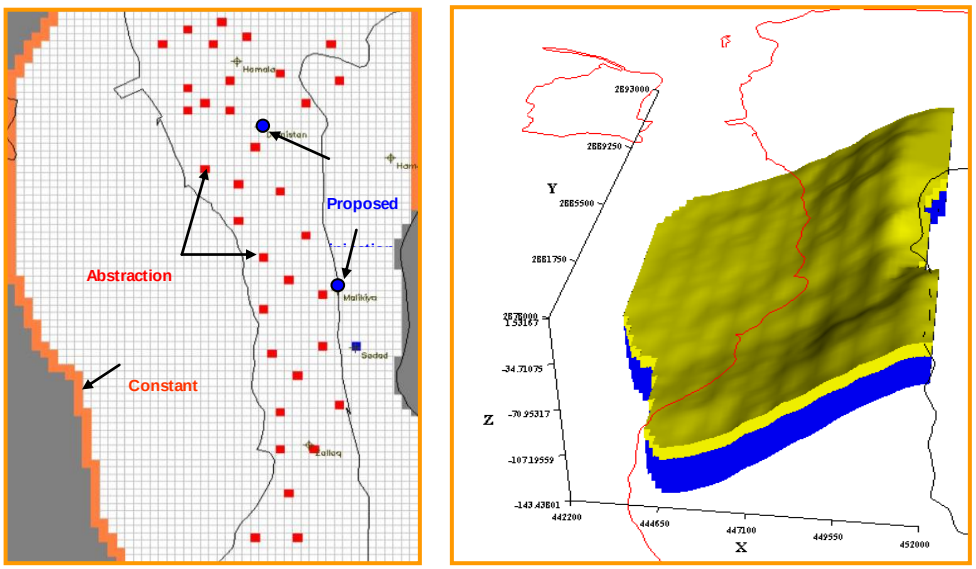

Figure 3. Numerical model grid design (200x200 m) and 3D view for the geometry of the Khobar aquifer zones in Western Bahrain Region.

The model was run under steady-state conditions for a one year period using the abstraction data for the year 2006 in the western region, which was about 62.3 Mm^3. The year was divided into 12 stress periods (i.e., 12 months), with each divided into 8 time steps (total 96 time step) in order to minimize the error that can be generated from the approximation of the time derivative, and to enable potentiometric head comparison, which are reported on a monthly basis. The seasonal variation in the abstraction was calculated from the observed data for the abstraction areas in the western region (given as annual abstraction; **Figure 4**), and the monthly percentage was obtained for each area. Then, the average monthly percentage for each abstraction area for the western region was calculated (**Figure 5**) and is used to calculate the input abstraction average daily rate for each abstraction area. This is

made due to many limitations and errors in the abstraction data. The abstraction seasonal trend in the western region is typical of an agricultural area, where maximum abstraction occurs in the summer months.

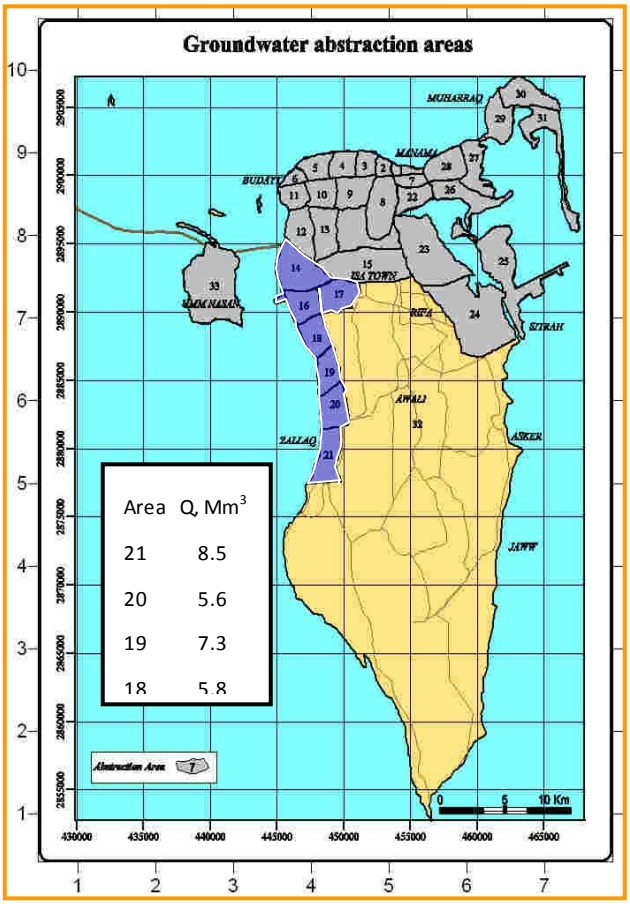

Figure 4. Groundwater abstraction areas (WRD, 2009).

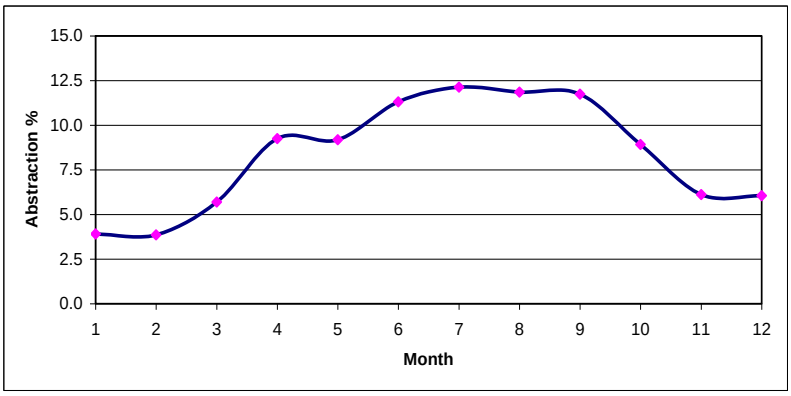

Figure 5. Calculated average monthly abstraction percentage for the western region in Bahrain.

Once the potentiometric head distribution in the aquifer was obtained, MT3DMS model is used to simulate the salinity of the aquifer using the 2006 salinity map as the initial concentration. **Figure (6a, b)** illustrate the simulated potentiometric heads and salinity for the upper Khobar zone, respectively.

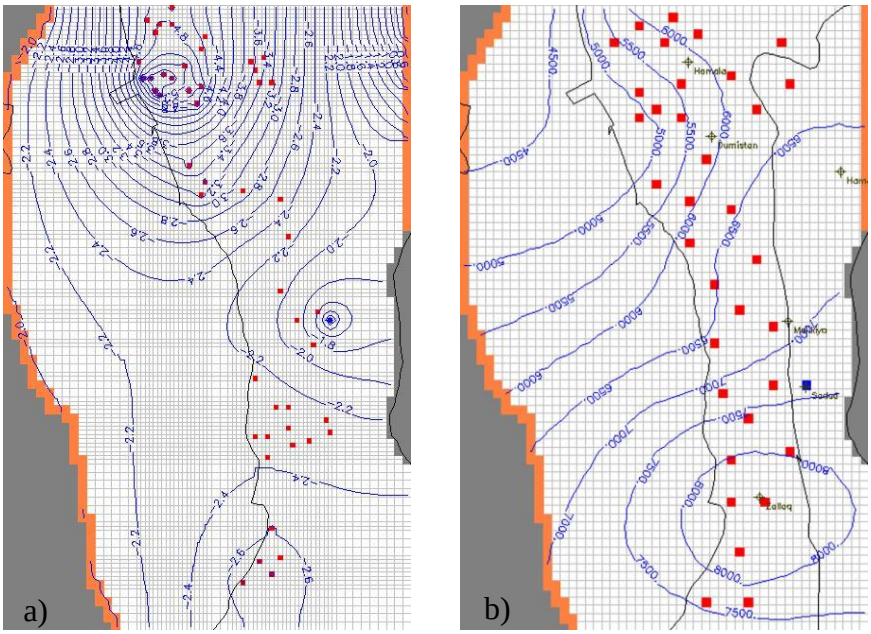

Figure 6. Simulated potentiometric heads (a) and salinity (b) distribution in the upper Khobar zone for the year 2006.

Adequate simulation and representation of the flow (potentiometric head distribution) and salinity for the 'B' aquifer zone for the year 2006, allowed the model to be used in evaluating the hydraulic efficiency and benefits for the two selected sites in the aquifer artificial recharge. The projected tertiary treated wastewater recharge quantities and quality data for five years, from 2010 to 2014 were calculated from the observed trends of the collected data of tertiary treated wastewater production, consumption, sea out-fall (surplus), and salinity for the period from 2005 to 2009 (**Figure 7**).

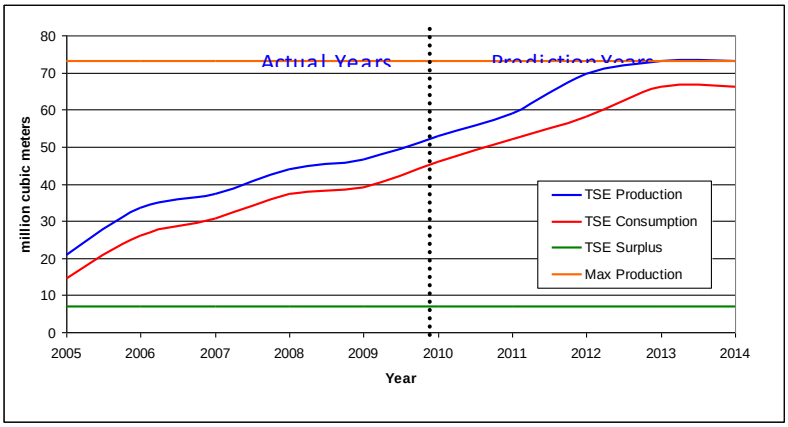

Figure 7. Tertiary treated wastewater production, consumption, and surplus observed in the years 2005-2009 (actual) and projected (2010-2014).

Six recharge scenarios were developed and simulated using the developed model. These are:

1. **National strategic water storage plan scenario**: Treatment of all wastewater received (200,000 m^3/day) to tertiary level and using all surplus quantities for recharge at the two locations equally. The total volume of injected treated wastewater in five years (2010-2014) will be 77 Mm3 (i.e., 38.5 Mm^3 per location).
2. **Surpluses storage scenario**: inject only the surpluses (7 Mm^3/year) at the two sites equally. The total volume of injected treated wastewater in five years will be 35 Mm^3.
3. **Inject all the quantities from scenario 1 (77 Mm^3) at one location:**
   a. Dumistan
   b. Malikiya
4. **Inject all the quantities from scenario 2 (35 Mm^3) at one location**
   a. Dumistan
   b. Malikiya

In all the artificial recharge scenarios, a salinity value of 3,500 mg/L is used for the injected water in the aquifer based on the observed Tertiary treated wastewater salinity (**Figure 8**). The salinity of the tertiary treated wastewater shows an improvement with time due to the increasing reliance on desalination in municipal water supply.

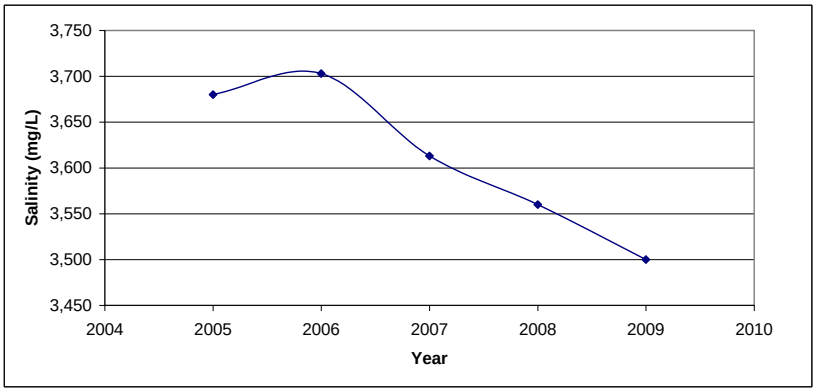

Figure 8. observed salinity of the tertiary treated wastewater, 2005-2009.

Figures (9) and **(10)** show the simulated results of the six scenarios, in terms of water level and salinity changes at 6 observation wells in the model, respectively. The first two observation wells are located in the injection wells (Dumistan and Malikiya) and are used to evaluate the effectiveness of artificial recharge in modifying the aquifer conditions within the vicinity of the two recharge sites. The other four observation wells are used to evaluate the effectiveness of artificial recharge in the areas surrounding the recharge locations; the third observation wells is located north of the Dumistan artificial recharge site (Hamala) and where a major domestic water supply wellfield is located; the fourth observation well is located in the middle distance between the two artificial recharge sites; the fifth observation well is located to the west of the two artificial recharge sites near the coastline; and the sixth observation well is located to the south of the Malikiya artificial recharge site.

In Malikiya and Dumistan observation locations, as expected the positive effect of the recharge is clearly shown in both water levels rise and salinity modification. In the other four locations there is an elevation in the water levels in general (**Figure 9**), but salinity reduction is not clearly evident. This is attributed to the recharge amount, the distance between the recharge well and observation well and the abstraction magnitude of the area by farmers. While the aquifer salinity is reduced at the early stages of the artificial recharge, it returns to the aquifer original salinity with continued abstraction in most of the areas (**Figure 10**).

It can be concluded from the simulation results of the above six scenarios indicated, in general, that there is an increase in the water levels and salinity modification from their present levels at all sites. However water level and salinity modification are more significant in scenarios 1, 3a and 3b, with the latter being more pronounced. Moreover, it is expected that with the continuation of artificial recharge beyond the prediction period, the impacts of artificial recharge on modifying the aquifer water levels and salinity changes would be more significant with time.

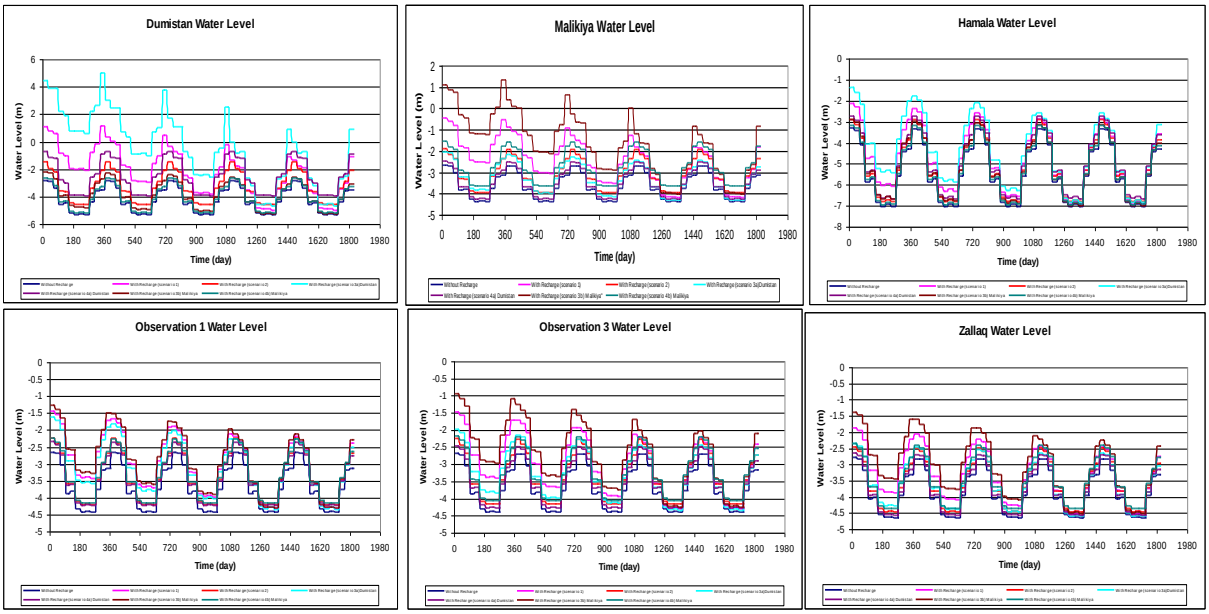

Figure 9. Simulated water level under the six artificial recharge scenarios, 2010-2014.

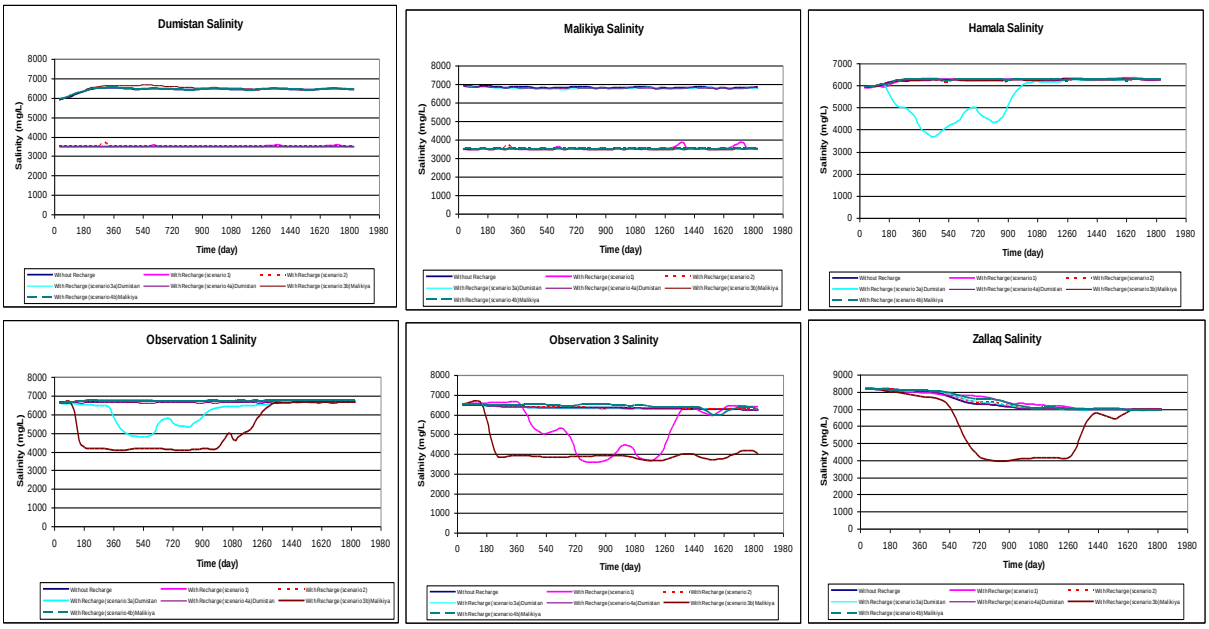

Figure 10. Simulated salinity under the six artificial recharge scenarios, 2010-2014.

In order to visualize the distribution of the salinity in the upper 'B' aquifer zone, salinity contour maps were prepared for the six scenarios. **Figure (11)** displays the simulated salinity distribution in the upper 'B' aquifer zone for the 6 scenarios at the end of the predictive simulation period (2014). It can be seen clearly from these salinity contour maps that scenario 3b (treatment of all received wastewater to the tertiary level and using the surplus

for artificial recharge in one location at Malikiya) is the best scenario in terms of modifying the salinity in the aquifer, followed by scenario 4b (using all the surplus of the tertiary treated wastewater for recharge in one location at Malikiya).

From the above simulation results, it can be concluded that in terms of hydraulic suitability and benefits, the Malikiya site represent the most suitable site for artificial recharge scheme in Bahrain using surplus tertiary treated wastewater, and that the hydraulic benefits of this scheme would be significant if it was associated with using large quantities of treated wastewater. Although currently the tertiary treated wastewater is being used directly for irrigation by farmers in the western region of Bahrain, environmental and health concerns are still raised about the use of this water in groundwater artificial recharge since groundwater in this region is also used for domestic water supply (drinking). Therefore, health risks associated with this process need to be also assessed before reaching such conclusion.

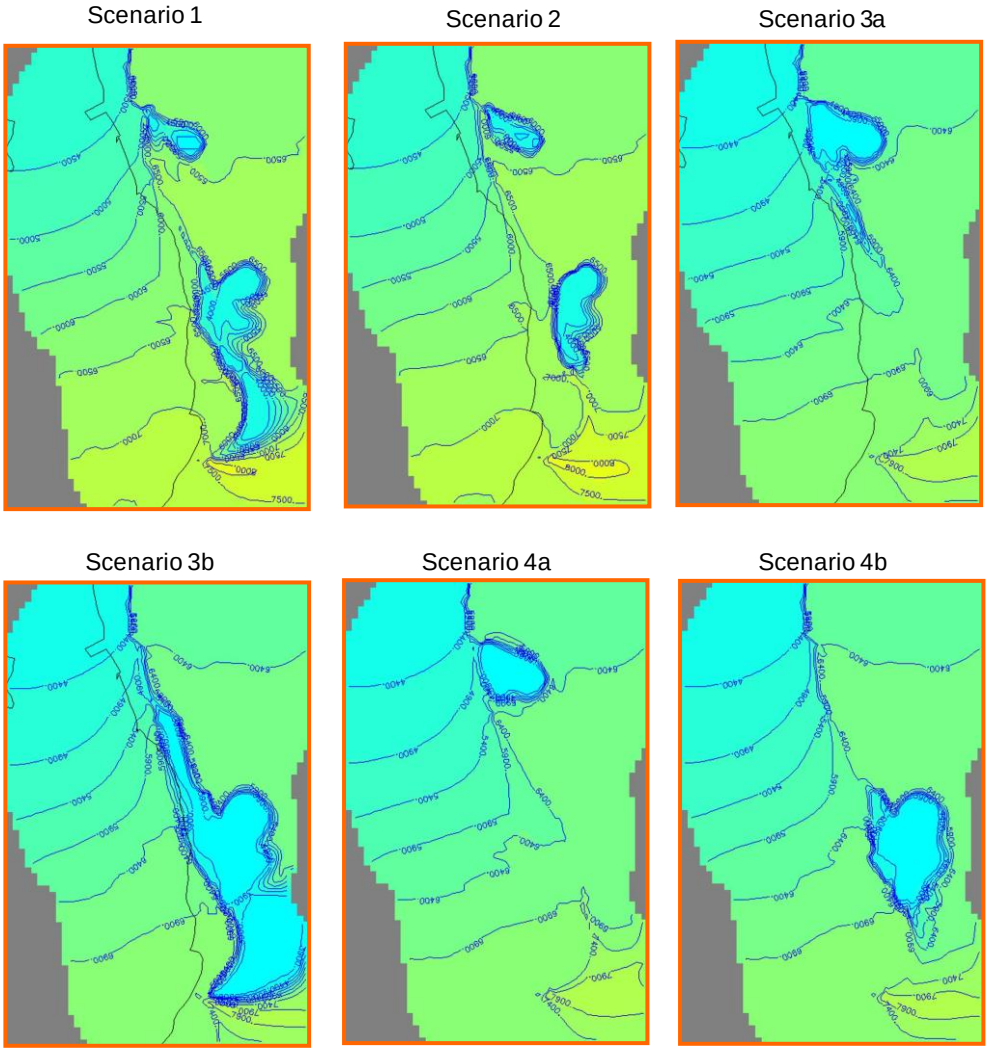

Figure 11. Simulated salinity distribution in the upper 'B' aquifer zone for the 6 scenarios at the end of the predictive simulation period (2014).

c. Health risk assessment

In this stage, the main health risk concerns of aquifer recharge and abstraction for drinking water were investigated. The injected treated wastewater should remain within the aquifer for a sufficiently long period of time so that chemical, physical, and biological processes eliminate any chemicals and microorganisms hazards associated with the treated wastewater. The health risk associated with treated wastewater will depend upon the quality of the water entering the sewage treatment plant and the effectiveness of the sewage treatment processes in removing known or potentially harmful chemicals and microorganisms (**Schlumberger Water Services, 2009**). Putting treated wastewater into natural environments, such as an aquifer, increases the retention time and thereby allows more time for the biodegradation of

contaminants that degrade more slowly (**Dillon *et al.*, 2006**). The attenuation processes during underground storage have been referred to as natural aquifer treatment. It has been recognized that natural aquifer treatment or soil aquifer treatment (SAT), could be used as an integral component of the treatment processes for reclaimed water or surface water, rather than just a beneficial byproduct of ASR and MAR systems (**Schlumberger Water Services, 2009**).

The potential health risks posed by treated wastewater injected into underground aquifers depends upon several main factors: (1) the chemical and microbiological composition of the treated wastewater; (2) physical, chemical, and biological conditions within the injection zone; (3) the attenuation rate of each compound or microorganism of concern within the injection zone; and (4) the retention time of the injected water within the injection zone (**Schlumberger Water Services, 2009**).

Two locations of concern were identified: 1) Hamala domestic water wellfield (located north of the Dumistan proposed artificial recharge location), which the Electricity and Water Authority is utilizing its water for household supply after blending with desalinated water; and 2) Irrigation water wells which farmers use directly for irrigation, and might also be used for drinking purposes. Based on the available data, two contaminants were selected for the risk assessment process and site-selection, pathogens and Nitrates.

The pathogens health risk of the recharge scenarios schemes were evaluated by using the advective transport model PMPATH (provided with MODFLOW package). The evaluation was based on that the minimum residence time for the recharged water should not be less than 200 days in the aquifer and before it is abstracted, which represent a 99% decline rate by natural groundwater attenuation for pathogens. **Figure (12)** displays the 200- days travel time of the recharged water in the 6 scenarios. As indicated above, the location with the highest risk is the Hamala domestic water supply wellfield, where the water produced from the wellfield is used directly for drinking, in addition to the farmer wells that might be used for drinking.

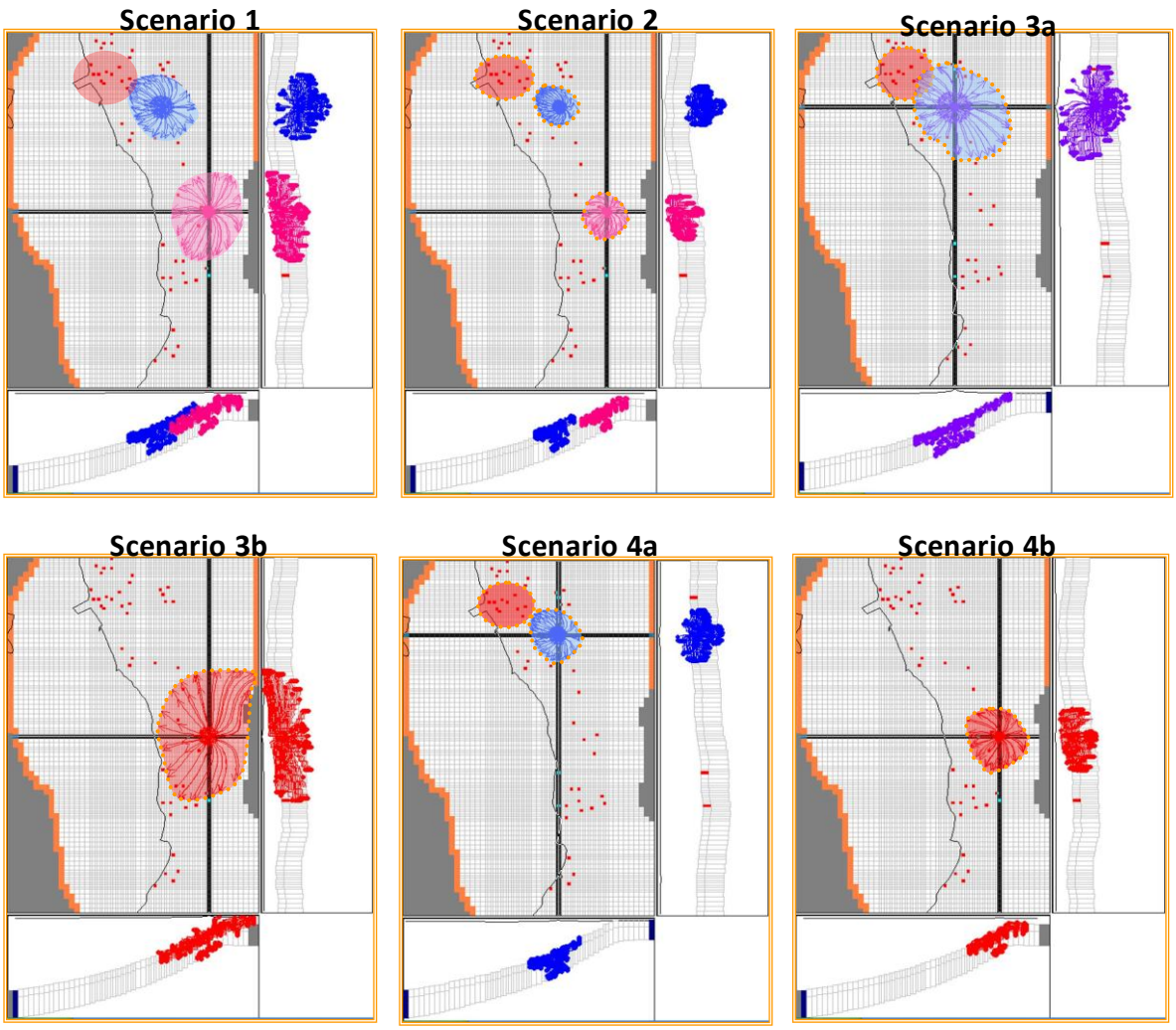

Figure 12. Calculated pathogen risk (200 days travel time) in the 6 scenarios.

The results of the assessment indicate that health risks exist in all recharge scenarios when considering Hamala wellfield and farmers wells. More specifically, artificial recharge scenarios 1, 2, 3a, and 4a are particularly of higher health risk in terms of pathogen contamination due to the proximity of the artificial recharge site (Dumistan) to Hamala wellfield in that there is a large probability in these scenarios that the recharged water will be captured by the domestic supply wellfield. Therefore, it is logical to eliminate Dumistan from the potential recharge sites. In other words, Malikiya recharge site would be the only location for such scheme. However, health risks still exist due the widespread farmers wells around this location. Although currently farmers in the western region of Bahrain are using tertiary treated wastewater directly for irrigation, this water is being supplied by special pipe system to their agricultural lands, and it can be safely assumed that farmers are aware about its origin and quality and are probably not using it for drinking. However, this would not be true for their water wells. Therefore, if such a scheme is implemented, an awareness program

about the process of artificial recharge by tertiary treated wastewater becomes a pre-requisite to minimize the health risks associated with it.

Further assessment and analysis of the health risks are carried out using the Malikiya location under large recharge volumes (i.e., scenario 3b, recharging all surplus quantity in Malikiya well; 77 Mm^3) using Nitrate pollution as a health hazard. The fate of Nitrate in the recharged water in the upper 'B' aquifer zone was simulated using MT3DMS transport model for a five-year period (2010-2014). The Nitrate was assumed to be non-reactive (i.e., no adsorption and no decay/transformation) to represent the worst case scenario.

The drinking water quality standard in the USA for Nitrate (NO_3-N) is 10 mg/L (**Chandler, 1989**). This value is used as a reference to evaluate the fate of Nitrate in groundwater by the model, and assess the risk of having the Nitrate concentration above the drinking water standards. Chemical analyses of the tertiary treated wastewater indicated that the maximum observed Nitrate concentration in 2006 and 2007 (data made available by **MOW, 2009**) was at less than 7 mg/L (6.7 mg/L), which is well below the maximum allowable concentration for drinking water. While it is expected that under these conditions the Nitrate concentration will never exceed the maximum allowable limit (i.e., 10 mg/L), it is important to evaluate the extent and direction of the Nitrate plume in the aquifer area surrounding the injection well, for some studies have shown a correlation between long-term ingestion of elevated Nitrate and increased incidence of certain cancers (**Skipton *et al*., 2008**).

Figure (13) displays the simulated Nitrate concentration for five years (2010-2014). The Nitrate plume expands with time as the tertiary treated wastewater injection continues with a concentration below 7 mg/L covering a large area surrounding the injection well. The plume direction is observed to be moving towards the northwest direction from the injection well, which is attributed to the extensive pumping in that area by farming activities as well as by the Hamala domestic wellfield.

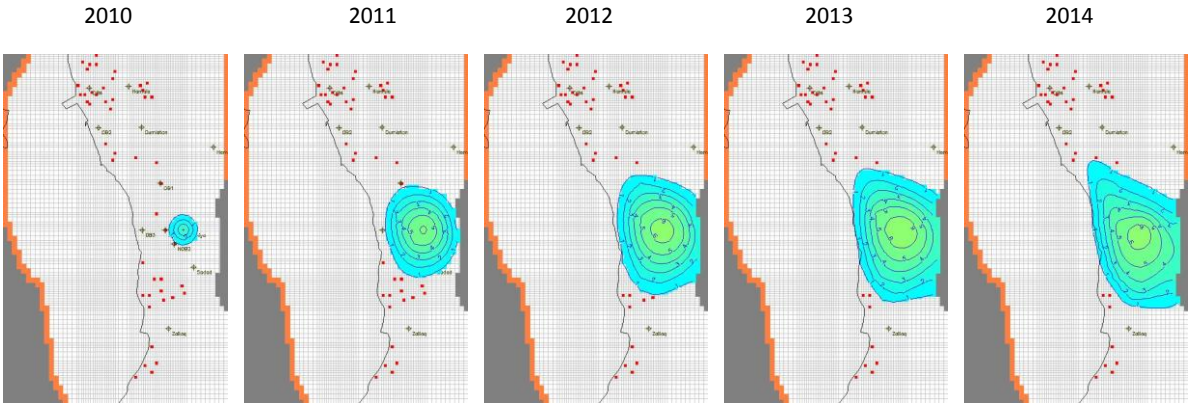

Figure 13. Simulated Nitrate concentration for the period 2010-2014 (5 year) under scenario 3b.

To further analyze the fate of Nitrate, the concentration at the end of the simulation period was analyzed spatially. **Figure (14)** shows that by the end of the 5-year simulation period, the Nitrate concentration plume originating from the injection well has extended about 3.8 Km, 4.0 Km, and 3.0 Km in the north, south and west directions, respectively.

In general, it can be concluded that Nitrate health risks associated with artificial recharge of having Nitrate concentration in the aquifer would be very limited and would be restricted to an area of about 4 km surrounding the injection well in Malikiya, provided that the maximum concentrations of the Nitrate in the tertiary treated wastewater stay at its observed levels. Furthermore, if the observed maximum Nitrate concentration persists, then there is no health risk of having it exceeding the maximum allowable limit of drinking water. Again as indicated earlier in the pathogen health hazard assessment, the health risks of Nitrates can be minimized by not having the farmers within the vicinity of the recharge location using groundwater abstracted from their wells for drinking. An awareness and education campaign among farmers would be necessary if such a recharge project is undertaken.

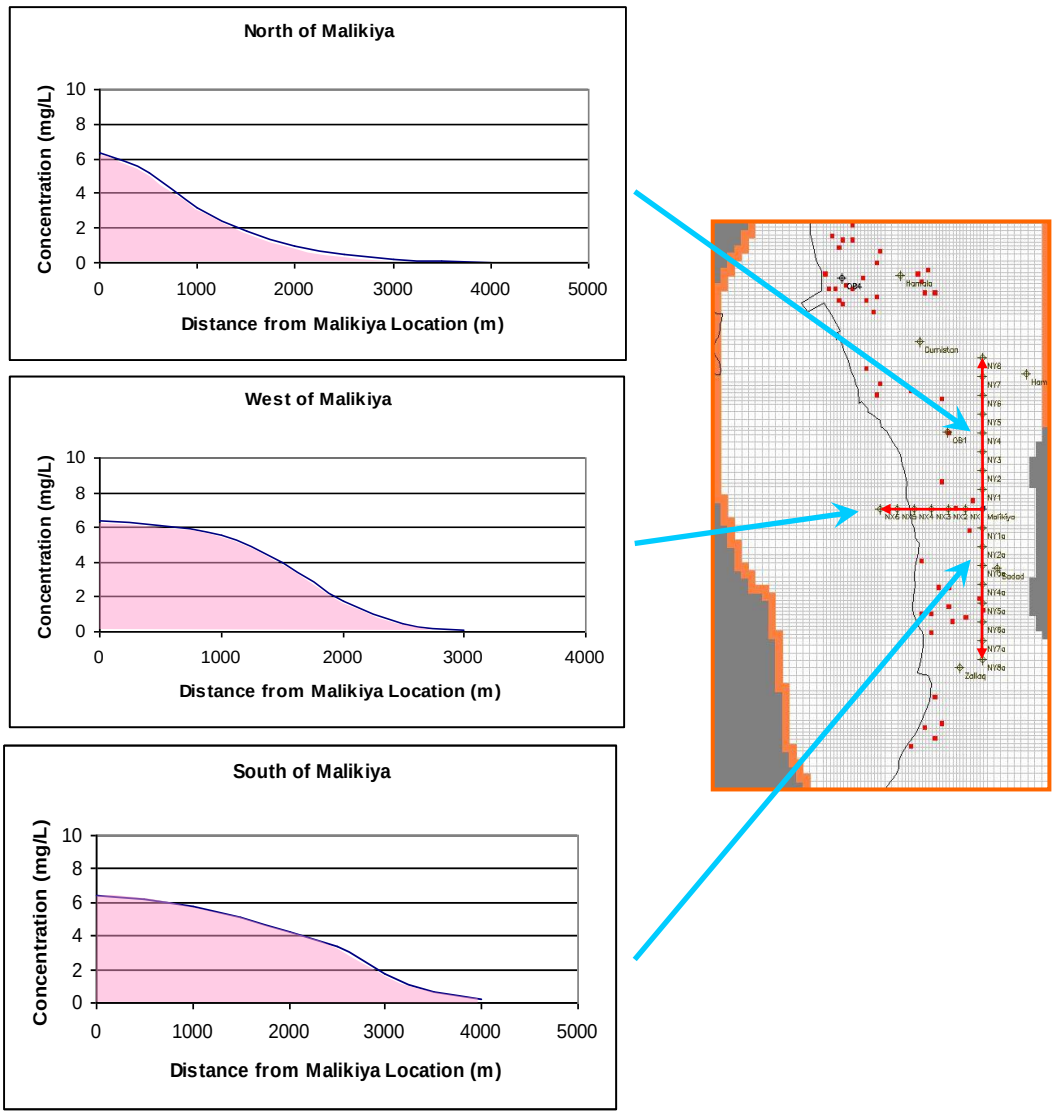

Figure 14. distance-concentration curves for the Nitrate concentration at the end of the 5 year simulation period (2014) under scenario 3b.

Conclusion and Recommendations

Based on the above modeling results to assess the health risks of groundwater artificial recharge by tertiary treated wastewater in Bahrain, it can be concluded that the most suitable location for artificial recharge is at Malikiya tertiary treated wastewater reservoir. It can also be concluded that in order to be an effective, artificial recharge should be made within a national strategic water storage plan that constitute a major component of a national water resources management policy and strategy, and utilizes all unused tertiary treated wastewater. A field pilot study for artificial recharge using tertiary treated wastewater at Malikiya

location to further evaluate the feasibility of artificial recharge and validate the modeling results is a pre-requisite for such plans.

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SESSION 3C:
CONVENTIONAL WATER RESOURCES MANAGEMENT

Keynote: Abdulla Abdulsalam, UNESCO-CWR, Sudan, Water Harvesting in Arid and Semi- Arid Areas: Challenges and Opportunities

Prof Abdall Ahmed's education includes a B.Sc. Civil Engineering - Khartoum Univ. 1978 and a PhD. in Hydraulics Engineering – Glasgow Univ. UK. He is head of Dam Reservoir Research Unit – Sudan and Director General of Gash Rehabilitation Corporation – Sudan. He is also Deputy Commissioner of Gezira Scheme – Sudan, Minister of Agriculture, Animal Wealth and Natural Resources, Professor of Water Resources – Omdurman Univ. Sudan, Director General of UNESCO Chair in Water Resources – Sudan, and Head and Member of several organizations and Scientific Societies – international, Regional and National.

Abstract:

Freshwater is facing great pressure due to rapid population growth and increase in water consumption as a result of the betterment in living standards. The Arab region in general is dry land and is facing physically water scarcity. This situation enforced the Arab region to look for solutions. Water Harvesting (WH) represents one of the potential solutions in response to water scarcity, which is escalating due to the climate change.

In this paper, the need for proper water harvesting techniques is highlighted. Several global WH practices are reported and discussed. Further, Sudan special indigenous WH techniques are reflected. The challenges and constraints facing the WH techniques are briefly explained. The practical methods to improve the later WH techniques are presented. Finally the lessons learned are reported and the opportunities will be identified ending with conclusions and recommendations.

Hydrological Feasibility Study of Surface Runoff Water Harvesting in Al-Ajeej Basin, North West Iraq

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Abstract

The hydrological characteristics of Al-Ajeej basin, which is located within south Sinjar plain of northwest Iraq, was analyzed to predict the possibility of surface runoff harvesting during the rainfall season in the upstream sites in this basin using watershed modeling system (WMS). The hydrological feasibility of constructing a small dam on Al-Ajeej wadi with some preliminary design calculations are presented. The best optimum dam site was selected to be located 3.95 km downstream the confluence of Al-Badee branch with Al-Ajeej wadi (35° $46'$ $6''$ Latitude and Longitude 41° $36'$ $11''$) having a catchment area of 3043 km^2. The proposed dam height is 12.5 meters and dam length is 1277 meters, while the normal storage volume of the reservoir is 38.8 million m^3. Constructing a dam in such sites characterized by water shortages all year long will aid in the sustainable development of such areas by increasing the cultivated lands, the agricultural products and also by modifying the income of the villagers living in this area, which will prevent them from leaving their lands to relocate to other places.

Keyword: Sustainability; Water harvesting; Small dams; Al-Ajeej Basin, WMS.

Introduction:

Due to the water scarcity for different uses in the south Sinjar mountain area, especially in the residential groups in Baaj district, it is mandatory and essential to conserve, stabilize these population groups and satisfy sustainable agricultural and dairy resources development. The importance of this area lays in the cultivation of strategic crops, such as wheat, on which the Iraqi country depends on. Experts state that water is available in the area during certain limited periods during the year (for a few months) but the actual input indicates a water shortage for most of the year as a result of non-homogenous distribution of water resources in different places and large amount of surface runoff flow draining towards the main wadi, Al-Ajeej wadi, leading to natural salty depressions across the Iraqi border to Syria, known as Al-Raudha depression.

Motivation and Aim of the study:

The study area (Al-Ajeej basin south sinjar plain) suffers from water shortages without any existing permanent surface water resources. In addition, this area has not been included in any previous engineering studies and will not be served by the proposed south Al-jazeera irrigation project. The basin of Al-Ajeej wadi drains the surface surcharge water quantities of the western north of south Al-jazeera plain out of the Iraqi border to Syria without any use. Another reason is the arid climate of the basin which leads to rain fall investment by storing these water quantities behind a proposed hydraulic structure, such as a small embankment dam constructed on this wadi.

The aim of the research work is to present a hydrological and topographical feasibility study for water resources development in Al-Ajeej basin by surface water harvesting during the rainfall season which drains and flows in the perennial Al-Ajeej wadi and to select the best optimum site on this wadi for constructing an embankment dam which is feasible and satisfies little economic cost with high usage coinciding with the water harvesting aspect.

Location of the study area:

The Al-Ajeej basin is located within the area of south Sinjar plain and Al-Baaj city at Ninavah governorate including the western north part of Al-jazeera palin in Iraq near the Iraqi-Syrian border. The total basin area is 5189 km^2 and extends between 4110 – 4260 long and lies between 36 25- 35 20 lat. About 4050 km^2 of this area is located in Iraq and 1139 km^2 in Syria. Sinjar mountain is located north of this basin; from the east, Al-Tharthar wadi;

Snaissla salty depression from the south; and Al-Khabour river basin in the Syrian lands from the west, (Figure 1).

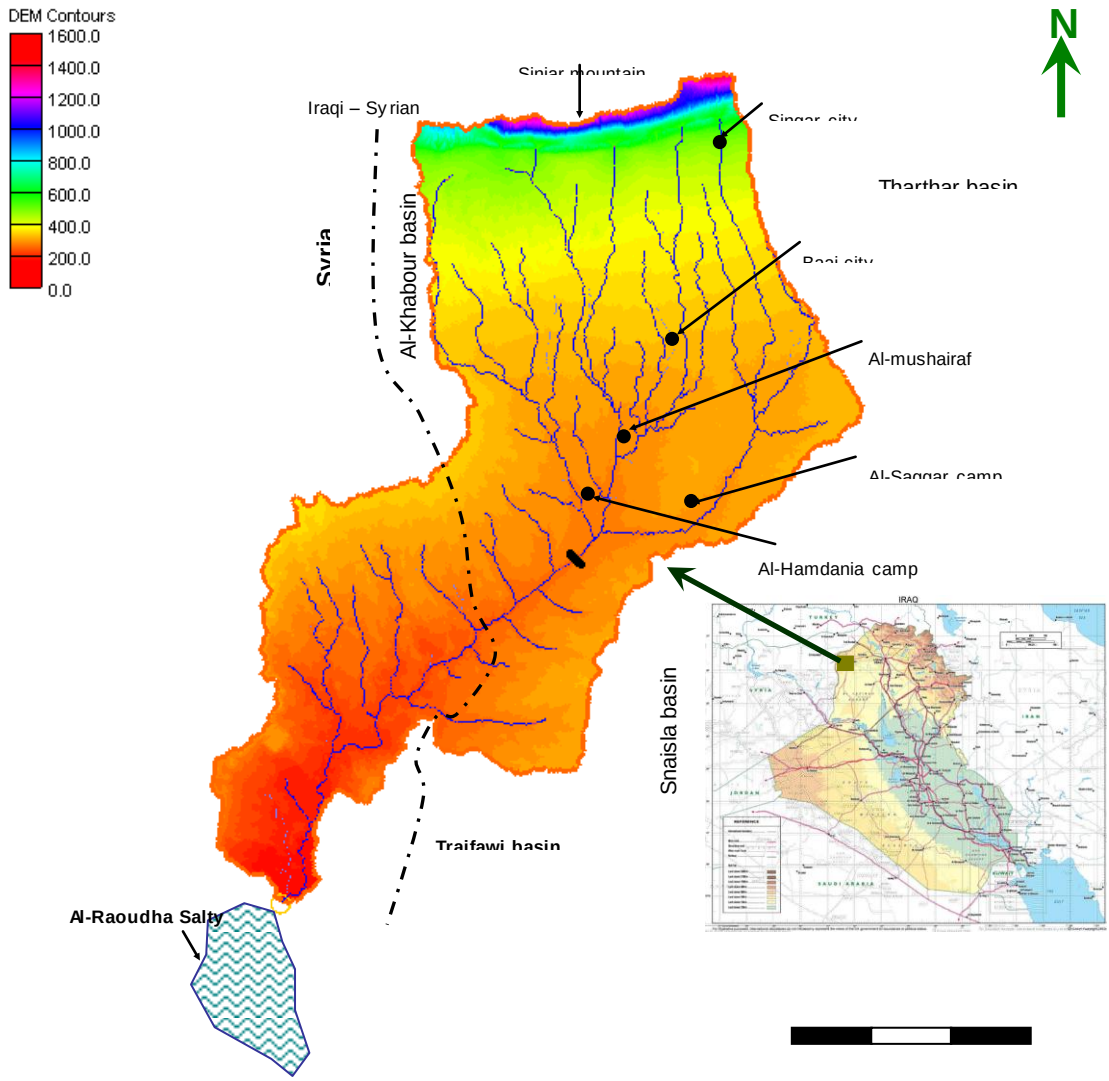

Fig.(1) Location Map of The Study Area.

The Climate:

The Al-Ajeej basin is located within the arid and semi-arid climate with high average air temperature, and high temperature difference between the day and night summers and winters with little rainfall and humidity (Al-Qassab , et.al. 1987). The rainfall quantities increase during October until May with snowfalls in the Sinjar Mountain in the north. The

maximum rainfall in Sinjar was 667 mm recorded in 1954, while the minimum was 92 recorded during the year 1947.

Literature Review:

Most of the previous studies concerning water availability within the study area (Abdulkadir 1973; Al-Sawaf 1997; Sharif 1981; Awad 1994;Al-Muhsin 1985; Al-Talabani 1986 and Sam 1989) focus on the geological formations storing water and types and characteristics of rocks and the ground water investigation. The study conducted by (Abdulkadir,1973) focused on the preliminary evaluation of some northern wadis of south Sinjar plain against the feasibility of dams construction to store rainfall water on their basins. The study conducted by (Rafiq, et.al, 2000) focused on the possibility of rain water harvesting through the basin of Sinjar mountain.

Geomorphological Description of Al-Ajeej Basin:

Al-Ajeej basin is classified as plainy lands, except Sinjar mountain and some high lands north of the basin. The basin extends from the north to the south, consisting of about eleven main wadis within Iraqi lands and three other main wadis in Syria. The Al-Ajeej basin consists of three main branches (Al-Hammal, Al-Khazrajia and Al-Badee) which originate from the south side of Sinjar mountain and extend between the water divide of Al-Khabour basin from the west and between Al-tharthar basin from the east.

The Al-Hammal branch intersects with Al-Khazrajia branch at a distance of about 27.5 km south of Al-Baaj city forming Al-Ajeej wadi, while Al-Badee wadi intersects with Al-Ajeej wadi southwest of Al-Baaj district at a distance about 28.8 km and 1.3 km southwest the intersection Al-Hamal with Al-Khazrajia branches. The geomorpological characteristics of these branches of Al-Ajeej wadi was investigated using the watershed modeling system (WMS) with the aid of a geographical information system, as listed in Table 1.

Table 1 Morphological characteristics of the main branches of Al-Ajeej basin

Geomorphological Parameters	Al-Hammal Basin	Al-Khazrajia Basin	Al-Badee Basin
Cachment Area (km^2)	885.48	1280.73	877.24
Basin slope (m/m)	0.0166	0.031	0.018
Average overland flow (km)	5.06	5.19	5.64
Basin length (km)	68.66	66.75	65.4
Basin Parameter (km)	279	258.5	211.7
Shape factor (mi2/mi2)	5.32	3.48	4.88
Basin Sinuosity Factor	1.28	1.09	1.12
Basin Average Elevation (m.a.s.l.)	353	402.3	366.8
Max Flow Distance (Km)	96.86	81.84	84.09
Max Flow Slope (m/m)	0.0111	0.0128	0.0066
Average basin width (km)	14.07	20.96	18.75
Time of concentration (hr)	13.9	10.5	12.7

Al-Ajeej Basin Soil:

Soil in Iraq differs from one place to another according to the material and existing geological formations and also the climatic conditions and vegetation cover in the site. The most soil type of Al-Ajeej basin contains calcareous gypsum with organic material due to the existing geological formation of Injana and Al-fatha in the basin, (Abdulkadir, 1973). The soil characteristics and its components describe the permeability degree which in-turn affects the hydrological elements starting from the surface runoff and infiltration, to the ground water storages.

Surface Water Sources in the Basin:

The water resources are characterized by the main wadis and their branches distributed through the basin. The springs and kahrizes exist in the north of the basin at the foothills of south side of Sinjar mountain, such as Jaddala spring (Fig.1). The ground water quantities cover the surface water shortage and its existence differs in the Al-Ajeej basin according to the climate, topography, existence of vegetation cover and geological formations. Rainfall is the more essential climatic parameter existing in the area which considers the only water source in the area for their feeding in large quantity in the northern zone of the basin. The topographical features of the basin and drainage pattern play an important role in the groundwater. The increasing numbers of wadies, narrowness, closeness between them and

their parallel drainage pattern leads to direct fast flash flow due to the direct rainfall without any time for infiltration processes which in-turn increases the opportunity of harvesting those surface runoff quantities by constructing dams.

Calculation of the Annual Runoff in Al-Ajeej Wadi:

(Rafiq,et.al, 2000) estimated the surface runoff in the study area as 10000-15000 m^3/km^2 using the Berkly equation. In the present study, the flowing runoff depth within the Al-Ajeej basin was estimated using the daily rainfall recorded data in Sinjar and Al-Baaj stations for the years (1994-2006) applying the SCS curve number method (Chow, 1988).
The curve number was derived from the hydrological soil group and land use and land cover. It was provided for moderate antecedent soil moisture conditions (ASM-II) then converted to ASM-I and ASM-III conditions reaching to the following regression equations:

$$CN\text{-}I = 0.3358 * 1.009^{CN\text{-}II} * CN\text{-}II^{1.038} \quad \ldots\ldots (1)$$

$$CN\text{-}III = 3.5610 * 0.9961^{CN\text{-}II} * CN\text{-}II^{0.8101} \quad \ldots\ldots (2)$$

Where; CN-I,II,III are the curve numbers for antecedent moisture condition I, II,III (Chow,1988).

Applying the above equations and by taking into consideration all the hydrological and physiographical factors of the Al-Ajeej basin, the average curve number value of 82 was found.

Watershed modeling system (WMS, 2005) was fed with all the hydrological and physiographical characteristics of the catchment area of Al-Ajeej wadi for the years (1994-2006). The annual runoff volume (Table 1) was calculated at the confluence of the three main branches of Al-Ajeej wadi (Al-Hammal, Al-Khazrajia and Al-Badee) shown in figure 2 as follows:

Table 1

Year	Annual Runoff volume (m^3)
1994	63,867,086
1995	51,436,209
1996	136,989,336
1997	21,165,293
1998	23,742,186
1999	9,045,001
2000	28,881,158
2001	81,531,890
2002	95,957,754
2003	25,423,839
2004	8,515,427
2005	70,542,827
2006	73,784,186
Average	**53,144,784**

Selection of Dam Site:

Using topographical topo-sheet map 1: 2500 and the digital elevation model (DEM) of the study area, a dam site was proposed to verify the criteria of less dam length, less amount of earth works and higher storage volume with a minimum ratio of surface area to the storage volume. The essential hydrological conditions and factors, such as available storage volume, geomorphological characteristics of the site, the engineering nature of the site including bed slope, and availability of the depression wadi were taken into consideration also. The proposed dam site was located 3 km downstream of the confluence of Al-Badee branch with Al-Ajeej wadi at coordinates of (35° $46'$ $6''$ Latitude and 41° $36'$ 11 Longitude) as shown in Figure 2. Figure 3 shows a topographical cross-section of the proposed dam site.

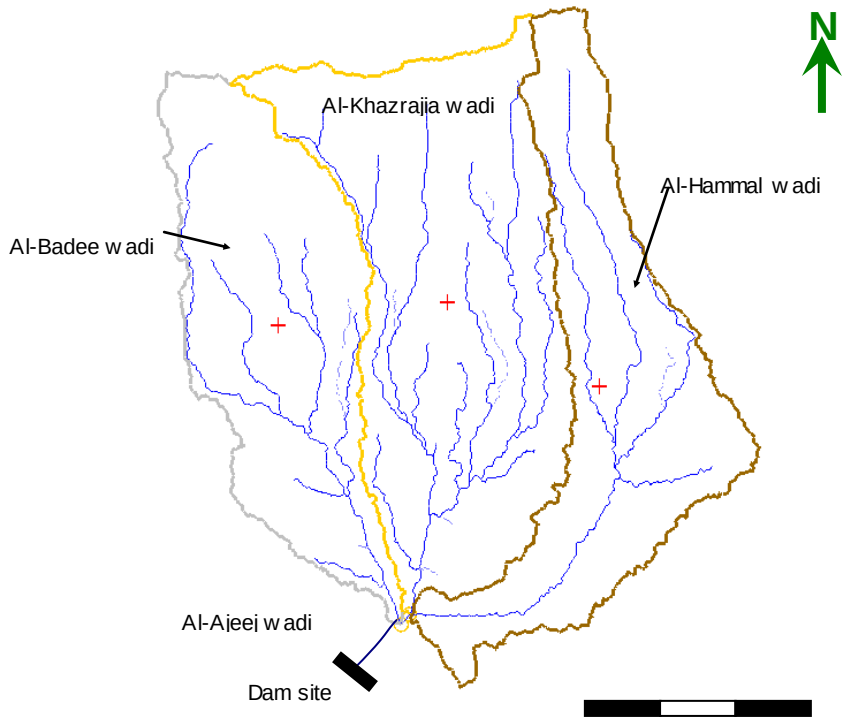

Fig.(2) Catchment area of the main branches of Al-ajeej wadi

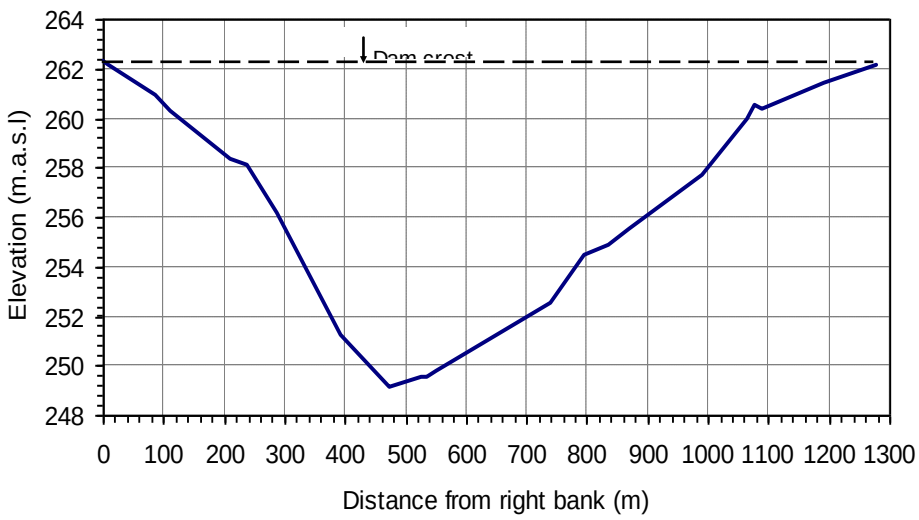

Fig.(3) Topographical cross-section of the proposed dam

Storage Volume of the Proposed Dam:

Depending on the allocated storage volume, surface area stage curve, the normal water level in the reservoir was proposed to be (261) m.a.s.l. taking into consideration the available calculated annual surface runoff of the basin and the demand for water from the residential population groups in the area to cover their domestic and agricultural purposes.

Probable Maximum Flood of Al-Ajeej Wadi:

The maximum water level in the dam was predicted depending on the maximum probable flood wave predicted for 100 year return period in the Al-Ajeej wadi using Synthetic unit hydrograph (Snyder method), used for un-gauged basins (Snyder,1938) with Gumble distribution for recurrence interval analysis.

Figure (4) shows the design synthetic flood hydrograph of Al-Ajeej basin in which the design peak discharge of Al-Ajeej basin is 1642 m^3/sec.

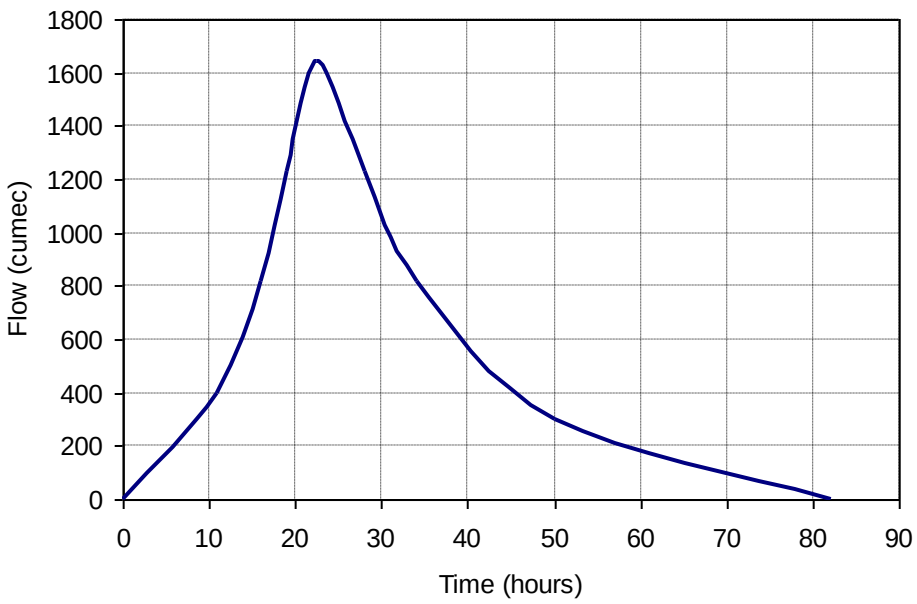

Fig.(4) Synthetic flood hydrograph of Al-Ajeej basin

Design of dam embankment:

1. The height of dam, the width at the crest and the base of the dam were selected depending on the calculated storage runoff volume. The embankment volume of the proposed earth dam was calculated depending on the Trapezoidal method assuming the upstream slope of 1:2.5 and downstream of 1:2 according to the proposed type of available material used in the embankment (Homogenous coarse silty clay) with dam height less than 15 m. Table 2 shows the proposed earth dam specification, while Table 3 shows the hydraulic characteristics of the reservoir behind the proposed dam at the normal water level in which its layout was shown in Figure 5.

Table 2

Bed Level (m.a.s.l.)	Dam length (m)	Dam height (m)	Dam width (m)	Dam base width (m)	Crest Dam level (m.a.s.l.)	Normal Water level (m.a.s.l.)	Normal Storage Volume (million m^3)	Volume of earth work (m^3)
250	1277	12.5	5	63.5	262.5	261	38.8	215217

Table 3

Normal water level (m.a.s.l.)	Reservoir length (km)	Average reservoir width (km)	Reservoir surface area (km)	Normal Reservoir storage volume (million m^3)
261	7.1	2.1	15.5	38.8

Proposed Design of Spillway Structure:

To release the probable maximum flood wave passing in Al-Ajeej wadi (1642 m^3/sec for 100 year return period) above the proposed normal water level in the reservoir, two options may be proposed: the first is constructing an ogee gated type spillway (6 gates with 10 meter length and 4.5 meter height) fixed on the crest of the spillway at elevation 256.5 m.a.s.l. The second option is to construct a rectangular weir across the whole cross-section of the proposed dam site (1277 m long) with a crest elevation 261 m.a.s.l. Figures 6 and 7 show a schematic diagram for the proposed options of the spillway structure.

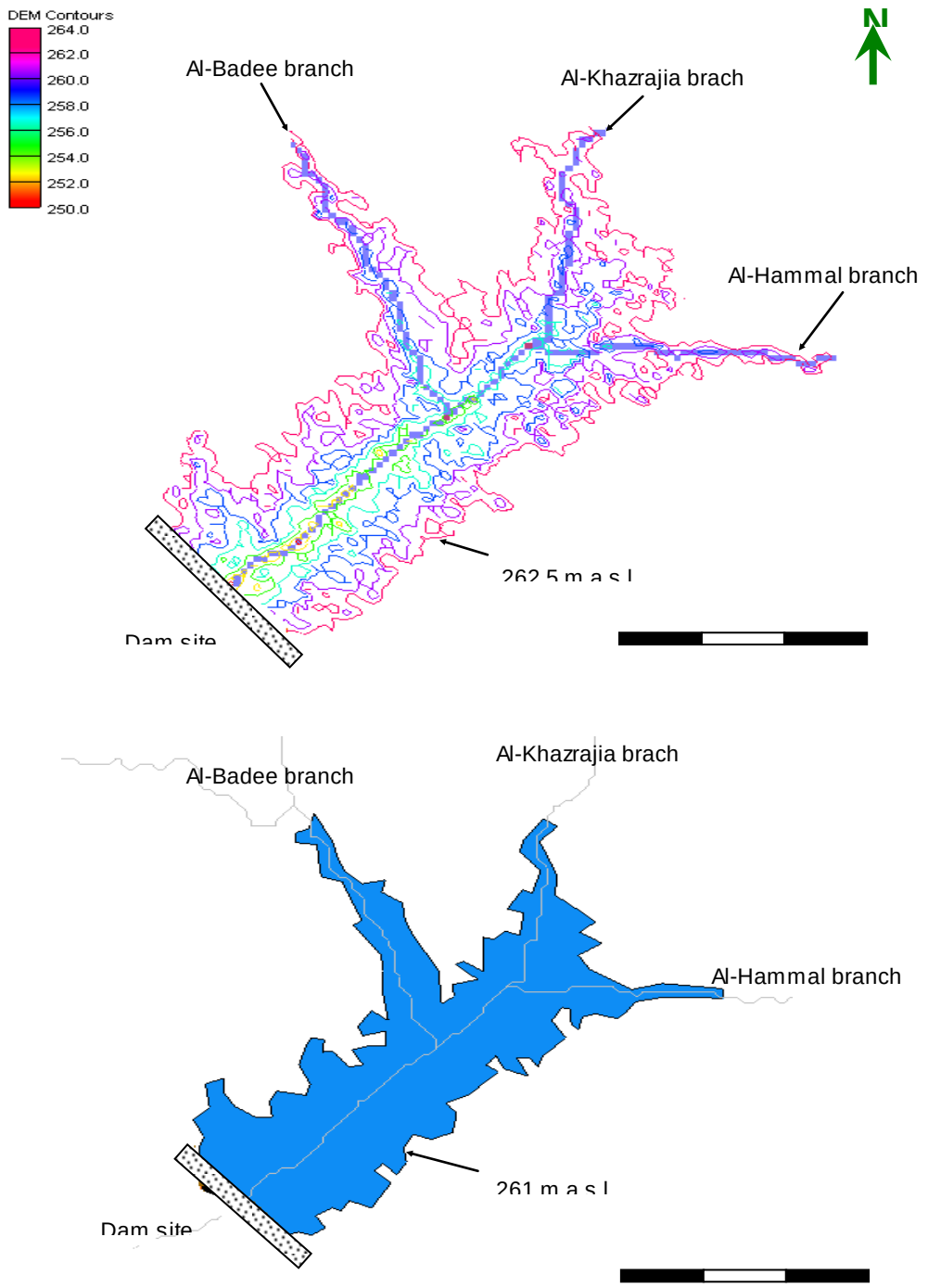

Fig.(5) Layout of Al-Ajeej reservoir.

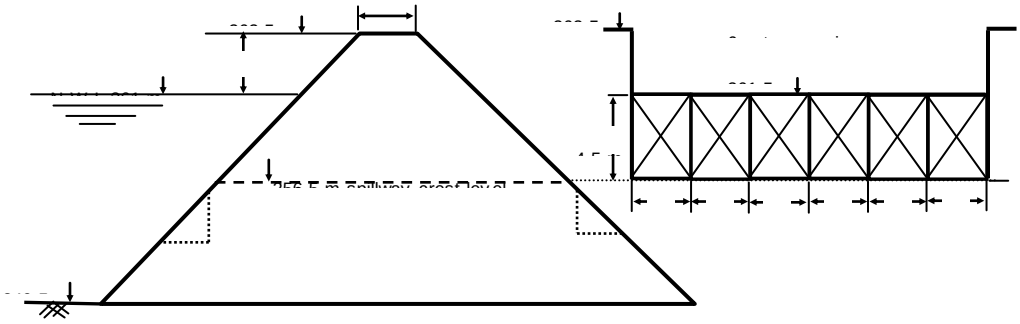

Fig.(6) Schematic cross-section of earth fill embankment dam.

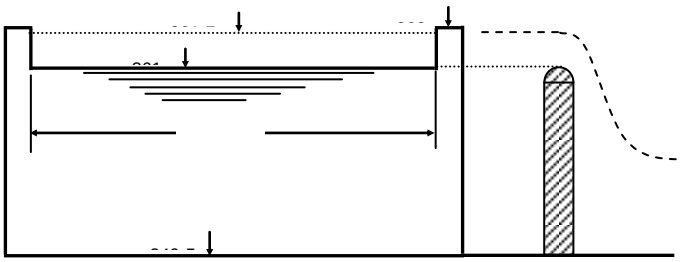

Fig.(7) Schematic cross-section of rectangular weir

Engineering Conclusions:

From the analysis of the hydrological and topographical data for the Al-Ajeej basin to test the feasibility of surface runoff water harvesting during the rainfall season in the Al-Ajeej wadi by proposing the construction of a small dam on this wadi, it was concluded that the average annual surface runoff volume of Al-Ajeej wadi is about 53.144 million m^3 at the proposed dam site which is located 3 km downstream the connection of Al-Badee branch with Al-Ajeej wadi. The dam length is 1277km while the dam height is 12.5 meter with the normal storage volume of 38.8 million m^3.

It is essential to construct a small dam at this best optimum site on Al-Ajeej wadi to verify the following:

Make use of surface storage volume in the proposed dam to cover the water demand from the population groups in the area and extend the cultivation lands and eliminate the probable desertification processes in the area.

Groundwater feeding which will in turn increase the water yield of the wells in the surrounding area which may be used as a supplemental water source in the drought periods.

Transfer large agricultural areas, depending on rainfall, to surface and supplemental irrigation.

Transfer many pasture areas to agricultural lands due to the availability of irrigation water.

The existence of the water surfaces behind the dam will lead to develop the tourist sector in the area and may in turn modify the income of the villagers and the people living their.

The author found that, hydrologically, it is feasible (strongly recommended) to construct a hydraulic structure such as small earth dam or weir in the selected site along the Al-Ajeej wadi.

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الضعف بتأثيرات الإستجابة اللا خطية للتغيرات بالأودية الموسمية

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الملخص

تعتبر أودية الجريان الموسمي، أحد المصادر المائية المتجددة بالمنطقة، وبالرغم من مساهمتها بنسب متفاوتة, إلا أنها دعّمت احتياجات المياه وسد جزء من العجز المتصاعد من المورد المائي بين دول الجزيرة العربية, حيث لعبت الأودية الموسمية دوراً أساسياً في دعم الإنتاج الغذائي بزيادة الرقعة الزراعية، ومصدر أساسي لتغذية الخزانات الجوفية. وفي ظل ممارسات بشرية بمجال الأودية ونطاقها الفيضي، وتغيرات مناخية أثرت بخصائص الأمطار المتساقطة وطبيعتها، ظهرت استجابة نظم الجريان السطحي لتلك التغيرات، ومنها التغيّر في درجات الحرارة وتأثيرها في الموازنة المائية للحوض، وموسمية ومعدل الجريان، ومورفولوجيه النظام، وتغيّر في أنماط وخصائص الغطاء النباتي. مجموعة تحولات ارتبطت بالتغيّر المناخي وأدت لحدوث عتبات (*Thresholds*) ظهرت نتائجها كإستجابة لا خطية (*Nonlinearity response*) بعمليات النظام الفيضي، يصعب التنبؤ بتوقيتها ونتائجها، وهو أمر انعكس بصورة مباشرة على المجتمعات المستفيدة من موارد الأودية، سواء في حجم ما هو متاح من المورد، أو ديمومته، وما يرافق ذلك من أخطار (*Hazards*) ناتجة عن التغير في طبيعة عمليات النظام الفيضي وما تسببه من مخاطر (*Risks*) بأصول (*Assets*) الإنتاج الزراعي وترسخ الضعف (*Vulnerability*) بالبنى الإنتاجية ومكوناتها. يهدف البحث إلى توضيح آلية عمل نظم الأودية الفيضية كنظم ديناميكية لا خطية، ويرصد طبيعة التحولات المؤثرة، وخصائص استجابة النظام الفيضي لها، من خلال نماذج من الأودية الموسمية، وصولا إلى ربط ضعف البنى الإنتاجية المعتمدة على مدخلات موارد الجريان المائي بردود النظام الفيضي للأودية الموسمية وتحديد تباينات المرونة (*Resilience*) والضعف لأصول النظام الاجتماعي – الاقتصادي اعتمادا على البيانات المكانية لأحواض الأودية الموسمية تجاه التعرض الطبيعي لديناميكية الجريان السطحي. إن النتائج المتوقعة للبحث ستبين العلاقة بين ديناميكية الأودية وخصائص إستجابتها للتحولات البشرية والطبيعية، ومنها التحولات المناخية، وصولا لملامح وإتجاهات تأثير تلك الإستجابة وتبايناتها بنطاقات الحوض، وأثرها في ترسيخ الضعف بأصول المجتمعات المحلية، ومدى إمكانية بناء قدراتها لزيادة مرونتها.

الكلمات المفتاحية: الأودية الموسمية، الإستجابة اللا خطية، الضعف، منظومة الإنتاج الريفي.

المقدمة

إلى منتصف القرن الماضي اعتبرت الأمطار الموسمية المصدر الأساسي للمياه في المناطق الجافة وشبه الجافة المدارية، ومنها إقليم شبه الجزيرة العربية. حيث اتسم الاحتياج المائي بتوازن بين مدخلات الأمطار الموسمية وإحتياجات المجتمعات المحلية, إلا إن التغيرات الاجتماعية ومنها الزيادة السكانية والتحولات الاقتصادية وإستحداث قطاعات جديدة مستهلكة للمياه والانتشار الواسع لاستخدام تقنيات الحفر والضخ من الأحواض الجوفية. وفي ظل تغيرات مناخية اتسمت بتذبذب معدلات الأمطار المتساقطة, وارتفاع درجات الحرارة التي أثرت بمعدلات التبخر – النتح, أصبح الجفاف أكثر ترسيخاً بالمنطقة وأدى الى ازدياد معدلات العجز بالإحتياج المائي، واتسمت الموازنة المائية باختلالات في ظل تصاعد لتلبية الطلب المتنامي من المورد المائي أمام عجز ما هو متاح فعلياً.

انعكست الاوضاع المائية على جميع مكونات النظام الاجتماعي – الاقتصادي، وبصورة خاصة تلك القطاعات الاجتماعية التي تعتمد على موارد أودية الجريان الموسمي كمدخلات إنتاج أساسية، وغالبيتها من المجتمعات الزراعية الريفية ذات النمط الانتاجي الاعاشي. ان المجتمعات الريفية الواقعة بالنطاق الهامشي الجاف وشبه الجاف هما الاكثر تأثراً بمعدلات الأمطار وكمية الجريان السطحي الموسمي. ونتيجة لما يتميز به اقليم شبه الجزيرة العربية من تذبذب وتباين بمعدلات الأمطار السنوية، أصبح المجتمع الريفي بالاقليم المداري الجاف وشبه الجاف وخاصة اقليم شبه الجزيرة العربية محكوماً بصورة دائمة في بناء قدراته الانتاجية واستقراره بأولويات مواجهة الضعف تجاه أمنه الغذائي وإستمرارية سبل الحياة لأفراده.

أغلب الدراسات الهيدرولوجية والجيومورفولوجية أكدت أن العلاقة بين مورفولوجية الأودية والعمليات الهيدرولوجية الناتجة عن الجريان تستند على الموازنة بين مكونات النظام لتؤدي الى حالات من تطور النظام والتوقع المسبق لما تؤول اليه مورفولوجية الوادي، وينعكس تأثير التغيرات المناخية والتعديلات البشرية بمجال نظم الأودية الموسمية على الدورة العامة لمراحل تطورها، سواء من خلال التوقف المرحلي لعمليات التطور، أو التعجيل بها، أو أبطاء حدوثها وهي أفكار ظلت مسيطرة لعقود بفكر المنشغلين بتطور مورفولوجية النظم السطحية ومن ضمنها الأودية المائية (Thornes. 1979)، الأفكار الأكثر سيطرة لتطور النظم السطحية المتأثرة بالتحولات الطبيعية والممارسات البشرية أُستنتجت من خلال الملاحظة لطبيعة النظام وردوده الديناميكية، لتبين أن التطور التاريخي للنظام البيئي في ظل التغيرات المتعاقبة وغير المتوقعة مرتبط بردود (إستجابة) لا خطية معقدة لتنتج تحولات لا يمكن التنبؤ بأبعادها (Phillips, 2006). ان الاستجابة اللا خطية للأودية تؤدي لتحولات مجالية بحدود النظام الفيضي أو أخطار طبيعية تؤدي في أبسط صورها الى ترسيخ الضعف أو كوارث فيضية. ومن خلال البحث يمكننا تتبع تأثيرات الضعف الناتج عن التحولات بنظم الأودية الفيضة وآثارها بأصول الانتاج الزراعي.

الأهمية الإستراتيجية لموارد نظم الجريان المائي بدول الخليج واليمن:

تعتبر المصادر المائية المتجددة، وبصورة خاصة نظم الجريان السطحي الموسمي (نظم الأودية الفيضية) ذات أهمية في الدعم المباشر للإحتياج المائي المتنامي، وهذا ناتج من مميزات ومنها سهولة استغلال المورد، وانخفاض تكاليفه الاقتصادية عند مقارنته بكل من المياه الجوفية ومياه التحلية البحرية والمياه

العادمة، وإمكانية الاستفادة منها على إمتداد مكاني واسع دون تكاليف نقل إضافية، حيث يستفيد من المورد كل المناطق التي يغطيها امتداده الجغرافي، وتساهم النظم الفيضية بمورد إرسابي داعم للنظم الزراعية، وتساهم نظم الجريان السطحي بالمحافظة على المكونات البيئية بنطاق الحوض وموئل لكثير من البيئات النباتية flora والحيوانية fauna، وتساهم النظم الفيضية بحماية فعّالة للتربة ومنعها من التدهور، وتمثل حاجز لمنع التصحر وزحف الكثبان الرملية. تعتبر الجمهورية اليمنية من أكثر دول المنطقة اعتماداً على موارد النظم المائية السطحية لسد جزء من احتياجاتها وتساهم نظم الجريان السطحي الموسمي بحوالي 4 مليار متر مكعب، تليها السعودية (2.2 مليار متر مكعب)، سلطنة عمان (0.9 مليار متر مكعب)، الإمارات (0.2 مليار متر مكعب)، وتبلغ مساهمة نظم الجريان السطحي حوالي 7.3 مليار متر مكعب سنوياً، وتمثل نسبة 60 % من مجمل الموارد المائية التقليدية (World Bank. 2007) (السطحية والجوفية) (جدول 1).

خصائص نظم الجريان السطحي:

تميزت الأودية الموسمية كغيرها من نظم الجريان السطحي بالأقاليم المدارية الجافة وشبه الجافة بمجموعة من الخصائص الطبيعية سواء من حيث مدخلاتها أو طبيعة إنسيابها أو مخرجاتها، وأثرت في طبيعة استغلال المورد المائي والتنبؤ بتحولاتها المكانية، مما أثر في وضع أسس للتخطيط المستقبلي تتضمن الإستفادة الكاملة من المورد, والعمل للحد من مخاطره المتوقعة.

تصنف الأودية المائية الموسمية بأقليم الجزيرة العربية ضمن نظم الجريان السطحي غير مكتملة التطور، سواء من حيث مورفولوجتها الشكلية أو عملياتها الهيدرولوجية، فأغلبها وجد أثناء سيادة العصور المطيرة في المنطقة، وخلال مراحل تطورها عمت المنطقة تحولات مناخية أكثر جفافا, مما أثر في أكتمال مراحلها التطورية والوصول الى مرحلة الانهار دائمة الجريان. لذا تميزت بصغر مساحة أحواضها، وموسمية جريانها، ومحلية منابعها مقارنة بأنهار كالنيل ودجلة والفرات.

جدول (1): المساهمة السنوية لنظم الجريان المائي السطحي بدول الخليج واليمن

الدولة	مساهمة نظم الجريان السطحي (مليار متر مكعب سنوياً)	مساهمة الموارد المائية التقليدية (السطحية والجوفية) (مليار متر مكعب سنوياً)	النسبة المئوية لمساهمة نظم الجريان السطحي إلى كامل مساهمة الموارد المائية التقليدية (السطحية والجوفية)
اليمن	4.0	5.5	% 73
السعودية	2.2	4.4	% 50
عمان	0.9	1.9	% 47
الإمارات	0.2	0.3	% 67
قطر	صفر	صفر	% 0
الكويت	صفر	صفر	% 0
البحرين	صفر	صفر	% 0
دول الخليج واليمن	7.3	12.1	% 60

World Bank: 2007. Making the Most of Scarcity: Accountability for Better Water Management Results in the Middle East and North Africa. Washington, D.C. 162-193.

أما من حيث مدخلاتها الهيدرولوجية, فتميزت الأودية الموسمية بالمنطقة على مدخلات الأمطار المتساقطة بنطاق حوض الوادي، أمطار تميزت بمعدلاتها المنخفضة ومن جهة اخرى بعدم موثوقيتها أو صعوبة التنبؤ بمعدلات وتوقيت هطولها. أغلب الأمطار التي تغذي الأودية تسقط خلال فترة زمنية محدودة خلال العام، ولذا إتسمت الأودية بموسمية جريانها السنوي، بل قد تتغير خلال توقيتها من عام لآخر متأثرة بعوامل طبيعية متعددة. أغلب الأمطار المتساقطة لا تغطي كامل الحوض بل تتركز بمناطق محددة من الحوض حيث بينت دراسة (Saudi Arabian Dames and Moore,1988) أن التباين المكاني للتساقط لخمسة من أحواض الأودية الموسمية بالمملكة العربية السعودية يمكن تحديده كل10 كيلومترات مربعة وتسقط الأمطار بصورة فجائية وبغزارة عالية حيث بينت القياسات حدوث عاصفة مطرية بلغ معدلها 144ملم بوادي رماح بغرب اليمن ومثلت 25 % من مجموع التساقط السنوي (اللهبي، 2001) مما يجعلها مصدر لأخطار متعددة وقوى فاعلة لاعادة تشكيل مورفولوجية النظام الفيضي.

تهيمن عمليات التدفق السطحي على الملمح الانسيابي للأودية الموسمية، حيث يبدأ جريانها بمجرد تساقط الأمطار، وفي الغالب يقل التصريف باتجاه اسفل الأودية نتيجة لارتفاع معدل فاقد الجريان السطحي وقلة الروافد الداعمة لجريان الوادي, لذا نجد مخرجات الأودية تميزت بالتطرف والفجائية وجريان غير منتظم ومتقطع في الغالب، مع تباين واضح في التدفق السنوي وتركز موسمي(Knighton. 1998) , لتظهر منحنيات التدفق السنوي حاد القمة.

نظم الجريان السطحي كنظم ديناميكية لا خطية:

بالرغم من الأهمية التاريخية للأودية المائية كمصادر متجددة، وتميزها عن غيرها من الموارد المائية بمجموعة من الخصائص الإيجابية، الا أنها وكغيرها من النظم البيئية السطحية نظم ديناميكية لا خطية (*Nonlinearity*) تميزت بسلوكها المعقد ومن ضمن ذلك عدم الاستقرار الديناميكي والفوضى الحتمية. ان التغيرات قصيرة الأجل والمحدودة بالنظام الفيضي قد تعطي نتائج طويلة الأمد وممتدة وغير متكافئة مع أسبابها. إن السبب الأساسي لحدوث عدم الإستقرار الديناميكي والفوضى بنظم الأودية الموسمية ناتج عن تغير بتوازن النظام (*Equilibrium*) وتحوّل في العلاقة بين مورفولوجية الوادي وعملياته الهيدرولوجية.

يفتقر النظام الفيضي الى التوازن بين مكوناته الأساسية، وتتخذ عملياته الديناميكية سلوك استجابة لا خطية بفعل حدوث عتبات (*Thresholds*) مؤثرة بطبيعة العلاقة بين مكوناته الشكلية (المورفولوجية) وحركة المادة (الجريان المائي) الطبيعية. يظل النظام الفيضي في حالة استقرار بتوازن بين مجموع عناصره المتعددة، وبتغير في عنصر محدد أو مجموعة عناصر بالنظام (تغير بمعدلات الجريان، تحولات مورفولوجية، تغيرات بمعدل الانحدار،0000) تبدأ أختلال العلاقة بين مكونات النظام وخلق عتبات (*Thresholds*) تتوافق أفقيا مع معدل التغيّر ورأسيا مع حجمه. إن الامتداد الزمني بين التوازن وحدوث عتبة بالنظام (أو بجزء منه) وعودة النظام إلى توازنه، يمثل أهمية في العلاقة بين الشكل

والعملية وتظهر تلك العلاقة من خلال استجابة الشكل لطبيعة التغير بالعملية أو العكس (Thornes. 1979. P.386).

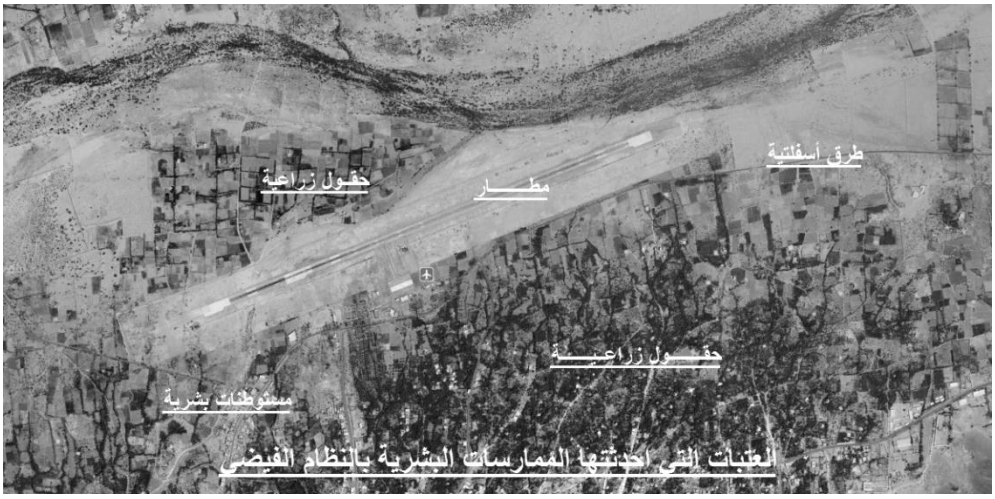
تؤدي التغيّرات المناخية والتعديلات البشرية الحادة بنظم أودية الجريان الموسمي وعموم النظم البيئية، إلى استجابة لا خطية (*Nonlinearity response*) (Phillips, 2006. P. 733)، لتؤشر في مجملها إلى تغيّرات حرجة بمكونات نظام الجريان الموسمي نتيجة لحدوث عتبات بنظام الجريان الموسمي. تظهر العتبات بنظم جريان الأودية الموسمية ضمن نمطين، فهي إما أن تكون جوهرية (*intrinsic*) ومتأصلة بديناميكية النظام الجيومورفولوجي (ويعزى تعرج المجاري المائية، ضمن أسباب أخرى، إلى تأثير العتبات الجوهرية)، أو عتبات عرضية (*extrinsic*) مرتبطة بعوامل خارجية، ومنها بفعل التحولات المناخية أو الحركات التكتونية أو الممارسات البشرية والتعديلات الهندسية بحوض الوادي.

نظراً الى محدودية العمليات التكتونية بأحواض الأودية الموسمية بإقليم الجزيرة العربية، فإن العتبات الناتجة عنها محدودة، الا أن تأثير التغيرات المناخية، وبصورة خاصة التغيّر بمعدلات الأمطار وموسميتها، والممارسات البشرية بمجال أحواض الأودية الموسمية ومنها الإنشاءات الهندسية، وتعديل مسارات روافد الأودية الموسمية، والتحولات الممارسة بمكونات النظم الفرعية بحوض الوادي (المياه الجوفية، الغطاء النباتي) تؤدي الى تحولات بتأثيرات الخزن (*storage effects*) كعلاقات النضوب والإشباع (*saturation and depletion relationships*)، أو العلاقات التنافسية (*competitive relationships*) ومنها على سبيل المثال العلاقة بين الغطاء النباتي وتعرية التربة (Inkpen, 2005). ان التغيرات الطبيعية، ومنها المناخية وتوسع مجال النظام الإجتماعي – الاقتصادي المعتمد في مدخلاته الانتاجية على موارد أودية الجريان الموسمي بالمجال الطبيعي للأحواض الفيضية يخلق مجموعة من العتبات المؤدية الى استجابة لا خطية بعمليات الأودية الموسمية، ويظهر تأثيراتها خلال موسم الجريان السطحي لتظهر كاستجابة غير متكافئة (*Disproportionately*) (مع حجم المدخلات الناتجة عن التعديل)، حيث إن التغيّرات المحدودة قد تنتج ردود غير متناسبة من حيث حجم النتائج الواسعة، وقد تؤدي الإضطرابات القصيرة إلى تأثيرات غير متناسبة ولإمتداد زمني غير محدد.

إرتبطت الإستجابة اللا خطية بعدم التوقعية لردود فعل سلوك الجريان السطحي، حيث تؤدي إلي تحوّل المسارات الفعلية للأودية وخلق مسارات غير متوقعة، وتغيّر بخصائص هيدرولوجية الأودية، سواء من حيث سرعة الجريان أو حجم الإرسابات المنقولة. وهي عوامل أدت الى ترسيخ عوامل الضعف (*Vulnerability*) بمنظومة الإنتاج الزراعي وأصوله (*Assets*)، وأصبح الضعف أكثر خطورة وتهديداً للمجتمعات المحلية بإنعدام مؤسسات فعّالة لإدارة أحواض الأودية الموسمية ومواردها المتاحة في ظل إنخفاض عام لمردود الإستثمار الزراعي. يؤدي التحول بخصائص جريان الوادي الى تعديل نطاق الغمر الموسمي وهو سبب كافي لجرف وتعرية التربة الزراعية وتدمير للبنى الإنتاجية الزراعية وإغراق لمستوطنات بشرية وبنى تحتية داعمة للإنتاج الريفي (جدول (2) صورة (1))، أو قد يؤدي التحول بنطاق الجريان الى طبع مساحات واسعة من الأراضي الزراعية الواقعة ضمن حدود حوض الوادي بسمات الجفاف، وفي أحسن الأحوال إلى زيادة تكاليف المياه من خلال زيادة مخصصات النقل والري للمزروعات بالمناطق المتأثرة بإنحسار الفيضان الموسمي.

جدول (2): العتبات المؤثرة في حدوث استجابات لا خطية بعمليات النظام الفيضي بأودية الجريان الموسمي في الجمهورية اليمنية

مصدر عتبات النظام الفيضي	أنواعها	تأثيرها على عمليات النظام الفيضي	إمكانية المعالجة
عتبات طبيعية مورفولوجية	العمليات التكتونية التساقط الصخري	حادة متوسطة إلى ضعيفة	غير متوفرة متوفرة
عتبات هيدرولوجية	تغير تردد وكثافة الأمطار موسمية الأمطار	حادة حادة إلى متوسطة	غير متوفرة غير متوفرة
تغيرات مناخية	التحولات الحرارية	حادة إلى متوسطة	جزئياً
عتبات هندسية	منشئات البنى التحتية الطرق والجسور المطارات	حادة إلى متوسطة حادة إلى متوسطة حادة إلى متوسطة	جزئياً جزئياً جزئياً
عتبات منظومة الاقتصاد الريفي	الحقول الزراعية الطرق الريفية تغير الغطاء النباتي التحول في رطوبة التربة	حادة إلى متوسطة متوسطة حادة إلى متوسطة متوسطة	جزئياً متوفرة جزئياً جزئياً



صورة (1): العتبات التي أحدثتها الممارسات البشرية بالنظام الفيضي لوادي حضرموت

يؤشر الضعف (*Vulnerability*) في معناه العام إلى مجموعة الخصائص المتاحة للفرد أو المجتمع والمرتبطة بقدرتهم على التوقّع، التحمّل، المقاومة والتعافي (Blaikie et al, 1994) من تأثير الأخطار الطبيعية ومن ضمنها التغيرات المناخية. يحدث الضعف نتيجة لعدم مقدرة النظام الاجتماعي – الاقتصادي عملياً على الإجهاد الناتج من صعوبة تأقلمه مع الشروط المستحدثة ومنها الشروط الطبيعية. ان الضعف ليس مرتبط فقط بقلة مصادر الدخل، بل أيضا نتاج لعوامل طبيعية، وسياسات حكومية، وتقاليد اجتماعية (Adger et al, 2005) ليؤثر بصورة مباشرة أو غير مباشرة على مكونات البنى الإنتاجية الريفية، لتظهر كمؤشرات متباينة بين مكونات الإنتاج الاجتماعي، وبالمقابل يستخدم مفهوم المرونة (*Resilience*) أو القدرة (*Capacity*) كنقيض للضعف، ويدلل كلاهما على الإمكانية أو المقدرة لمجموعة ما من مقاومة تأثير الخطر، وسهولة التعافي من آثاره. إن للضعف إمتداد في المقياس الزمني، حيث يقاس بتأثيره السلبي على مصادر الإعاشة المستقبلية، وليس فقط بتأثيره وقت حدوث الخطر، مفهوم الإعاشة مرتبط بالإمكانيات والمصادر المتاحة للفرد أو الجماعة التي يمكن استغلالها لإشباع إحتياجاتهم، وتتضمن تلك الامكانيات المعلومات والمعارف وشبكات التواصل الإجتماعي والحقوق القانونية، بالاضافة إلى الأصول (Wisner et al, 2004)، ويمكن من خلال بناء قدراتهم، الوصول اليها والإستعانة بها في الحد أو التخفيف من مستوى الضعف قبل وبعد تأثير الخطر. ومن خلال إستعراض أهم مكونات منظومة الأنتاج الريفي، يمكننا تحديد اتجاهات ضعفها المرتبطة بإستجابة الأودية الموسمية للتغيرات الطبيعية والتعديلات البشرية، وسبل زيادة مرونتها.

تعتبر الأودية الفيضية من نظم المخاطر الطبيعية المتعددة، لأسباب سبق ذكرها. لحدوث المخاطر الفيضية شروط محددة تتمثل في:

1. أخطار طبيعية (*Natural hazards*) ناتجة عن تردد وكثافة العمليات الطبيعية غير المتزنة (*Metastable equilibrium*) نتيجة تعدد العتبات (*Thresholds*) بالنظام الفيضي، ويمكنها أن تحدث أضراراً بمكونات النظام الاجتماعي – الاقتصادي ومن ضمنها البنى الاجتماعية والهيكلية. وقد تتحول الى كوارث عند:
2. وقوع كل من مكونات النظام الاجتماعي - الاقتصادي ومن ضمنها البنى الاجتماعية والهيكلية بمجال التعرض الطبيعي (*Physical Exposure*) لأخطار عمليات النظام الفيضي.
3. وإرتباط النظام الاجتماعي – الاقتصادي ومكوناته الاجتماعية والهيكلية بمقومات الضعف وعدم المرونة.

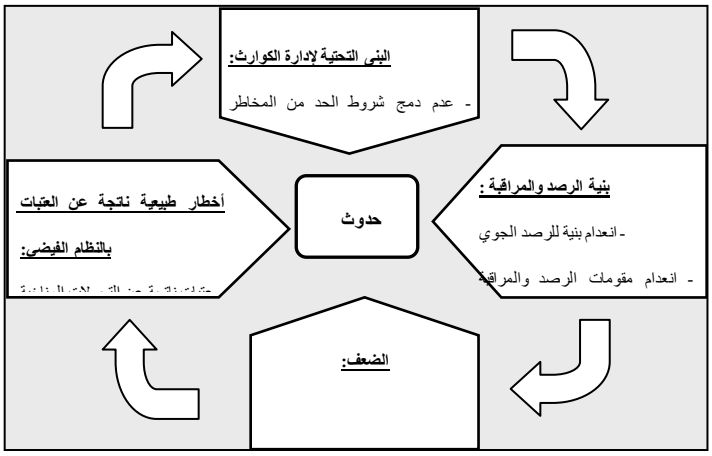
بتوفر تلك الشروط، تزداد إحتمالية حدوث المخاطر الطبيعية والكوارث الفيضية الناتجة عن النظام الفيضي، وتزداد تأثير خسائرها بأصول الأنتاج الزراعي، حيث:

المخاطر والكوارث = أخطار x التعرض الطبيعي

تأثرت النظم الفيضية الموسمية بالممارسات البشرية، وهو إنعكاس للنمو الإقتصادي والتحولات الحضرية والتغير في إستخدامات الأرض والبنية التحتية (Pizarro and Lall, 2005) بمجال عمليات النظام الفيضي، إضافة إلى تعديل المجاري الفيضية. إن مجاورة النظام الاجتماعي – الاقتصادي ومنظومته الإنتاجية جعلها تحت تأثير التعرض الطبيعي (*Physical Exposure*) لأخطار العمليات الطبيعية للنظام الفيضي (صورة (2))، وفي ظل تردي اقتصادي للمجتمع وبنيته الاقتصادية الهيكلية نتيجة لتردي القيمة الإقتصادية لمخرجات الإنتاج الريفي، ارتبطت منظومة الإنتاج الريفي بالضعف

وعدم مرونة كامل مكوناته. إن سيادة الأوضاع السابقة جعل النظام الإجتماعي – الإقتصادي لديه القابلية لتردد المخاطر، وحدوث الكوارث (*Disasters*) شكل (1).

صورة (2): أعجاز نخل خاوية بفعل فيضان وادي حضرموت عام 2008م



شكل (1): المقومات المتاحة لتردد الكوارث بالأودية الموسمية

يتوقع للجمهورية اليمنية سيناريوهات ثلاث للتغيرات المناخية وتأثيرها على الأمطار ودرجات الحرارة وما يرتبط بها من أثر على الجريان السطحي الموسمي بالأودية ومعدلات التبخر – النتح وانعكاس ذلك على الأنتاج الريفي والمخاطر الهيدرولوجية المتوقعة إستناداً الى بيانات 1990م كسنة أساس والتحولات خلال الفترات 2030م 2050م, والعام 2080مكما يوضحها الجدول رقم (3). ان التوقعات المطروحة لتردد الفيضانات بالأودية الموسمية باليمن، تتوقع لوادي حضرموت وهو أكبر أحواض الأودية اليمنية الموسمية أن يتأثر بتدفق موسمي يزيد عن سنة الأساس بمعدل 40% في العام 2030م وبتردد فيضاني

حاد كل 50 عام إذا ما إتجهت التحولات المناخية نحو مناخ دافئ ورطب، بينماإذا إتجهت التحولات نحو مناخ حار وجاف فإن ذلك يؤدي الى إنخفاض معدل الجريان بالوادي نحو 55 % عن سنة الأساس، وهي أوضاع مهما كان إتجاهها سوف تهدد حوالى مليون نسمة يقطنون ضمن مسار المجرى الرئيسي للوادي بالنزوح.

جدول رقم (3): التحولات المناخية والسيناريوهات المتوقعة بالجمهورية اليمنية

السيناريو	العام	الجريان السطحي	التغذية الجوفية	التبخر – النتح	التوقعات المحتمله
سنة الأساس	1990	% 0	% 0	% 0	
وسط	2030	% 4	%4	%2	زيادة بمعدل الجريان السطحي مع زيادة بسيطة بمعدل التغذية الجوفية الى العام 2050م، يلي ذلك هبوط بمعدل الجريان السطحي والتغذية الجوفية بحلول عام 2080م مع تغيرات محدودة بمعدلات التبخر النتح.
	2050	% 30	%2	%2	
	2080	%22-	%12-	% 0	
حار وجاف	2030	%55-	%31-	%6-	إنخفاض كبير بالجريان السطحي ليصل إلى مراحل حرجة في العام 2080م يرافقه إنخفاض حاد بمعدل التغذية الجوفية، مع إنخفاض بمعدل ثابت للتبخر النتح نتيجة للجفاف.
	2050	%32-	%32-	%6-	
	2080	%78-	%55-	%11-	
دافي ورطب	2030	%147	%54	%13	مضاعفة معدل الجريان خلال النصف الأول من القرن لينخفض قليلا في النصف الثاني من القرن وبنفس الوتيرة وإن كان بمعدلات أقل من الجريان السطحي. يزداد معدل التغذية الجوفية إرتفاع معتدل بمعدلات التبخر – النتح.
	2050	%137	%41	%10	
	2080	%66	%27	%9	

World Bank: 2010. Yemen Assessing the Impacts of Climate Change and Variability on the Water and Agricultural Sectors and the Policy Implications. p 30-31.

مؤشرات الضعف بمنظومة الإنتاج الريفي

لطبيعتها الطبوغرافية، نجد أن معظم الأراضي الزراعية في الجمهورية اليمنية تتوزع ضمن حدود أحواض الأودية الموسمية، لتستفيد من مواردها المائية السطحية خلال موسم الفيضانات، ولذا ارتبطت شروط مرونة وضعف منظومة الإنتاج الريفي الزراعي بهيدرولوجية الأودية ومواردها. وبإعتبار أن الموارد المائية مدخلات أساسية للإنتاج الريفي فإن مؤشرات الضعف البيئي هي إنعكاس للتحولات المناخية، والتأثيرات البشرية الممارسة على النظم السطحية وإستجابة النظم البيئية ومن ضمنها الأودية الموسمية للتغيرات. ولصعوبة قياس العلاقة المباشرة بين تأثير إستجابة الأودية الموسمية للتغيرات بضعف أصول الأنتاج الريفي، أستخدم الباحث حساب مؤشرات الضعف البيئي *(The Environmental Vulnerability Index) (EVl)*.

تهدف نتائج حساب مؤشرات الضعف البيئي إلى إيضاح ثنائية العلاقة بين الإنسان والبيئة من خلال تحديد مستويات المخاطر الآنية وسبل التكيف ومقدار تحمل الحوادث المستقبلية، ويؤسس لبناء إجرائي أكثر تأقلماً لإدارة مناطق الضعف البيئي.

يستند تقييم الضعف البيئي إلى 50 مؤشر، منها 6 مؤشرات طقس ومناخ، 4 مؤشرات جيولوجية و 6 مؤشرات جغرافية و 28 مؤشر للموارد والخدمات و 6 مؤشرات تتناول الجانب البشري والسكاني، ومن خلال حساب مدخلات بيانات المؤشرات المتوفرة بقواعد البيانات الدولية أو البيانات الإحصائية القطرية، يمكننا حساب مؤشرات الضعف البيئي* لدولة ما أو إقليم أو منطقة جغرافية محددة، ومن المدخلات يتم الحصول على مؤشرات رئيسية سبع هي الضعف تجاه التغيرات المناخية، الضعف تجاه التعرض للكوارث الطبيعية، الضعف تجاه تهديدات التنوع الحيوي، الضعف تجاه التصحر، الضعف تجاه الموارد المائية، الضعف تجاه الزراعة والصيد السمكي والضعف تجاه الصحة العامة. (Kaly, et al, 2004).

اتجاهات الضعف البيئي

بينت مؤشرات الضعف تجاه التحولات المناخية للجمهورية اليمنية ومنطقة السهل الترسيبي لوادي زبيد، من خلال بيانات عام 2004م وبيانات العام 2009م كما مبين بالجدول (4)، أن الاتجاه العام لمؤشرات الضعف تجاه التحولات المناخية تتجه نحو الضعف عموماً (يتضمن المقياس 7 درجات، حيث تتجه المؤشرات نحو الضعف كلما ارتفع المعدل والعكس نحو المرونة), سواء على مستوى الجمهورية اليمنية, أو منطقة الدراسة, مع بعض الاختلافات في المؤشرات، حيث سجلت انحداراً سلبياً نحو الضعف تجاه التغيرات المناخية.

سجلت معدلات الضعف البيئي تراجعاً باتجاه ترسيخ الضعف، وأُعتبر أن الضعف تجاه الموارد المائية هو الأكثر حدة وإن كانت منطقة السهل الترسيبي لوادي زبيد هي أفضل حالاً عن الوضع العام لليمن، يعتبر صعوبة الوصول للموارد المائية سبب أساسي في ضعف المؤشرات الأخرى المرتبطة بمنظومة الإنتاج الريفي وعامل أساسي لترسيخ الضعف تجاه الصحة العامة والتصحر وتهديدات التنوع الحيوي, إن اليمن ومنطقة الدراسة التي تتأثر بالتحولات المناخية في الوقت الراهن، تتطلب معالجات حادة وأكثر تكلفة للمحافظة على مصادر الموارد المائية المتجددة، والبحث عن بدائل تتوافق وإمكانيات الاقتصاد الريفي.

* يتم حساب المؤشرات من خلال برنامج Microsoft Excel (Beta) 5-1 -05 مسبق التصميم

جدول رقم (4): مؤشرات الضعف البيئي المؤثرة بمنظومة الإنتاج الريفي

المؤشر	السهل الترسيبي لوادي زبيد		الجمهورية اليمنية	
تاريخ بيانات المؤشر	2009م	2004م	2009م	2004م
الضعف تجاه التحولات المناخية	3.82	3.64	3.77	3.23
الضعف تجاه الكوارث الطبيعية	2.88	2.8	3	2.18
الضعف تجاه تهديدات التنوع الحيوي	3.65	3.3	3.66	3.42
الضعف تجاه التصحر	4.25	3.85	4	3.82
الضعف تجاه الموارد المائية	4.35	4	5	4.82
الضعف تجاه الزراعة والصيد السمكي	3.66	3.20	4.15	3.39
الضعف تجاه الصحة العامة	3.72	3.4	3.65	3

الخاتمة

بإعتبار أن الأودية الموسمية رافد أساسي لتبية إحتياجات المجتمعات المحلية من المياه، ومدخل إنتاجي لمنظومة الإنتاج الزراعي للمجتمعات الريفية، الا أن التغيرات المناخية والممارسات البشرية والتعديلات الهندسية أدت الى حدوث عتبات بالنظام الفيضي لتظهر ردود إستجابة النظام بصور متعددة وغير متوقعة ولتنعكس بصورة مباشرة على منظومة الانتاج الزراعي وتعمل على تكريس الضعف بالأصول الإنتاجية، بينما يؤدي الضعف المترسخ مسبقا بالأصول الإنتاجية إلى تحول الأخطار الفيضية الى مخاطر وكوارث. إن التوجه نحو تنمية القطاعات الريفية غير الزراعية ومنها قطاع الصيد السمكي قد يقلل من وقوع كامل الأصول الريفية بمجال المخاطر ويقلل من الخسائر بأصول الإنتاج الزراعي ويحد من تكاليف الدعم الموجه الى القطاع الزراعي. التوجه نحو نشر التعليم وبناء مهارات غير تقليدية للشباب في ظل نمو سكاني مرتفع للمجتمع اليمني سوف يزيد من مرونة الأسرة الريفية.

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Rainfall Variability & its Impact on Water Resources in Oman

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Abstract

The mechanism of rainfall variability in Oman was investigated using time series of monthly precipitation as measured by a dense observational network. The nationwide network of meteorological stations active during the last four decades of the 20th century in Oman is characterized by different periods of function. In this work we consider only data from common windows, focusing on the period 1984–2007, during which a large number of measuring stations are available. Mean characteristics of the rainfall data were investigated for 20 stations, and then variations of Oman's station normalized rainfall series and spatial distribution of the normalized rainfall index were analyzed. Reanalysis data was used to investigate large-scale atmospheric properties during the winter rainfall in the northern of Oman and during the summer monsoon in the southern part. The data used in the analysis were derived mainly from the National Center for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) reanalysis project, which is currently the most extensive data record available. For the purpose of this study, five different analyses were carried out (NCEP/NCAR analysis): sea level pressure (SLP), geopotential height (GPH), wind vectors, outgoing long wave radiation (OLR) and specific humidity. These investigations have permitted to diagnose the main atmospheric processes that govern the rainfall variability in Oman.

Keywords : Rainfall variability, Oman, water resources

Introduction

By virtue of its position astride the Tropic of Cancer (Figure 1), the Sultanate of Oman belongs to the arid region of the world, according to the Koppen and Geiger classification (1928). However, it is a land of climate diversity, from the intense summer heat of ArRub al Khali to the moderate climate on the Hajar mountains. In between, one passes from the hyper-arid (<100mm rainfall) coastal plains, through the arid (100-250 mm rainfall) higher plains and foothills to the semi-arid (250-300mm rainfall) mountain slopes and summits of the northern of Oman (Ghaznafar and Fisher, 1998). The southern part of the country is influenced by the summer monsoon from June to September. The Sultanate of Oman is influenced by air masses from four different directions, the Mediterranean, central Asia, the tropical maritime regime of the Indian Ocean and tropical Africa (Figure 2).

The polar Continental air-mass affects Oman during winter. This air mass originates over Central Asia. It is characterized by very low temperatures at the surface. Occasionally the region is also affected, during winter, by the Polar Maritime air that has the north Atlantic as its source region. This air-mass makes brief incursions during the winter months in connection with mobile "weather systems" moving from west to east. During summer, the Tropical Continental air-masses are formed over the hot and dry land surfaces of North Africa in late spring and early summer when surface heating is extreme. With the beginning of the summer months, the thermal equator marches north with the northward progress of the sun, allowing the Tropical Maritime air mass to form, and during this time, the Indian Monsoon circulation affect southern coast of Oman. These four atmospheric influences largely operate at different times of the year, bringing a variable degree of seasonal "weather", and hence rainfall, to the Sultanate of Oman (Charabi and Al-Hatrushi, 2009).

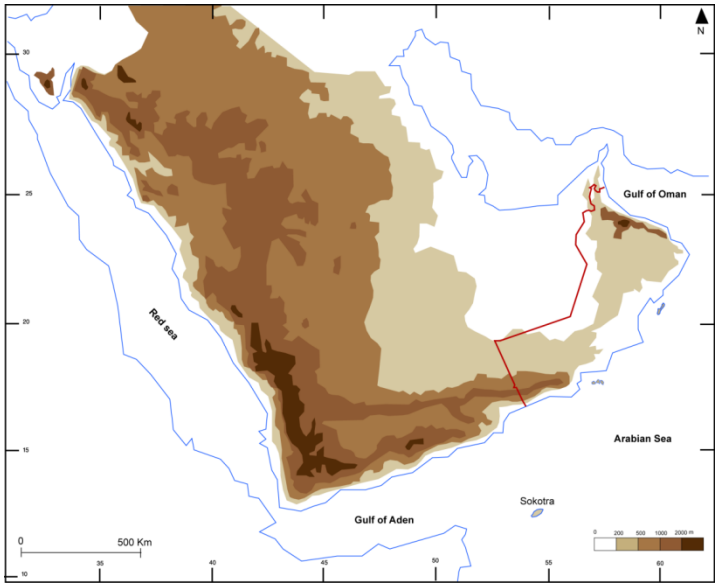

Figure 1. Location of the Sultanate of Oman

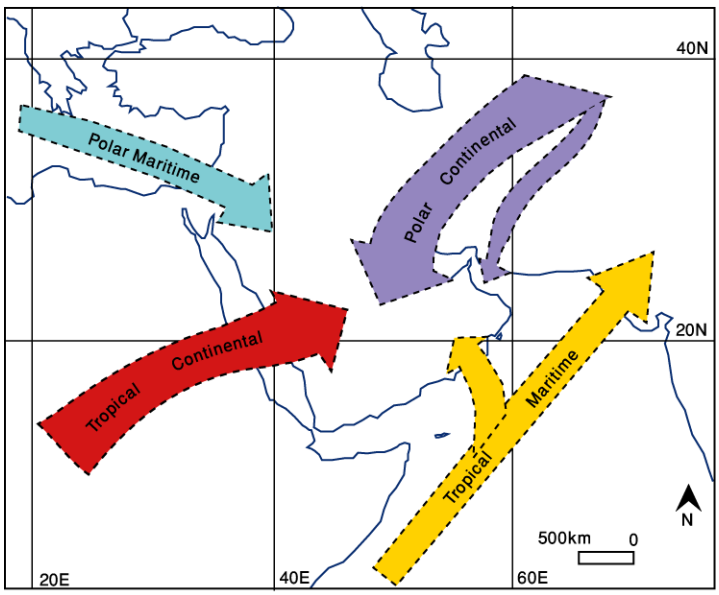

Figure 2. Air masses that have influence on the climate of Oman

The Sultanate of Oman is, also, characterized by restricted resources of freshwater, in combination with extremely high summer temperatures and high evaporation rates. Furthermore, during the last four decades the country witnessed spectacular socio-economic developments which intensify the anthrophic pressure on the limited water resources that call for a quantitative assessment of the possible impact of climate change. As a first step in estimating possible future changes and their impacts, it is necessary to carefully determine the current and past climatic variability and scrutinize the atmospheric circulations which are the main forcing factors for controlling variability of climate variable. In the face of ever-increasing uncertainty and fluctuations in the global water cycle, investigation of precipitation variability is considered to be an effective means for enhancing water management capabilities.

Data & methodology

In this study, a normalized rainfall index was used. The normalized rainfall anomaly (Asy) for a given station is computed with

$$Asy = (Rsy - Rs) / \sigma s$$

where Rsy is the rainfall total for the station s during a year (or a season), and Rs and σs are the long-term mean and standard deviation of the annual (or seasonal) rainfall total for that station, respectively. The area-averaged normalized rainfall anomaly (Ary) is defined as

$$Ary = (1 / Ns) \sum Asy$$

Where Ns is the number of country-wide (or regional) stations operating in a year y.
Data sets related to rainfall variability in Oman is obtained from the Directorate General of Meteorology and Air navigation. For the large-scale atmospheric properties of rainfall, the data used in the analysis were related mainly to the National Center for Environmental Prediction (NCEP) and the National Center for summer Atmospheric Research (NCAR) reanalysis project (Kalnay et al., 1996).

Mechanism producing main rainfall in Oman

The variety of the topography and the large latitudinal extent provide different types of precipitation and make it vary both spatially and temporally. There are four synoptic atmospheric mechanism causing rainfall over Oman:
During winter, the northern of Oman is exposed to the inflow of moisture flows from the North Atlantic and the Mediterranean Sea. This atmospheric moisture is advected by the mobile upper troughs and low pressure systems. This atmospheric mechanism is very active during December, January and February (Figure 3).

During summer, the Indian Monsoon circulation affect southern coast of Oman, bringing rainfall to the Mountains of Dhofar from June to September.

During summer, also, the Hajar Mountain range becomes a key factor in inducing a significant amount of rainfall during summer months. Sea breeze circulations are primarily responsible for the formation of this local orographic convection

During spring, Oman Convergence Zone across the interior regions with the axis of activity around 20°N. A northwesterly low-level flow from the Arabian Gulf meets a marine southeasterly flow from the Arabian Sea. At Fahud 60% of the annual total of c. About 30 mm falls during March-May, whilst on Masirah Island more than 50% of the annual total falls during this period

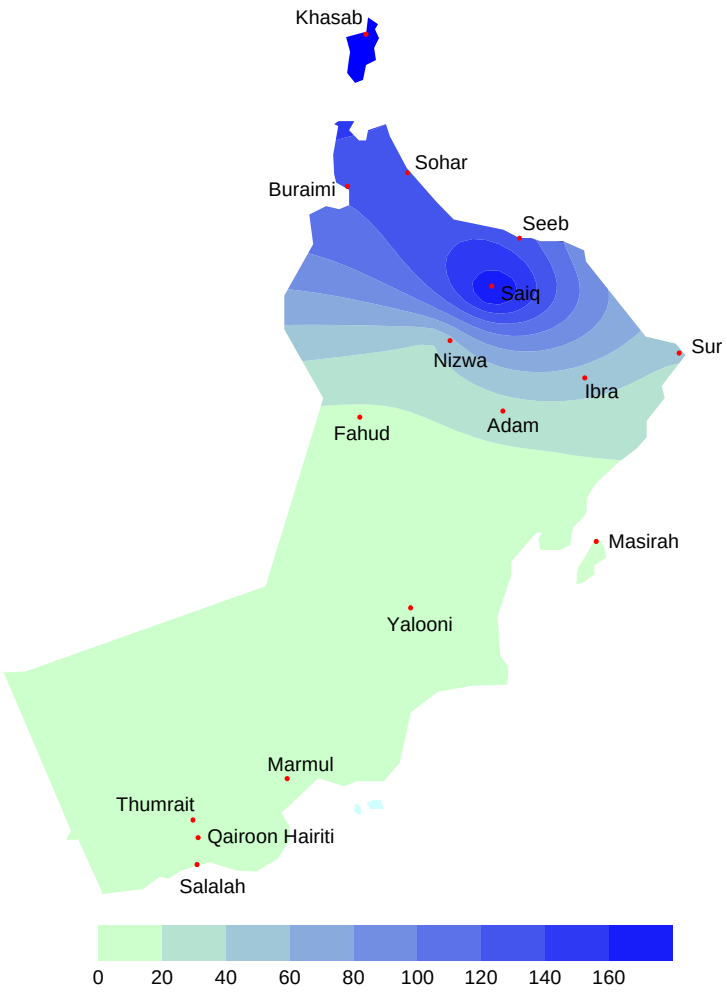

Figure 3. Spatial variability of winter rainfall in Oman

Rainfall variability and water resources

Oman is characterized by an arid desert climate with an average annual precipitation of about 150 mm or less. 46.3% of the countrywide annual rainfall occurs during the winter season. Contributions of spring and summer rainfall are about 13.6% and 34,4%, respectively, of the annual total. Autumn Rainfall declines to about 5% of the annual total. Figure 4 shows the spatio-temporal variability of rainfall along the year.

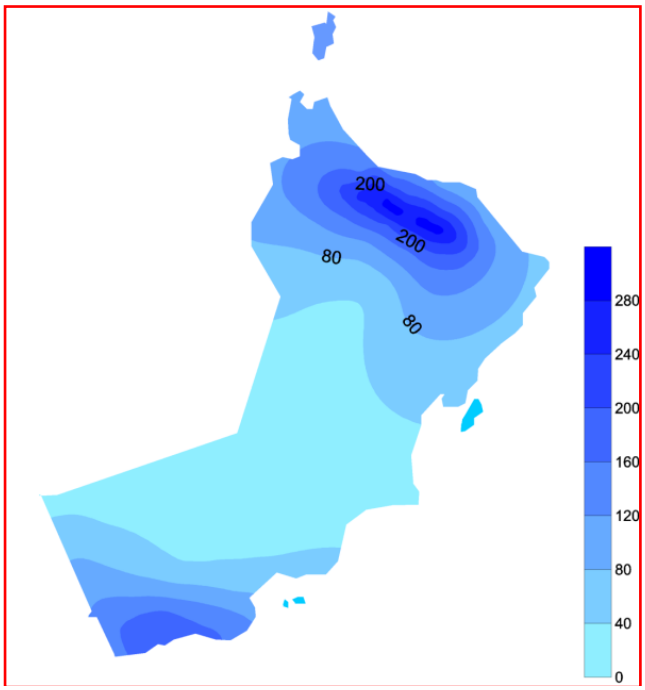

Figure 4. Spatio-temporal variability of rainfall along the year

The quantity of rainfall in Oman is strongly variable from year to year. Figure 5 clearly shows a succession of relatively dry years in the southern part of Oman. A severe prolonged drought is also observed in the north of Oman. This prolonged drought, ultimately affects the water sector in Oman because the rainfall is used to recharge aquifers. To enhance the aquifers recharge in Oman, several dams was constructed during the last decade. The objectives of the government are to reduce marine intrusion and maintain a strategic reserve of fresh water resources, which can be used in emergency cases. For instance, the available fresh water from rainfall is not enough to reach these ultimate objectives due to the continuous process of maritime intrusion. According to the climate projection of the Intergovernmental Panel on Climate change (IPCC, 2007), the droughts period in this part of the world will increase. Based on that, deep studies are required to quantify the relationship between rainfall and runoff and to build hydrological scenarios to better face the water stress in Oman.

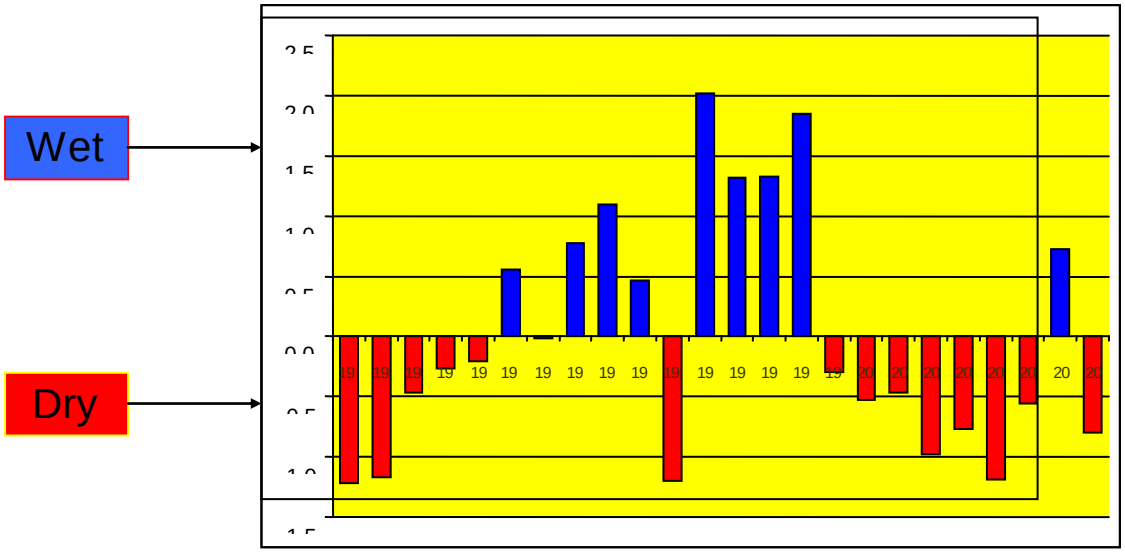

Figure 5. Frequency of dry and wet period, in the southern part of Oman between 1984 and 2007.

Conclusion

The results obtained in this study may help in investigating the future scenario of rainfall in the region but more detailed and area specific study is still required. It is foreseen from the increasing trend of precipitation variability over temporal and spatial scales that climate variability will be more serious challenge then climate change. It will be easier to adopt climate changes in terms of changing precipitation regime but climate variability embedded with extreme (wet/dry) precipitation episodes will be hard to manage by practitioners (Naheed and Rasul, 2010).

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Variation of Soil Moisture Contents at Selected Sand Dunes in Saudi Arabia

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Abstract

Water movement in the unsaturated zones, together with the holding capacity of these zones, have greater impact on the growth of vegetation and groundwater storage. Surface soil moisture content exhibits a high degree of spatial and temporal variability. In the present study, soil samples were collected from four locations in a sand dune area. The temporal moisture contents at these locations were also measured at variable depths down to 3.5 m from the surface. The occurrence of rainfall was also recorded near to the sampling sites. Spatial variability of moisture contents within the top few meters reaching the bottom of the dunes were also analyzed. The distribution of the moisture contents within the sand dune and its implication on groundwater recharge has been discussed.

Keywords: Soil moisture, Sand dunes, groundwater recharge, Al-Qassim, Saudi Arabia

Introduction

Soil moisture is the key defining variable that integrates all components of the surface energy balance and as such is of major importance to climate models and their surface schemes (Rodriguez-Iturbe 2000). The runoff, which percolates from the surface, has a degree of variability in both space and time which are controlled by many factors such as weather, soil texture, vegetation and topography (Richard et al 2004). Under extreme dry conditions, water is the prime factor influencing environmental change, and affecting the availability of soil-water limits, the number, and size of plant species in arid areas (Nash et al 1991). The soil-water dynamics is therefore of great importance for the vegetation system (Pan et al 2008) and aquifer recharges (Kumar 1998).

Various studies show that a significant portion of the annual rainfall infiltrates through the dunes which can be a source of major recharge to the aquifer formation outcrops covered by the dunes (Prill 1968; Dincer et al 1974; Al-Turbak and Al-Hassoun 1992; Al-Hassoun and Al-Turbak 1993). Allison et al. (1985) investigated the rates and mechanisms of local recharge in a semi-arid environment beneath two major landscape settings overlain by dunes in South Australia. Winter (1986) studied the effect of groundwater recharge on the configuration of the water table beneath dunes. The study included the analysis of water-level fluctuations in about 30 observation wells and within 5 lakes in the sand hills of Nebraska. It indicated that water table configuration beneath dunes in that area varied considerably, depending on the configuration of the topography of the dunes. The recharge beneath dunes was also affected by the dune configuration.

The main objective of the present study is to estimate the amount distribution of soil-moisture contents due to a series of rainfall events. The study also analyzes physical soil characteristics of the sand dune.

Physical properties of Soil

The study was conducted in sand dune areas located within Al-Qassim region. Soil samples were collected from the surface and from different depths within the sand dune to determine the soil physical properties. Soil samples were analyzed to determine grain size distribution, hydraulic conductivity, porosity, specific gravity, unit weight and moisture content (by weight). Depth to sampling ranges from zero to 5 cm from the surface to 70 - 75 cm (sites 1 and 2) and from zero to 5 cm at the surface to 100 cm (sites 3 and 4). Percentage of sand was concluded after carrying out sieve analysis on each sample. The hydraulic conductivity was determined using constant-head Permeameter. Other parameters were estimated employing conventional methods.

Table 1 lists the physical parameters of soil samples at different sites. The unit weight (wet) for the samples ranges between 1.79 and 1.91 gm/cm^3. The unit weight (dry) was estimated in another group of experiments to range between 1.45 and 1.66 gm/cm^3 with an average value of 1.59 gm/cm^3. The percentage of sand in all samples ranges between 90.44% and 99.06%. The value for the saturated hydraulic conductivity ranges between 1.32 x 10^{-3} cm/s and 13.64 x 10^{-3} cm/s. The average values of the saturated hydraulic conductivities at sites 1 to 4 are 3.24 x 10^{-3}, 12.70 x 10^{-3}, 7.68 x 10^{-3} and 10.70 x 10^{-3} cm/s, respectively.

Table 1 Physical property of samples collected from the sand dune

Site No.	**Depth of Sampling (cm)**	**Unit weight (γ_d)**	**Specific gravity**	**% of Sand**	**Porosity (n)**	**Hydraulic Conductivity (10^{-3} cm/s)**
1	5	1.91	2.70	99.44	0.295	1.32
	75	1.89	2.68	93.79	0.297	5.15
2	5	1.91	2.65	97.46	0.300	13.36
	70	1.83	2.65	93.52	0.310	12.03
3	5	1.88	2.66	97.26	0.294	9.59
	100	1.84	2.66	97.30	0.301	5.76
4	5	1.85	2.66	97.76	0.302	7.75
	100	1.79	2.66	99.06	0.328	13.64

Depth-wise moisture contents

Data on moisture variation within the top few meters of the sand dune were collected. Four sites were selected to study soil moisture variability. Moisture content in the soil was also measured at the four sites. Probes of borehole type were installed at each site at 1 m, 2 m and 3.5 m depths to measure the moisture content of the sand using TRIME system. Another probe was used to measure content at the surface of the dune. The readings of these instruments were taken weekly in the wet season.

Figure 1 presents the temporal moisture contents measured at the soil surface (actually 25 cm below the surface) using the TRIME system. Precipitation was measured near the experiment location using an automatic weather station. The low moisture content recorded between the periods of 26 Feb to 28 March can be related to no rainfall in this period. The high moisture

contents on 29 January can easily be correlated with the occurrence of high rainfall occurring the same day. This is in all likelihood that the moisture contents were measured immediately after the rainfall. Although, comparison of the moisture content of two significant rainfall events shows that the effect of comparatively less rainfall occurred on 31 March (12.2 mm) is more significant that comparatively more rainfall occurred on 11 May (28 mm), this infers effect of evaporation on moisture contents. The average daily evaporation in the month of March and May is 7.8 mm and 12.2 mm. Apart from meteorological effects, the possibility of error due to delay in the measurement of moisture contents can't be ruled out. The measurements of moisture contents, if not concurrent to the occurrence to time of precipitation may also add significant error.

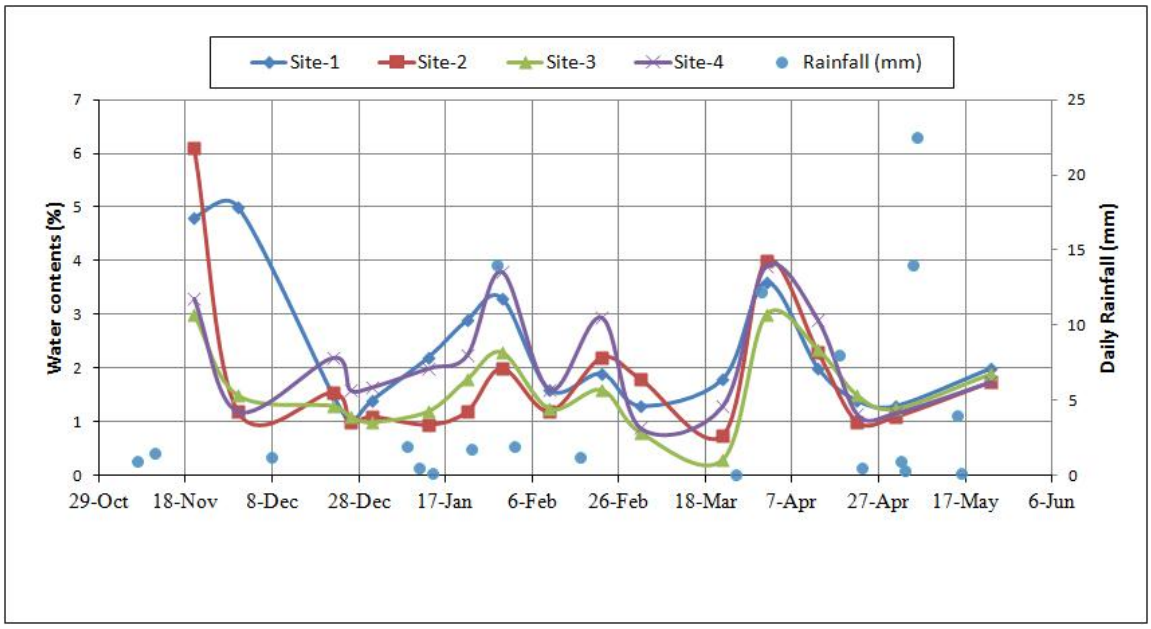

Fig.1 Variation of water content with the observed rainfall

Data on variability of moisture content within the whole sand dune profile is available from samples taken during drilling of two boreholes in the study area. The first borehole was drilled to a depth of 14 m. It is located close to site 1 and its elevation is a little bit lower than site 1. The second borehole was drilled down to 27 m at the crest of a comparatively high dune. It is located close to the site 2. The drilling depths of two boreholes represent bottom of the dunes at their respective location. The drilling and measurement within both the wells was done in April.

Table 2 shows daily amounts of rainfall in the study area. Figures 2 and 3 show the variation of moisture content (by volume) at the first and the second boreholes, respectively. These figures show the actual moisture contents at the time of drilling down to the bottom of the dune. It is interesting to observe that the 0-2 meter depth contains high moisture contents at both boreholes. This is probably the effect of the rainfall occurred in the preceding March with a total of 29.4

mm. The total precipitation for the study area was 231.8 mm while the mean annual precipitation for the whole region is around 120 mm. Both figures show a drier zone in the middle with higher moisture contents in the lower part of the dune. Thus, exceptional high rainfall in the preceding year is correlated with the high water content at deeper depth in both the boreholes.

The values of moisture content in the middle and lower parts of sand dune as indicated in Figures 2 and 3 ranges between 4 and 8% by volume. For other types of soils, these values are not considered high. However, for pure sand these moisture contents (as an average) are equal to field capacity or even higher. This raises the question of possible utilization of the moisture within these dunes. In some sand dune areas, the water table is very close to the surface. For this situation, the recharge is effective and there is no need to do more. However, if the water table is much deeper than the bottom of the sand dune or if the layer below the dune is of low

Table 2 Daily Rainfall in the Study area

Month	**Date**	**Daily Rainfall (mm)**
February	18	0.8
	21	6.2
	22	14
	23	10
March	4	0.6
	20	5.6
	21	9.8
	23	0.2
	29	0.6
	30	0.4
	31	12.2
April	1	0.8
	3	0.6
	5	4.4
	6	3.2
	7	6
	8	0.2

	23	4.6
	24	7.4
	25	8.6
	26	0.2
May	10	2.6
	11	28
	12	5.8

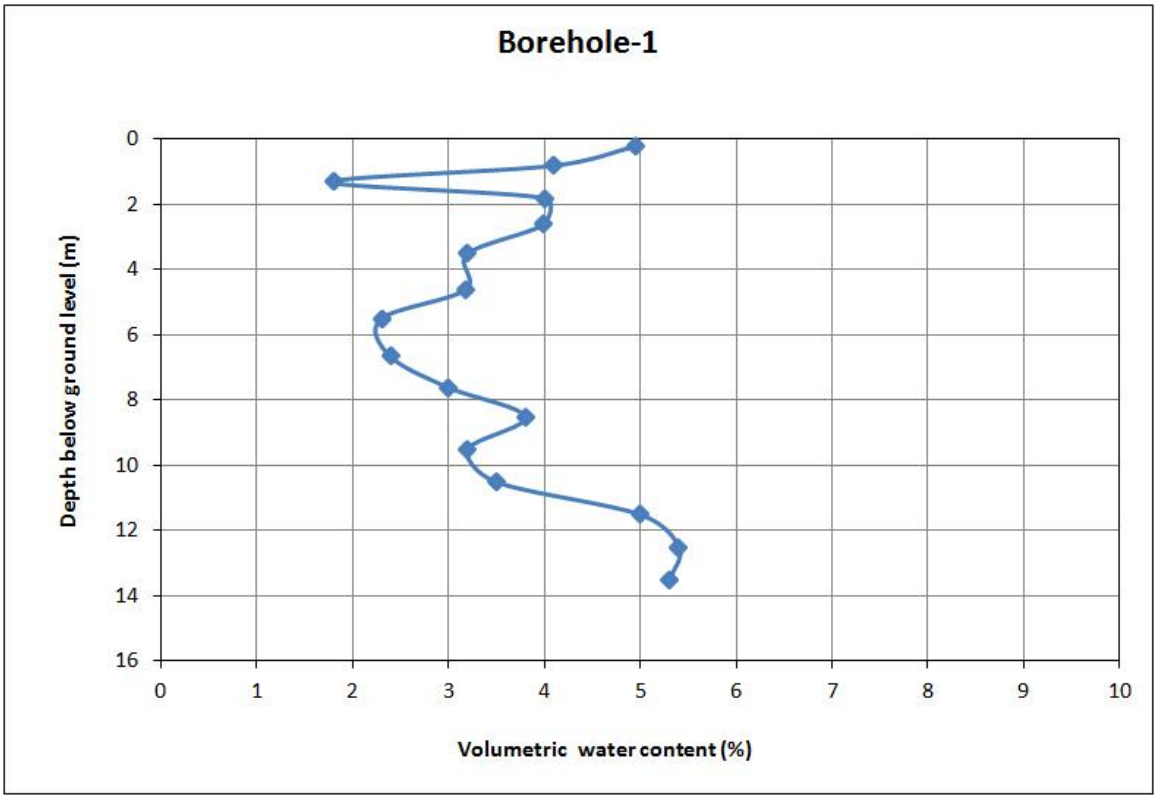

Fig.2 Variation of water contents with depth at Borehole-1.

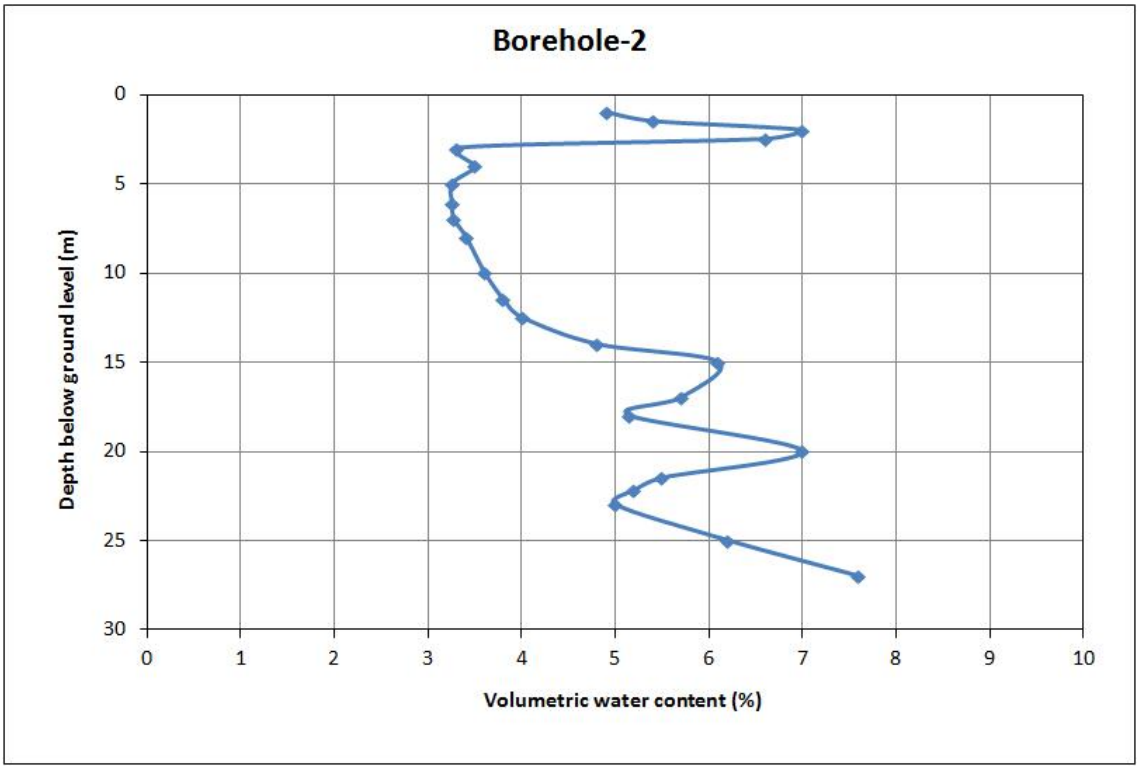

Fig.3 Variation of water contents with depth at Borehole-2.

permeability, this moisture will not be effective in recharging the ground water. In these cases, one possible way of utilizing this moisture is through planting certain desert trees within the sand dunes. This will be very beneficial since it will stabilize the dune, create better environment and provide areas for recreation. An essential requirement for this will be how to locate suitable areas within the sand dune.

Conclusion

The results show that significant amount of moisture is caught within the sand dune profile. The moisture contents are influenced by rainfall intensity, evaporation, and the time of measurement. The distributions of moisture contents throughout the profile of the two deep holes were explained and its implication on recharge was discussed in relation to occurrences of rainfall. The utilization of the caught moisture for planting trees at some locations in sand dune areas seems to be a very beneficial way of improving the environment of desert region. This use, however, needs more research to be carried out in the area of soil moisture movement within sand dunes.

Acknowledgement

The author is thankful to Deanship of Scientific Research (DSR), King Saud University for its support and constant encouragement throughout the study.

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Hydrus-2d Numerical Modeling for Sand-Fadr Mixture Barrier Layer for Landfill Covers

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Abstract

The objective of the present study is to predict the impact of cover and barrier layers and estimate their potential effect on the percolation rates through the landfill system. The HYDRUS-2D numerical model was used to simulate percolation through the Sand-FADR mixture hydraulic barrier layer, which is considered to be the main component of landfill cover. The input data for HYDRUS-2D modeling is taken from the experimental work on Sand-FADR Mixture such as permeability and retention curve data. The success of the cover may be gauged through the computed water content through the successive cover layers. The results show the water content distribution in the landfill cover depth with and without vegetated layer. The results indicate that the Sand-FADR mixture is acceptable as a hydraulic barrier layer. This is because the volumetric water content does not cause an increase in the initial volumetric water content (0.2 cm^3 cm^{-3}) below a depth of about 40 cm. For the case of vegetated layer above the Sand-FADR mixture, the water content increased only within the top 20 cm under the 15 cm thick vegetated layer. Similarly, the water content increased only within the top 15 cm of the barrier layer in case of Sand-FADR mixture barrier layer without vegetated layer. In case of inclined section, results indicate that the water content increased within only the top 15 cm of the barrier layer. This value is less than the corresponding value in case of the horizontal section because of the surface run off of water due to the slope of the layer. Therefore, the critical section is always the horizontal section.

Key words: Hydrus-2D, landfill cover, hydraulic barrier layer, fatty acid distillation residuals.

1. Introduction

The barrier layer is used in landfill liner to restrict the migration of pollutants from the landfill into the environment. In addition, the layer is used to limit the ingress of water into landfill due to precipitation. However, in other cases the cover may serve other equally important functions. The commonly used barrier layers are composed of compacted natural inorganic clays or clayey soils. The low hydraulic conductivity of compacted clayey soils makes them potential materials for use as liners and covers in landfills for environmental protection, and has the longest history of successful application as isolation barriers in landfills. Because of the shortage of clay at many locations, different substitutions have been investigated to get hydraulic barrier layer from different mixtures or waste materials. Some of these substitutions are the soil-ash mix, waste sludge materials such as paper sludge and construction sludge, petroleum contaminated soils, granite residual soil, and sand-bentonite mixture. This mixture achieves good performance but with relatively high cost. However, for waste containment systems, it is desirable to achieve its required purposes at minimum cost. Therefore careful consideration should be given to the choice of materials for the construction of the hydraulic barrier layer, which is considered the main component of landfill cover and liner.

In the present paper, numerical simulation model of water flow through a new economical mixture is studied as a hydraulic barrier layer (Hafez et al., 2007). The HYDRUS-2D numerical model (Simunek et al., 1999; Simunek, 2003; Rassam et al., 2003) was used in this paper. The numerical modeling methodology presented is an attempt for predicting the impact of cover and barrier layers and estimating their potential effect on the percolation rates through the landfill system.

1.1. Background

According to the USEPA standards and specifications, the Resource Conservation and Recovery Act (RCRA) subtitles C and D specify minimum requirements for engineered covers for hazardous and solid waste landfills, respectively. While, the adopted methodology in this study targets municipal waste landfill covers, the approach could easily be applied to any cover incorporating clay layers (USEPA, 1998 and 2008). According to (Dwyer, 2001), a Clay Barrier cover (Figure 1) for non-hazardous waste landfills should consist, at a minimum, of a 45 cm clay barrier having a hydraulic conductivity $\leq 1x10^{-5}$ cm s^{-1} and less than or equal to the hydraulic conductivity of the base liner. The latter requirement is to avoid buildup of leachate within the landfill. The typical standard for the saturated hydraulic conductivity, K_s, of landfill liners is $\leq 10^{-7}$ cm s^{-1}. This dictates a $K_s \leq 10^{-7}$ cm s^{-1} for the cover barrier based on the criterion noted earlier. Nonetheless, the minimum requirement of $K_s \leq 10^{-7}$ cm s^{-1} was adopted in this study.

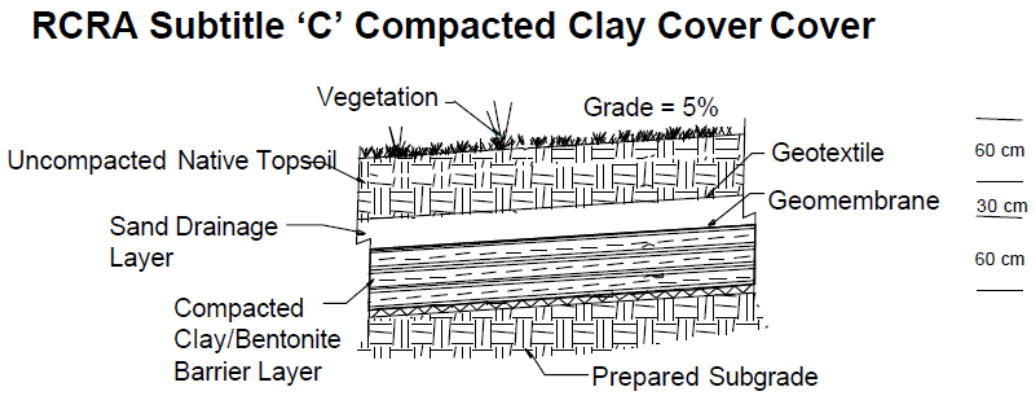

Figure 1. Profile of compacted clay cover

The same value was used in simulating the clay barrier test cover of the "Alternative Landfill Cover Demonstration" in New Mexico (Dwyer, 2003). Lower conductivity values would necessitate higher compaction water contents and thus induce more drying cracks and undergo greater increases in the altered saturated hydraulic conductivity. The clay barrier is assumed to be protected by a 15 cm minimum erosion or vegetated soil layer. Gas collection and drainage layers may also be necessary (Daniel, 1995), but are not considered in this modeling effort. The performance of clayey soils as hydraulic barriers is affected by various parameters. The internal fabric of the compacted clay barrier at the level of the mini-fabric (clod-size) units is key in affecting the hydraulic conductivity (Mitchell and Songa, 2005). Low values of hydraulic conductivity suitable for use in waste containment applications could only be obtained if clods and inter-clod pores are eliminated, which is most likely for compaction conditions wet of optimum, with high effort and methods producing large shear strains, e.g. sheepsfoot rollers (Benson and Daniel, 1990). Indeed, the permeability of a silty-clay compacted at wet of optimum may be 10 to 1000 times less than the permeability of the same soil compacted to the same dry density at a water content dry of optimum (Istock, 1989). Consequently, laboratory tests on wet compacted clays may yield low permeabilities indicating a nearly impervious soil. However, when a compacted clay soil is exposed to the atmosphere, water evaporates inducing shrinkage in all directions. As a result, the soil layer cracks and seepage rates increase dramatically. In this context, the relative effect of the drying/shrinkage increases with the as compacted water content. Consequently shrinkage strains, and therefore desiccation cracks, increase with compaction water content (Istock, 1989). According to Daniel (1995), the field results provided by Montgomery and Parsons (1989) showed that a 15-45 cm-thick topsoil layer was not able to protect clay barriers from desiccation and cracking in a relatively arid area of Wisconsin.

1.2. Application of HYDRUS-2D for landfill cover

HYDRUS-2D and its parent code, SWMS_2D (Simunek et al., 1994) have been used for a wide range of applications and conditions. Several studies have used HYDRUS-2D to estimate soil hydraulic parameters from multi-step extraction technique (Inoue et al., 1998), transient flow (Simunek et al., 1998), cone penetrometer data (Kodesova et al., 1998), and disc infiltrometer data (Simunek et al., 1998). Davis et al. (1997) coupled SWMS_2D with MODFLOW and MT3D for risk-based remediation modeling of contaminated sites.

HYDRUS-2D has been used for risk analysis (Abbaspour et al., 1997) of landfill covers and performance evaluation of landfill covers (Wilson et al., 1998). Abbaspour et al. (1997) included parameter uncertainty in the risk assessment of a landfill in Switzerland using SWMS_2D to analyze two-dimensional flow and transport. Wilson et al. (1998) used HYDRUS-2D to compare the performance of a monolayer to a subtle-layered ET cover design with regard to the ability of layering to disrupt preferential flow paths. They ran compaction tests on various particle-size fractions of material from the borrow source for a low-level waste repository at the Nevada test Site. They determined the saturated hydraulic conductivity, and water retention characteristics on each size fraction compacted to 83% and 90% maximum dry density. These data were incorporated into HYDRUS-2D to simulate infiltration for a 100-yr, 6-hour storm event for various cover designs. They simulated preferential flow fingering by assigning a Ks value in a vertical path of nodes that constituted 5% of the cross-sectional area to be four orders of magnitude higher than the remaining nodes. The location of the 5 percent cross-sectional area preferential flow finger was randomly selected for each layer. Based upon the HYDRUS-2D preferential flow analysis, they found that the monolayer cover would need to be 26 percent thicker on average to limit infiltration for the single storm event. Davis et al. (1997) coupled SWMS_2D with MODFLOW and MT3D for risk-based remediation modeling of contaminated sites. HYDRUS-2D has been used for risk analysis (Abbaspour et al., 1997) of landfill covers and performance evaluation of landfill covers (Wilson et al., 1998). Abbaspour et al. (1997) included parameter uncertainty in the risk assessment of a landfill in Switzerland using SWMS_2D to analyze two-dimensional flow and transport. Verification of the HYDRUS-2D code was accomplished by the developers by comparing simulations with both the UNSAT2 (Neuman, 1973) and SWATRE (Belmans et al., 1983) codes. The transport portion of HYDRUS-2D was verified by comparison with an analytical solution for a two-dimensional steady-state groundwater flow problem (Simunek et al., 1996). The comparison with UNSAT2 was made for a one-dimensional infiltration experiment modeled by UNSAT2 (Davis and Neuman, 1983). A homogenous soil column at an initial pressure head of -150 cm was subjected to ponded infiltration at the surface (a constant head BC). The open bottom boundary was modeled as seepage face BC, and the column sides as no flux BC. Good agreement between UNSAT2 and HYDRUS-2D was observed to demonstrate verification. A more rigorous verification test was made by comparing HYDRUS-2D to SWATRE (Feddes et al., 1978) results for a one-dimensional field profile. The soil profile consisted of two layers with a 30-cm thick root zone. Actual precipitation and potential transpiration rates were used for the atmospheric BC at the surface. The bottom BC was a deep drainage BC with the groundwater level set to 55 cm below the surface and the initial condition was taken to be in equilibrium with the groundwater level. Pressure heads, transpiration rates, and bottom discharge rates showed excellent agreement with SWATRE results to show verification. Gribb and Sewell (1998) further verified the parent code (SWMS_2D) by making comparisons to a general purpose partial differential equation solver, PDE2D. They found that water volumes in the flow domain were consistent for the four scenarios tested. Pohll et al. (1996) coupled SWMS_2D with an overland flow model to simulate recharge below nuclear subsidence craters. They calibrated the overland flow model by adjusting the catchment area to match field measurements of run-on into the crater and calibrated the crater topography to match the measured pond depths in the crater. Comparisons of the simulated to measured moisture profiles are a validation test for HYDRUS-2D. They considered the model to be in good agreement with measurements given the apparent vertical heterogeneity of the single vertical profile within a three-dimensional flow field and the approach of simulating the profile as homogenous. Although water balance models are not able to fully

investigate the hydrology of capillary barriers, a Richards' equation-based model can be utilized. Kampf et al. (1998) used HYDRUS-2D to simulate the capillary barrier system of an engineered landfill cover. They investigated the process known as capillary diversion, or the breakthrough point of a capillary barrier where the downward vertical flow through the capillary layer equals the infiltration rate, q, from the top of the cover. The field measurements of two landfill facilities in Germany were used to compare the simulation results of the HYDRUS-2D model. Nofziger et al. (1994) performed sensitivity analyses on four widely used vadose zone transport models (RITZ, VIP, CMLS, and HYDRUS) to compare their behavior. HYDRUS is a predecessor of HYDRUS-2D and should behave similarly, since they are both founded upon the SWMS code. Nofziger et al. (1994) stated that of these four models, the HYDRUS model is most suited for detailed use by research scientists. The sensitivity analysis found that the HYDRUS model was particularly sensitive with respect to the amount of pollutant leached, to the partition coefficient, saturated water content, and the van Genuchten n parameters. For travel time, the model was especially sensitive to the van Genuchten n parameters, saturated water content, partition coefficient, root water uptake potential, and bulk density. For the pulse width, the model was sensitive to the van Genuchten n coefficient, bulk density, saturated water content, and dispersivity. All three of these processes were insensitive to the residual water content and diffusion coefficient. Sensitivity of the flow predictions was not addressed.

2. Materials and methods

2.1. Barrier layout

The input data for HYDRUS-2D modeling is taken from the experimental work on Sand-FADR Mixture (Hafez et al., 2007) such as permeability and retention curve data, the precipitation for 100 days (winter period) is taken as the maximum case for Egypt and was obtained from the Center of Climate of Agriculture Egyptian Ministry (ref), the evaporation and transpiration were taken as the minimum for more safety.

In this paper, unit horizontal and inclined area (1m X 1m) of landfill cover is considered to be modeled by HYDRUS-2D, the sections have depth of 75 cm (15 cm is vegetated cover layer and 60 cm as hydraulic barrier layer) (Figure 2). The vegetated layer is composed from the in situ sand for economic considerations. The hydraulic barrier layer is Sand-FADR Mixture that is invented in this research, the default depth of the barrier layer is taken as 60 cm according to the specifications of the Environmental Protection Agency (USEPA, 1998).

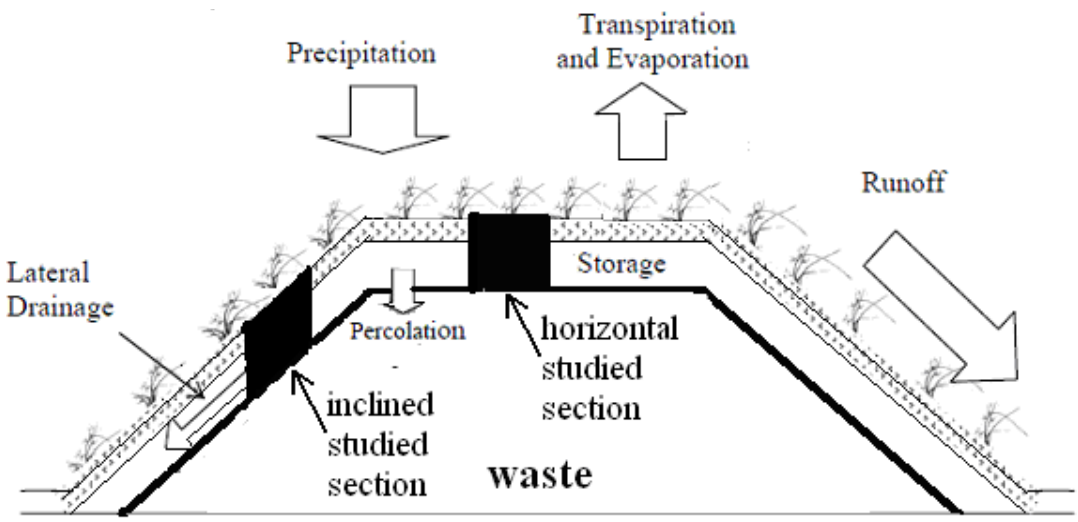

Figure 2. Studied section of landfill cover

2.2. HYDRUS-2D model

Hydrus-2D (Simunek et al., 1999) simulates a 2-D Darcian flow for unsaturated and saturated soil conditions. It allows for 2D flow simulation and includes evapotranspiration effects while assuming that the effect of the air phase on the liquid flow is insignificant. The Hydrus-2D model solves Richards' equation (1), for variably saturated flow in isotropic and anisotropic porous media, using the Galerkin-type linear Finite Element Method (Simunek et al., 1999).

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i}\left[\left(K_{ij}^{A}\frac{\partial h}{\partial x_j} + K_{ij}^{A}\right)\right] - S \qquad 1$$

Where θ is the volumetric water content ($cm^3\ cm^{-3}$), h is the pressure head (cm), S is a sink term for water uptake by plants (day^{-1}), xi (i=1,2) are the spatial coordinates (cm), t is time(days), K_{ij}^{A} are components of a dimensionless anisotropy tensor K^A, and K is the unsaturated hydraulic conductivity function (cm day^{-1}) given by:

$$K(h,x,z) = K_r(h,x,z)K_s(x,z) \qquad 2$$

Where, Kr is the relative hydraulic conductivity and Ks is the saturated hydraulic conductivity (cm day^{-1}).

For planar flow in a vertical cross-section, $x_1=x$ is the horizontal coordinate and $x_2=z$ is the vertical coordinate, the latter taken to be positive upward. For this study S was not considered because the simulations assumed that water loss owing to evapotranspiration was accounted for by using the net rainfall.

The relevant Hydrus-2D parameters used in this study to simulate the landfill cover are presented in Table 1. Parameter values, particularly those related to the numerical model of the layered cover system, were adopted based on extensive trials at optimizing model stability and reducing accumulated errors (through varying the mesh size and distribution, time steps and tolerances). The model boundaries were selected given the 2-D nature of the problem and that the cover system is layered and inclined. As such, the right boundary (upstream) is taken

as a no flux boundary, the left boundary (downstream) is the seepage face, and the bottom face is a free drainage boundary.

Table (1). Numerical model characteristics used in the present simulation

	Parameters	value
Time Discretization	Initial	0 day
	Final	100 days
	Initial time step	0.1 day
	Minimum time step	0.0001 day
	Maximum time step	5.0 days
	Number of print time	10
Iteration	Maximum number of iterations	20
	Water content tolerance	0.0001 cm^3 cm^{-3}
	Pressure head tolerance	0.1 cm
Rectangular dimensions	Horizontal rectangular dimension	100 cm
	Vertical rectangular dimension	75 cm
	Number of vertical columns	21
	Number of horizontal columns	16
Boundary conditions	Top	Atmosphere
	Bottom	Free drainage
	Right side	No flux
	Left side	No flux
	Initial condition in water content	0.2 cm^3 cm^{-3}
Vegetation	Type	grass
	Root depth	15 cm
	Root distribution factor	1
Root water uptake model	Feddes et al. (1978)	Grass (Wesseling, 1991)

2.3. Unsaturated soil hydraulic properties

The HYDRUS-2D code uses the unsaturated hydraulic properties θ(h) and K(h) defined by van Genuchten, (1980), who obtained a predictive closed-form equation for the unsaturated hydraulic conductivity function by using the statistical pore-size distribution model of Mualem (1976). The original van Genuchten equations for the soil water retention, θ(h), and hydraulic conductivity, K(h), are defined as:

$$\theta(h) = \begin{cases} \theta r + \dfrac{\theta s - \theta r}{\left(1+(\alpha h)^n\right)^m} & h < 0 \\ \theta s & h \geq 0 \end{cases} \qquad 3$$

and

$$K(h) = \begin{cases} K_s K_r(h) & h < 0 \\ K_s & h \geq 0 \end{cases} \qquad 4$$

Where

$$K_r = S_e^{\tau}\left[1-(1-S_e^{1/m})^m\right]^2 \qquad 5$$

and θ is soil water content (cm^3/cm^3), θ_r and θ_s are the residual and saturated water contents ($cm^3\ cm^{-3}$), respectively, h is the soil pressure head (cm), and α (cm^{-1}), n, and m are constants which defined the shape of the curve, and τ is an empirical constant assumed equal to 0.5 (van Genuchten, 1980). Furthermore, m =1-1/n and the degree of saturation is defined as $Se=(\theta-\theta_r)/(\theta_s-\theta_r)$. Modified form of Eq. (3) is also provided in the HYDRUS-2D code and adds additional flexibility in the description of the hydraulic properties near saturation (Simuenk et al., 1999). The values of α , m and n are obtained by fitting Eq. (3) to the soil water retention data using RETC model (van Genuchten et al., 1991).

Parameter values for θr; θs; α; n; and Ks representative for each of the sand and sand-FADR mixture are obtained by fitting Eq. (3) to the soil water retention data using RETC model (van Genuchten et al., 1991) given in Table 2. All values were taken from the literature review. Fig. 3 depicts the soil water retention curves in terms of the water content and also shows the corresponding unsaturated hydraulic conductivity functions calculated with Eqs. (4) and (5). Owing to the extreme differences in shape of the soil hydraulic functions, representative for porous media varying from very coarse to very fine materials, the hydraulic behavior of the different soil types is very different.

Table (2). Hydraulic parameters used in modeling the landfill cover

Soil type	Hydraulic parameters	
Sand	θ_r = 0.045 $cm^3\ cm^{-3}$	van Genuchten et al. (1991)
	θ_s = 0.43 $cm^3\ cm^{-3}$	
	α = 0.145 cm^{-1}	
	n = 2.68	
	K_s = 712.8 cm day^{-1}	
Sand-FADR mixture	θ_r = 0.057 $cm^3\ cm^{-3}$	Hafez et al. (2007)
	θ_s = 0.404 $cm^3\ cm^{-3}$	
	α = 0.046 cm^{-1}	
	n = 1.9	
	K_s = 0.008 cm day^{-1}	

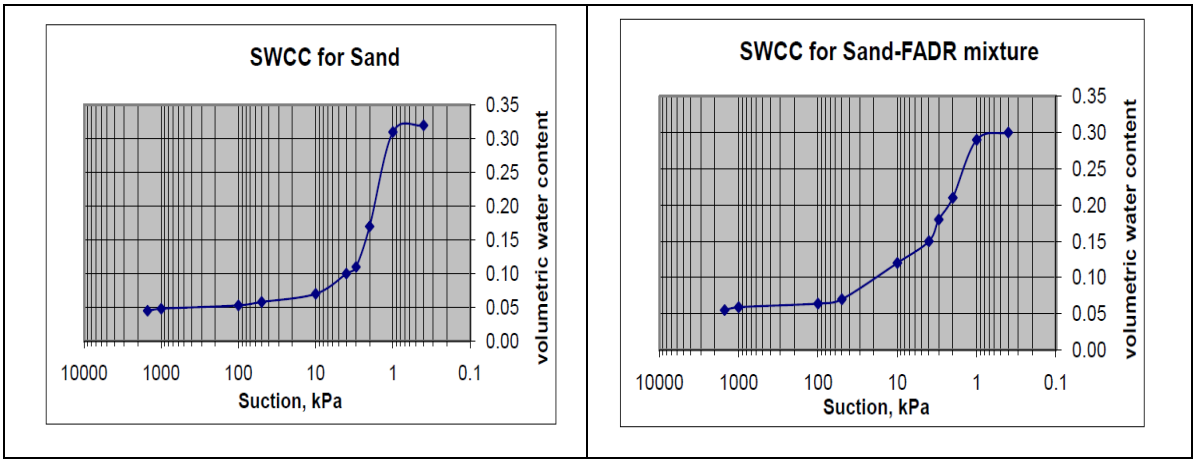

Figure 3. Soil water characteristic curve of sand-FADR mixture

2.4. Initial and boundary conditions

The solution of Eq. (1) requires knowledge of the initial distribution of the pressure head within the flow domain:

$$h(x,z,t) = h_0(x,z) \text{ for } t = 0 \qquad 6$$

where h_0 is a prescribed function of x and z. In addition to initial conditions, boundary conditions have to be specified along the boundaries of the flow domain. Typical boundary conditions include specified flux (Neumann type),

$$-\left[K\left(K_{ij}^{A}\frac{\partial h}{\partial x_j} + K_{ij}^{A}\right)\right] = \sigma_1(x,z,t) \;\; for\,(x,z)\varepsilon\Gamma_N \qquad 7$$

and specified gradient boundary conditions,

$$\left(K_{ij}^{A}\frac{\partial h}{\partial xj} + K_{ij}^{A}\right)n_i = \sigma_2(x,z,t) \;\; for\,(x,z)\varepsilon\Gamma_G \qquad 8$$

where Γ_N, and Γ_G indicate Neumann and gradient type boundary segments, respectively, σ_1 and σ_1 are prescribed functions of x; z, and t; and n_i are the components of the outward unit vector normal to the boundary Γ_N, and Γ_G.

The boundary conditions applied in the present modeling study are a variable flux top boundary and free drainage bottom boundary condition. The former equals a long-term average net rainfall rate of 0.15 cm day^{-1}, and the latter corresponds to a unit vertical hydraulic gradient simulating free drainage. Two alternative net rainfall rates are also considered, namely for very dry (0.01 cm day^{-1}) and very wet (0.5 cm day^{-1}) climatological conditions. The left and right boundaries of the domain are zero flux boundary conditions. The initial water content condition for each soil type is included in Table 1 and assumes relatively wet initial conditions for the entire barrier, but drier conditions for the surrounding soil.

2.5. Numerical solution strategy

A solution of the flow equation [Eq. 1] is obtained by using the Galerkin finite element method with linear basis functions and the appropriate initial and boundary conditions. The

set of algebraic equations are solved iteratively using either Gaussian elimination or the conjugate gradient method. The iterative process continues until a satisfactory degree of convergence is obtained, i.e. until at all nodes in the region the absolute change in pressure head (or water content) between two successive iterations becomes less than some small value determined by the imposed absolute pressure head (i.e. 10 cm) (or water content, i.e. 0.0001 cm^3 cm^{-3}) tolerance.

The most critical case of landfill cover barrier layer is obtained when the vegetated layer is removed by animals or for any reason. Thus this study model the two cases, the first case is that the barrier layer is covered by vegetated layer, the second case is that the vegetated layer is removed from the top of the barrier layer (Sand-FADR Mixture). The two sections studied in the landfill are shown in Figure 2 and the three cases are also shown in Figures 4, 5 and 6.

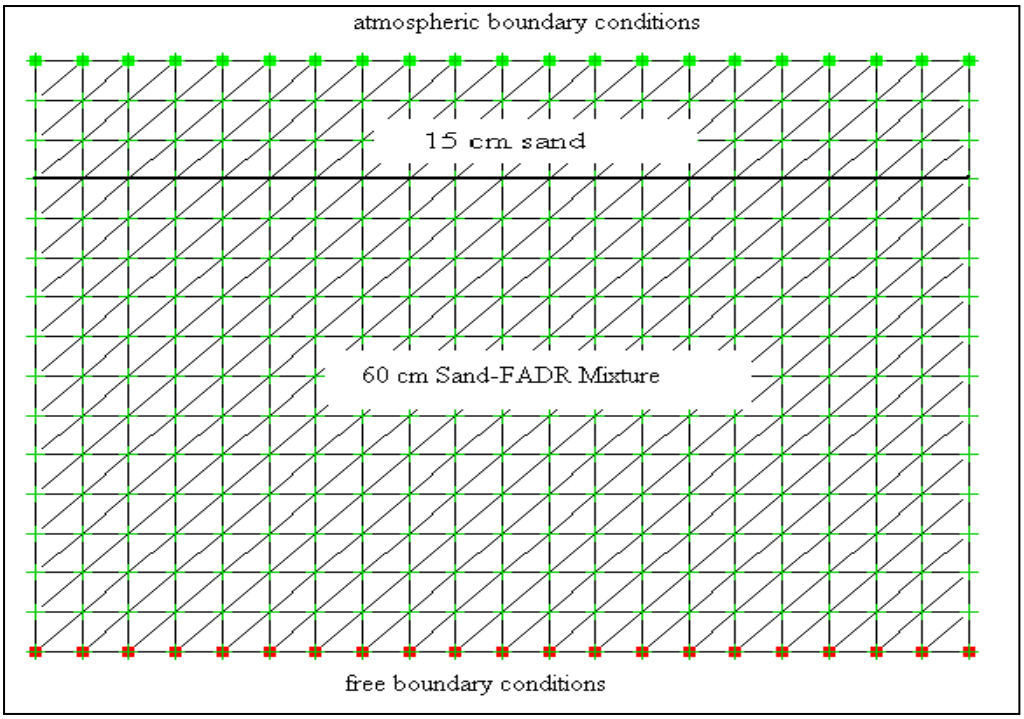

Figure 4. Barrier layer covered by vegetated layer horizontal section

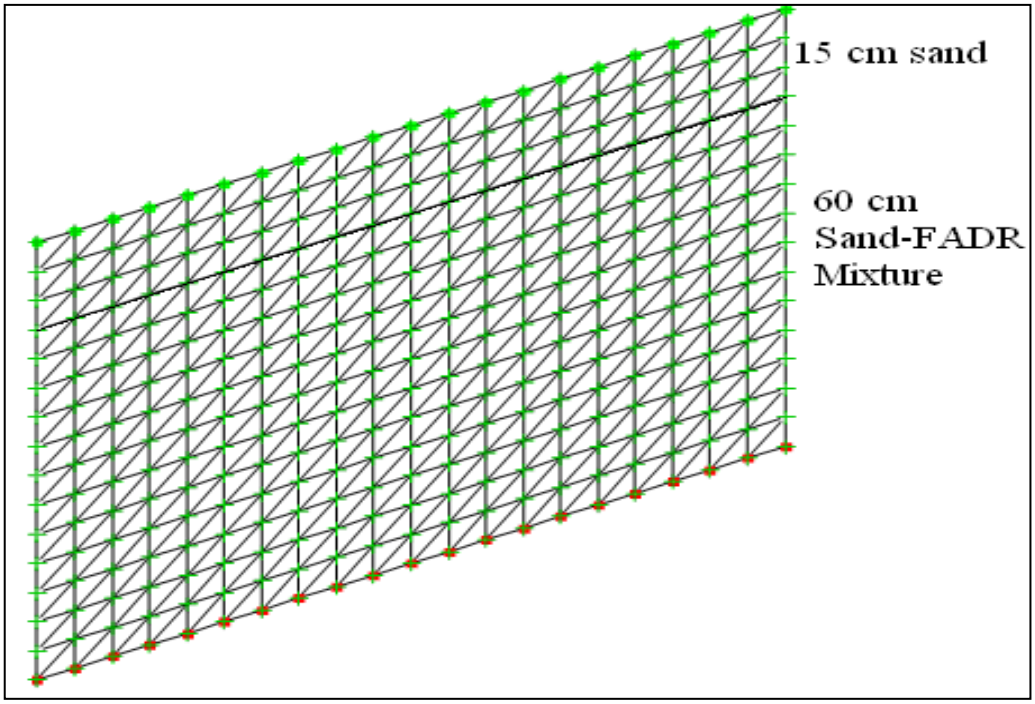

Figure 5. Barrier layer covered by vegetated layer for inclined slope

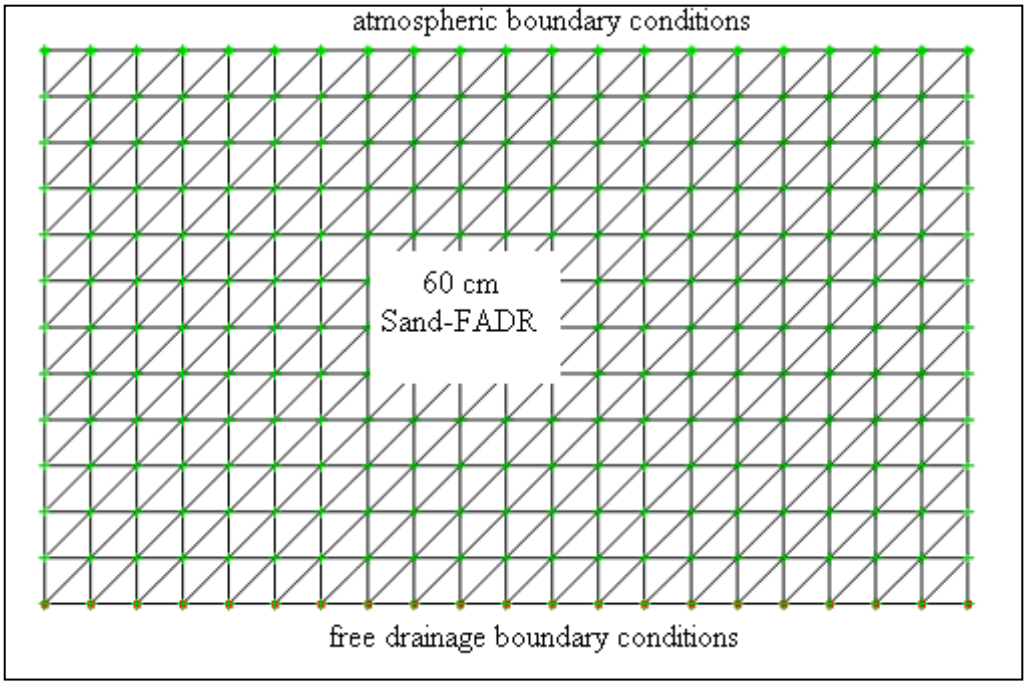

Figure 6. Barrier layer without vegetated layer

3. RESULTS AND DISCUSSION

The role of a properly designed and constructed landfill cover is to limit the percolation of water to the waste. At the design stage, the success of the cover may be gauged through the computed water content through the successive cover layers. Figures 7, 8 and 9 show the

water content distribution in the landfill cover depth with and without vegetated layer. It is noted from the figures that the Sand-FADR Mixture is excellent as hydraulic barrier layer because the water content don't increase the initial condition (0.2 cm^3 cm^{-3}) in depth of 40 cm, by other meaning for case of vegetated layer the water content increased only in 20 cm under the 15 cm in the vegetated layer (total of 35 cm), and the water content increased only in 15 cm depth of barrier layer in case of Sand-FADR Mixture barrier layer without vegetated layer. The inclined section results in Figure 9 show that the water content increased in only the first 15 cm, this value is less than the horizontal section (Figure 7) because the surface run off of water due to slope of the layer thus insures that the critical section is the horizontal section.

The role of proper designed constructed landfill cover is to limit the percolation of surface water applied through rainfall through the waste below and down to the bottom of hydraulic barrier. The success of the cover may be evaluated through the computed water flux through the cover layers.

Under the present conditions, the cumulative water flux under the FADR hydraulic barrier(bottom boundary) at the end of simulation period reached about 6.87, 9.37 and 4.21% of total rainfall for horizontal section(15 cm vegetative cover+60 cm Sand-FADR mixture layer), inclined section (15 cm vegetative cover+60 cm Sand-FADR mixture layer) and horizontal section (60 cm of Sand-FADR mixture layer only). The water balance error did not exceed 3% in all cases.

The cumulative water flux are less than the field measurements in other sites, where percolation was high as 60% of precipitation as reported by Gee et al. (1994) and Khire et al.(2000).

Further studies should be conducted for evaluation of multiple layer barriers and the sensitivity of cover design to the changing in the rainfall rate and also for long periods not for small period such as in the present study. All these factors can improve and help in selecting barrier design.

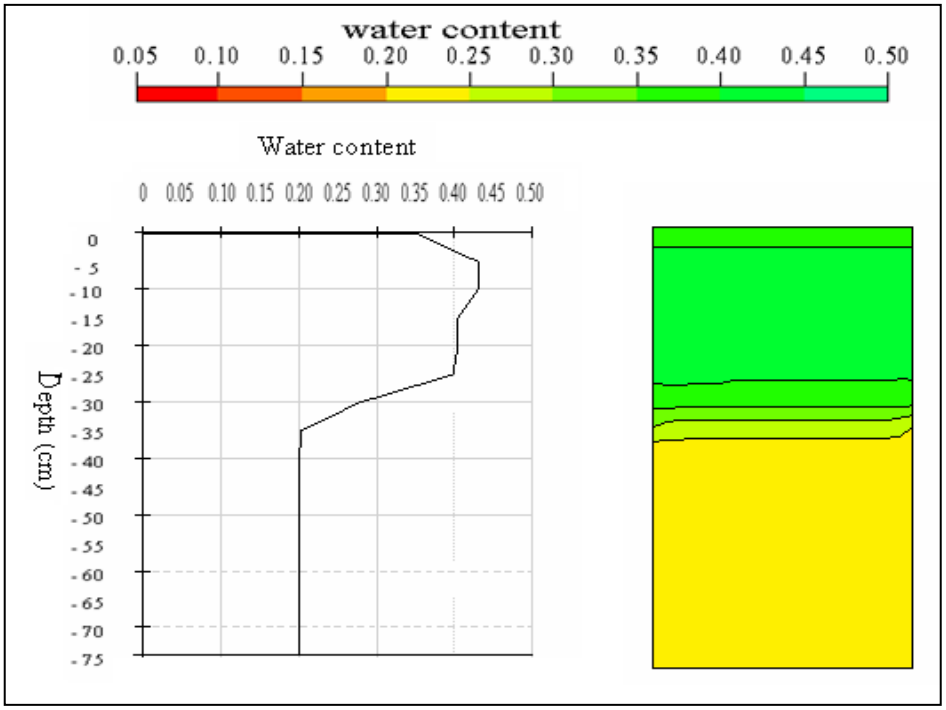

Figure 7. Water content distribution in the 15 cm sand vegetated layer and 60 cm Sand-FADR mixture barrier layer

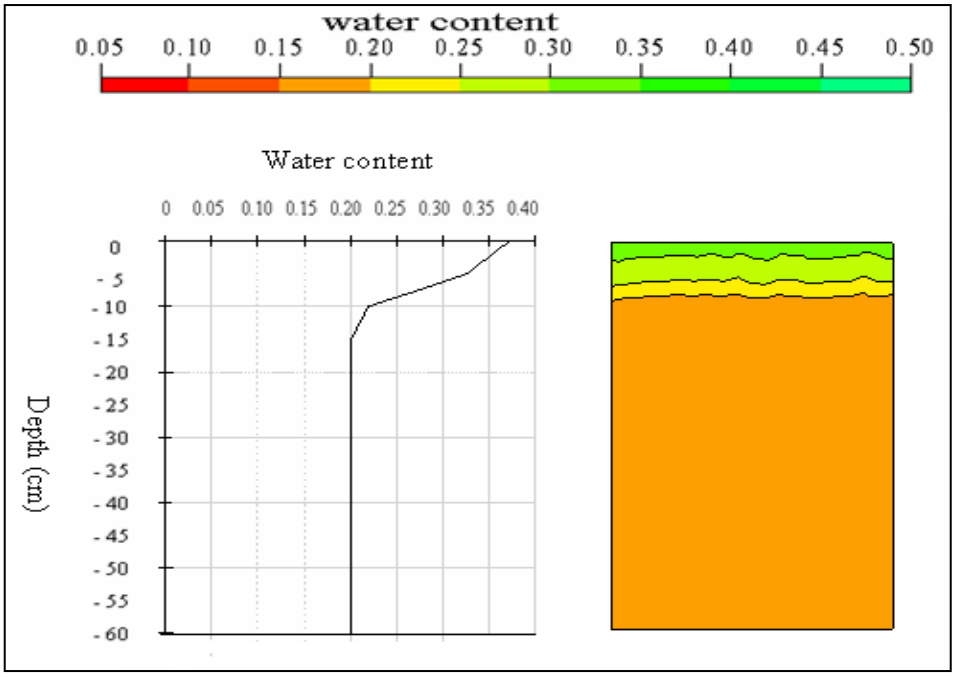

Figure 8. Water content distributions in the 60 cm Sand-FADR mixture barrier layer

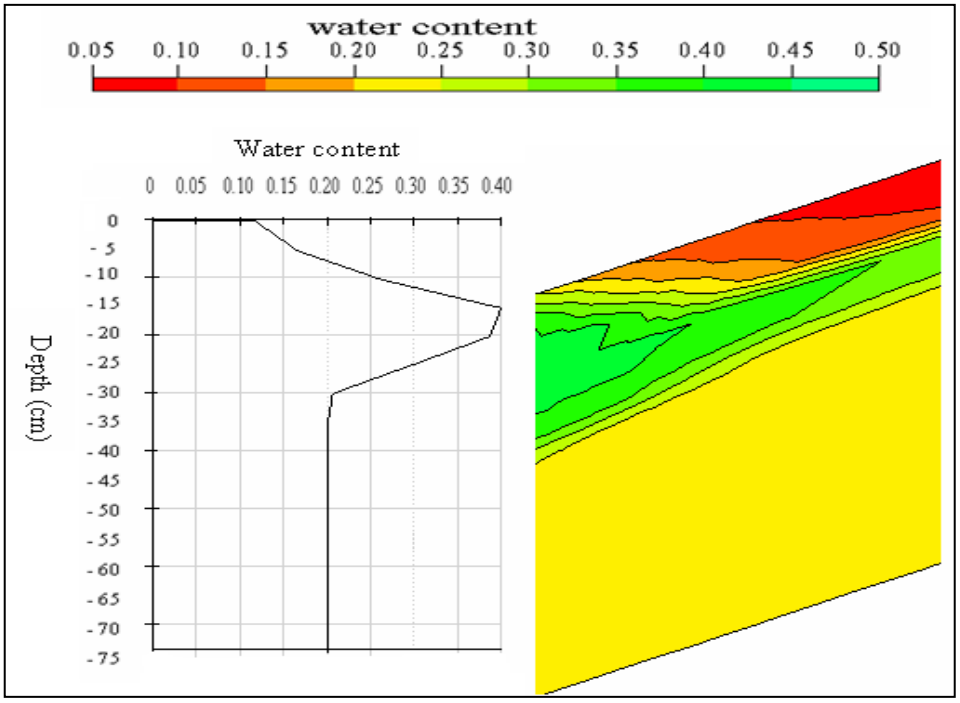

Figure 9. Water content distribution in the 15 cm sand vegetated layer and 60 cm Sand-FADR mixture barrier layer for inclined side cover section

4. CONCLUSION

The numerical modeling with HYDRUS-2D was used to simulate and predict the percolation through a Sand-FADR mixture barrier layer (60 cm thick) with and without 15 cm vegetative cover layer. For the studied period (100 days), the Sand-FADR mixture layer was able to restrict the water percolation through the vegetative cover, therefore the cumulative percolation at the bottom boundary was less. The cumulative water flux under the FADR hydraulic barrier(bottom boundary) at the end of simulation period reached about 6.87, 9.37 and 4.21% of total rainfall for horizontal section(15 cm vegetative cover+60 cm Sand-FADR mixture layer), inclined section (15 cm vegetative cover+60 cm Sand-FADR mixture layer) and horizontal section (60 cm of Sand-FADR mixture layer only). The water balance error did not exceed 3% in all cases. Further studies should be conducted for evaluation of multiple layer barriers and the sensitivity of cover design to the changing in the rainfall rate and also for long periods not for small period such as in the present study. All these factors can improve and help in selecting barrier design.

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Water Resources Management in an Arid Area: Estimation of Groundwater Depletion in Sana'a Basin, Yemen

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Abstract

Over-exploitation of the groundwater resources is the major problem leading to aquifers depletion in the Sana'a Basin (SB), one of the major semi-arid highland basins of Yemen. Irrigated agriculture is the chief economic activity in the SB and consequently, depletion places socioeconomic development in jeopardy. Owing to the lack of sustainable management, enforcement of laws and institutional arrangements, government intervention is not likely to alleviate the crisis. The groundwater in SB has been in depletion since abstraction exceeded the recharge volumes. Estimates of the depletion were made based on the groundwater level records in different periods in the three main aquifers i.e. Quaternary Alluvium, Quaternary and Tertiary Volcanic and Cretaceous Tawilah Sandstone aquifers beside the effective porosity or specific yield. The results showed that the estimated depleted groundwater volume from the Alluvium aquifer since 1973, pre-development time, until 2007 reached 470.54 MCM, while it reached in Volcanic aquifer 1705.66 MCM during the interval of 1985-2007. In the Sandstone aquifer, the most depleted aquifer in SB, the estimated depleted groundwater quantity reached 101.01 MCM during the period of 1993-2007. This critical situation of groundwater depletion in the three aquifers in SB requires a trial to mitigate this problem. This can be achieved through artificial recharge to the shallow zones of the Alluvium aquifer and by construction of storage dams for rainwater harvesting in the highly fractured areas of Volcanic and Sandstone aquifers to maximize the recharge to these depleted aquifers. One non-governmental approach would be to adopt an annual abstraction quota. Approaching the crisis at a grass-roots level and relying on enhancing community role and taking advantages of the present customary law and traditional/indigenous management knowledge are the main characteristics of this strategy for optimum and sustainable utilization of water resources. Banning deep wells drilling, controlling of abstraction, improving irrigation efficiency and institutional arrangement and changing in cropping pattern are highly recommended.

Key Wards: Hydrogeology, Groundwater depletion, Sana'a basin, Tawilah aquifer, Water crisis.

Introduction

Groundwater is a valuable resource both in Yemen and throughout the world. In the Sana'a Basin (SB), it is the sole source for both irrigation and the urban water supplies. Over-exploitation of the groundwater resources is the major problem leading to groundwater depletion in SB, one of the major semi-arid highland basins of Yemen. The rapid growth of the population of Sana'a city from 80,000 to 1,700,000 in 1972 and 2006 respectively and the rapid increase of the area under groundwater based irrigation in SB lead to a steady decline of groundwater levels from about 3 m in early 1970 to more than 200 m in 2006 which was reflected on the sharp shortage on water supply (HYDROsult 2010). In this paper, a trial was made to study this problem since 1973, pre-development time, till now. The SB is an inter-mountain plain located in the central Yemen Highlands. It is located between 390,000 and 460,000 East and 1,750,000 and 1,665,000 North with an elevation of about 2200 **m**eters **a**bove **s**ea **l**evel (masl). It is surrounded to the west, south and east by mountains rising to about 3,000 masl (Figure 1). It has an area of 3200 km^2 and forms the upper part of Wadi Al Kharid's catchment, a sub-catchment of the Wadi Al Jawf. The climate is semi-arid with an average annual rainfall of 235 mm at Sana'a city (WEC, 2004).

The stratigraphic sequence of SB ranges from Precambrian to Recent with some periods of missing. The Phanerozoic rocks of SB mainly consist of sedimentary and volcanic rocks. The subsurface data reveals the presence of the Precambrian rocks as in Arhab and Al-Hatarish wells which represent the deepest wells drilled in SB (Kruseman and Vasal, 1996). The different lithostratigraphic units in SB from older to younger are the Kohlan Sandstone Formation of Triassic–Jurassic age, the Amran Group of Jurassic age, the Tawilah Group of the Cretaceous age, the Tertiary Volcanics Group of the Tertiary age, the Quaternary Volcanics and the Alluvial deposits of the Quaternary age. The surface distribution and outcrops of these lithostratigraphic units are shown in the geological map of SB (Figure 2). The structural trends which controlled the formation of SB are inherited from the Proterozioc trends which have been rejuvenated during the early Jurassic time, where a deep depression was formed by NW-SE trend. The SB is subjected to different tectonic trends of compression and extension regimes. The extensional regime is the most dominant structures in the area and obscured all the old structures (SAWAS 1996).

The hydrogeological setting of SB is complex. Each aquifer is often seemed to be in lateral or vertical hydraulic continuity with another (Italconsult, 1973 and HYDROsult, 2010). The hydrogeological cross-section (Figure 3) shows that groundwater aquifers in SB include the Quaternary Alluvium, Quaternary and Tertiary Volcanics and Cretaceous Tawilah sandstone.

Aquifer Description:

The Alluvium aquifer is a poorly permeable aquifer which has been heavily exploited in the SB due to its proximity to the urban area. It is regionally unconfined, but locally semi-

confined covers about 15 % of the SB (about 480 km^2, WEC 2004). It shows three or four depositional basins (Foppen 1996). The maximum thickness of this aquifer is located north of Sana'a city (300 m), while the depth is about 100 m in the south. The recharge to this aquifer is generally due to infiltration from rainfall and runoff from the surrounding catchments and laterally from the adjacent aquifers. The permeability for coarse grained horizons reaches 1.1 m/day and for the sandy loam horizons, the value is 0.7 m/day (Mosgiprovodkhoz, 1986). The specific yield reaches 0.01(SAWAS, 1996). The transmissivity ranges between 3.6 to 82 m^2/day. In spite of their large extent and volume, their high clay content and lack of thick sand layers make them poorly productive (Howard Humphry 1985) and highly depleted.

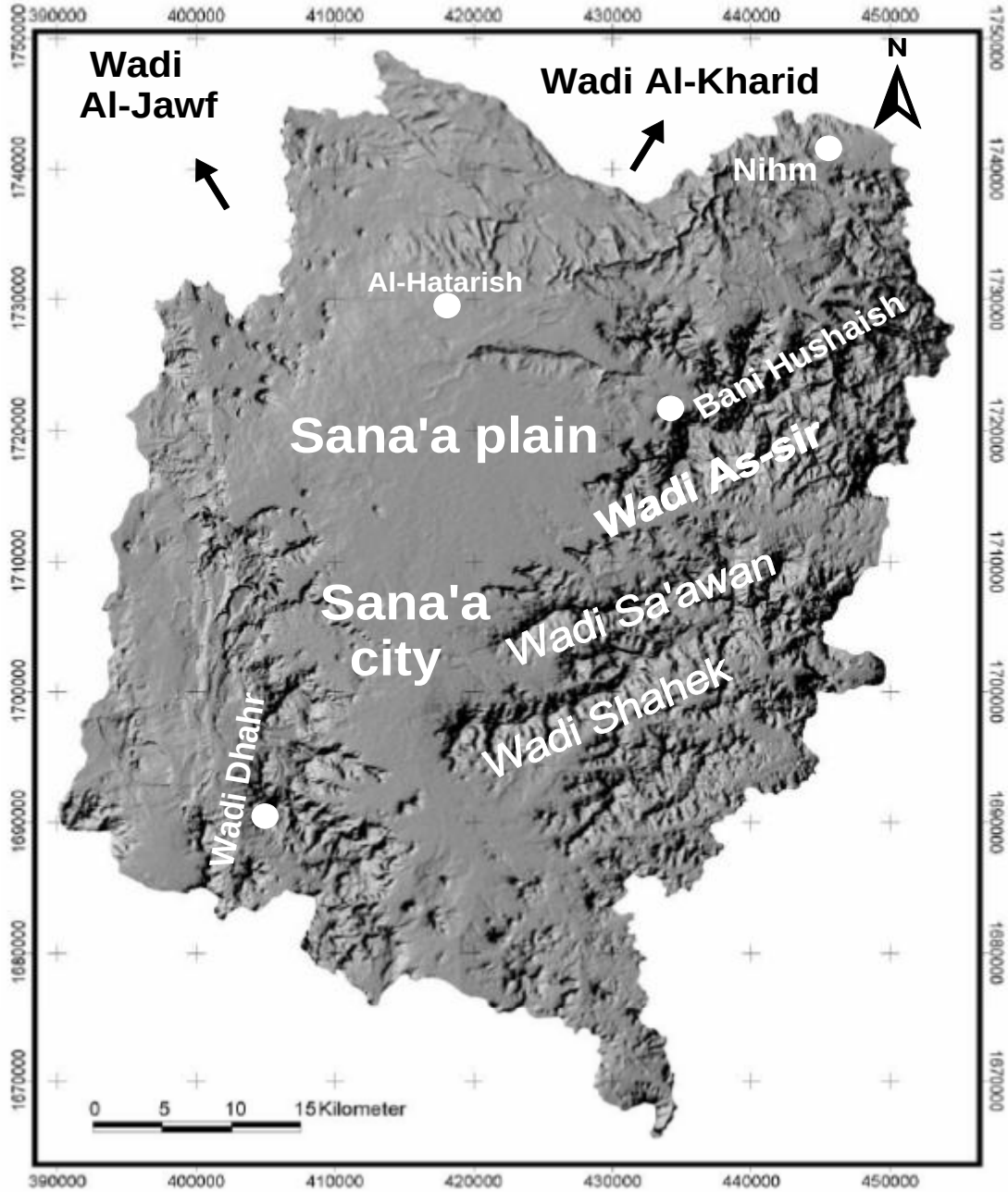

Figure 1: Location map of Sana'a Basin (SB), Yemen

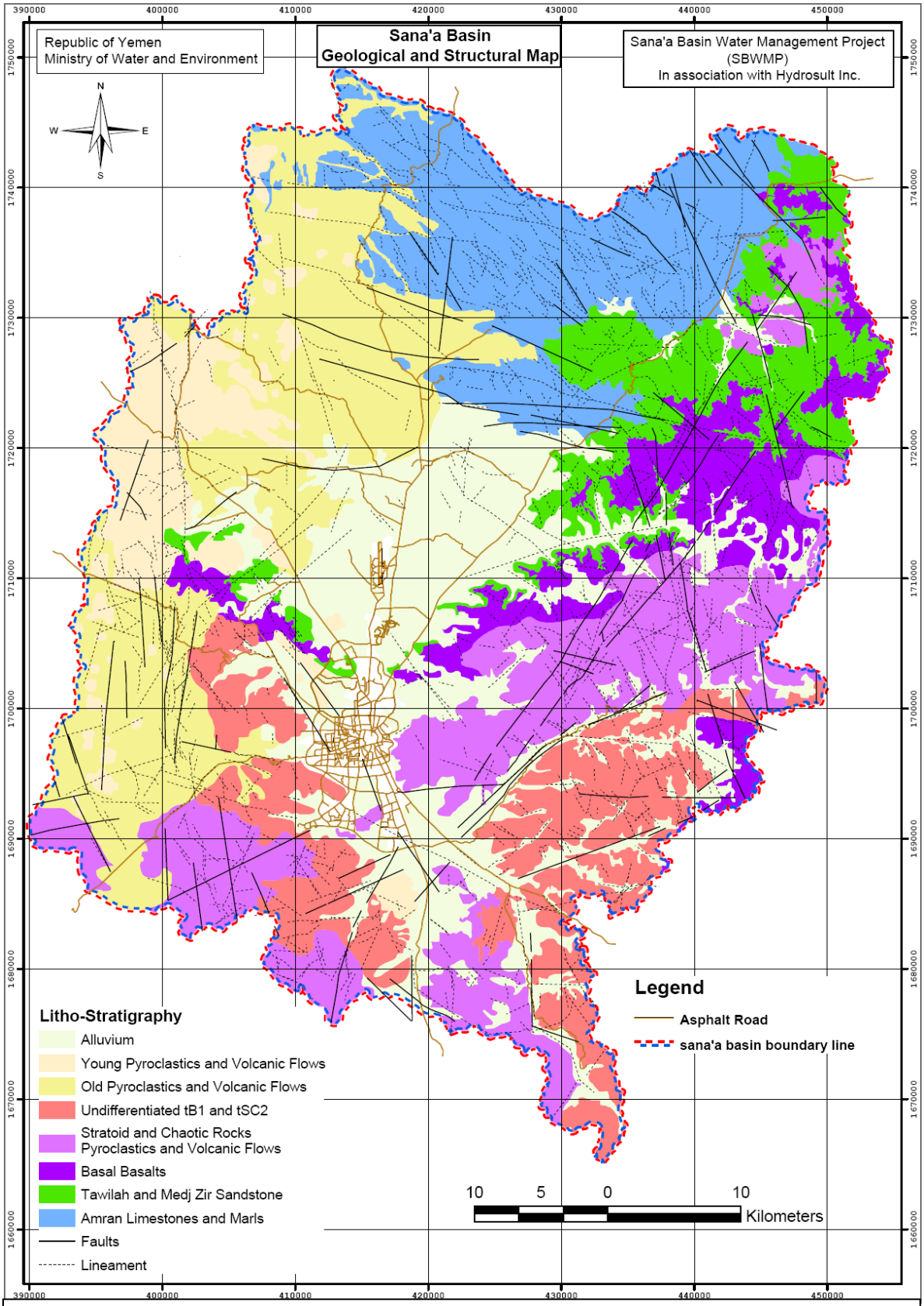

Figure 2: The geologic map of SB (after HYDROsult Inc., 2010)

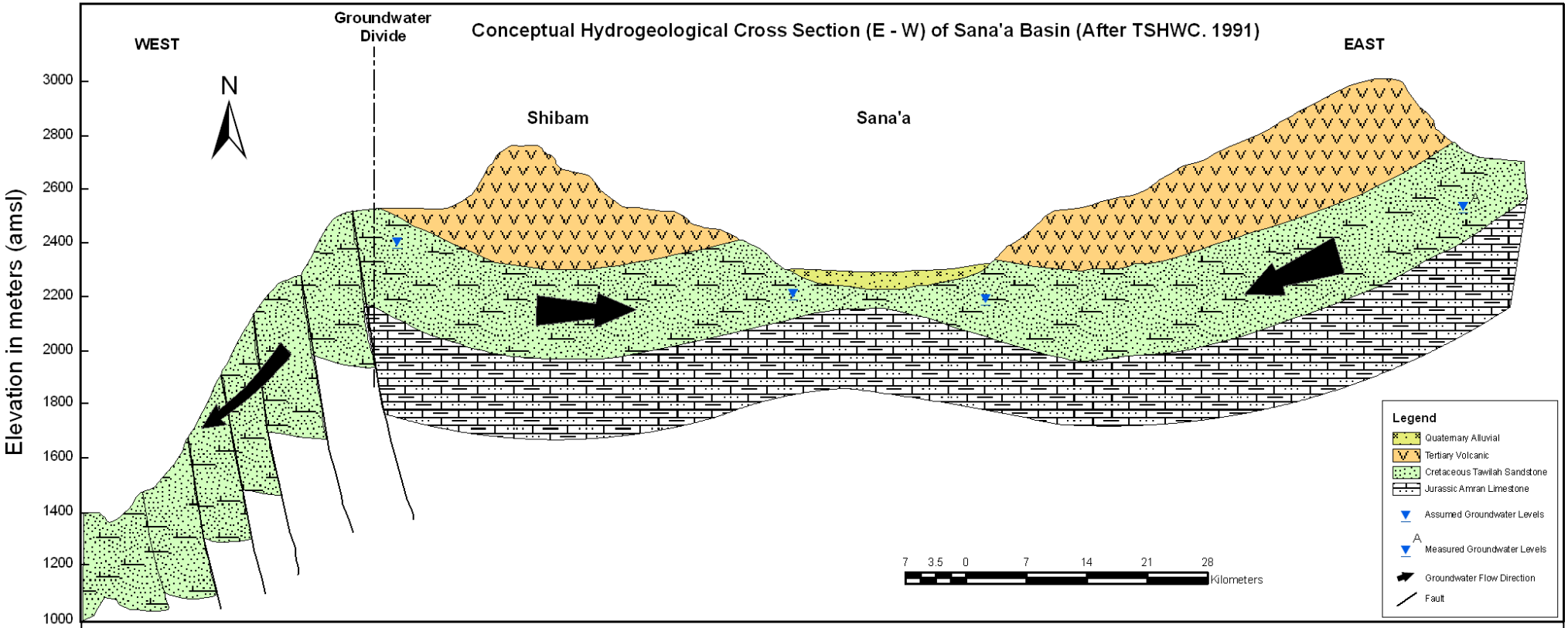

Figure 3: Hydrogeological cross-section of Sana'a basin in East West direction

The Tertiary volcanics act as an aquiclude, except where primary permeability occurs in sediments between flows. It outcrops over about 35% of the area of SB (Foppen, 1996) and the thickness increases rapidly southwards to about 600 m (SAWAS, 1996). The recharge to this aquifer is generally due to infiltration from rainfall and runoff through fractured system.

The Cretaceous Tawilah Sandstone forms the main aquifer in SB. It has low regional permeability, but locally higher permeability is found in weathered and fractured zones. It outcrops over about 15 % of the basin and exposed at Al-Hatarish, Wadi Dhahr, Bani

Hushaish and Nihm areas. The thickness of this aquifer ranges from 300 to 400 m and reaches 500 m in the south, where it has been protected from erosion by the overlying Tertiary Volcanics (Naaman, 2004). The recharge to the shallow zone of this aquifer is generally due to infiltration from rainfall and runoff through fractured system, while the deep zone is non-renewable (HYDROsult 2010).

Groundwater abstraction

Over the past thirty years or so, groundwater extraction in SB has dramatically increased both for agriculture and municipal water supply, and has severely disturbed the balance between natural recharge and use causing a rapid decline in water levels. The volume of groundwater recharge in SB has been subject to great debate and the best estimate is about 100 Mm^3/year. Estimated water use in the year 2000 was 250 Mm^3 (200 to 210 Mm^3 for agriculture, 38 Mm^3 for domestic supplies and 3.5 Mm^3 for industry). The annual deficit is, therefore, estimated at 150 Mm^3/year, leading to a rapid depletion of groundwater storage (WEC, 2004).

Materials and Methods

The data used in this paper were collected through 40 field trips carried out in SB during the period of 2006-2007 under Sana'a Basin Water Management Project (SBWMP) by HYDROsult and NWRA(National Water Resources Authority)-Sana'a branch team. The long term groundwater level records were collected from the library of the Water and Environment Centre (WEC) (Bloemendaal, 1990, 1991, Jica, 1992, Saeed, 1996, WEC, 2004) beside the recent records monitored by the project team work. The methodological approach used in this paper is based on the field measurements and GIS techniques to weight the depletion mapping. The groundwater depletion map indicates the loss in quantity of groundwater stored in the aquifer over a certain period. The depletion map is prepared from groundwater level contour maps of the beginning and the end of a certain period. The groundwater depletion volume (D) in any aquifer can be estimated by the following relation (HYDROsult INC., 2010):

D (m^3) = Aquifer surface area (m^2) * difference in groundwater table (m) * effective porosity.

The total depletion of groundwater in the SB is calculated to be equal to the sum of depletion of the unconfined parts of the Alluvium, Volcanics and Tawilah Sandstone aquifers. The specific yield (the volume of water which can be drained from the aquifer by gravity) of the unconfined parts of these aquifers was estimated. According to SAWAS groundwater model, it approaches 2% and 10% for the Alluvium and Volcanic aquifers respectively. Moreover, ten samples representing 10 members of the two formations of the Tawilah Sandstone aquifer were collected and examined to determine the effective porosity of the Tawilah Sandstone aquifer (Table 1). The determination of the effective porosity was carried out in the Egyptian Petroleum Research Institute Corelab (EPRI CORELAB). Some of the weathered core samples were affected by the high confining pressure in such a manner that their determined effective porosity values were unrealistically high (core samples no. 1, 5, 7, 8 and 9). Accordingly, in the mapping of aquifer depletion, an average value of 7.1% is used for effective porosity, which represents the mean value of effective porosity of both Ghiras and Medj-zir formations (core sample no. 2 & 10 respectively), representative of the Tawilah sandstone group.

Table 1: Effective porosity of different members of the Tawilah Sandstone

Sample No.	Formation	Member	Effective porosity%	Grain density gm/cc
1	Ghiras	Thula	19.1	2.64
2	Ghiras	Thula	7.6	2.64
3	Ghiras	Shibam	13.5	2.63
4	Ghiras	Kawkaban	--	--
5	Medj-zir	Zijan	21.3	2.67
6	Medj-zir	Kura	11.4	2.67
7	Medj-zir	Kura	19.1	2.73
8	Medj-zir	Kura	19.6	2.56
9	Medj-zir	Lahma	17.1	2.66
10	Medj-zir	Lahma	6.6	2.66

Note: Sample no. 4 was not tested. It was unconsolidated & could not sustain confining pressure of 1000 psi.

RESULTS AND DISCUSSIONS

Groundwater depletion in Alluvium aquifer

The Alluvium aquifer is considered to be depleted at the locations of over-pumping. The dried areas in the Alluvium aquifer reached 80.7 km^2 from pre-development until now (1972-2007). Based on the five water table maps developed for the Alluvium aquifer during the years 1972, 1985, 1993, 2001 & 2007, four groundwater depletion maps were constructed (Figures 4, 5, 6 & 7). These maps indicate that, from 1972, pre-development time, until 1985, it is noted that the depleted area covers the eastern wadis, particularly in the southern part (Figure 4). The total depleted area reached 367 km^2 (40% of the total area of the Alluvium aquifer). During this interval, the greatest groundwater depletion depth reached 2.5 m. The deepest increment of groundwater depletion depth, from 1.5 to 2.5 m, covered an area of about 5.8 km^2 and represented 2% of the depleted area. The shallowest increment of groundwater depletion depth,

from 0 to 0.5 m, covered an area of 332 km^2 in the southern part of the Alluvium aquifer, representing 90% of the depleted area. The estimated depleted groundwater volume during this time interval reached 231.55 Mm^3 (Table 2). Moreover, during the years of 1985-2007, depletion of the Alluvium aquifer slightly increased and covered an area of 371.5 km^2 (41% of the aquifer surface area), with an increase of about 5 km^2. During this interval, the greatest groundwater depletion depth reached 3 m. The estimated quantity of depleted groundwater volume during this time interval reached 371.5 Mm^3 (Table 3). The depletion shown in (Figure 5) may be attributed to the low rate of recharge from the western and eastern wadis, as well as the rapid increase in the number of drilled wells. Otherwise, the depleted area was increased during the interval of 1993-2007 (Figure 6). The Alluvium aquifer depletion problem was critical as indicated by the increasing blue colored areas characterized by groundwater depletion depth of 0.5 m in the northern part of the aquifer, particularly at Bayt Al Khawi (Figure 6). This explains the great number of dry hand-dug wells in this aquifer, which was stated in the well inventory of WEC (2004). The total depleted area covered 487.5 km^2, and represents 52% of the aquifer surface area. During this interval, the greatest groundwater depletion depth reached 2.8 m. The estimated depleted groundwater volume in this time interval reached 240.2 Mm^3 (Table 4). In general, during the interval of 1993 - 2007, due to the concentration of wells between Bani A'sim and Al-Ghiras with heavy uncontrolled pumping, the red-colored depleted areas with groundwater depletion depth of more than 3 m appeared in these locations. In addition, the depleted area reached 471.8 km^2, during the period of 1973-2007 (Figure 7), which represents 52% of the total surface area of the Alluvium aquifer. Moreover, the yellow-colored areas (with groundwater depletion depth from 1 to 2 m) appeared in the central part of the northern area of the aquifer, while the critical red-colored areas were only present in southern parts of the aquifer. This may be attributed to the low rate of recharge in the southern aquifer areas, as well as over-pumping in the northern part. The estimated depleted groundwater volume in this time interval reached 470.54 Mm^3 (Table 5).

Table 2: Groundwater depletion volume (Mm^3) in the Alluvium aquifer (1972-1985)

Time interval	Area color (Fig. 3A)	Depleted area (km^2)	Groundwater depletion depth increment, m		Depletion depth, m	Groundwater depletion volume, Mm^3
			From	To		
1972-1985	Red	5.8	-1.5	-2.5	**1**	**14.5**
	Cyan	8.3	-1	-1.5	**0.5**	**12.45**
	Yellow	21.1	-0.5	-1	**0.5**	**21.1**
	Blue	332	0	-0.5	**0.5**	**183.5**
Total depleted water volume, Mm^3						**231.55**

Table 3: Groundwater depletion volume (Mm^3) in the Alluvium aquifer (1985- 2007)

Time interval	Area color	Depleted area	Groundwater depletion		Depletion depth, m	Groundwater depletion volume,
			From	To		
1985-2007	Red	12.2	-2	-3	1	**12.2**
	Yellow	38.5	-1	-2	1	**38.5**
	Blue	320.8	0	-1	1	**320.8**
Total depleted water volume, Mm^3						**371.5**

Table 4: Groundwater depletion volume (Mm^3) in the Alluvium aquifer (1993- 2007)

Time interval	Area color (Fig. 3C)	Depleted area (km^2)	Groundwater depletion depth increment, m		Depletion depth, m	Groundwater depletion volume,Mm^3
			From	To		
1993-2007	Red	15	-1.5	-2.8	0.3	4.5
	Cyan	46.4	-1	-1.5	0.5	23.2
	Yellow	51.5	-0.5	-1	0.5	25.75
	Blue	374.5	0	-0.5	0.5	186.75
Total depleted water volume, Mm^3						240.2

Table 5: Groundwater depletion volume (Mm^3) in the Alluvium aquifer (1972- 2007)

Time interval	Area color (Fig. 3D)	Depleted area (km^2)	Groundwater depletion		Depletion depth, m	Groundwater depletion volume,Mm^3
			From	To		
1972-2007	Red	2.1	-3	-3.4	0.4	**0.84**
	Cyan	35.7	-2	-3	1	**35.7**
	Yellow	100	-1	-2	1	**100**
	Blue	334	0	-1	1	**334**
Total depleted water volume, Mm^3						**470.54**

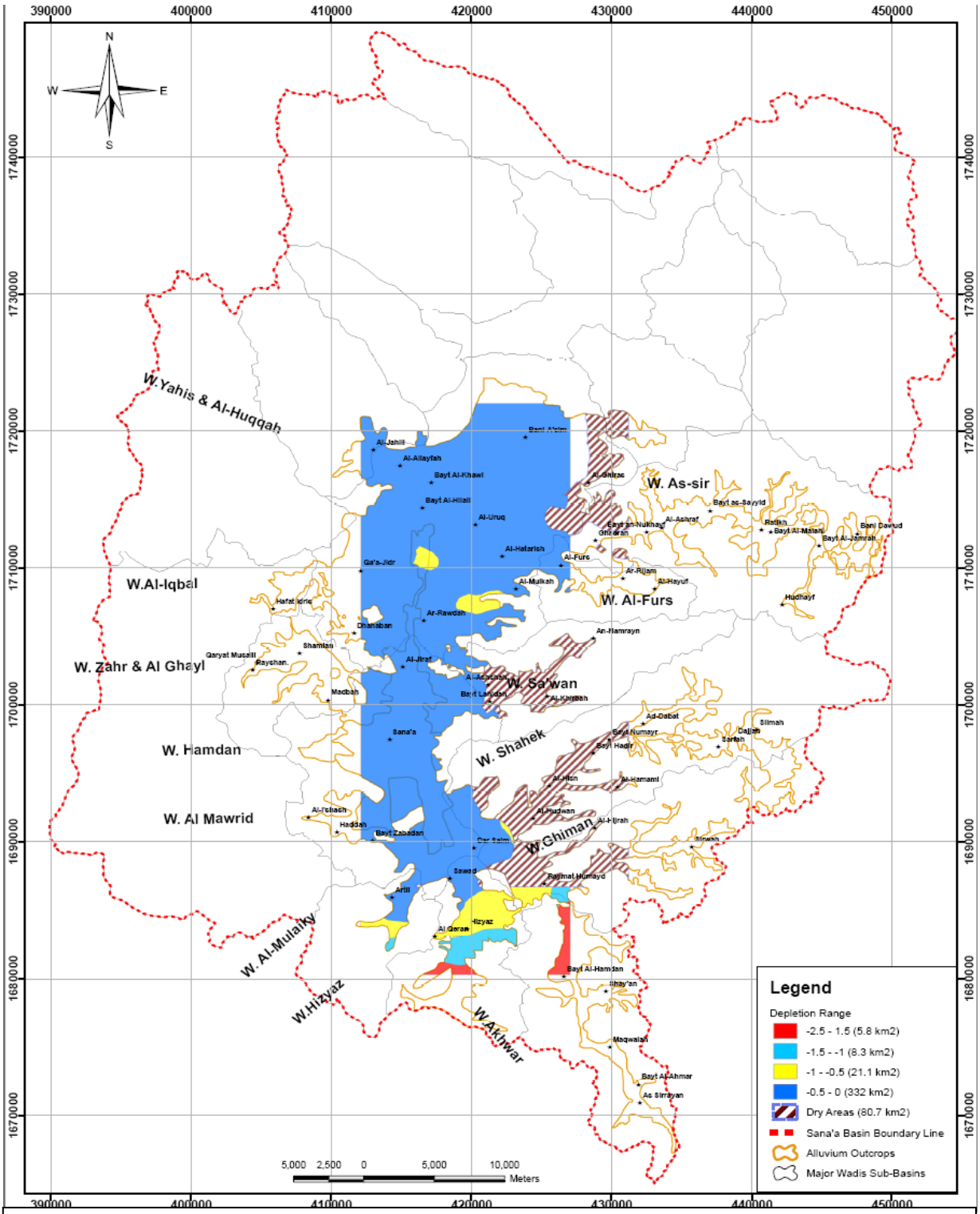

Figure 4: Groundwater depletion zonation map of Alluvium aquifer in SB during 1972-1985

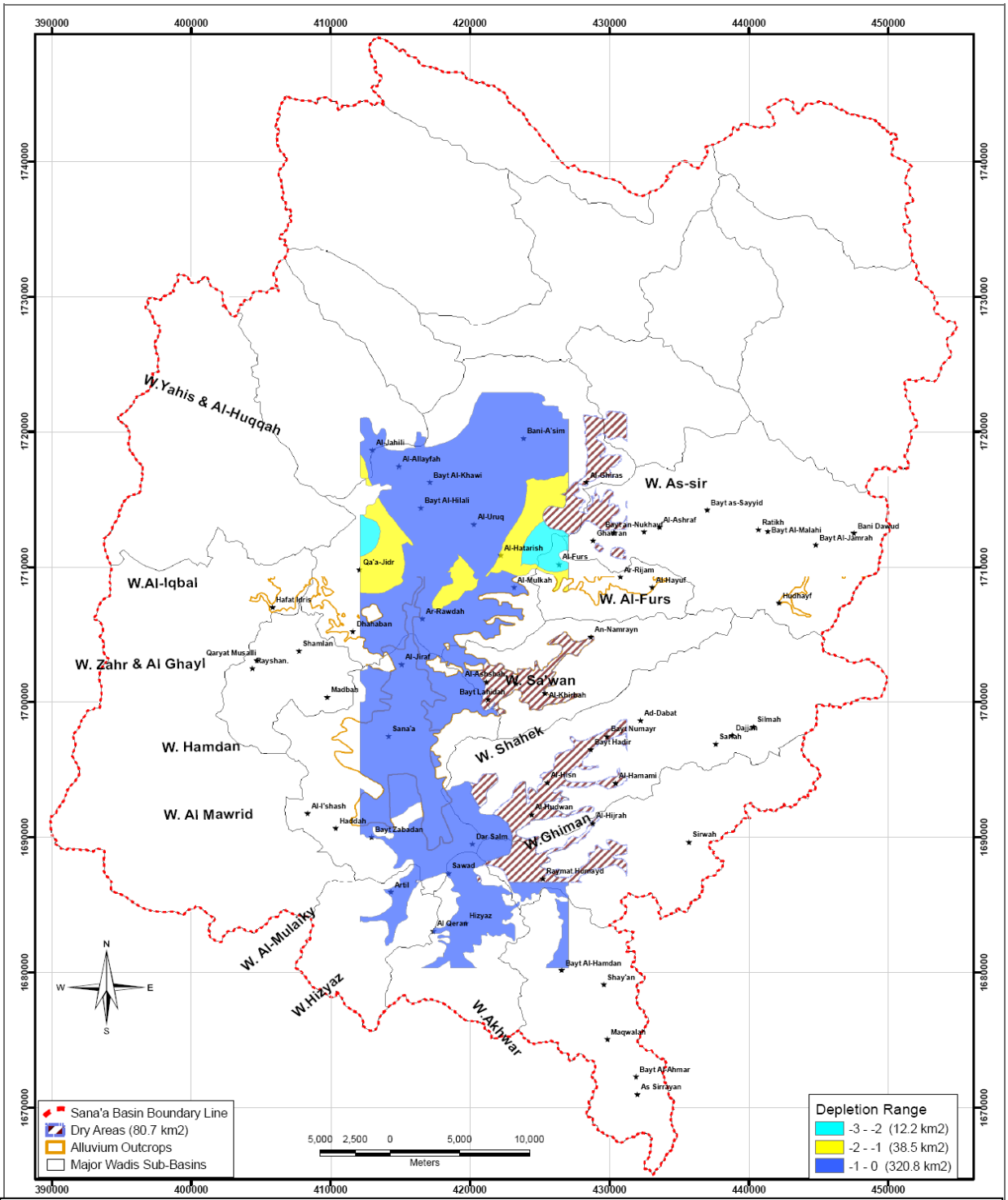

Figure 5: Groundwater depletion zonation map of Alluvium aquifer in SB during 1985-2007

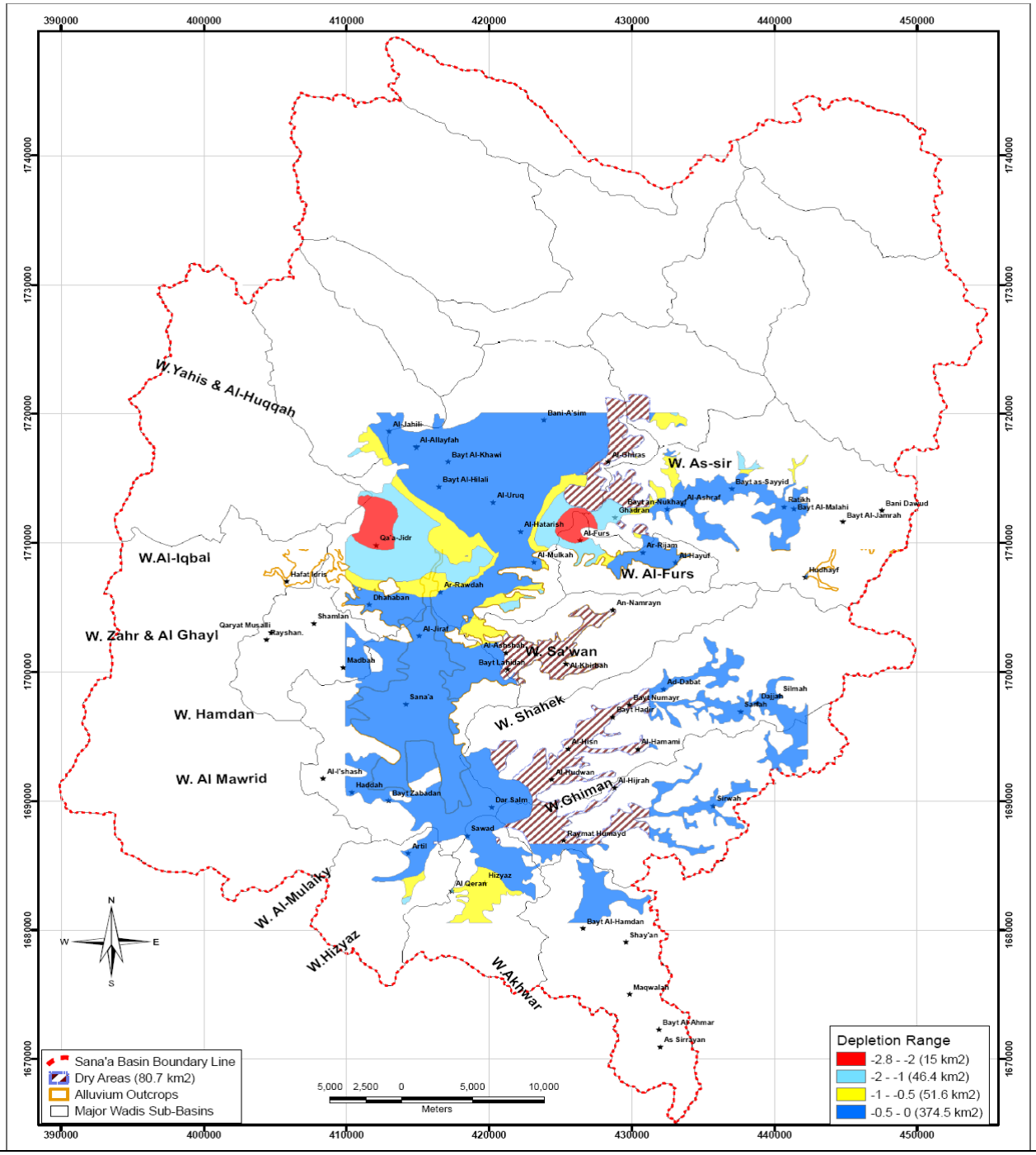

Figure 6: Groundwater depletion zonation map of Alluvium aquifer in SB during 1993-2007

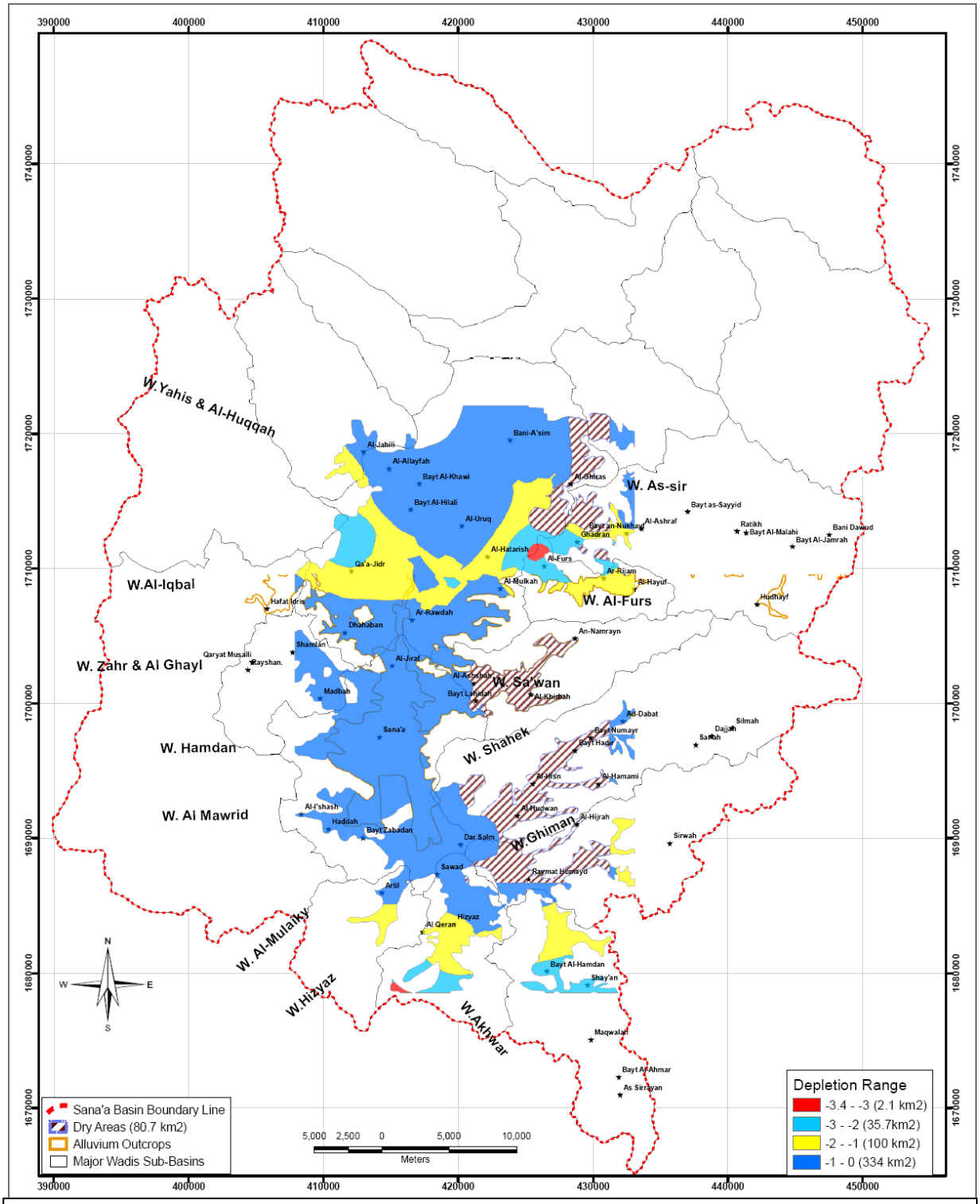

Figure 7: Groundwater depletion zonation map of Alluvium aquifer in SB during 1972-2007

Groundwater depletion in the unconfined Volcanic aquifer:

The outcrops of the Volcanic aquifer cover an area of 1924.3 km^2 or 59.5% of the area of SB (HYDROsult, 2010). Initially, the dried areas of the Alluvium aquifer (80.7 km^2) were considered part of the underlying Volcanic aquifer in estimating the quantity of groundwater depletion from the Volcanic aquifer. The area of the Volcanic aquifer corresponding to the rest of the Alluvium aquifer area was masked to prevent an error resulting from duplication in estimation of the Volcanic aquifer depletion areas. Specific yield of 0.1 was applied for the estimation of the depletion of the outcrops of this aquifer (SAWAS 1995). Based on the three water table maps developed for the Volcanic aquifer during 1985, 1993 and 2007, two depletion mapswere constructed to shed light on the depletion phenomenon in the unconfined Volcanic aquifer in SB during the intervals of 1985-1993 and 1985-2007 (Figure 8). The depletion map of this aquifer (1985-1993, Figure 8) shows that the total depleted area reached 822.4 km^2 (41% of the total area of the Volcanic aquifer plus 80.7 km^2 of the overlay dried areas of Alluvium aquifer). During this interval, the greatest groundwater level decline reached 50 m. The deepest increment of decline, from 35 to 50 m, covered an area of about 35.5 km^2, representing 4% of the total depleted area. The shallowest increment of decline, from 0 to 15 m, covered an area of 601.3 km^2 in the southern part of the Volcanic aquifer, representing 73% of the total depleted area. The estimated depleted groundwater quantity during this time interval reached 1140.80 Mm^3 (Table 6).

Table 6: Groundwater depletion in the unconfined Volcanic aquifer (1985-1993)

Time interval	Area color (Fig. 4)	Depleted area (km^2)	Water level increment, m		Decline depth, m	Specific yield	Depleted water, Mm^3
			From	To			
1985-1993	Red	35.5	-35	-50	15	0.1	53.25
	Cyan	77.3	-25	-35	10	0.1	77.30
	Yellow	108.3	-15	-25	10	0.1	108.30
	Blue	601.3	0	-15	15	0.1	901.95
Total depleted water volume, Mm^3							**1140.80**

In addition, the total depleted area reached 1,267.8 km^2 during the interval of 1985-2007 (Figure 9) (63% of the total area of the volcanic aquifer plus 80.7 km^2 of the overlaid dried areas of Alluvium aquifer). During this time interval, the greatest groundwater level decline reached 51.2 m. The deepest increment of decline, from 35 to 51.2 m, covered an area of about 78 km^2 and represented 6% of the depleted area. The shallowest increment of decline, from 0 to 15 m, covered an area of 779 km^2 in the southern part of the volcanic aquifer and represented 61% of the total depleted area. The estimated depleted groundwater quantity in this interval reached 1705.66 Mm^3 (Table 7).

Table 7: Groundwater depletion in the unconfined Volcanic aquifer (1985-2007)

Time interval	Area color (Fig. 4)	Depleted area (km^2)	Water level increment, m		Decline depth, m	Specific yield	Depleted water, Mm^3
			From	**To**			
1985-2007	Red	78	-35	-51.2	16.2	0.1	126.36
	Cyan	81.2	-25	-35	10	0.1	81.20
	Yellow	329.6	-15	-25	10	0.1	329.60
	Blue	779	0	-15	15	0.1	116.85
Total depleted water volume, Mm^3							**1705.66**

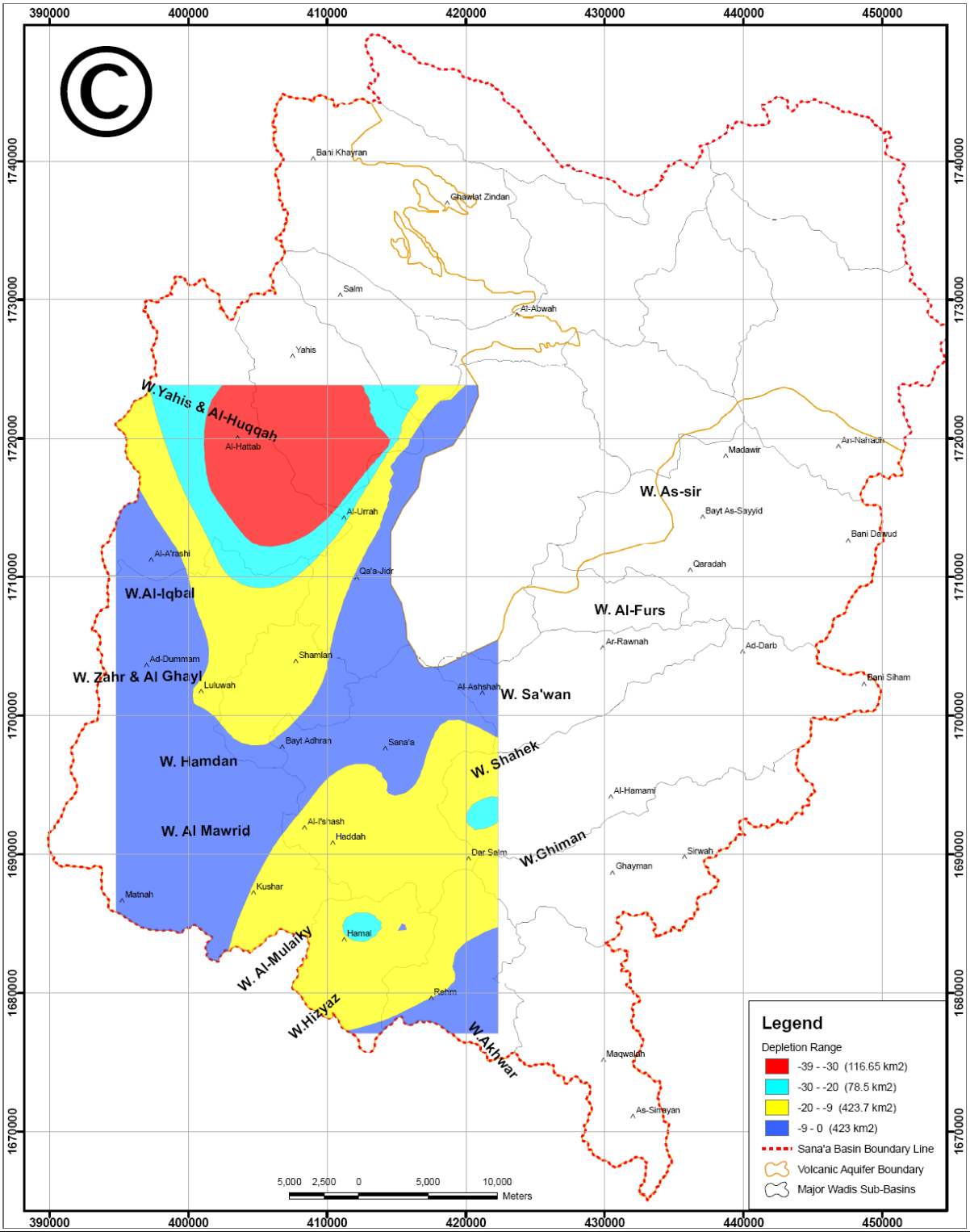

Figure 8: Groundwater depletion zonation map of Volcanic aquifer in SB during 1972-2007

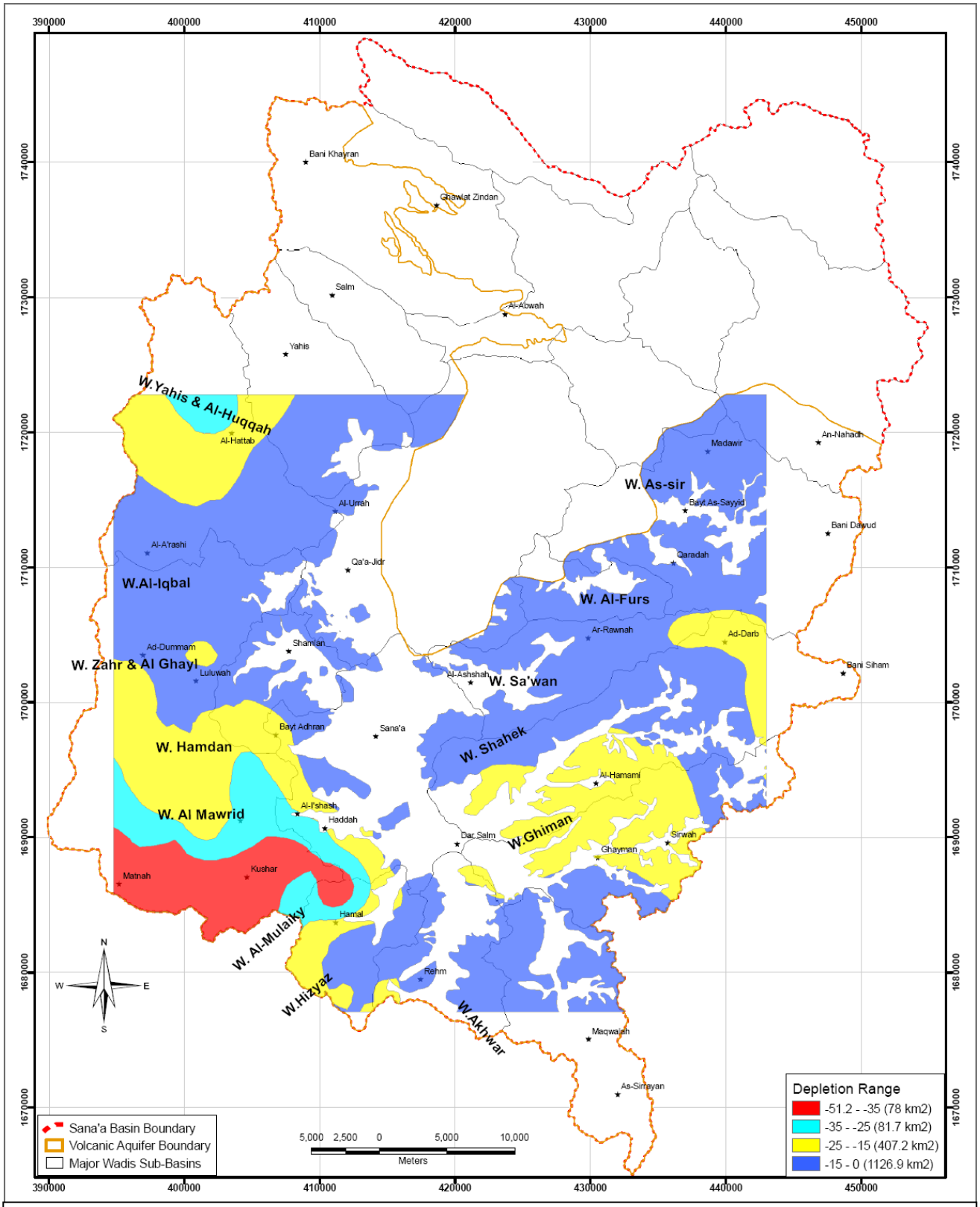

Figure 9: Groundwater depletion zonation map of Volcanic aquifer in SB during 1985-2007

The outcrop of the Tawilah sandstone aquifer covers 270.968 km^2 which represents 7.67% of the area of SB (HYDROsult, 2010). The depletion mapping of the unconfined outcrops was based mainly on the available data surveyed during the interval of SBWMP project in the eastern outcrops of this aquifer, due to scarcity of monitoring well and groundwater level data. In addition, the southern part of the Tawilah sandstone aquifer has no hydrogeological data since it is buried under thick cover of the Tertiary Volcanic group.

Table 8: Groundwater depletion in the unconfined Tawilah sandstone aquifer (1993-2001)

Time interval	Area color (Fig. 9)	Depleted area (km^2)	Water level decline, m		Decline depth, m	Specific yield	Depleted water, Mm^3
			From	To			
1993-2001	Cyan	0.1	70	100	30	0.071	0.21
	Yellow	9.7	28	70	42	0.071	28.92
	Blue	24.1	0	28	28	0.071	47.91
Total depleted water volume, Mm^3							**77.04**

Available groundwater level data enable construction of the groundwater depletion map of the Tawilah sandstone aquifer during the interval of 1993-2007 (Figure 10). It is noticed from the figure that the depleted area covers the eastern side only due to a lack of data for the western side during this interval. The total depleted area reached 33.9 km^2 (22% of the total area of the outcrops of the Tawilah sandstone aquifer). During this interval, the greatest groundwater level decline reached 113 m (corresponding to depletion contour line of -8) and covered an area of about 0.1 km^2 of the depleted area (0.3% of the depleted area). The lowest decline of groundwater level reached 42 m (depletion depth of 3m) and covered an area of 33.6 km^2 in the southern part of the outcrops of the Tawilah sandstone aquifer (99% of the total depleted area). The estimated depleted groundwater quantity in this interval reached 101.01 Mm^3 (Table 9).

Table 9: Groundwater depletion in the unconfined Tawilah sandstone aquifer (1993-2007)

Time interval	Area color (Fig. 10)	Depleted area (km^2)	Water level decline, m		Decline depth, m	Specific yield	Depleted water, Mm^3
			From	To			
1993-2007	Cyan	0.1	85	113	28	0.071	0.20
	Yellow	0.2	42	85	43	0.071	0.61
	Blue	33.6	0	42	42	0.071	100.20
Total depleted water volume, Mm^3							**101.01**

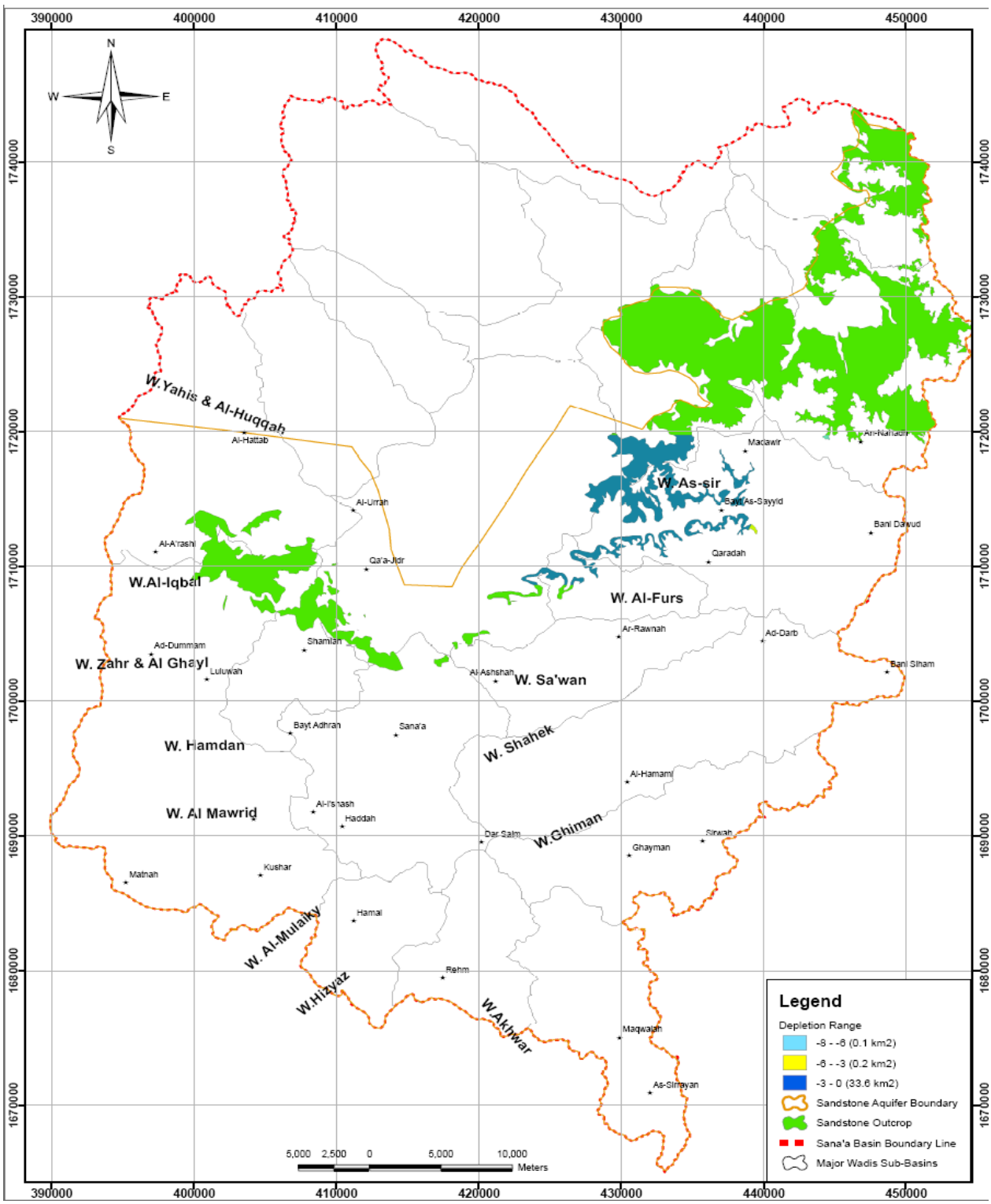

Figure 10: Masked groundwater depletion zonation map of the unconfined Tawilah sandstone aquifer in SB during 1993-2007

Accordingly, a trial was made to check the depletion mapping in certain periods without and with applying the masking process, respectively (HYDROsult Inc., 2010) (Figure 11 and 12). The masking process means that the dried areas of the Alluvium aquifer are considered part of the underlying Tawilah sandstone aquifer in estimating the quantity of groundwater depletion from the Tawilah sandstone aquifer. The area of the Tawilah sandstone aquifer corresponding to the rest of the Alluvium aquifer area was masked to prevent error resulting from duplication in estimation of the Tawilah sandstone aquifer depletion areas. The depletion areas in the case of non-masked map (Figure 11) were estimated to be 137.4 km^2 for depletion depth from 0 to 2 m (that corresponds to groundwater level decline between 0 and 28 m, applying the average specific yield value of 0.071); 71.9 km^2 for depletion depth between 2 and 5 m (water level decline between 28-70 m); 27.5 km^2 for depletion depth from 5 to 7 m (groundwater level decline between 70-100 m); and 24.9 km^2 for depletion depth between 7 and 9.9 m depths (groundwater level decline between 100 and 141 m). These areas are marked in Fig. 5 by blue, yellow, cyan and red colors, respectively. After masking is applied to the aquifer outcrops, the areas of depletion were recalculated to be 24.1 km^2 for depletion depth from 0 to 2 m, 9.7 km^2 for depletion depth of 2 to 5 m, and 0.1 km^2 for depletion depth from 5 to 7 m respectively. The depletion depth between 7 and 9.9 m has disappeared from the masked map (Figure 11). From the above mentioned comparison, it was concluded that the masking process is essential for obtaining an accurate estimation of groundwater depletion values. Based on this assumption and on the processed data available for the periods of 1993-2001 and 1993-2007, two masked depletion maps were constructed (Figure 11 and 12). During the interval of 1993-2001 (Figure 11), the total depleted area of groundwater of Tawilah sandstone aquifer reached 39.9 km^2. The moderately depleted areas, from 0 to 2 m depth (groundwater level decline between 0 and 28 m), cover 24.1 km^2 and occupy 71% of the total depleted area. The total volume of water depleted during the interval 1993-2001 is estimated to be 77.04 Mm^3 (Table 12).

Summary and Conclusion

The groundwater in SB has been in depletion since abstraction volumes increased to volumes greater than recharge volumes. Estimates of the depletion were made based on the groundwater level maps in the present three aquifers. The specific of the unconfined parts of these aquifers was estimated. According to SAWAS (1996), it approaches 2% and 10% for the Alluvium and Volcanic aquifers respectively and, 7.1 % for Sandstone aquifer as determined from porosity of 10 rock samples representing the different members of the two main formations of Tawilah sandstone aquifer. Observation of the groundwater levels shows that the water table has declined, in case of Alluvium aquifer, by maximum value of 34 m since 1973, or more than 100 m in eastern areas, where the aquifer has dried. For the Volcanic aquifer, the maximum decline reached 51.2 m since 1985, while it reached 141 m since 1993 in case of Tawilah sandstone aquifer. The summary of the historical groundwater depletion estimated in the three studied aquifers is tabulated in Table 10. The maximum depletion quantity of Alluvium aquifer reached 618.8 MCM (during 1993-2001), which reflects the uncontrolled drilling of wells, which led to dryness conditions in the peripheries areas of this aquifer in this interval. In the same time, the Volcanic aquifer has been affected by the dryness condition of the Alluvium aquifer and its

water storage loss reached 1.705 km^3. The depletion in the Tawilah sandstone aquifer, during the same period reached 101.6 Million m^3. This critical situation of groundwater depletion requires a trial to maximize the recharge to these depleted aquifers from rain water harvesting in the highly fractured areas. Controlling of abstraction and changing in cropping pattern is highly recommended.

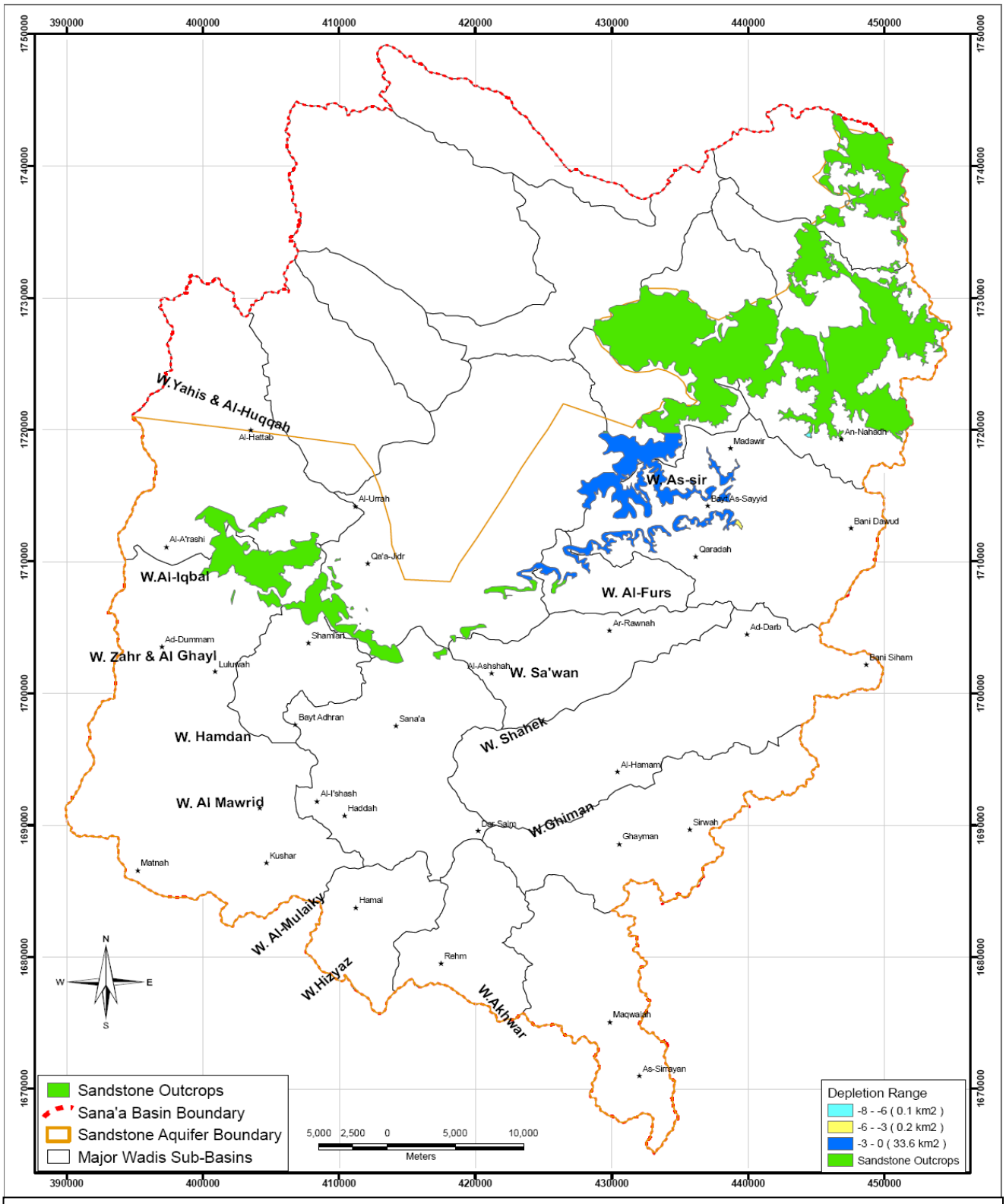

Figure 11: Masked groundwater depletion zonation map of the unconfined part of the Sandstone aquifer in SB during 1993-2001

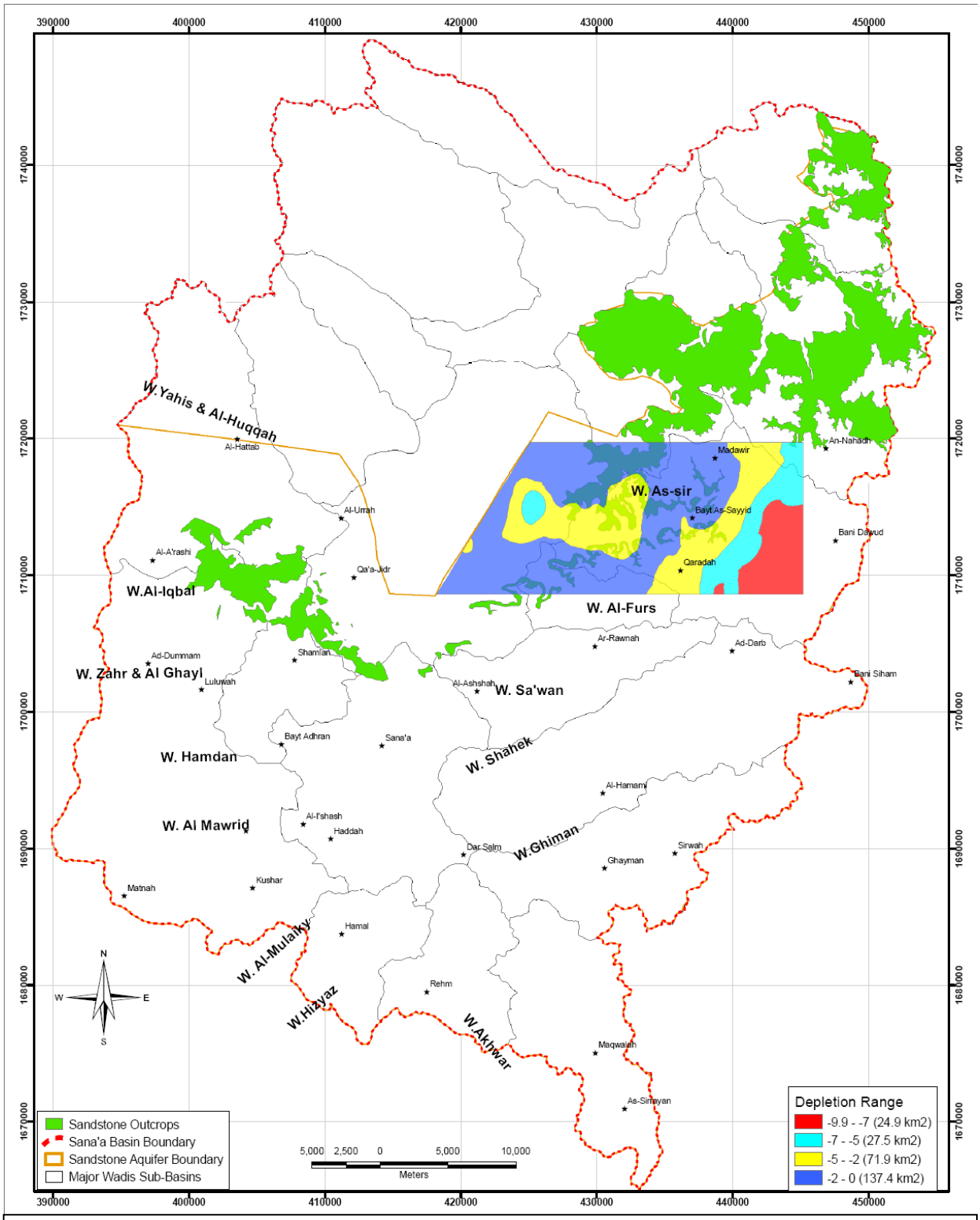

Figure 11: Non-masked groundwater depletion zonation map of the unconfined part of the Sandstone aquifer in SB during 1993-2001

Table 10: Summary of groundwater depletion volumes in SB

Time period	Groundwater depletion volume, Mm^3			
	Alluvium aquifer		Volcanic aquifer	Tawilah sandstone aquifer
	With dried	Without dried		
1973-1985	231.55	---	---	---
1985-1993	---	---	1140.80	---
1993-2001	---	618.8	---	77.5
2001-2007	---	478.64	---	---
1973-2007	470.54	550.83	---	---
1985-2007	371.5	---	1705.66	---
1993-2007	240.2	313.15	---	101.6

Acknowledgements

The data of this work were presented from the SB Water Management Project (SBWMP). Assistance from project team work of HYDROSULT, WEC, and TNO are gratefully acknowledged. We thank the Chairman of NWRA-Sana'a Branch and his team work for the use of their data and their support and cooperation.

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SESSION 4:
DESALINATION MANAGEMENT

Keynote: Adil A. Bushnak, Bushnak Group and Moya Bushnak, Sustainable Desalination in the Arab Countries: Prospects & Challenges

Dr. Adil A. Bushnak

He is the Chairman of Moya Bushnak and also the chairman of Bushnak Group which has several companies active in water, environment and energy related technologies and services headquartered in Jeddah, KSA. Dr. Bushnak was actively involved in the establishment of WSTA as well as "IDA" and was later elected its first Arab President for the period 1987-1989. He founded the Saudi Water & Power Forum and serves as is its chairman. He also co-founded Sarajevo Business Forum and serves as the Honorary Counsel General of Bosnia & Herzegovina in Jeddah. In addition, he served as a Director of Jeddah Chamber of Commerce & Industry and co-founded many NGO's. He earned a Ph.D. in Civil Engineering from the University of Michigan.

Abstract:

The role of desalination for water security in GCC countries will continue to increase which requires a comprehensive review of present policies and old practices for a key source of water to be sustainable with minimum economic and social impact. All new desalination plants must be run by renewable energy because the cost of water will be much cheaper for future generations and more fuel can be exported rather than burned for free. Programs to convert existing plants to be based on RE must also be implemented soon. GCC countries should be a global hub for RE technology and industry. What is the role of public & private sectors to meet these challenges? What is the role of R&D and training centers? How can we make desalination a driver for economic and social transformation?

Keynote: M. Taniguchi, TORAY, Japan, High performance RO membranes and membrane system for high concentration seawater desalination

MASAHIDE TANIGUCHI is an assistant general manager of Water Treatment & Membrane Technical Dept., TORAY Industries in Japan. He took his Master Scholarship of Chemical Engineering from University of Tokyo in 1991. Then, he entered Toray Industries and has been engaged in R & D of the membranes, modules and the water treatment technologies using membranes until 2004. During that period, he also studied the membrane modification for water treatment as a visitor at Rensselaer Polytechnic Institute for two years. From 2004 to 2007, he was a chief process engineer especially for seawater desalination at Water Treatment System Dept. Now, he is managing the development of the various membrane (MF, UF, NF, RO) related processes for water treatment as seawater desalination, drinking water production and wastewater treatment and reuse.

Abstract:

Reverse osmosis (RO) membrane is one of the most innovative desalination technologies to solve the global water shortage, especially in the Middle East. However, many areas of the Middle East face on the Arabian Gulf, where the TDS concentration is extremely high, the temperature variation is large, and the biological activity is large due to the temperature and the shallow and closed waters.

For this purpose, Qatar Electricity & Water Company (QEWC) and Water Re-use Promotion Center (WRPC) of Japan conducted the joint challenge to operate continuously SWRO plant, 200 m^3/day, with highly saline seawater at Dukhan, Qatar, from 2005 to 2009. This plant consisted of sand filtration followed by the ultra-filtration (UF) as pre-treatment process, and seawater RO (SWRO), Toray's TM820H-400, followed by pure water RO with permeate circulation process for boron removal. As a result of this challenge, the plant was successfully operated including ultra-filtration and SWRO without bio-fouling.

During and after the challenge above, Toray had been developing variation of high performance SWRO membranes for various characteristics of seawaters in the world by utilizing Toray's membrane polymer design technologies, fiber and textile technologies for the support layer, and the new analytical technologies such as positron annihilation lifetime spectroscopy (PALS) and Transmission electron microscope (TEM). For the desalination in the Middle East, the new innovative SWRO membrane element, designated TM820K-440 with excellent salt rejection performance, average of 99.86% (99.75% for TM820H-400), was developed. It also showed large water productivity of 6,400 gpd (6,000 gpd for TM820H-400) at standard condition, and boron rejection of this membrane element has reached 96 %. The rejecting performance is the

highest level among commercialized SWRO membrane elements, and it can achieve highly improved product water quality and operating cost.

Keywords
Desalination; energy saving; reverse osmosis; seawater; water quality

Inland Desalination with Zero Liquid Discharge: Prospective, Challenges, and Recent Developments.

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Abstract

Groundwater is the main water source for drinking, industrial, and agricultural use in many countries worldwide. In the absence of surface water supply, the use of groundwater becomes essential, especially in the case of rural communities. Underground reservoirs constitute over 95% of the total fresh water available for human use. Typical groundwater supplies have low coliform and total bacterial counts, low turbidity, clear color, pleasant taste, and low odor. Accordingly, groundwater has higher quality than surface water, and the quality is quite uniform throughout the year that makes it easy to treat. A disadvantage of groundwater supplies is that groundwater aquifers may have moderate to high concentrations of dissolved solids because of seawater intrusion and other human activities that makes water brackish. This in turn has led to extensive use of desalination systems to produce good quality water from brackish groundwater. Clearly, any desalination process produces high quality product water and a reject concentrate (brine) that must be disposed of properly. The reject brine from desalination plants not only contains high concentrations of salts but it also contains other chemicals such as pretreatment chemicals (antiscalents, antifouling, etc). In addition, any other harmful components such as heavy metals will be concentrated in the reject brine, so improper disposal of reject brine from inland desalination plants results in several environmental problems. The management of brine from inland desalination plants can be a significant problem in case they are placed far from the coast. Options for brine disposal from inland desalination plants are deep well injection, evaporation ponds, disposal into surface water bodies, disposal to municipal sewers, and irrigation of plants tolerant to high salinities. Nevertheless, theses alternatives have economic and/or environmental drawbacks that make them unsuitable options in most cases. Therefore, the need for affordable inland desalination has become critical in many regions where communities strive to meet rapidly growing water demands with limited freshwater resources. Zero Liquid Discharge (ZLD) Desalination is an attractive alternative for inland desalination. In ZLD, concentrate is treated to produce desalinated water and essentially dry salts; consequently there is no discharge of liquid waste from the process. The advancement of ZLD science and associated reduction of ZLD costs will be of tremendous benefit and will alleviate the water supply challenges faced by many communities worldwide. This article reviews prospective, current trends, challenges, and recent developments in inland desalination and brine management alternatives with emphasis on ZLD.

Keywords: inland desalination, brine management, zero liquid discharge, reverse osmosis

1. Groundwater Resources.

Water resources present naturally in the environment can be generally divided into freshwater and saline water according to the amount of dissolved solids it contains. Quality and quantity of different water resources are of high importance. Information on the quantity of major water resources on Earth is present in Table 1.

Table 1. Estimates of major water resources on Earth [1].

Water Resource	Volume, (1000 km^3)	Percent of total water	Percent of total fresh water
Saline water:			
Oceans/seas	1,338,000	96.54	-
Saline/brackish groundwater	12,870	0.93	-
Saltwater lakes	85	0.006	-
Freshwater:			
Glaciers and permanent snow covers	24,064	1.74	68.70
Fresh groundwater	10,530	0.76	30.06
Fresh lakes	91	0.007	0.26
Wetlands	11.5	0.001	0.03
Rivers	2.12	0.0001	0.006

Freshwater is naturally found on Earth's surface and in underground aquifers, and mainly characterized by low content of dissolved solids. These water sources are considered to be renewable resource, by effect of natural water cycle. Fresh groundwater is the water located under the Earth's surface i.e. subsurface water which is mainly located in pores or spaces of soil and rocks or in aquifers below the water table. In many regions, groundwater contains high content of dissolved salts compared to that of surface water; with salinity level around 500-2,000 mg/L, however brackish groundwater is characterized by its higher salinity than that of fresh groundwater with values of 2,000-10,000 mg/L [2] and is mainly present in aquifers that are much deeper.

The majority of world population use surface water or groundwater as the main source for domestic, agriculture, and industrial water supplies. The common groundwater sources are pumped wells or flowing artesian wells. In absence of surface water supply, it is clear that the use of groundwater becomes essential especially in the case of rural communities. Underground reservoirs constitute a major source of fresh water, in terms of storage capacity; they contain over 95% of the total fresh water available for human use.

2. Groundwater Quality.

Pure water is a colorless, odorless, and tasteless liquid. Water is strong polar solvent capable of dissolving many natural and synthetic substances, of inorganic and organic nature. In addition, it is able to suspend many solids, and hence it is very hard to be found pure in nature. The quality of groundwater is mainly determined by its content of dissolved solids and gases. Usually the nature and concentration of dissolved solids present in the groundwater source will depend on

characteristics of the aquifer and on travelling time or velocity of groundwater flow through the rock formation [3].

Typical groundwaters, as they undergo natural filtration while passing through sand formations, have very low suspended solids content, low turbidity, clear color, pleasant taste, and low odor. However, while water is travelling through the soil formations, groundwater may carry dissolved solids if the soil formations are relatively soluble. The type and concentration of dissolved solids released from soil to groundwater may vary based on the soil composition, travelling time and flow velocities. Groundwaters in general have higher hardness when compared to surface waters. This is mainly due to the dissolution of limestone and dolomite formations. Living organisms present in water such as microbes are generally absent from groundwater due to natural filtration, and hence groundwater has low coliform and total bacterial counts.

In general groundwater has higher quality than surface waters, and the quality is quite uniform throughout the year making it easy to treat. However, groundwater may contain moderate to high dissolved solids. The high concentration of dissolved solids makes the water brackish and the removal of such dissolved solids requires use of desalination process to treat the water to a level of dissolved solids that makes it suitable for a certain use.

3. Brackish Groundwater Desalination.

Technical and economical evaluations of desalinating groundwater have started early in 1960s. The first major brackish groundwater desalination plants was built in Florida, USA with capacity of 2.62 mgd, followed by another one using RO in mid-1970s with capacity of 0.5 mgd [4]. A combination of field investigations and computer simulation modeling were used to assess the economic suitability of using highly brackish groundwater for large scale abstraction for feeding reverse osmosis desalination plant in many countries around the world and specifically in the Arabian Gulf Countries, which showed that brackish groundwater can be considered as high quality source of feedwater for desalination plants [5-8].

The major misconception of considering that the groundwater quality is relatively stable over time is very critical for design purposes. The groundwater quality tends to show salinity increase with time, and hence the initial and future groundwater qualities should be considered [8]. The deteriorating quality of groundwater is becoming of high concern globally; this deterioration is mainly due to human activities such as over abstraction and seawater intrusion. The seawater intrusion is a very common problem worldwide especially, in near coastal areas. It is a natural phenomenon in which saline water from sea or ocean moves into the fresh groundwater in coastal aquifers resulting in salinity increase [10, 11].

Desalination of seawater and brackish water has become a reliable method for water supply all-over the world and had been practiced successfully for many decades. The worldwide desalination capacity increased dramatically from around 35 million m^3/d in 2005 [12] to about 60 million m^3/d by 2009 [13]. Desalination in general can be classified according to the feed water source into seawater and brackish groundwater desalination. In 2006 around 56 % of the world desalination capacity was for seawater desalination, and 24 % for brackish water [12]. Desalination processes are many and can be classified according to the technology used, mainly as thermal and membrane desalination. The common processes for desalination have been changed from expensive techniques with extensive energy requirements to a sustainable method

for drinking water supply. The selection of desalination process for a certain purpose depends on several factors, such as source water and quality, energy cost, final water quality, fouling propensity, temperature, and overall process cost. Table 2 shows the worldwide, US, and Gulf Corporation Council GCC desalination capacity by process type.

The desalinated water quality differs from process to another, with thermal desalination producing very high quality product water with salinity about 2-10 mg/L [14]. However for membrane process the quality of product water depends on many factors such as feedwater quality, design recovery, and membrane properties, but generally the product water will have higher salinity than that produced from thermal desalination.

Table 2. Desalination capacity distribution according to process type [12].

Process Type	Worldwide	United States	GCC Countries
RO	46	69	28
MSF	36	1	54
ED	5	9	-
VC	5	3	-
MED	3	1	9
NF	-	15	-
Others	5	2	9

The final water product quality depends on the application in which it is to be used for, ranging from very high quality for process water to specified quality as per the regulation for drinking water. Drinking water standards vary slightly from country to another with the most widely used is the United States Environmental Protection Agency US-EPA drinking water standards with 500 mg/L for total dissolved solids [15]. However the World Health Organization WHO guidelines for drinking water quality suggest total dissolved solids of 600-1,000 mg/L to be acceptable [16]. On the other hand the Food and Agriculture Organization, FAO suggests a total dissolved solids up to 2,000 mg/L is acceptable for irrigation purposes [17].

In desalination, thermal technologies were the only viable option for long time and have provided the major portion of the world's desalination capacity. Thermal desalination is usually used for cases where high salinity feed waters are used i.e. seawater, high recoveries are required, high feedwater temperature, and low energy cost. However, the main drawback is the extensive energy consumption [18]. On the other hand, growth of membrane science allowed membrane desalination to overtake thermal desalination as the leading desalination technology. Membrane desalination in general and commercial RO in particular have been undergoing appreciable development. Important factors in the expansion of RO applications are their favorably low power requirements and continuous technical improvements in membranes. RO was first applied to brackish groundwater with first large scale plants in the late 1960s. A decade later, RO membrane is suitable for seawater desalination and becomes a strong competitor to conventional thermal desalination by the 1980s [19].

Reverse Osmosis (RO) Membrane Desalination.

Osmosis is a natural physical process, where the solvent (i.e. water) moves through semi-permeable membrane (i.e. permeable to solvent and impermeable to solute) from low solute to higher solute concentration creating differential pressure called osmotic pressure, which depends mainly on the concentration difference, temperature, and nature of solute. The process continues till the hydraulic pressure difference is equal to the osmotic pressure. In reverse osmosis RO, hydraulic pressure with value greater than that of osmotic pressure is applied to the concentrated solution, resulting in reversing the osmosis process and in net solvent or water flow from the concentrate to the dilute solution [20]. RO membranes do not have a distinct pore that traverses the membrane. It consists of polymeric material forming a layered, web-like structure characterized by high rejection of about 99 % to most of the dissolved solids present in water [21]. The driving force for RO process is the applied hydraulic pressure which varies considerably from 15-25 bars for brackish water to 60-80 bars for seawater [20].

Nanofiltration (NF) Membrane Desalination.

The Nanofiltration NF term was first introduced by FilmTech in the 1980s to describe membranes that allow selectively and purposely some ionic solutes to path through the membrane. The membrane's selectivity was towards solute of about 1 nm cutoff, and hence the term nano comes from [22]. Nanofiltration is an intermediate between RO membranes and ultrafiltration membranes [23]. NF membranes have permeability for monovalent ions and very low permeability to multivalent ions and organics [24], As a result, NF membranes were used mainly for removal of hardness and natural organic matter, as pretreatment before RO and MSD for seawater desalination [25], and for groundwater quality enhancement [26-29]. Nanofiltration membranes operate in a similar fashion to that of RO membranes, except of lower driving pressure and hence lower energy requirements, higher flowrates, and lower product water quality [30].

There are many other desalination processes that are available today, some of which are still at the research and development stages. These processes include Electrodialysis/Electrodialysis Reversal ED/EDR, Forward or direct Osmosis FO, solar, ion-exchange, freezing, and membrane distillation. These processes may have promising features over the currently used desalination processes such as less corrosion and scaling problems, less energy consumption, and less need for pre and post treatment.

4. Scaling and Fouling in Desalination Process.

Fouling is a phenomenon that plagues the operation of desalination units. The deposition of foulants on mass transfer surface (in case of membrane desalination) results in reducing water productivity and quality, therefore as the fouling deposit builds up, the energy consumption increases to accommodate for the required product flow till the unit is cleaned [31, 32]. Fouling of membrane surface can be caused by any of the rejected constitutes, and can be generally classified into 1) chemical fouling or scaling caused by sparingly soluble inorganic salts exceeding their saturation level, 2) physical or colloidal fouling caused by particulate matter, 3) biological fouling or biofouling due to the formation of biofilms of microorganisms, and finally 4) organic fouling caused by natural organic matter (NOM) [20].

Brackish groundwater has high quality as it is mainly characterized by low suspended solids, low bacterial count, and low organic matter content. Therefore, the most found type of fouling in this case is scaling by sparingly soluble inorganic salts. The general approach to avoid scaling and fouling by sparingly soluble salts, is to estimate the saturation level of these salts according to the feed water quality, design recovery, and operation conditions and try to operate below such saturation levels where the solution is stable[32].

The dissolved solids present in groundwater results from chemical weathering or dissolution of geological formations i.e. minerals which can be attributed to the direct contact of groundwater with the calcium carbonate, and calcium sulfate rocks. In addition sulfate may result from biological oxidation of reduced sulfur species. As a result the different aspects of scaling by calcium sulfate and calcium carbonate have been intensively studied [33-35].

Silica originates from the dissolution or chemical weathering of amorphous or crystalline SiO_2 and major clay minerals [36]. Crystalline silica has a very low solubility in water, however amorphous silica can have solubility up to 120 mg/L at pH 7 [37, 38]. Silica in water can be classified into 1) soluble or dissolved silica which contains monomers, dimmers, and polymers of silicic acid, and 2) insoluble or colloidal silica, which results from high polymerization of silicic acid. Due to its severe effect on membrane desalination performance and lifetime of membranes, great attention has been paid to silica fouling [39-42].

The primary goal of pretreatment is to lower fouling propensity during desalination process, and pretreatment depends mainly on the water resource quality [18]. Scale inhibitors or antiscalents are chemicals that are added to water during pretreatment to prevent scale formation and usually work synergically with dispersant polymers. However, most traditional antiscalents are successful in scale control for crystalline mineral precipitates but not silica because it is amorphous [43].

5. Brine Disposal from Inland Desalination.

Brine, concentrate, or reject are names for a stream that is produced from any desalination process. In any desalination process, two streams are produced: 1) high quality product water, and 2) brine stream that contains higher concentrations of the salts originally present in the feed water in addition to the chemicals added in the pretreatment and during desalination such as antiscalants [44]. To reduce energy consumption, cleaning time, it is paramount to mitigate fouling. The common approach is to operate at conditions where the solution is stable, hence scaling and fouling is minimized. However working at lower recoveries to avoid the fouling of membrane will increase the flow of brine stream generated, which present the main trade-off for desalination operation.

In the case of seawater desalination plants the problem of brine disposal is readily solved by discharging brine back to the sea. However, brine management in inland desalination plants can be problematic in case they are placed far from the coast. Some of the conventional options for brine disposal in this case are: 1) disposal into surface water bodies, 2) disposal to municipal sewers, 3) evaporation ponds, 4) deep well injection, and 5) irrigation of plants tolerant to high salinities [45]. The main factors that influence the selection of a disposal method, among others, are: 1) volume or quantity of concentrate, 2) quality and constitutes present in the concentrate, 3) physical and geographical considerations, 4) capital and operational costs, 5) availability of

receiving site, 6) permissibility of the option, facility future expansion plan, and 7) public acceptance. All of these factors together will affect the cost of brine disposal that can range from 5 -33 % of the total desalination cost [46]. The brine disposal method should be considered after the necessary studies and investigations have been performed in order to minimize the brine stream to be disposed off, and hence reduce the cost of subsequent disposal. This is mainly achieved by employing the proper feed water pretreatment, proper desalination process, and maximizing the system recovery.

5.1. Disposal to Surface Water Bodies and Sewers Systems.

Disposal of brine to surface water bodies, if available, presents the option of taking into account that brine stream is diluted by mixing with the water body. However, the salinity of the receiving body might increase, and hence the self-purification capacity of the receiving water should be considered. So disposal to surface water should be permitted only to avoid dramatic impact on environment [47]. Another option is to dispose the brine to the local sewage system; this has many advantages such as use of available sewage system, and lowering the BOD of the domestic sewage water. However, that should be practiced carefully as the salinity of sewage water might increase which might affect the wastewater treatment facility especially biological treatment step. This might also render treated municipal sewage effluent unsuitable for agriculture use when disposing brines with high salinity [47].

5.2. Disposal to Evaporation Ponds.

The brine is discharged into a large surface area pond, where the water is naturally evaporated. Use of evaporation ponds is practiced primarily in the arid and semi-arid areas, particularly in Middle East and Australia. Evaporation ponds are probably the most widespread method for brine disposal from inland desalination plants. Simple evaporation ponds have many advantages such as being easy to construct, low maintenance and operation cost, no equipment are needed specifically mechanical equipment; making it the most appropriate method in arid areas with high evaporation rates, low rainfall, and low land cost [47]. Use of evaporation ponds for cultivation of brine shrimps has been studied as well, giving ideal place for brine-shrimp production as it presents mono-culture environment under natural conditions with absence of any food competitors or predators [46].

The basic concern associated with use of evaporation pond for brine disposal is leakage of brine through soil. This may result in subsequent contamination and increasing salinity of the aquifer. Electrical conductivity and concentration of salts in the evaporation ponds can be used as indicators for leakage in the pond, where insignificant increase is a strong indication of brine leakage through the soil [46]. Deterioration of soil and groundwater quality in areas nearby evaporation ponds used for brine disposal in kingdom of Saudi Arabia KSA, United Arab Emirates UAE, and Oman was investigated and reported as one of the drawbacks of using of evaporation bonds [48, 49]. Reduction in production from agricultural lands caused by deposition of airborne salts from dried concentrate of evaporation bonds, and formation of eyesores caused by improper disposal of concentrates on nearby land can be another disadvantage of brine disposal to evaporation ponds. Most of the evaporation ponds installed recently are lined with polymeric sheets. Furthermore, double lining is strongly recommended with proper monitoring for leakage.

In conclusion, while operation and maintenance costs for evaporation ponds are minimal, large land areas are required which increases as the plant capacity increases, and pond construction costs are high due to lining and monitoring requirements. Consequently, proper evaporation ponds are often cost prohibitive and impractical for handling significant concentrate flow. Furthermore, water evaporated from a pond is often a lost resource.

5.3. Deep Well Injection.

In deep well injection, the brine is injected back underground to a depth of a few hundreds to thousands of meters. Deep well injection includes permitting considerations, which look for identification of adequate geologic confining unit, and design considerations which focus on the tubing and packing installed inside the final cemented casing, compatibility of the concentrate, expected concentrate flow, and leak detection and monitoring systems [50]. One of the very attractive options is to use depleted oil and gas fields, which encounters many advantages such as making use of the readily available wells, long experience encountered with the operation of such wells. However, before applying this option the fields should be tested physically and chemically for accepting the brine stream [51, 52].

Generally site selection for installing of such deep wells is the most important step and hence hydrological and geological conditions should be considered. The wells should never be installed in areas vulnerable to earthquakes [47]. In spite of availability of such option to many inland desalination plants, many factors should be considered such as site selection, high cost, possibility of corrosion and subsequent leakage in the well casing, seismic activity which could cause damage to the well and subsequently result in leakage, uncertainty of the well life, and pollution of groundwater resources [53].

6. Inland Desalination with Zero Liquid Discharge.

Based on the aforementioned brine disposal issues, it is imperative to find alternative desalination with Zero Liquid Discharge (ZLD) that provides more efficient concentrate management. In ZLD, brine is treated to produce desalinated water and essentially dry salts. Therefore, there is no discharge of liquid waste. There have been many attempts to achieve a successful inland desalination with ZLD, however more attention and further research work and process developments are needed in order to develop a cost-effective ZLD desalination.

Advancement of ZLD science and reduction of ZLD costs will be of tremendous benefit and will alleviate the water supply challenges faced by many communities worldwide. ZLD desalination eliminates the brine disposal and management problems usually encountered with inland desalination plants. In addition, ZLD provides several advantages such as 1) Maximizing water recovery; as ZLD systems should be able to provide more product water or less plant size, 2) Preserving natural resources; which are mainly groundwater and land both quantitatively and qualitatively, 3) Byproduct salts; the dry salts produced can be treated as added value product rather than solid waste, 4) Integerability and applicability; ZLD system can be integrated to any existing inland desalination plant of any size and location.

6.1. Current Zero Liquid Discharge Schemes for Inland Desalination.

Little literature work is available on ZLD systems for inland desalination; however three main schemes can be concluded and summarized as follow:

- Applying thermal processes directly for further brine concentration [53].
- Applying chemical treatment to the brine, followed by further membrane desalination, and brine concentration [54, 55].
- Applying ED/EDR process to the brine stream making use of higher recovery encountered with such units [18, 56].

Brine treatment and second stage desalination result in significant reduction in the volume of final brine, to undergo concentration and final drying/crystallization. The final brine stream will be subjected to a final salt production stage mainly by crystallization and drying. Options for integrating different units in different setups can be investigated with an overall objective of ZLD desalination and production of salts can be generated, and should be evaluated for process optimization [57].

The second scheme, in which brine is treated chemically to remove scale-forming constitutes, achieving high removal of such constitutes rendering the treated brine suitable for further membrane separation to recover more water, is the one receiving high attention recently. With the two-stage membrane desalination process incorporated with the intermediate brine treatment step, recovery up to 95% can be achieved. It also reduces the volume of brine to be handled by the final evaporation step, which results in lowering the energy requirements and hence the overall process cost.

6.2. Lime Softening for Brine Treatment in Zero Liquid Discharge Systems.

Intermediate brine treatment employed before further brine desalination using a second stage RO is receiving more attention recently. The objective is to remove the scale-forming constitutes typically calcium, magnesium, carbonate, sulfate, and silica. It is hard to have a single treatment that is able to efficiently remove all of these constitutes. Furthermore, most of the tested chemical treatment processes were not able to completely remove such constitutes. However the achieved removal efficiency was good enough to prevent such constitutes from limiting the recovery in the secondary membrane desalination process.

Lime softening is one of the widely used processes for reduction of water hardness and alkalinity in water treatment plants. This is usually achieved by addition of alkali, usually lime ($Ca(OH)_2$) or sodium hydroxide (NaOH) and sodium carbonate (Na_2CO_3) depending on the quality of water to be treated [58]. Removal of calcium and magnesium is one of the major targets for brine chemical treatment, particularly calcium in order to avoid calcium sulfate and calcium carbonate scale formation [32, 33, 35].

Silica removal during the lime softening was extensively studied, and it was found that silica removal could be removed by co-precipitation with metal hydroxides, specifically iron, manganese, and magnesium hydroxides, or by precipitation as magnesium and calcium silicate [59]. Addition of sodium aluminate and aluminum sulfate was found to enhance the removal of silica during the softening process by co-precipitation with aluminum hydroxide [61, 62]. Conventional softening process is slow, requires extensive space, and generates large volume of sludge [63]. As a result, a more advanced process designated Compact Accelerated Precipitation Softening (CAPS) was developed to enhance the performance of the lime softening process in which the saturated solution is passed through cake of calcium carbonate to enhance crystallization and approach equilibrium rapidly [64-66]. Although it has been applied mainly to

water treatment plants, softening processes were found to be very effective and promising when applied for brine treatment where high calcium, magnesium, and silica removals from brine streams can be achieved [67 -71].

Sulfate usually present in the brine streams in high concentrations, relative to those of calcium, magnesium, carbonate, and silica. However in presence of calcium, saturation and hence scaling due to calcium sulfate is very likely to happen [32, 33, 35]. Although lime softening processes were found to be very effective in removal of calcium, magnesium, carbonate, and silica, such process had no success for removal of sulfate. Several attempts have been made to remove sulfate by precipitation as calcium sulfate (gypsum) by addition of calcium in the form of lime [72] or calcium chloride [73]. Removal of sulfate as calcium sulfate below 1300 mg/L was found to be difficult though due to solubility limits. However addition of aluminum as aluminum sulfate or alum, aluminum chloride, aluminum nitrate, and sodium aluminate was found to enhance the removal of sulfate far below this value by formation of more complex solids which has much lower solubility [74, 75].

6.3. Final Brine Concentration and Salt Production.

The treated brine after being concentrated in secondary membrane desalination has to be further concentrated reaching zero liquid. Zero liquid and dry salts cannot be by membrane desalination, and hence the concentrated brine has to be subjected to thermal process for brine concentration followed by crystallization or drying to produce dry salts. Thermal processes such as single stage, multi stage, and solar evaporators are usually employed for further brine concentration. Such units have dual purpose objectives of further recovery of water and brine concentration up to about 250,000 mg/L, with recovery above 90%. Final salt production can be achieved after brine concentration which usually performed in crystallizers or dryers [53]. In addition to the salts produced from final crystallizer/dryer that can be assumed as byproducts from ZLD desalination, the precipitated solids from brine chemical treatment can be considered as another byproduct or added value product. This precipitate is rich in calcium as calcium carbonate, magnesium as magnesium hydroxide, and silicate of calcium and magnesium, in addition to gypsum in case of sulfate removal. Such chemicals can find a wide range of applications such as road pavement, cement industry, and others.

6.4. Cost Associated with Zero Liquid Discharge Systems.

While ZLD can be successfully achieved through different ZLD schemes, the cost associated with each ZLD alternative should be carefully considered. It is easily noticeable that employing a secondary membrane desalination step is important for reduction of both capital and operating costs over the conventional thermal ZLD systems. A cost comparison for standard bench mark brine treatment by brine concentration and evaporation to advanced brine chemical treatment and secondary RO desalination for brine of different qualities has shown that a cost reduction ranging from 48-67%, with reduction in energy requirement of 58 - 72% using the advanced ZLD system can be achieved [54].

Inland desalination with zero liquid discharge usually has higher product water cost when compared to conventional inland desalination systems with direct brine discharge. However, it

becomes more economically attractive compared to other brine disposal methods. The higher cost is attributed to the several units such as chemical treatment, secondary membrane desalination, brine concentration, and crystallization/drying employed. However, the additional cost is balanced by the incentive of water resources conservation and environment protection by maximizing water recovery and minimizing wastewater discharge [53].

6.5. Developments and Research Needs for Zero Liquid Discharge Desalination.

Zero liquid discharge is an attractive alternative for inland desalination process. It overcomes the brine disposal limitations currently faced for applying inland desalination. Although different zero liquid discharge schemes are currently developed or under development, further development is needed to resolve its various technical, operational, and economical issues. The essential elements for successful ZLD inland desalination are brine treatment, process development, energy requirements, and process economics, which should be given more attention and further research and development efforts.

7. Conclusions.

Groundwater presents the main source of potable water to communities that do not have access to surface water. The deterioration of groundwater quality, specifically salinity is of high concern. This leads to the use of desalination techniques to overcome such problems. The use of membrane desalination systems in general and reverse osmosis in particular is very beneficial due to capacity flexibility, lower energy requirements, and in turn lower cost for brackish groundwater desalination. However, the generation of brine stream is the main problem facing such systems and it should be managed properly. Inland desalination with zero liquid discharge eliminates brine disposal issues while conserving water resources and minimizing environmental impacts.

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Exergy analysis of large ME-TVC desalination units

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Abstract

Large numbers of low temperature Multi-Effect Thermal Vapor Compression (ME-TVC) desalination units have been installed recently in most of the GCC countries. The majority of these units were commissioned in UAE. The unit size capacities of these units were increased exponentially from 1 to 8.5 Million Imperial Gallon per Day (MIGD) between 1991 and 2008. The new trend of combining ME-TVC with conventional multi-effect led to this tremendous increase - more than eight times -during a very short period. Moreover, the unit size capacity of this technology is currently available with 10 MIGD, and research studies are expected to increase this unit capacity up to 15 MIGD in the near future. Hence, this technology becomes highly attractive and competitive against Multi Stage Flash (MSF) desalination system.

A mathematical model of ME-TVC desalination system is developed in this paper, using Engineering Equation Solver (EES) Software. This model is used to evaluate and improve the system performance of some new commercial ME-TVC units having capacities of 2.4, 3.8 and 6.5 MIGD using energy and exergy analysis. The model results were compared against the available actual data which showed good agreement.

Keywords: Desalination, exergy, Multi-effect, Thermal vapor.

1. Introduction

Several low temperature Multi-Effect Thermal Vapor Compression (ME-TVC) desalination units have been installed recently in most of the GCC countries. The total installed capacity has increased up to 500 MIGD between 2000 and 2010. The majority of these units were commissioned in the UAE by SIDEM Company. The unit size capacities of these units were increased exponentially from 1 to 8.5 million imperial gallons per day (MIGD) between 1991 and 2008 as shown in Fig.1. The new trend of combining ME-TVC with conventional multi-effect units led to this tremendous increase, more than eight times, during a very short period. Moreover, the unit size capacity of this technology is currently available with 10 MIGD, and it is expected to increase up to 15 MIGD in the near future. Hence, this system becomes highly attractive and competitive against Multi Stage Flash (MSF) desalination system and it is predicted to get a considerable increase in the desalination market in future, particularly, in the GCC countries.

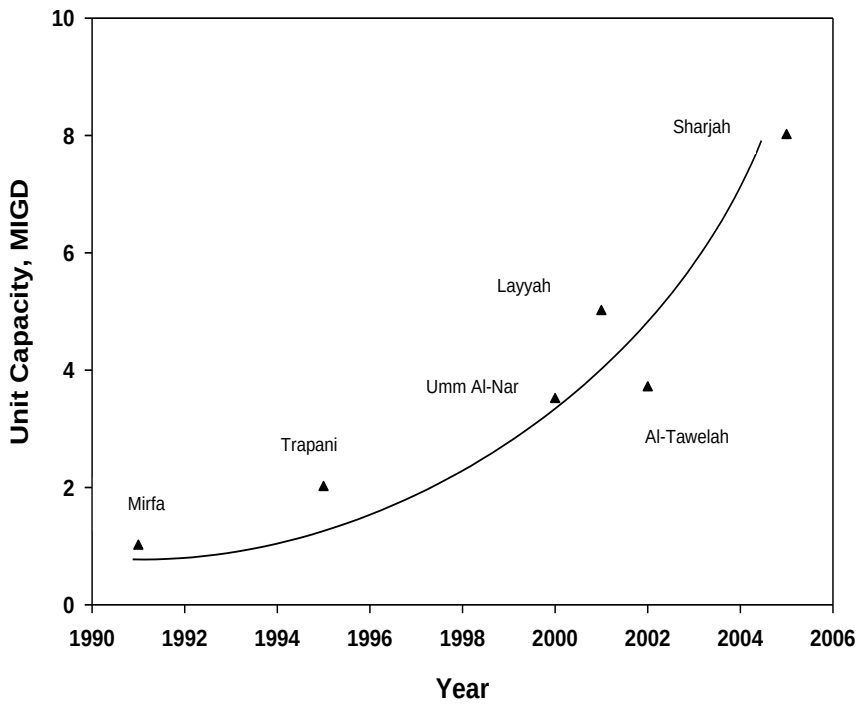

Fig. 1. The increase of unit size capacity of ME-TVC desalination systems.

Several studies have been published since the early of 1990's concerning ME-TVC desalination system. Some includes field studies other describes different conceptual designs. Diverse mathematical models were also developed since then, in most of these publications for simulation and economic evaluation purposes. A summary literature review of these studies were reported in (Al-Juwayhel et al, 1997) and (El-Dessouky & Ettouney, 1999). On the other hand, limited studies were published handling ME-TVC desalination system from exergy (Second law) point of view since the mid of last decade, but it has been carried out in several published works recently.

A mathematical model of a ME-TVC desalination system is also developed in this chapter, using Engineering Equation Solver (EES) Software. This model is used to evaluate and improve the performance of some new commercial ME-TVC units having capacities of 2.4, 3.8 and 6.5 MIGD using energy and exergy analysis. The model results were compared against the actual data.

2. Process description

A schematic diagram of this arrangement is shown in Fig. 2, where two identical ME-TVC units are combined with a single MED unit, where as the vapor produced in the last effect of each ME-TVC unit (D_j) is split into two streams. The first stream D_r is entrained by a thermo-compressor and other part (D_f) is used as a heat source to operate low temperature multi effect distillation unit (LT-MED).

The configuration consists of the following components (1) a number of horizontal falling film evaporators (n effects), (2) two thermo-compressors, (3) a number of feed heaters, (4) five main pumps (distillate, feed, condensate, cooling and brine disposal pumps) to circulate the streams, (5) an end condenser and (6) a number of flashing boxes.

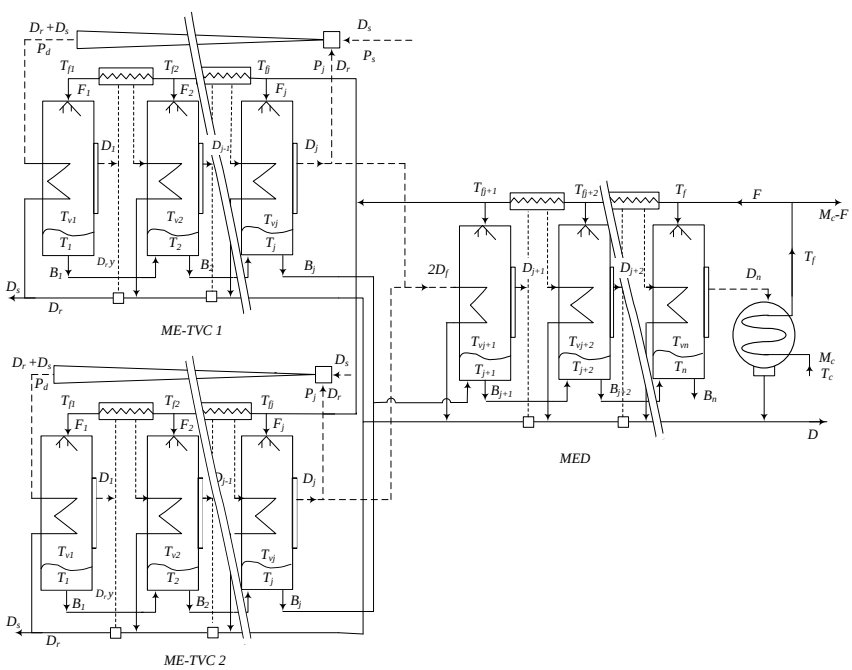

Fig. 2. A schematic diagram of two ME-TVC units combined with a conventional MED unit.

3. Thermal analysis

First and Second Laws analysis are used in this section to develop a mathematical model of the ME-TVC desalination system. The model is developed by applying mass and energy conservation laws to the thermo-compressor, evaporators, feed heaters and end condenser. The following assumption were used to simplify the analysis: steady state operation, negligible heat

losses to the surrounding, equal temperature difference across feed heaters, salt free distillate from all effects and variations of specific heat as well as boiling point elevation with the temperature and salinity are negligible. The number of effects is assumed to be even in this analysis for example n= 4, 6, 8, 10 and 12.

The brine temperature in each effect is less than that of the previous one by ΔT. So, if the brine temperature in the effect i is assumed to be T_i, then the brine temperature in the next effect $i+1$ and so on up to the last effect n and can be calculated as follow:

$$T_{i+1} = T_i - \Delta T, \qquad i = 1,\ 2,...n \tag{1}$$

The temperature of the vapor generated in the effect i, T_{vi} is lower than the brine temperature by the boiling point elevation plus non equilibrium allowance, where T_{vi} is a saturation temperature corresponding to the pressure in the effect P_i.

$$T_{vi} = T_i - (BPE + NEA), \qquad i = 1,\ 2,\ldots n \tag{2}$$

The temperature difference between the effects is assumed to be the same in this analysis and can be calculated as follows:

$$\Delta T = \frac{T_1 - T_n}{n-1} \tag{3}$$

The feed seawater temperature flowing into each effect (T_{fi}) can be calculated as follows:

$$T_{fi} = T_f + [n-(i+1)]\cdot \Delta T \qquad i = 1,\ 2,\ 3....n \tag{4}$$

3.1 Mass and energy balance

The feed seawater flow rate F is distributed equally to all effects at a rate equal to F_i which can be calculated as follows:

$$F_i = \frac{F}{n+j} \quad , \quad j = \frac{n}{2} \tag{5}$$

The brine leaving the first effect enters into the second effect and so on up to the last effect n, and the brine from the last effect is rejected. The brine leaving the first, second and last effect can be calculated considering mass balance law as follows:

$$B_i = F_i - D_i \tag{6}$$

$$B_{i+1} = \sum_{i=1}^{j}\left(F_{i+1} - D_{i+1}\right) \tag{7}$$

$$B_n = 2\cdot\sum_{i=1}^{j}\left(F_i - D_i\right) + \sum_{j+1}^{n}\left(F_{j+1} - D_{j+1}\right) \tag{8}$$

The salt mass conservation law is applied, assuming that the distillate is free of salt, to find brine salinity from the first, second and last effect as follows:

$$X_{bi} = \frac{F_i \cdot X_f}{\left(F_i - D_i\right)} \tag{9}$$

$$X_{bi+1} = \frac{F_{i+1}\cdot X_f}{\sum_{i=1}^{j}\left(F_{i+1} - D_{i+1}\right)} \tag{10}$$

$$X_{bn} = \frac{F_n \cdot X_f}{2 \cdot \sum_{i=1}^{j} (F_i - D_i) + \sum_{j+1}^{n} (F_{j+1} - D_{j+1})} \tag{11}$$

The vapor generated in the first effect by boiling only and can be determined from the energy balance of the first effect as follows:

$$D_1 = \frac{[(D_s + D_r) \cdot (h_d - h_{fd})]}{L_1} - F_1 \cdot C \cdot \left(\frac{T_1 - T_{f1}}{L_1} \right) \tag{12}$$

The amount of vapor released from the second up to j can be expressed respectively as follows:

$$D_2 = (D_1 + D_r \cdot y - F_1 \cdot y) \cdot \frac{L_1}{L_2} + B_1 \cdot \frac{C \cdot \Delta T}{L_2} - F_2 \cdot C \cdot \frac{(T_2 - T_{f2})}{L_2} \tag{13}$$

$$D_j = [(D_{j-1} + \sum_{i=1}^{j-2} (D_i + D_r) \cdot y - (j-1) \cdot F_j \cdot y)] \cdot \frac{L_{j-1}}{L_j} + B_{j-1} \cdot \frac{C \cdot \Delta T}{L_j} - F_j \cdot C \cdot \frac{(T_j - T_{fj})}{L_j} \tag{14}$$

The vapor formed in the last effect of each ME-TVC unit D_j is divided into two streams; one is entrained by the thermo-compressor (D_r) and the other is directed to the MED unit.

$$D_j = D_r + D_f \tag{15}$$

The two streams of D_f are used as a heat source to operate low temperature multi effect distillation unit (LT-MED).
So, the vapor formed in first, second and last effect of this unit can be calculated as follows:

$$D_{j+1} = 2 \cdot D_f \cdot \frac{L_j}{L_{j+1}} + 2 \cdot B_j \cdot \frac{C \cdot \Delta T}{L_{j+1}} - F_{j+1} \cdot C \cdot \frac{(T_{j+1} - T_{fj+1})}{L_{j+1}} \tag{16}$$

$$D_{j+2} = \left(D_{j+1} + \sum_{i=1}^{j} (D_i + D_r) \cdot y - (j+n) \cdot F_{j+2} \cdot y \right) \cdot \frac{L_{j+1}}{L_{j+2}} + 2 \cdot B_{j+1} \cdot \frac{C \cdot \Delta T}{L_{j+2}} - F_{j+2} \cdot C \cdot \frac{(T_{j+2} - T_{fj+2})}{L_{j+2}} \tag{17}$$

$$D_n = [(D_{n-1} + \sum_{i=1}^{n-2} (D_i + D_r) \cdot y - (j+n-1) \cdot F_i \cdot y)] \cdot \frac{L_{n-1}}{L_n} + 2 \cdot B_{n-1} \cdot \frac{C \cdot \Delta T}{L_n} - F_i \cdot C \cdot \frac{(T_n - T_f)}{L_n} \tag{18}$$

The total distillate output from all effects is equal to

$$D = 2 \cdot \sum_{i=1}^{j} D_i + \sum_{j+1}^{n} D_{j+1}, \quad i = 1,2,...3 \tag{19}$$

The energy balance of the thermo-compressor is used to calculate the enthalpy of the discharged steam as shown in equation (20),

$$h_d = \left(\frac{\left(\frac{D_s}{D_r} \right) \cdot h_s + h_{g(j)}}{1 + \left(\frac{D_s}{D_r} \right)} \right) \tag{20}$$

The most essential part in modeling the ME-TVC desalination system is to determine the ratio of motive steam to entrained vapor (D_s/D_r) in such thermo-compressors. An optimal ratio will improve the unit efficiency by reducing the amount of motive steam (Utomo et al., 2008). This

ratio is a direct function of discharge pressure (P_d), motive steam pressure (P_s) and entrained vapor pressure (P_j) in terms of compression ratio (CR) and expansion ratio (ER) as follows (El-Dessouky & Ettouney, 2002; Al-Najem et al., 1997):

$$CR = \frac{P_d}{P_j} \tag{21}$$

$$ER = \frac{P_s}{P_j} \tag{22}$$

Several methods are available in the literature to evaluate entrainment ratios; most of these methods need lengthy computation procedures and use many correction factors (El-Dessouky & Ettouney, 2002). Two simple methods are used to evaluate this ratio in this study: (1) Power's graphical data method (Al-Najem et al., 1997), (2) El-Dessouky and Ettouney's semi–empirical model (El-Dessouky & Ettouney, 2002). Although Power's method is a straightforward and the entrainment ratio can be extracted directly in terms of compression ratio and expansion ratio, it is too difficult to use in such optimization and simulation models. The developed semi–empirical model in method 2 is applicable only if the motive fluid is steam and the entrained fluid is water vapor (Al-Juwayhel et al., 1997). The pressure and temperature correction factors were eliminated for simplicity and the model equation is modified as shown in equation (23); results were tested and compared with that obtained by Power's graphical method for validity in the following range of motive pressure $3000 \geq P_s \geq 2000$ (kPa).

$$\left(\frac{D_s}{D_r}\right) = 0.235 \frac{(P_d)^{1.19}}{(P_j)^{1.04}} (ER)^{0.015} \tag{23}$$

3.2 Exergy Balance

An exergy balance is also conducted to the system to find the exergy destruction (I) in each component; in thermo-compressor, effects, condenser and the leaving streams in kJ/kg according to the following equation:

$$I = T_o \cdot \Delta S = E_{in} - E_{out} \tag{24}$$

Where ΔS is the entropy increase, E_{in} is the input exergy and E_{out} is the output exergy

Thermo-compressor

The exergy destruction in the thermo-compressor can be expressed as follows:

$$I_{ej} = D_s \cdot [(h_s - h_d) - T_o \cdot (S_s - S_d)] - D_r \cdot [(h_d - h_{gj}) - T_o \cdot (S_d - S_{gj})] \tag{25}$$

Effects

The exergy destruction in the first, second and last effect can be expressed respectively as follows;

$$I_{e1} = (D_s + D_r) \cdot [(h_d - h_{fd}) - T_o \cdot (S_d - S_{fd})] - D_1 \cdot L_1 \cdot \left(1 - \frac{T_o}{T_{v1}}\right) - F_1 \cdot C \cdot \left[(T_1 - T_{f1}) - T_o \cdot In\left(\frac{T_1}{T_{f1}}\right)\right] \tag{26}$$

$$I_{e2} = (D_1 + D_r y - F_2 y)\cdot L_1 \cdot \left(1 - \frac{T_o}{T_1}\right) + B_1 \cdot C \cdot \left[\Delta T - T_o \cdot In\left(\frac{T_1}{T_2}\right)\right] - D_2 \cdot L_2 \cdot \left(1 - \frac{T_o}{T_2}\right) - F_2 \cdot C \cdot \left[(T_2 - T_{f2}) - T_o \cdot In\left(\frac{T_2}{T_{f2}}\right)\right] \quad (27)$$

$$I_{en} = \left[D_{n-1} + \sum_{i=1}^{n-2}(D_i + D_r)\cdot y - (j+n-1)F_i \cdot y\right]\cdot L_{n-1}\cdot\left(1 - \frac{T_o}{T_{n-1}}\right) + 2\cdot B_{n-1}\cdot C\cdot\left[\Delta T - T_o \cdot In\left(\frac{T_{n-1}}{T_n}\right)\right] - D_n \cdot L_n \cdot \left(1 - \frac{T_o}{T_n}\right) - F_i \cdot C \cdot \left[(T_n - T_f) - T_o \cdot \ln\left(\frac{T_n}{T_f}\right)\right] \quad (28)$$

Condenser and Leaving Streams

The exergy destruction in the condenser, and in the leaving streams, D_r ,D_f and B_n can be expressed using the following equations respectively:

$$I_c = D_n \cdot L_n \cdot \left(1 - \frac{T_o}{T_n}\right) - M_c \cdot C \cdot \left[(T_f - T_c) - T_o \cdot \ln\left(\frac{T_f}{T_c}\right)\right] \quad (29)$$

$$I_{Dr} = D_r \cdot C \cdot \left[(T_{vj} - T_c) - T_o \cdot \ln\left(\frac{T_{vj}}{T_c}\right)\right] \quad (30)$$

$$I_{Df} = D_f \cdot C \cdot \left[(T_{vj} - T_c) - T_o \cdot \ln\left(\frac{T_{vj}}{T_c}\right)\right] \quad (31)$$

$$I_{Bn} = D_n \cdot C \cdot \left[(T_n - T_c) - T_o \cdot \ln\left(\frac{T_n}{T_c}\right)\right] \quad (32)$$

3.3 Thermal load

The heat transfer area of an effect can be obtained from the latent heat of condensation (thermal load) of each effect as shown in equation (33), where ΔT_e is the temperature difference across the heat transfer surface.

$$Q = U_e \cdot A_e \cdot \Delta T_e \quad (33)$$

Therefore, the heat transfer area for the first, second and last effect can be obtained as follows:

$$A_{e1} = \frac{(D_s + D_r)\cdot[h_d - h_{fd}]}{U_{e1}\cdot(T_d - T_1)} \quad (34)$$

$$A_{e2} = \frac{(D_1 + D_r \cdot y - F_1 \cdot y)\cdot L_1}{U_{e2}\cdot(T_{v1} - T_2)} \quad (35)$$

$$A_n = \frac{[(D_{n-1} + \sum_{i=1}^{n-2}(D_i + D_r)\cdot y - (j+n-1)\cdot F_i \cdot y]\cdot L_{n-1}}{U_{en}\cdot(T_{vn-1} - T_n)} \quad (36)$$

The overall heat transfer coefficient (U_e) depends mainly on the type, design and material of the tubes (El-Dessoukey et al.,2000), and for simplicity it can be calculated as follows (El-Dessouky & Ettouney, 2002):

$$U_{ei} = \frac{\left(1939.4 + 1.40562 \cdot T_i - 0.0207525 \cdot (T_i)^2 + 0.0023186 \cdot (T_i)^3\right)}{1000} \tag{37}$$

The cooling seawater flow rate can be obtained by applying the energy conservation law on the condenser as shown below:

$$M_c = \frac{D_f \cdot L_n}{C \cdot (T_f - T_c)} \tag{38}$$

The latent heat of condensation of the un-entrained vapor D_f flowing to the condenser is used to increase cooling seawater temperature to feed seawater temperature. The thermal load of the condenser is used to calculate the condenser heat transfer area as follows:

$$A_c = \frac{D_f \cdot L_n}{U_c \cdot (LMTD)_c} \tag{39}$$

The logarithmic mean temperature difference and the overall heat transfer coefficient of the condenser can be obtained from equations (40) and (41) respectively (El-Dessouky & Ettouney, 2002).

$$(LMTD)_c = \frac{(T_{vn} - T_f) - (T_{vn} - T_c)}{\ln \frac{(T_{vn} - T_f)}{(T_{vn} - T_c)}} \tag{40}$$

$$U_c = 1.7194 + 3.2063 \cdot 10^{-2} \cdot T_{vn} - 1.5971 \cdot 10^{-5} \cdot (T_{vn})^2 + 1.9918 \cdot 10^{-7} \cdot (T_{vn})^3 \tag{41}$$

Similarly, the heat transfer area of the feed heaters can be expressed as follow assuming that the overall heat transfer coefficient of the feed heaters are equals to that of the condenser.

$$A_{fi} = \frac{(i) F_i \cdot C \cdot \Delta T_f}{U_f \cdot (T_{fi} - T_{fi+1})} \cdot \ln \frac{(T_{vi} - T_{fi+1})}{(T_{vi} - T_{fi})}, \qquad i = 1,\ 2, \ldots n-2 \tag{42}$$

3.4 System performance

The system performance of the ME-TVC model can be evaluated in terms of the following:

Gain output ratio, *GOR*

The gain output ratio is one of the most commonly performance used to evaluate thermal desalination processes. It is defined as the ratio of total distilled water produced (D) to the motive steam supplied (D_s).

$$GOR = \frac{D}{D_s} \tag{43}$$

Specific heat consumption, Q_d

One of the most important characteristics of thermal desalination systems. It is defined as the thermal energy consumed by the system to produce 1 kg of distilled water, where L_s is the motive steam latent heat in kJ/kg

$$Q_d = \frac{D_s \cdot L_s}{D} \tag{44}$$

Specific exergy consumption, A_d

The specific exergy consumption is one of the best methods used to evaluate the performance of the ME-TVC based on the second law of thermodynamics. It considers the quantity as well as the quality of the supplied motive steam. It is defined as the exergy consumed by the motive steam to produce 1 kg of distillate when the steam is supplied as saturated vapor and leaves as saturated liquid at ambient temperature equal to T_o , according to the following equation [15]:

$$A_d = \frac{D_s}{D} \cdot \left[\left(h_s - h_{fd} \right) - T_o \cdot \left(S_s - S_{fd} \right) \right] \tag{45}$$

where h_s, S_s are the inlet motive steam enthalpy and entropy at saturated vapor and h_{fd}, S_{fd} are that of the outlet condensate at saturated liquid.

Specific heat transfer area, A_t

The specific total heat transfer area is equal to the sum of the effect, feed heaters and the condenser heat transfer areas per total distillate product (m^2/kg/s).

$$\frac{At_d}{D} = 2 \cdot \sum_{i=1}^{j} \frac{A_{ei}}{D_i} + \sum_{j+1}^{n} \frac{A_{ei}}{D_i} + \sum_{i=1}^{n-2} \frac{A_{fi}}{D_i} + \frac{A_c}{D} \tag{46}$$

Specific exergy destruction, I_t

This term shows the total exergy destruction due to heat transfer in the thermo-compressor, evaporators, condenser and the leaving streams per unit of distillate water.

$$I_t = \sum \frac{I_i}{D} \tag{47}$$

where I_i is the exergy destruction in each component in kJ/kg.

4. Sensitivity analysis

A sensitivity analysis will be presented in this section to investigate the system performance variations and simulation of Al-Jubail ME-TVC unit in KSA. This project belongs to Marafiq Company and it is currently considered as the largest ME-TVC desalination plants in the world, it consists of 27 units each of 6.5 MIGD as shown in Fig.3.

The available data of this unit in the literature are: the gain output ratio, number of effect, motive pressure and the unit capacity. The data are used along with the model equations to evaluate the system performance of the plant.

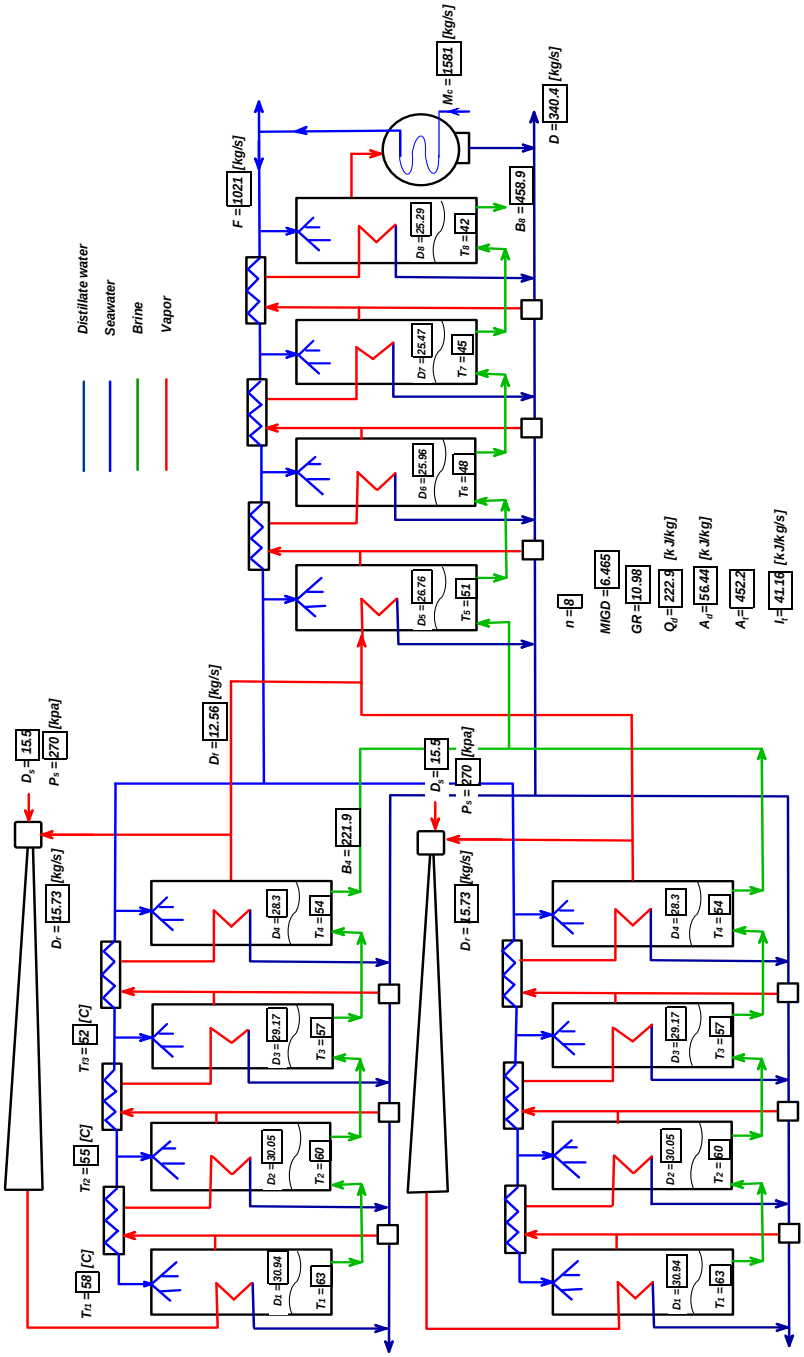

Fig.3. Flow sheet diagram similar to Al-Jubail (Marafiq) ME-TVC unit, 6.5 MIGD.

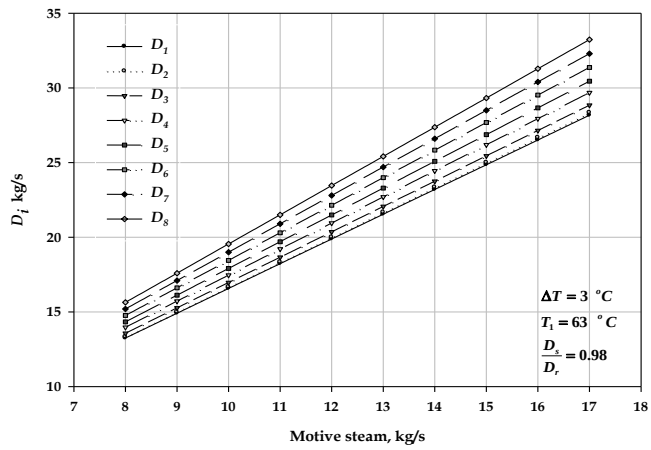

Fig.4. The effect of motive steam on the distillate production from the effects.

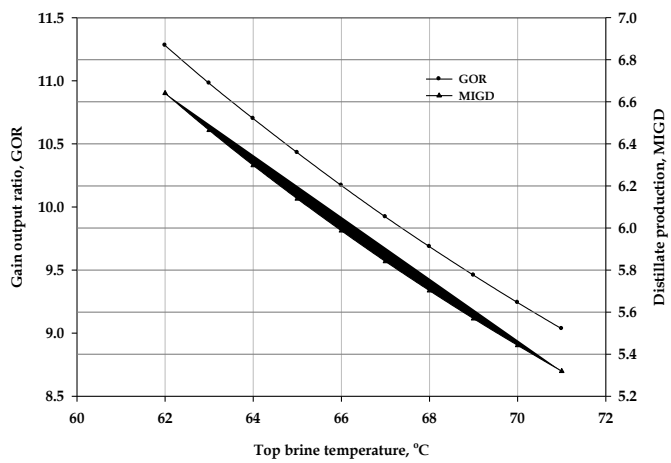

Fig.5. The effect of top brine temperature on the distillate production and gain output ratio.

Fig.4. shows the effect of motive steam flow rate on the vapor formed in each effect of this unit, at T_1= 63 ^oC and ΔT=3 ^oC. The total distillate production can be controlled by adjusting the motive steam flow rate. The reason is when the motive steam flow rate increases the entrained vapor also increases for constant entrainment ratio (D_s/D_r), this will lead to generate more vapor and consequently more distillate water.

The variation of the gain output ratio and the distillate production as a function of top brine temperature is shown in Fig.5. It is cleared that as the top brine temperature increases the distillate output production decreases and consequently gain output ratio decreases. The reason is when the top brine temperature increases; the vapor latent heat decreases as well as the amount of feed sensible heating increases and this fact is illustrated in equation 12.
The direct dependence of the top brine temperature on the specific heat consumption and the specific exergy consumption are shown in Fig. 6. Both of them increase linearly as the top brine

temperature increases, because higher top brine temperature leads to higher vapor pressure and consequently larger amount of motive steam is needed to compress the vapor at higher pressures.

Fig.7. demonstrates the variations of the specific heat transfer area as a function of temperature difference per effect at different top brine temperatures. The increase in the specific heat transfer area is more pronounced at lower temperature difference per effect than at lower top brine temperatures.

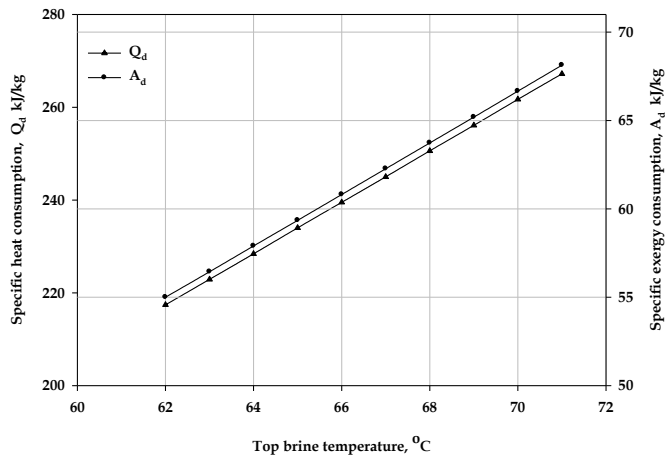

Fig.6. The effect of top brine temperature on the specific heat consumption and specific exergy consumption.

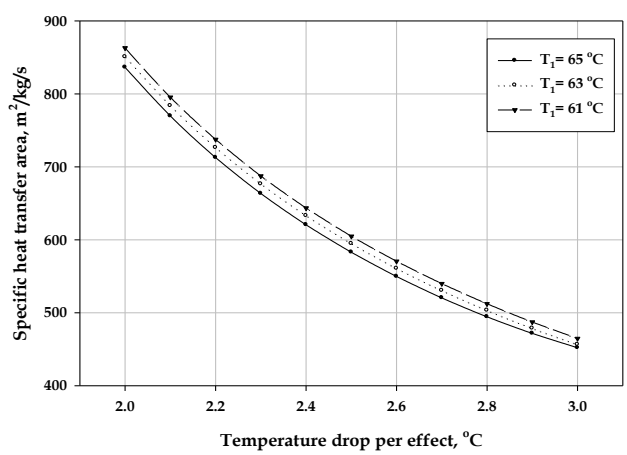

Fig.7. The effect of temperature drop per effect on the specific heat transfer area at different top brine temperatures.

The exergy analysis is also used to identify the impact of the top brine temperature on the specific exergy destruction for different ME-TVC units as shown in Fig.8. It shows that as the top brine temperature increases, the specific exergy destruction of ALBA, Umm Al-Nar and Al-Jubail plants are increases. It shows also that Al-jubail unit has the lowest values compared to other units. Fig.9 gives detail values of exergy destruction in different components of Al-Jubail units, while Fig.10 pinpoints that thermo-compressor and the effects are the main sources of

exergy destruction. On the other hand, the first effect of this unit was found to be responsible for about 31% of the total effects exergy destruction compared to 46% in ALBA and 36% in Umm Al-Nar as shown in Fig.11.

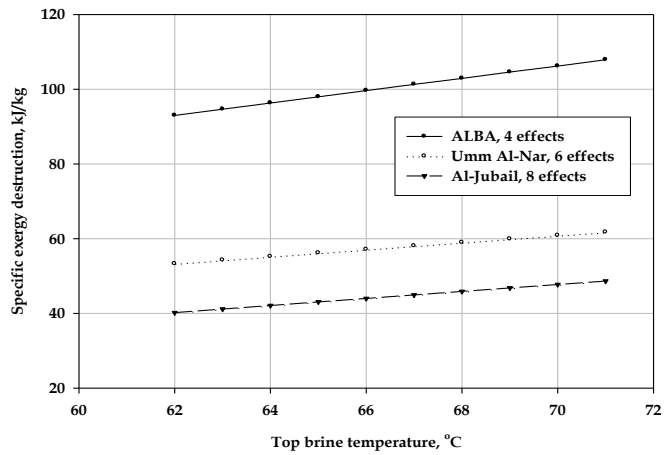

Fig.8. The effect of top brine temperature on the specific exergy destruction for different units.

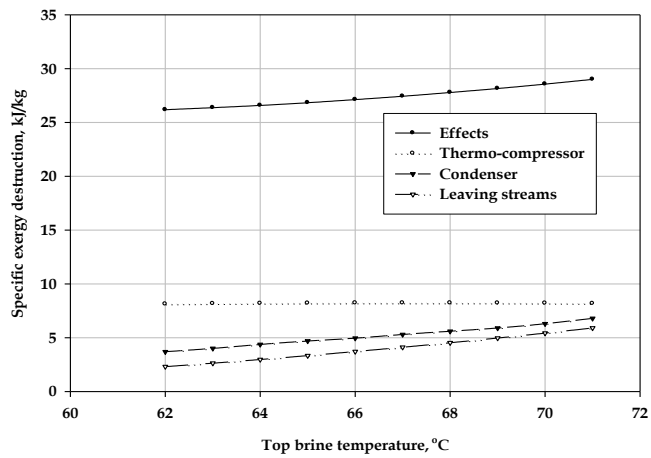

Fig.9. The effect of top brine temperature on the specific exergy destruction in different components of Al-Jubail ME-TVC unit.

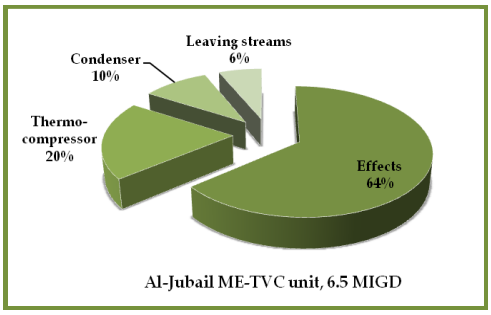

Fig.10. The exergy destruction in the effects, thermo-compressor, condenser and leaving streams of Al-Jubail unit.

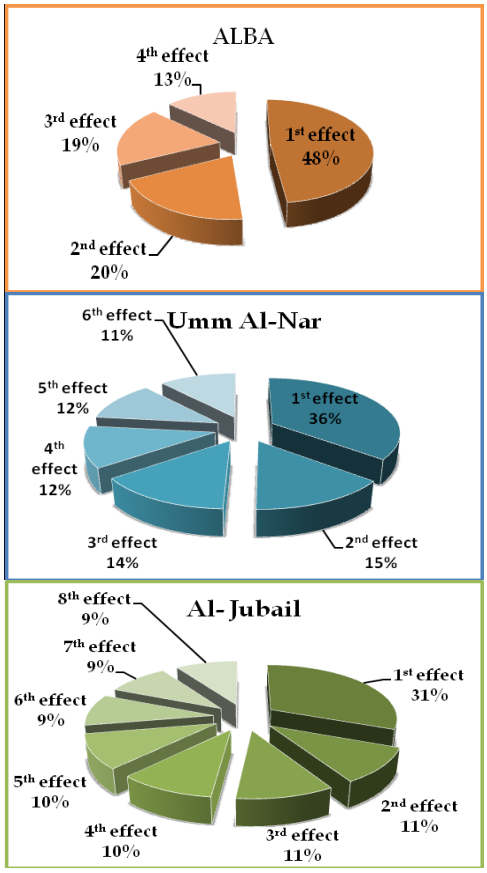

Fig. 11. The exergy destruction in the effects of ALBA, Umm Al-Nar

6. Conclusions

Exergy analysis shows that the specific exergy destruction in ALBA unit (94.65 kJ/kg) is almost twice that in Umm Al-Nar and Al-Jubail units (54.24 kJ/kg and 41.16 kJ/kg respectively) because high motive pressure of 21 bars is used in ALBA compared to low motive pressure of 2.8 bars in other units. The analysis indicates that thermo-compressor and the effects are the main sources of exergy destruction in these units. On the other hand, the first effect of this unit was found to be responsible for about 31% of the total effects exergy destruction compared to 46% in ALBA and 36% in Umm Al-Nar. The specific exergy destruction can be reduced by increasing the number of effects as well as working at lower top brine temperatures.

Lessons Learned from Evaluation of Different Spiral Wound SWRO Membranes in Gulf Seawater

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Abstract

Selection of membranes with optimum performance is vital for SWRO desalination plants. Hence, five different membranes (viz. A, B, C, D1 and D2) were evaluated for a duration of more than 1.5 years. Membranes were evaluated in a running Train of a SWRO plant located eastern coast of Saudi Arabia, which contains spiral wound membranes (viz. E). These spiral wound membranes are from different manufactures having different inherent properties in terms of membrane area and spacer thickness. Also, there was limited control over the operating conditions as the membranes were operated as a part of a commercial SWRO Train. Hence, these membranes were forced to operate on different operating conditions, especially in terms of water flux and recovery. These membranes were operated at an average flux ranging from 11 to 15 $l/m^2/h$ as well as recovery up to 45%. The study revealed that membranes C, D1 and D2 had best initial productivity, which was 30% more than that of membranes A and B. Salt passage results also showed that membranes C, D1 and D2 were the best with Membrane A being close in range. The Membrane B showed relatively poor performance compared to all other membranes tested. The result of increase in ΔP, which is an indication of fouling resistivity, showed that Membrane D1, then Membrane D2 were the best followed by Membranes A and C. Again Membrane B was found to be very poor in fouling resistivity (ΔP increase). The study showed that it is not only important to select a membrane of very good performance but also it is essential to select optimum operating conditions, especially the membrane flux and recovery in order to sustain the membrane performance. The paper highlights major criteria to be adopted for selection of a membrane for SWRO plant as well as the operating conditions of the same.

Keywords: Seawater desalination, Reverse Osmosis, Spiral wound membranes, Gulf sea.

1. Introduction

Presently, Saudi Arabia is leading the world in production of desalinated water by both MSF and SWRO processes. At present, the total of all desalinated water capacity worldwide from the sea and other raw water sources stands at 70 million m^3/d [1]. The Saline Water Conversion Corporation (SWCC) is the major user of seawater desalination plants in the Saudi Arabia with present production capacity of 990.8 million m^3/year, 54.1% of which is produced by eastern coast plants and the remaining 45.9% produced by western coast plants [2]. Al-Jubail SWRO plant was commissioned in year 2000 utilizing fully aromatic polyamide hollow fine fiber (HFF) membranes (11 trains) and Thin Film Composite (TFC) spiral wound membranes (4 trains), with a total capacity of 90,909 m^3/d from both types. The SWRO plant receives feed water from an open intake at depth range of 4 to 10 meters [3]. This study was carried out to identify suitable replacement membranes for the discontinued HFF membranes. The idea was to evaluate a number of membranes at a time to have more choices. Hence, a total of five different spiral wound membranes from four different manufactures were evaluated in parallel. Various leading membrane manufactures offered their membranes for evaluation. The present study describes results of the membrane evaluation which was carried out for duration of 14,000 hours.

2. Experimental

2.1 Equipment & Materials

A total of 5 sets of 3 pressure vessels (8" size) in series were installed on a train utilizing spiral wound membranes (identified as membrane E) at Al-Jubail SWRO plant; each pressure vessel was equipped with 2 elements of SWRO membranes of standard 8" × 40" size which include different membranes and identified as A, B, C, D1 and D2. Detailed specifications of SWRO membranes provided by membrane manufacturers are shown in Table 1.

Table 1. Details of five different membrane used in performance evaluation

No.	Parameter	Membrane				
1	Membrane identification code	A	B	C	D1	D2
2	Active area (ft^2)	370	300	400	320	400
3	Max. Flux (m^3/d)	24.6	19	24.6	23	28.4
4	Salt Rejection (%)	99.6	99.8 (Cl)	99.8	99.8	99.75
5	Max. operating pressure (bar)	82.7	82.7	82.7	82.7	82.7
6	Max. operating temperature (C^o)	45	45	45	45	45
7	Max. Chlorine Conc. (ppm)	<0.1	<0.1	<0.1	<0.1	<0.1
8	Max. feed water SDI	5.0	5.0	5.0	5.0	5.0

2.2 Experimental Set-Up

The detailed description of the Al-Jubail Seawater Reverse Osmosis (SWRO) Plant, where the experiment was carried out, is given elsewhere [4]. Pretreatment received feed seawater from an open intake. In the pretreatment prior to Dual Media Filters, Ferric Chloride was dosed at a concentration of 3.0 mg/liter and Sulphuric acid was dosed to maintain a pH value of 6.9 at the inlet of Dual Media Filter. Acid was further dosed just before the cartridge filters to achieve a pH value of 6.8. After the cartridge filters, Sodium Bisulphite (SBS) was dosed to remove any residual chlorine from feed seawater. As dual protection, SBS was also dosed at the suction of High Pressure Pumps. SWRO membranes along with pressure vessel were installed in one of the 15 trains by substituting existing pressure vessels, a schematic diagram of which is shown in Fig.1. Membranes received pretreated seawater from Al-Jubail SWRO plant pretreatment section and it was operated at same feed pressure as that of the Train. Hence, it was not possible to control the recovery of the membranes evaluated. The evaluation was for a period of about 14,300 hours, which includes shutdowns of the train for various reasons. The data of plant operation was recorded on daily basis and was normalized according to ASTM 4516 procedures [5].

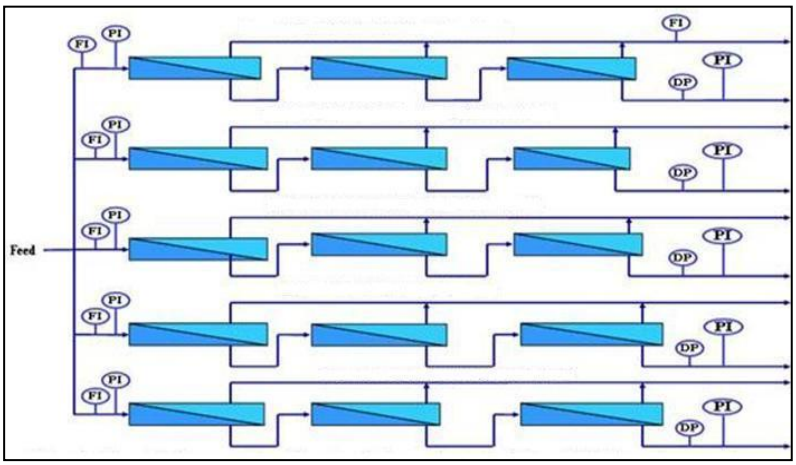


Figure1. Schematic diagram of arrangement of modules used to evaluate five different SWRO membranes at Al-Jubail SWRO Plant

3. Results and Discussion

3.1 Issues Encountered during Membrane Evaluation

As the entire experiment was conducted on a commercial SWRO Train, which was continuously operated to produce water to meet water demands, efforts were taken not to disturb normal operation and production of the plant. This leads to shortcomings in membrane evaluation such

as lack of control over operating conditions of SWRO membranes as well as failure to fulfill maintenance requirements of membranes and related equipment when needed. Hence, all membranes were operated at the same feed pressure as that of the Train, which at times resulted in operation of membranes above its design limits of recovery and flux. In addition, during failures of O-rings or occurrences of leaks in pressure vessels, maintenance could not be carried out on the spot forcing isolation of particular membranes until next scheduled shut down period. In this way, some membranes operated more than others making a true comparison of these membranes extremely difficult. Although, the total evaluation period was about 14,300 h, membranes evaluated were in operation from 6,200 h to12,050 h which include plant shut downs and isolation periods of membranes during O-ring failures and/or leaks, etc.

3.2 Performance of Membrane A

Membrane A was in operation for about 12,000 h and is the membrane which had maximum operation period. This means, it had least O-ring/ mechanical failures. The membrane performance for the entire period is shown in Fig. 2. Due to high feed pressure (about 80 bar), initially the membrane was operated at high recovery of about 45% and a flux of about 16 $l/m^2/h$, which is only slightly more - flux rate than the design value of that of Membrane E of the Train, which is about 15 $l/m^2/h$. Later, the recovery was reduced to normal value of about 35% (Fig.2c). The feed flow was maintained between 6 to 8 m^3/h as shown in Fig.2a. Feed temperature was in the range of 14 to 37 ^oC and SDI ranged between 2.32 – 4.3. The permeate flow was initially about 3 m^3/h during high recovery operation and reduced to about 2.5 m^3/h after one month of operation as can be seen in Fig. 2b. The calculated normalized product flow showed decrease towards the end of 14,000 h operational period to about 2.1 m^3/h from an initial value of 3.3 m^3/h for a net reduction in flow of about 36.4%. This amounts to 26.4% reduction in flux per year, which indicates significant fouling on the membrane. Although, disinfection by formalin followed by chemical cleaning using detergent was carried out at about 5,500h along with the entire Train chemical cleaning, no improvement was observed in the performance showing the ineffectiveness of cleaning in removing foulants on the membrane surface. Differential pressure, which is another indicator of fouling was found to increase continuously throughout the test period, which steadily increased from an initial value of 1 bar to about as high as 6 bar towards the end of the experiment indicating slow build up of fouling on the membrane surface and confirming that fouling is one of the major factor that reduced the membrane flux. During the initial test period the permeate conductivity was about 400 µS/cm which increased up to 900 µS/cm during summer which showed slight increase towards the end of the experiment which can be attributed to membrane fouling. The normalized salt passage was initially in the range of 0.8% and increased to about 1.6% towards the end of test period as shown in Fig. 2d. In short, it can be concluded that although the membrane had satisfactory performance, its flux and salt rejection has been reduced with long term operation mainly because of the membrane fouling.

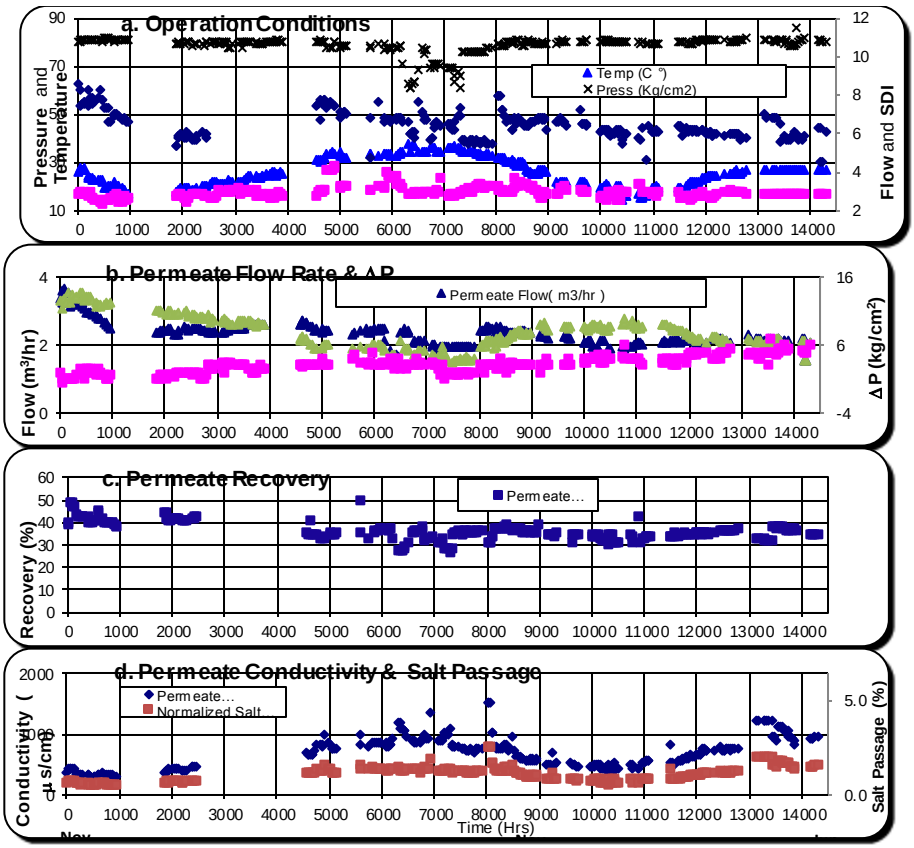


Figure 2. Performance of Membrane A : (a) operation conditions, (b) permeate flow rate, (c) recovery and (d) conductivity vs. operating hours

3.3 Performance of Membrane B

Membrane B was in operation for about 11,000 h and its total period of operation was very close to that of Membrane A indicating lower o-ring/ mechanical failures. The membrane performance for the entire period is shown in Fig. 3. Similar to Membrane A, due to high feed pressure (about 80 bar), the membrane was initially operated at high recovery of about 50% and a flux of about 17 l/m^2/h, which is more than the design flux of Membrane E which is about 15 l/m^2/h. Later the recovery decreased to about 40%, which was maintained during rest of the test period (see Fig. 3c). The variation in feed flow was large and was between 3 to 9 m^3/h as shown Fig.3a. Feed temperature was in the range of 14 to 37 ^{o}C and SDI ranged between 2.32 – 4.3. The permeate flow was initially about 3 m^3/h during high recovery operation and reduced to about 1.5 m^3/h towards the end of operation as can be seen in Fig. 3b. The normalized product flow showed a decrease towards the end of 14,000 h operation to about 1.3 m^3/h from an initial value of 3.6 m^3/h for a net reduction in flow of about 63.9%. This amounts to 50.5% reduction in flux per

year, which indicates significantly high fouling on the membrane and is more fouled than Membrane A. Here also the chemical cleaning was found to be ineffective as in the case of Membrane A. Differential pressure was found to increase continuously throughout the test period which steadily increased from an initial value of <1 bar to about as high as 7 bar towards the end of the experiment indicating slow build up of fouling on the membrane surface which is more than that observed in Membrane A. During the initial period, the permeate conductivity was high at about 800 µS/cm which increased up to 1400 µS/cm during summer and further increased towards the end of experiment which is higher than that of Membrane A. The normalized salt passage was initially in the range of 1.3% and increased to about 3% towards the end of test period as shown in Fig. 3d, indicating poor rejection property of Membrane B in addition to higher fouling of membrane. In short, it can be concluded that although membrane had satisfactory performance in terms of flux compared to Membrane A, the salt rejection was very poor. Moreover, both flux and salt passage reduced at higher rate during long term operation, mainly due to membrane fouling.

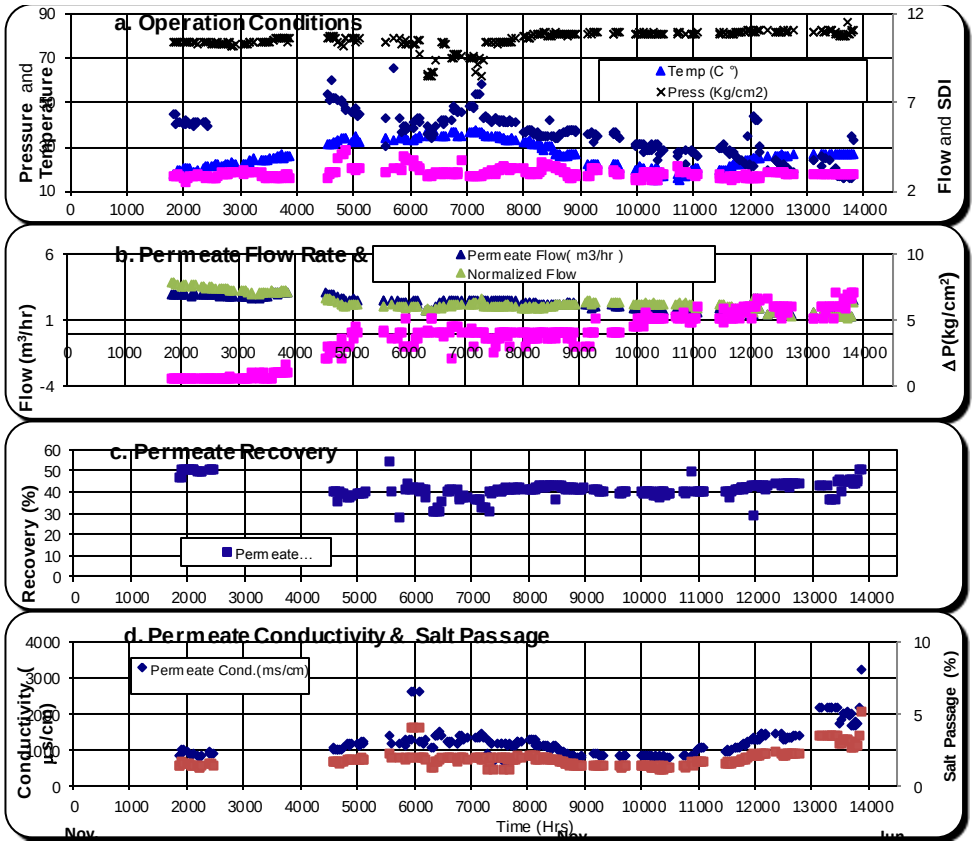


Figure 3. Performance of Membrane B: (a) operation conditions, (b) permeate flow rate, (c) recovery and (d) conductivity vs. operating hours

3.4 Performance of Membrane C

Membrane C was in operation for about 6,200h and its total period of operation was the lowest among all membranes tested indicating highest o-ring mechanical failures. The membrane performance for the entire period is shown in Fig. 4. Similar to Membranes A & B, due to high feed pressure (about 80 bar), initially the membrane was operated at high recovery of about 50% and a flux of about 16 $l/m^2/h$, which is slightly more than the design flux of Membrane E of about 15 $l/m^2/h$. Later, the recovery was reduced to about 40%, which was maintained during rest of the test period (Fig 4c.). The variation in feed flow was between 6 to 10 m^3/h as shown Fig.3a. Feed temperature was in the range of 14 to 37 ^oC and SDI ranged between 2.32 – 4.3.

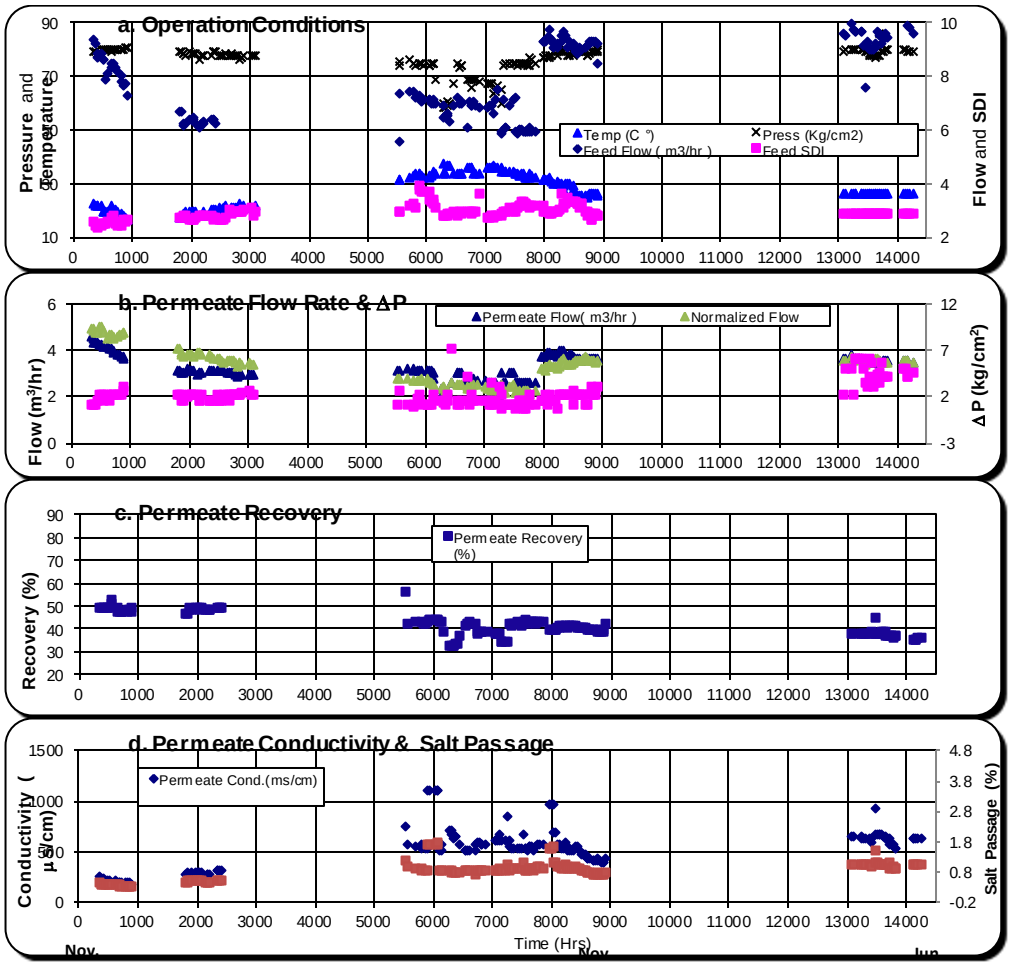


Figure 4. Performance of Membrane C: (a) operation conditions, (b) permeate flow rate, (c) recovery and (d) conductivity vs. operating hours

The permeate flow was initially about 4 m^3/h during high recovery operation and reduced only to about 3.5 m^3/h towards the end of operation as can be seen in Fig. 4b. The normalized product flow showed a decrease of normalized flow to about 3.5 m^3/h towards the end of 14,000 h operation from an initial value of 4.7 m^3/h for reduction in flow by 25.5%. This amounts to 36.2% reduction in flux per year, which indicates considerable fouling on the membrane and is slightly more fouled than the Membrane A but less than Membrane B. In this case also chemical cleaning was found to be ineffective in restoring the performance as observed with Membranes A & B. Differential pressure was found to be <1 bar during most of the period and increased to about 4 bar towards the end of the experiment indicating less effect of fouling on the membrane, most probably due to low operation period. During the initial period, the permeate conductivity was very low at about 200 µS/cm which increased - up to 600 µS/cm during summer which showed no further increase towards the end of the experiment and found to be lower than that of Membrane A. The normalized salt passage was initially in the range of 0.3% and increased to about 1% towards the end of test period as shown in Fig. 4d, indicating very good rejection property of Membrane C. In short, it can be concluded that although membrane had very good performance in terms of flux as well as salt rejection compared to Membrane A, the long term operation results are unavailable for this membrane. Moreover, both flux and salt passage reduced with long term operation at higher rate due to membrane fouling.

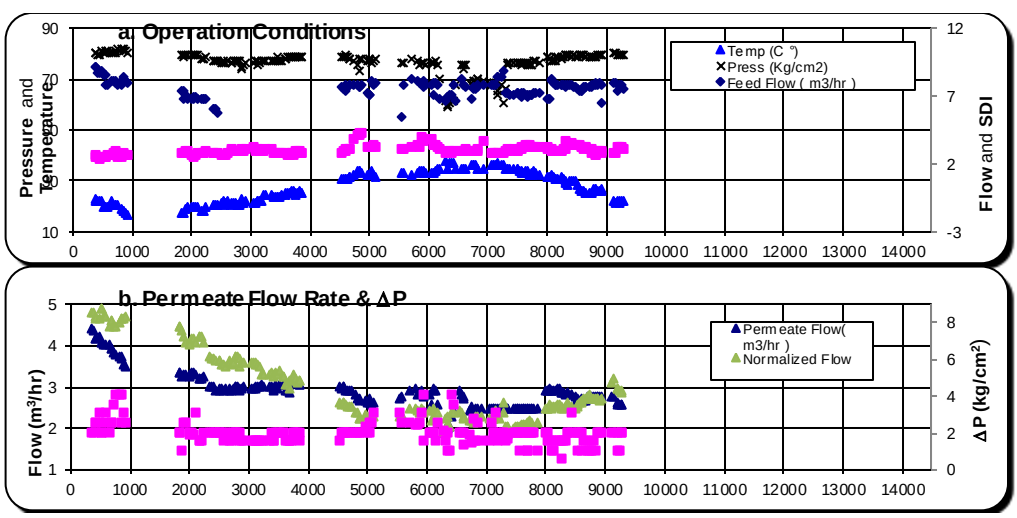
3.5 Performance of Membrane D1

Two models of Membrane D were evaluated; one with lower surface area and thicker feed spacer and other one with larger surface area and thinner feed spacer, where the former model is identified as Membrane D1 and the latter model is Membrane D2. The Membrane D1 was in operation for about 6,700 h and its total period of operation was the slightly above Membrane C which has the lowest operating period among all membranes tested indicating high rate of o-ring/ mechanical failures. The membrane performance for the entire period is shown in Fig.5. Similar to other membranes, due to high feed pressure (about 80 bar), initially the membrane was operated at high recovery of about 50% and a very high flux of about 19 l/m^2/h, which is much higher than the design value of Membrane E which is about 15 l/m^2/h. Later, the recovery was reduced to about 35%, which was maintained during rest of the test period (see Fig. 5c). The variation in feed flow was between 6 to 9 m^3/h as shown Fig.5a. Feed temperature was in the range of 14 to 37 ^oC and SDI ranged between 2.32 – 4.3. The permeate flow was about 4 m^3/h initially during high recovery operation and reduced to about 2.7 m^3/h towards the end of operation as can be seen in Fig. 5b. The normalized product flow calculated showed a decrease of normalized flow to about 2.8 m^3/h towards the end of operation from initial value of 4.6 m^3/h for a net reduction in flow by 39.1%. This amounts to 51.2% reduction in flux per year, which indicates a substantial fouling on the membrane and is more fouled than membranes A & C and comparable to that of Membrane B. This could be attributed to operation of the membrane at higher flux compared to other membranes. Here also, the chemical cleaning failed to provide any positive results. Differential pressure was found to be steady at about 2.5 bar during most of the period indicating that fouling did not affect feed spacer especially because of the higher thickness of the feed spacer. During the initial period, the permeate conductivity was very low at about 200

µS/cm which increased - up to 600 µS/cm during summer and showed no further increase towards the end of experiment which is very similar to that of Membrane C. The normalized salt passage was initially in the range of 0.3% and increased to about 1% towards the end of test period as shown in Fig. 5d, indicating very good rejection property of Membrane D1. In short, it can be concluded that although membrane had very good performance in terms of flux as well as salt rejection similar to Membrane C, the long term operation results are not available for this membrane as in the case of Membrane A. Moreover, both flux and salt passage reduced with long term operation at higher rate due to membrane fouling. This could be mainly attributed to operation of the same at extremely high flux rate.

3.6 Performance of Membrane D2

The Membrane D2 was in operation for about 11,200 h and the total period of operation was closer to Membranes A & B which have the highest operating period among all membranes tested indicating low rate of o-ring/ mechanical failures. The membrane performance for the entire period is shown in Fig. 6. Similar to other membranes, due to high feed pressure, initially the membrane was operated at high recovery of about 50% and a very high flux of about 18 $l/m^2/h$, which is much higher than the design value of Membrane E of Train, which is about 15 $l/m^2/h$. Later, the recovery was slowly reduced and reached to about 35% towards the end of test period (Fig. 6c). The variation in feed flow was between 6 to 9 m^3/h as shown Fig. 6a. Feed temperature was in the range of 14 to 37 ^oC and SDI ranged between 2.32 – 4.3.



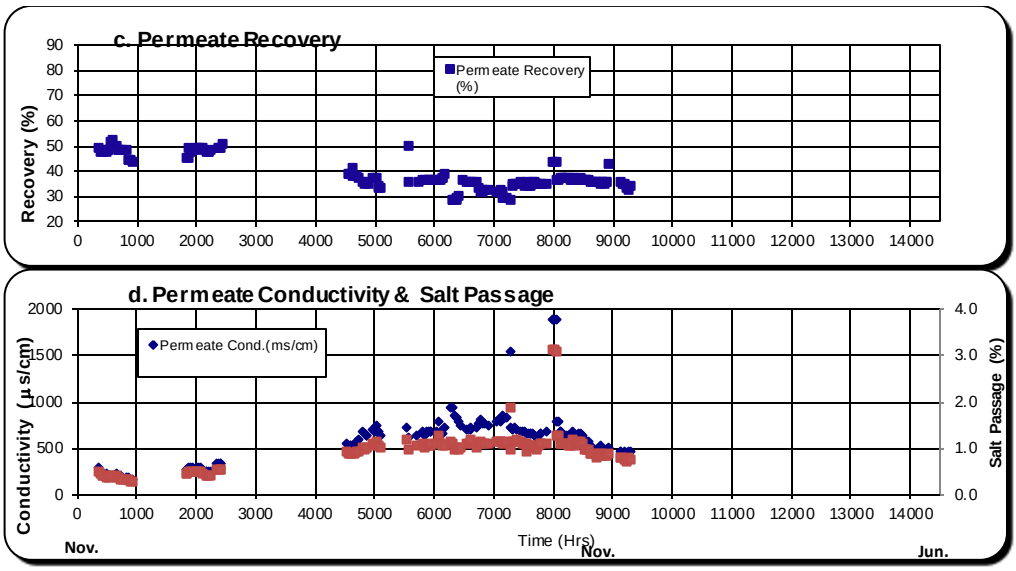


Figure 5.Performance of Membrane D1: (a) operation conditions, (b) permeate flow rate, (c) recovery and (d) conductivity vs. operating hours

The permeate flow was about 4 m^3/h initially during high recovery operation and reduced only to about 2.8 m^3/h towards the end of operation as can be seen in Fig. 6b. The calculated normalized product flow showed a decrease towards the end of operation to about 2.5 m^3/h from initial value of 4.7 m^3/h for a net reduction in flow by 46.8%. This amounts to 36.5% reduction in flux per year, which indicates significant fouling on the membrane and is similar to that of Membrane C. Chemical cleaning failed to restore the performance similar to the rest of the membranes. Differential pressure was found to increase steadily from initial value of about 2.0 bar to value of about 5 bar indicating that fouling was slowly building upon the feed spacer which is comparatively thinner than that of Membrane D1. During the initial period, the permeate conductivity was very low at about 200 □S/cm which increased up to 700 □S/cm during summer which further increased towards the end of experiment to 800 □S/cm. The normalized salt passage was initially in the range of 0.4% and increased to 1.6% towards the end of test period as shown in Fig. 6d, indicating relatively good salt rejection property of Membrane D2 compared to other membranes. In short, it can be concluded that the membrane had relatively good performance in terms of flux as well as salt rejection. Moreover, both flux and salt passage reduced with long term operation at higher rate due to membrane fouling. This could be mainly attributed to operation of the same at extremely high flux rate.

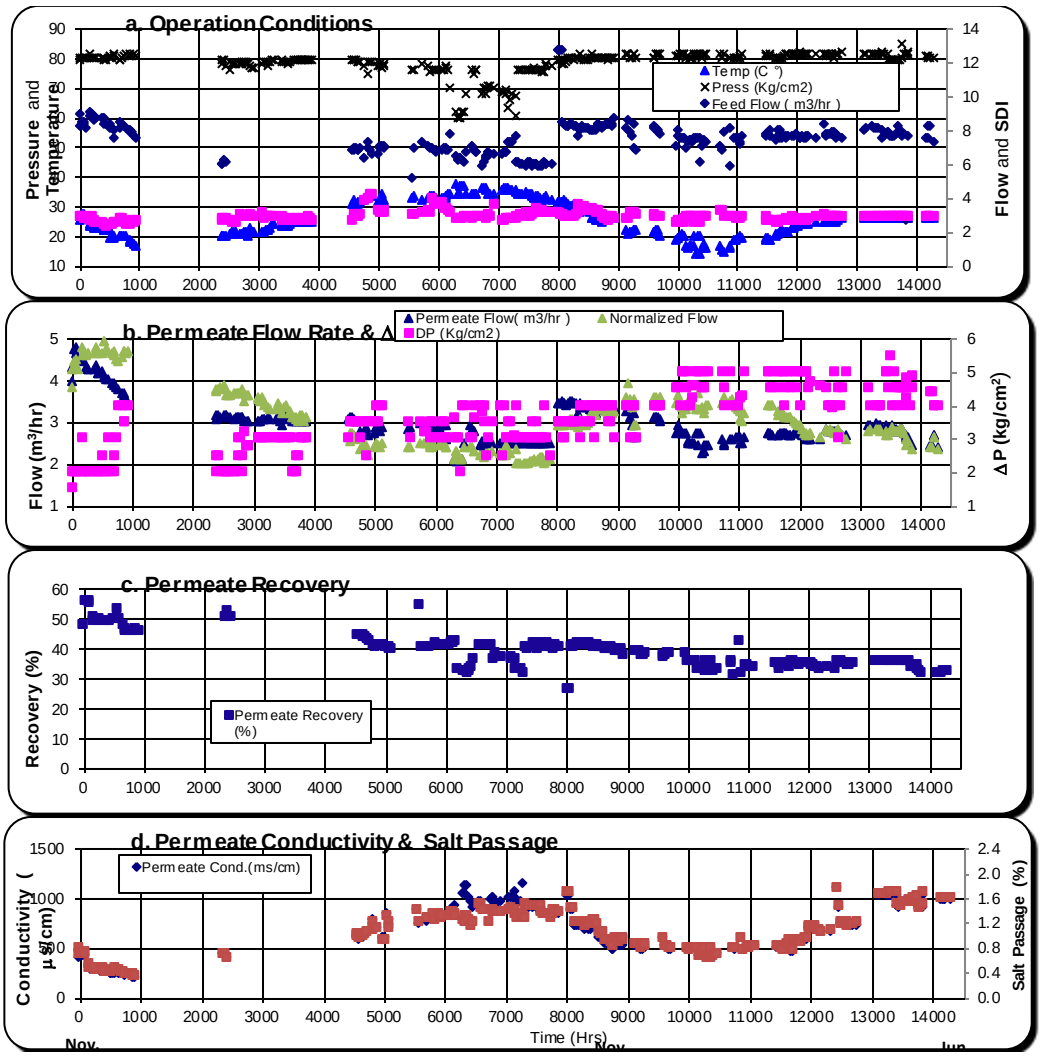


Figure 6.Performance of Membrane D2: (a) operation conditions, (b) permeate flow rate, (c) recovery and (d) conductivity vs. operating hours

3.7 Chemical Analysis Results

Chemical analyses of permeates of membranes were conducted on monthly basis. The major parameters of interest were the totals dissolved solids (TDS) content in the final product. The results of product analyses from all membranes are shown in Fig. 7. It is clear from the figure that TDS content follow the conductivity trend. It showed that Membrane C had lowest content of TDS (< 300 ppm) followed by Membrane D1 which had TDS < 400 ppm. Membrane D2 had TDS < 500 ppm, which is similar to that of Membrane A. The worst performance among all the membranes was observed with Membrane B, which had TDS < 750 ppm.

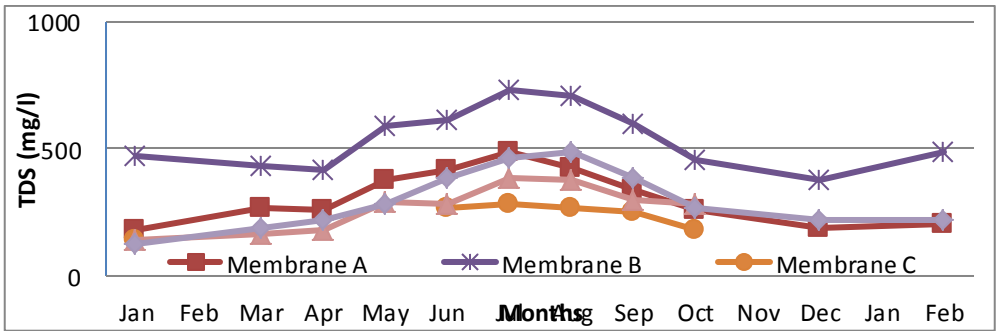


Figure 7. Permeate quality of all five membranes analyzed in terms of total dissolved solids vs. months

3.8 Performance Comparison of Membranes

Table 2 compares performance of all five membranes evaluated in terms of productivity (flow), average flux, product quality (salt passage) as well as resistance to fouling (ΔP). It can be seen from the table that both Membranes C & D1 had lowest net operating time, which is almost half of that of the rest of membranes operation period. Hence, a real comparison is extremely difficult in this case. In order to minimize the effect of operating period on the membrane performance, comparisons were made by either extrapolating or interpolating the data whichever applicable, on a yearly basis assuming that the variation is linear.

Table 2. Comparison of performance among the evaluated spiral wound membranes

Net operation hours		A	B	C	D1	D2
		12,054	11,094	6174	6,704	11238
Average normalized flow	Initial (m^3/h)	3.3	3.6	4.7	4.6	4.7
	Final (m^3/h)	2.1	1.3	3.5	2.8	2.5
	Reduction per year (%)	26.4	50.5	36.2	51.2	36.5
Average Flux ($l/m^2/h$)		11.21	13.0	14.6	16.2	13.3
Average normalized salt passage	Initial (%)	0.6	1.43	0.34	0.35	0.48
	Final (%)	1.6	3.2	1.0	0.9	1.6
	Increase per year (%)	122	99	275	205	177
Average differential pressure (ΔP)	Initial (bar)	1.5	0.5	1.8	2.7	2.5
	Final (bar)	5.1	6.0	4.4	1.7	4.5
	Increase per year (%)	174	869	205	-48.4	64

The comparison of normalized flow showed that both Membranes D1 & D2 as well as Membrane C had the highest productivity in terms of product flow, whereas Membrane A & B had comparatively lower productivity by about 30%. This was also the case in the earlier study conducted at Red Sea where Membranes C & D2 were found to have the best performance in terms of productivity [6]. Among the high productivity membrane, retention of productivity which is indicated by reduction in flow per year showed that Membranes C and D2 had better fouling resistant property than Membrane D1. The higher productivity loss of Membrane D1 could be attributed to comparatively higher average flux (16.2 $l/m^2/h$) operation of membrane which accelerated fouling on Membrane D1 leading to faster production loss. Although, Membrane A had lower initial productivity, it has shown to be capable of maintaining the productivity with less reduction in flow per year compared to any other membranes, which can be attributed to its low average permeate flux. Membrane B which had low initial productivity also showed higher rate of reduction in productivity per year which is equal to that of Membrane D1. In general, it was shown that lower the flux the lower the decline in normalized flow per year. It is known that for SWRO plant operating on an open intake feed water, the recommended permeate flux [7] is 12 – 15 $l/m^2/h$, where the lower limit is for highly fouling feed water. Hence, it may be noted that a low flux operation may be preferred in Al-Jubail to minimize the faster performance reduction. With regard to normalized salt passage Membranes C, D1 & D2 showed best performance initially followed by Membrane A as these membranes produced best product quality. Membrane B was the worst among all membranes evaluated. However, the increase in normalized salt passage per year was least for Membrane B. The other membrane is Membrane A which had the least increase in salt passage per year that proves the ability of Membrane A in maintaining its performance even though it is lower than other membranes, probably due to its low flux operation. Membrane C showed highest increase in salt passage per year, which had lowest initial salt passage. Lowest increase in differential pressure per year was observed with

Membranes D1 & D2. Membrane D1 showed rather a decrease in □P, indicating that foulant did not adhere to the feed spacer. This could be attributed to thicker (32 mil) feed spacer of Membrane D1 compared thinner (28 mil) feed spacer of Membrane D2. Membrane C had low □P (~ 2 bar) during the most of operation period and increased (~4.4bar) towards the end of the test after resuming operation after a long period of isolation. Membrane A showed a steady increase in □P with time. Membrane B had highest increase in □P per year which confirms the poor performance of the same among all other membranes.

4. Conclusions

A total of five different membranes, which was labeled as Membranes A, B, C, D1 and D2 were evaluated for a period of more than 1.5 years. Membranes were evaluated in one of the running Trains of Jubail SWRO plant, which had Membrane E. Hence, it was unable to control operating parameters for individual membranes and whatever the conditions set for operating Membrane E was utilized. Even, maintenance work for individual membrane could not be performed when required and has to be delayed until the shutdown of entire train which apparently led to some membranes, especially Membranes C & D1 to operate only 50% of the time. These factors made it difficult to have true comparison among the membranes. However, to offset the effect of variation in operating time on membrane performance, the decline in performance per year was calculated by either extrapolating or interpolating (whichever is applicable) data assuming the reduction in performance is linear and logical conclusion were made out of available data. Probably, results may be slightly different if operating conditions such as recovery and flux are controlled. The study revealed that Membranes C, D1 & D2 had best productivity, which is 30% more than that of productivity of Membranes A & B. Salt passage results also showed that Membranes C, D1 & D2 are the best performers. Membrane A - also showed salt passage very close to this range. Membrane B was the worst performer among all membranes tested, which was also found in the previous study [6]. The result of increase in □P, which is an indication of fouling resistivity, showed that Membrane D1 was the best performer followed by Membrane D2. Membranes A & C follow Membranes D1 & D2 whereas Membrane B was found to be the worst performer among all. Although, the performance of Membrane A was lower than that of Membranes C, D1 & D2, it has shown to have better ability in maintaining its performance throughout the test period. This was mainly attributed to its low flux operation compared to other membranes. On the contrary, Membrane D1 has shown poor ability in maintaining its performance especially the productivity, which was attributed to operation of membrane at higher flux compared to other membranes. Based on TDS content in the permeate, the best membranes which can be applied in a single stage SWRO plant are Membrane C followed by Membrane D1. Membranes A & D2 have acceptable performance. Of course, one needs to consider the fact that former two membranes operated only 50% of time than that of latter two. If all membranes were operated at the same time, results may vary. Previous study [6] also indicated that membranes from Membranes C & D2 had superior performance compared to membranes. Although, it is difficult to make precise recommendations due to limitations in the experimental set-up, from available data, it could be concluded that Membranes C, D1 & D2 are superior in terms of productivity as well as salt passage. Any of these membranes may be used as

a replacement to existing membrane E, especially a membrane like membrane D1 due to its thicker feed spacers (34 mil) that has ability to handle fouling. Moreover, operation of these membranes at lower flux about 12 $l/m^2/h$ may be preferred to maintain the long term membrane performance, which requires additional 132 membranes for a membrane with 370 ft^2 surface area or 86 membranes for a membrane with 400 ft^2 surface area in addition to 480 membranes available in existing Train. On the other hand, if a higher flux operation is preferred to avoid adding pressure vessels to the existing Train, an efficient chemical cleaning method should be identified which has the capability of maintaining long term performance of membranes. Finally, for a real comparison of membranes, it is recommended to avoid utilizing a running train where the operating parameters of individual membranes cannot be controlled.

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Electrochemical inactivation of *Legionella pneumophila* using anodic oxidation on Boron Doped Diamond electrode

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Abstract.

Legionella bacteria are the waterborne pathogens commonly found in chlorinated potable water and linked to nosocomial infections. Especially, *Legionella pneumophila* can survive and colonize water systems, particularly in warm water system. On-site supplemental disinfection of water systems might be one of the approaches to prevent nosocomial infections. In this work, the inactivation *L. pneumophila* using a single compartment electrochemical flow cell equipped with Boron Doped Diamond (BDD) anode and Titanium cathode was investigated. The bactericidal activity of galvanostatic electrolysis using BDD anode was evaluated on synthetic contaminated waters containing *L. pneumophila*. BDD-anodic oxidation at current density of 50 mA cm^{-2} of *L. pneumophila* at cell density of 10^7 - 10^8 CFU mL^{-1} achieved total death of *Legionella* bacteria in treated water samples within 60 min electrolysis. The effects of some experimental parameters (current density, NaCl concentration, cell density, and flow rate) on kinetics and efficiency of BDD-anodic oxidation during electrochemical disinfection of *L. pneumophila* suspensions were also examined. The results have indicated that the bactericidal activity of BDD anodes increases with increasing current density and NaCl concentration. This can be explained by the contribution of mediated oxidation with electrogenerated oxidants including hydroxyl radicals, hydrogen peroxide, ozone and free chlorine in the inactivation mechanism of *Legionella* bacteria at high current densities. This research work has shown that BDD anode is promising tool for inactivation of waterborne pathogens in water and wastewater disinfection.

Key words. Waterborne pathogens, *Legionella pneumophila*, water disinfection, electrochemical inactivation, Boron Doped Diamond electrode, bactericidal activity

1. Introduction.

Water contamination is a major cause of water borne diseases and seriously threatens public health. In general, chlorine is the commonly used chemical method of disinfection, providing both primary and residual disinfection. Unfortunately, there are several disadvantages of using chlorine such as unfavorable taste and odor, its ineffectiveness when used alone against some resistant microorganisms, and the generation of potentially toxic byproducts such as organo-halogenated compounds (trihalometanes, THMs). Various alternatives, including non-oxidizing biocides, ozone, ultraviolet light, chlorine dioxide, chloramines, copper-silver ionization and thermal disinfection, have been explored for disinfecting bacteria-contaminated water. However, these methodologies have shortcomings that are difficult to resolve such as high cost, expensive maintenance, instantaneous treatment and handling of chemical.

The selection of an adequate method for water disinfection depends on bactericidal efficiency, ease to control, operating cost-effectiveness, as well as low risk to the environment. Electrochemical water disinfection is rarely used but is a convenient and highly efficient way to produce bacteria-free water. This technique works without the addition of chemical compounds to the water to be treated, but is nevertheless based on the biocide action of various chemical substances. In particular, electrochemical oxidation has been used for the removal of biorefractory organic pollutants and micro-toxic substances from several specific types of industrial wastewater. Also, the use of electrolytic methodology to eliminate microorganisms in natural water for drinking water production has been well documented [1-6]. Although numerous previous studies have proposed application of electrochemical water disinfection, breakthroughs in technology are still required for economically practical application [4,6].

Boron doped diamond (BDD) thin-film electrode has excellent chemical and electrochemical stability and high overpotential for oxygen and hydrogen evolution, and these properties revealed to be superior to those of platinum (Pt) and glassy carbon electrodes. Electrochemical oxidation using BDD anodes has recently been considered as an advanced oxidation technology [7] due to the production of large quantities of hydroxyl radicals from water electrolysis [8-9]. This electrochemical method has been successfully utilized for the treatment of wastewaters containing non-biodegradable compounds at both laboratory and full scale [10-12].

The aim of this work was to demonstrate the application potential of boron-doped diamond electrodes (BDD) in electrochemical disinfection of water contaminated with waterborne pathogens. Legionella pneumophila was used as typical model pathogen and microbial indicator of water quality to assess the bactericidal efficiency. The influence of operating conditions (current density, NaCl concentration, bacterial cells density, and flow rate) on disinfection efficiency and bactericidal activation was investigated to estimate the role of different oxidants (e.g. hydroxyl radicals and free chlorine) in the electrochemical disinfection process.

2. Materials and Methods.

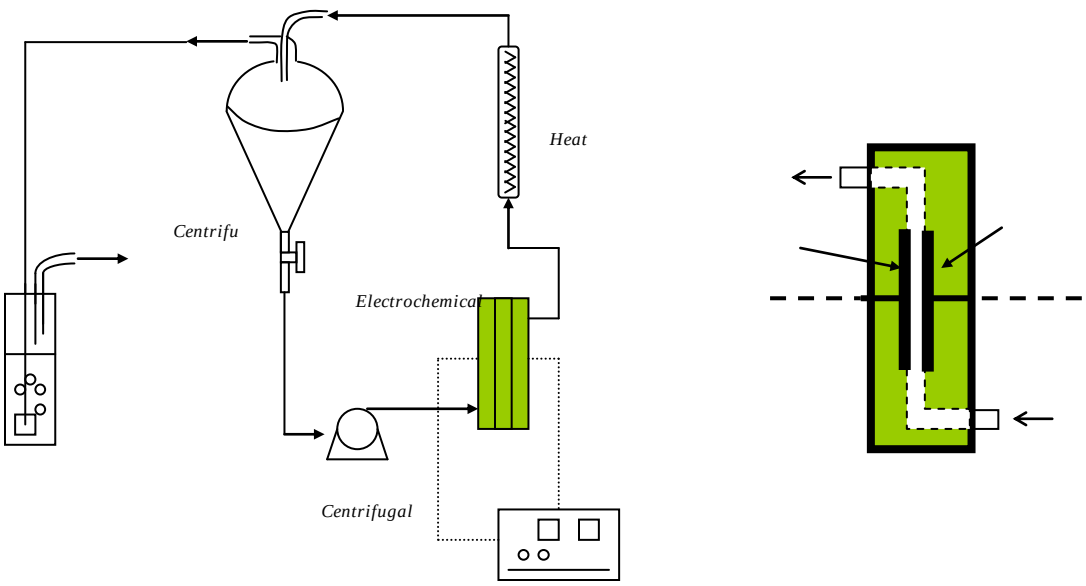
2.1. Preparation of Boron doped diamond electrode

Boron-doped diamond films were provided by CSEM (Switzerland) and synthesized by the hot filament chemical vapor deposition technique (HF CVD) on single-crystal p-type Si <100>

wafers (0.1 cm, Siltronix). The temperature range of the filament was 2440–2560 °C and that of the substrate was 830 °C. The reactive gas was methane in excess hydrogen (1% CH_4 in H_2). The dopant gas was trimethylboron with a concentration of 3 ppm. The gas mixture was supplied to the reaction chamber at a flow rate of 5 dm^3 min^{-1}, providing a growth rate of 0.24 µm h^{-1} for the diamond layer. The resulting diamond film thickness was about 1 µm. This HF CVD process produces columnar, random texture, and polycrystalline films with an average resistivity of 0.01 Ω.cm. Prior to be used in galvanostatic electrolysis assays, the electrode was polarized for 30 minutes with a 1 M H_2SO_4 solution at 50 mA cm^{-2} to remove any impurity from its surface.

2.2. Galvanostatic electrolysis set-up

The galvanostatic electrolyses were carried out in a single-compartment electrochemical flow cell (Figure1). Diamond-based material was used as anode and stainless steel (AISI 304) as the cathode. Both electrodes were circular (100 mm diameter) with a cross sectional area of 78 cm^2 each and an electrode gap of 9 mm. The electrolyte was stored in a glass container (500 ml) and circulated through the electrolytic cell using a centrifugal pump. A heat exchanger was used to maintain the temperature at 25 °C. The electrolyte flow rate through the cell was varied from 250 to 1250 mL min-1.



(a) **(b)**

Figure 1. Experimental setup: a) layout of semi-pilot plant; b) details of the electrochemical cell.

2.3. Preparation of *L. pneumophila*-contaminated water samples

L. pneumophila suspensions (GTC/GIFU 00296) were received from the department of Micrbiology, Faculty of Sciences of Gabes. L. pnemophila suspensions were precultured with charcoal yeast extract (CYE) medium containing α-ketoglucorate (Becton Dickinson) at 37 °C for 72 h. Legionella pneumophila were centrifuged at 3000 rpm for 30 min at 4 °C and resuspended in 2 L phosphate buffered saline (PBS, pH 7) at a bacterial density of approximately 10E+7-8 colony-forming units (CFU) mL^{-1}. The bacterial suspension was then used as contaminated water sample.

2.4. Analytical procedures.

The total disinfectant concentration was measured by DPD standard method and expressed as total chlorine (ppm), including all the disinfectants in the solution, free and combined chlorine, peroxo-disulfates, peroxo-bicarbonates, hydrogen peroxide, and etc.
The survival of *L. pneumophila* cells in water samples taken at each sampling point was detected by bacterial fluorescence staining and by colony forming on prepared CYE medium with added α-ketoglucorate. The fluorescent staining procedure was performed for each sample taken at a desired time. 10 mL of *L. pneumophilla*-contaminated water sample was centrifuged and the bacterial pellet was re-suspended in 90 μL of PBS buffer. Then 10 μL of the 100 μL bacterial stain solutions (green or red) were added to the bacterial suspension and incubated at room temperature for 10-15 min. The stained bacteria were viewed by fluorescence microscopy (AxioImagerA1 SP, Carl Zeiss) and the bacterial cell death rate was quantified using an image analysis system comprising a digital counter (AxioCamMRc SP, Carl Zeiss) and software (Scion Image, freeware). The BacLight bacterial Viability kits employed two nucleic acid stains: a green-fluorescent SYTO 9 stain labels both live and death bacteria, whereas propidium iodide penetrates only bacteria with damaged membranes and STYO 9 fluorescence is reduced when both dyes are present. Thus live bacteria with intact membrane were fluorescent green, whereas dead bacteria with damaged membranes were fluorescent red. The L. pneumophilla death rate was calculated as (Eq.1):

$$\text{Bacterial Death Rate } (t=t)=100\times \frac{\text{Red Fluorescent}(t=t) - \text{Red Fluorescent } (t=0)}{\text{Green Fluorescent } (t=0)} \quad (1)$$

In order to verify the results observed in the staining experiment, the cultural count of L. pneumophilla cells in water samples were detected by the colony formation method with CYE medium with added α-ketoglucorate. The water samples were diluted with PBS buffer solution in a tenfold dilution series. 1 mL aliquots of each dilution stage of the water samples were mixed with CYE medium with added α-ketoglucorate at 45 °C in a 10 cm Petri dish and were allowed to cool to room temperature. After the medium solidified, the dishes were incubated at 35 °C for 24-48 h to determine the number of CFUs. The bacterial survival rate was calculated as (Eq. 2):

$$\text{Bacterial Survival Rate } (t=t)=100\times \frac{\text{CFU } (t=t)}{\text{CFU } (t=0)} \quad (2)$$

3. Results and discussion.

Table 1 shows change in bacteria cell density (CFU number) when *L. pneumophila* was injected into 0.05 M NaCl aqueous solution and as can be seen from Table 1, no significant change was observed with time. These preliminary results confirmed that *L. pneumophila* remains stable in 0.05 M NaCl aqueous solution (pH 7.2) during 1 h at 25 °C.

Table 1. *L. pneumophila* stability in 0.05 M NaCl (pH 7.2) aqueous solution at 25 °C.

Time (min)	L. pneumophila (CFU mL^{-1})
0	4.5×10^7
30	4.2×10^7
60	4.6×10^7

The efficient inactivation of *L. pneumophila* bacteria is dependent on the ability of galvanostatic electrolysis on BDD anodes to produce strong oxidants. Marselli et al. [8], have confirmed that large amounts of hydroxyl radicals can be electrogenerated from water discharge on BDD electrodes. These radicals are very powerful oxidants and are able to react non-selectively with waterborne pathogens in water to inactivate them and damage bacterial cells and prevent their growth. Furthermore, recent investigations have shown that other strong oxidants such as ozone, hydrogen peroxide, persulfates, perphosphates, and hypochlorites can also be generated from the electrochemical oxidation of water and supporting electrolytes on BDD anodes. In particular, the electrolysis of aqueous solutions containing chloride ions using BDD electrodes can lead to the formation of hydroxyl radicals and active chlorine species which are largely used for water disinfection (Eq. 3-8) [6-12].

$$H_2O \qquad HO^{\bullet} + H^+ + e \qquad (3)$$
$$H_2O + Cl^- \qquad ClO^- + 2H+ + 2\,e \qquad (4)$$
$$2\,Cl^- \qquad Cl_2 + 2e \qquad (5)$$

For weakly acidic, neutral and alkaline conditions, Cl_2 is unstable and it reacts rapidly with HO- to produce HClO/ClO^- ions:

$$Cl_2 + 2\,OH^- \qquad ClO^- + Cl^- + H_2O \qquad (6)$$
$$Cl_2 + OH^- \qquad HClO + Cl^- \qquad (7)$$

Chlorine dioxide can also be produced as oxidant from:

$$Cl_2 + HClO + H_2O \qquad ClO_2 + 3H^+ + 2Cl^- + e \qquad (8)$$

Additionally, ozone and hydrogen peroxide can be formed from oxygen and water oxidation/reduction on BDD anodes (Eq. 9-11):

$$H_2O + O_2 \qquad O_3 + 2H^+ + 2\,e \qquad (9)$$
$$3\,H_2O \qquad O_3 + 6H^+ + 6\,e \qquad (10)$$

$$H_2O + O_2 + 2e \qquad H_2O_2 + 2\,OH^- \qquad (11)$$

However, little information is available in the literature regarding the amount of total oxidants formed during electrolysis of water containing sodium chloride (NaCl). The amount of oxidants, measured as mg Cl_2 L^{-1}, formed during galvanostatic electrolysis of water using BDD anodes largely depends on NaCl concentration and current density. The electrochemical inactivation of *Legionella* bacteria using BDD-anodic oxidation can be attributed to the electrochemically produced oxidants including hydrogen peroxide, ozone and free chlorine which could attack the bacterial cell wall and membrane, and disrupt the membrane integrity. Thus, it is important to measure the amount of total oxidants formed during galvanostatic electrolysis and to evaluate the influence of NaCl concentration and current density on oxidants production.

Figures 2 and 3 present the influence of NaCl concentration and current density on the production of oxidants, as mg Cl2 L-1, during galvanostatic electrolysis of aqueous solutions using BDD anode. Increasing NaCl concentration or current density increases the amount of oxidants measured at the end of electrolysis period. As shown in Figures 2 and 3, changes of oxidants concentration with time exhibits similar profiles: oxidants concentration increases linearly and rapidly during the first hour and then remained stable for the rest of treatment time. The observed maxima for oxidants concentrations may be explained in terms of two opposite phenomena: stability of oxidants and mass transfer control. These results proved that galvanostatic electrolysis produce sufficient amount of oxidants susceptible to inactivate waterborne pathogens in water.

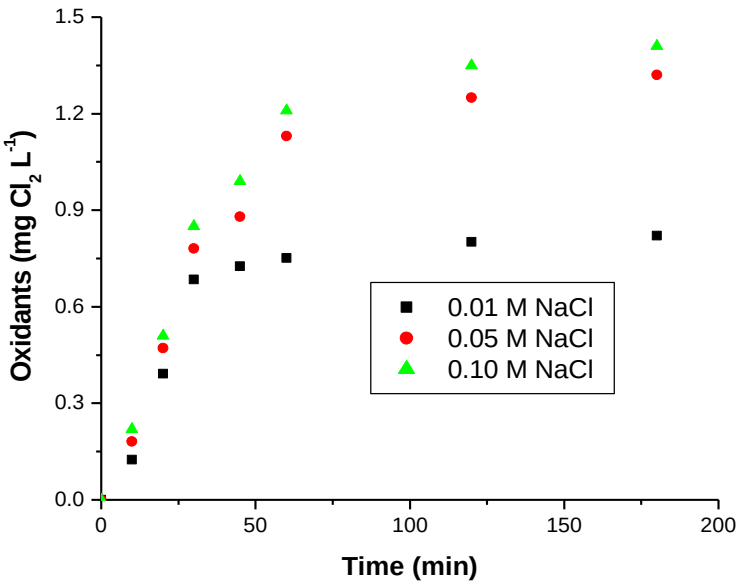


Figure 2. Influence of NaCl concentration on the production of oxidants in mg Cl2 L-1 during galvanostatic electrolysis of aqueous solutions. Experimental conditions: Current density: j=50 mA cm-2; flow rate: 250 mL min-1; T = 25 °C; pH 7.2.

Figure 4 presents the influence of current density on the changes of bacterial survival with time during galvanostatic electrolysis of L. pneumophila-contaminated aqueous solutions containing 0.05 M NaCl. As can be seen, the increase of current density from 20 mA cm-2 to 50 mA cm-2 leads to decrease of the bacterial survival from 49 % to 18 %, respectively after 2 hrs. The increase of the current density to 100 mA cm-2 achieves a complete inactivation of Legionella bacteria within 1 h. The fact that partial bactericidal effects were observed for lower current density than 100 mA cm-2 revealed that the amount of oxidants produced during galvanostatic electrolysis using BDD anodes were not sufficient to totally inactivate L. pneumophila bacterial cells.

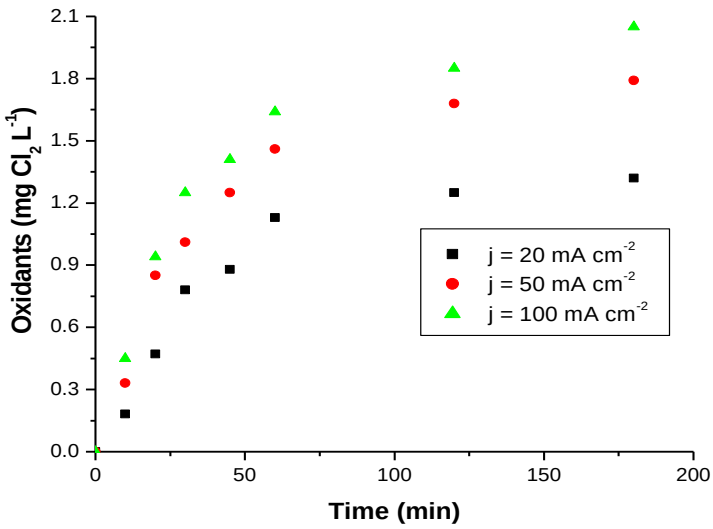


Figure 3. Influence of current density on the production of oxidants in mg Cl2 L-1 during galvanostatic electrolysis of aqueous solutions. Experimental conditions: Electrolyte: 0.05 M NaCl; flow rate: 250 mL min-1; T = 25 °C; pH 7.2.

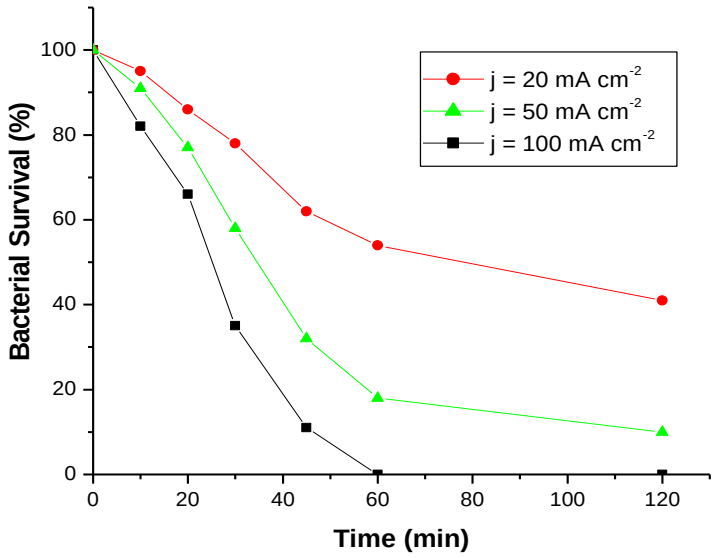


Figure 4. Influence of current density on the bacterial survival during electro-disinfection of Legionella-contaminated aqueous solutions by galvanostatic electrolysis. Experimental conditions: Electrolyte: 0.05 M NaCl; L. pneumophila bacterial density: 4.4 107 CFU mL-1; flow rate: 250 mL min-1; T = 25 °C; pH 7.2.

Figure 5 shows the influence of current density on the change of bacterial survival with time during galvanostatic electrolysis of L. pneumophila-contaminated aqueous solutions at a fixed current density of 50 mA cm-2. As can be observed, the increase of NaCl concentration greatly enhanced the bactericidal efficiency of the electrochemical process. The growth of L. pneumophila was completely inhibited in 0.1 M NaCl aqueous solution within 1 hr; while galvanostatic electrolysis of Legionella-contaminated 0.01 M and 0.05 M NaCl aqueous solutions achieved only 68 and 90 % of bacterial death after 2 hrs. In addition, increasing NaCl concentration resulted in increasing the ionic conductivity of Legionella-contaminated water samples, which decreases the voltage and thus total costs reductions. The role of Cl− has been also verified through an experiment performed on bacteria contaminated water sample by adding 0.05 M NaClO4, which is an inert supporting electrolyte that does not form free chlorine. The result obtained in this case has shown that only 32 % of bacteria death can be reached after 1 hr treatment. It is worthily noted; however, that when NaCl is used as supporting electrolyte, hazardous chlorinated by-products can be formed which should be taken into consideration if water samples contain organic impurities.

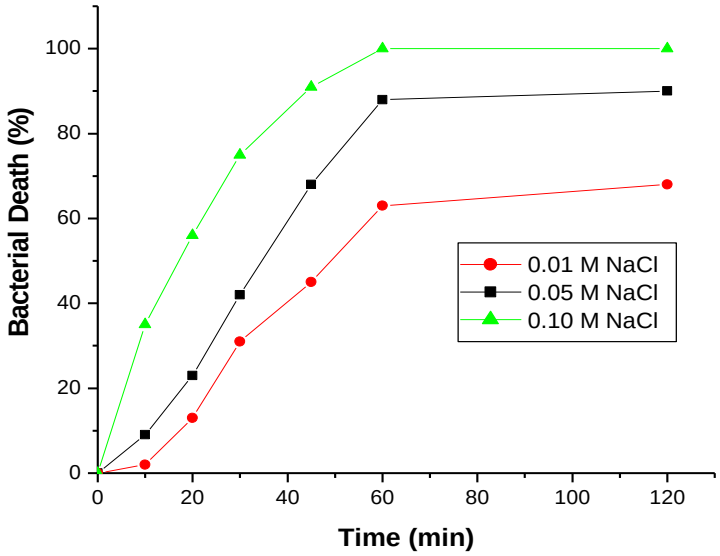


Figure 5. Influence of NaCl concentration on the bacterial death during electro-disinfection of Legionella-contaminated aqueous solutions by galvanostatic electrolysis. Experimental conditions: Current density: j=50 mA cm-2; L. pneumophila bacterial density: 4.4 107 CFU mL-1; flow rate: 250 mL min-1; T = 25 °C; pH 7.2.

The influence of initial bacterial cells density, in the range 107-108 CFU mL−1, on bacterial survival is shown in Figure 6. In all cases, complete bacterial death has been achieved, but the

required contact time increases with the increase of bacteria cells density. The continuous production of free chlorine and other oxidants during galvanostatic electrolysis of bacteria-contaminated water is expected to reach complete bacterial death independently of bacterial population. The strong bactericidal action observed at the BDD anode material can be attributed to surface and bulk process: at the electrode/solution interface, high amounts of hydroxyl radicals as well as local acidic conditions can lead to cell death, whereas in the bulk of the solution, the disinfection can be attributed to the electro-generated oxidants. Moreover, it has been documented that electric field is destructive to the cells of the micro-organisms [5,6]. The cell membrane of the microorganisms is the central site of attack for hydroxyl radicals as well as other strong oxidants. Oxidation of the membrane results in loss of essential cell functions leading to its death.

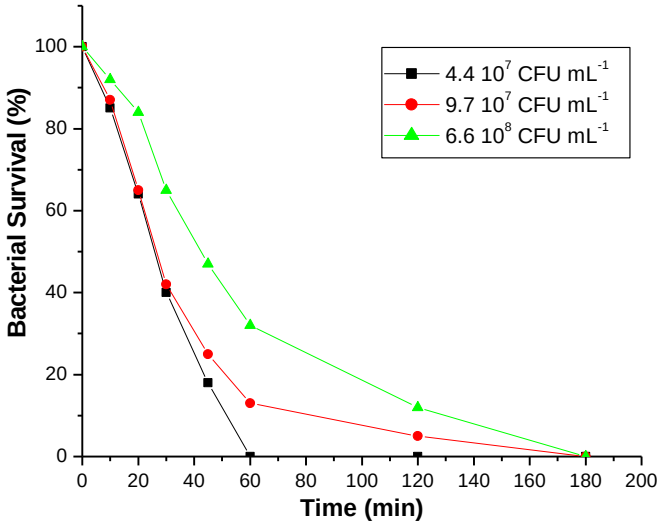


Figure 6. Influence of bacterial density on the bacterial survival during electro-disinfection of Legionella-contaminated aqueous solutions by galvanostatic electrolysis. Experimental conditions: Current density: j=50 mA cm-2; Electrolyte: 0.05 M NaCl; flow rate: 250 mL min-1; T = 25 °C; pH 7.2.

The results of galvanostatic electrolyses using BDD anodes in one compartment electrochemical cell of Legionella-contaminated water samples with different recirculation flow rates in the range between 250 mL min-1 and 1250 mL min-1 are given in Table 2.

Table 2. Influence of flow rate on bactericidal activity of galvanostatic electrolysis on BDD anodes. Experimental conditions: Current density: j=50 mA cm-2; Electrolyte: 0.05 M NaCl; pneumophila bacterial density: 4.4 107 CFU mL-1 T = 25 °C; pH 7.2.

Flow rate (mL min-1)	Contact time (min)	Legionella (CFU mL-1)
0	0	44,000,000
250	60	ND
500	60	ND
750	60	5,000,000
1250	60	18,000,000

It is remarkable that the flow rate has significant influence on bactericidal activity of galvanostatic electrolysis on BDD anodes. Complete bacterial death has been achieved for flow rates of 250 and 500 mL min-1; however the increase of flow rate to 750 and 1250 mL min-1 decreased the bactericidal activity. This can be explained by the fact that the increase of the flow rate decreased the contact time between electrolyte and BDD anodes and between oxidants produced and microbial cells. It can be concluded that the electrochemical disinfection efficiency depends on the dose of oxidants produced by electrochemical oxidation of the electrolyte, the stability of these oxidants, and contact time.

4. Conclusion.

Laboratory experiments have demonstrated that galvanostatic electrolysis using BDD anodes was capable to completely inactivate L. pneumophila bacteria in optimized conditions. Increasing current density and NaCl concentration in the one-compartment electrochemical cell results in increasing bactericidal activity and enhances the rate of Legionella death. Legionella-contaminated water should be recycled continuously with flow rate < 500 mL min-1 to generate an optimal amount of oxidants and to allow adequate contact time to attack bacterial cells. The inactivation of Legionella bacteria using electrochemical oxidation on BDD anodes can be ascribed to the oxidants electrogenerated from water and supporting electrolyte oxidation on BDD surface including hydroxyl radicals, hydrogen peroxide, ozone and free chlorine. The obtained results show the potential of electrochemical oxidation using BDD anodes for water disinfection. Further research will be done in order to obtain essential information for kinetic modeling development under field conditions.

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تقييم طريقة التناضح العكسى فى تحليه المياه لبعض مناطق مدينة طرابلس الليبية.

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كلية البيطرة والعلوم الزراعية - جامعة الزاوية- ليبيا

الملخص

أجريت هذه الدراسة فى بعض مناطق مدينة طرابلس بهدف معرفة تركيز بعض العناصر وتقييم جودة المياه من الناحية الكيميائية لمياه مختلفة المصدر (أبار- وشبكة عامة) بعد تحلية المياه بطريقة التناضح العكسى. تم تجميع العينات وتدوين البيانات عليها من حيث الموقع ، و مصدر العينة وتاريخ أخد العينة. كما تم تحليل العينات وتقدير تركيز العناصر والأملاح التي شملت الأملاح الكلية الذائبة (T.D.S) وتركيز أيون الهيدروجين (pH) والأيونات الذائبة الموجبة الصوديوم (Na^{+}) والبوتاسيوم (K^{+}) والكالسيوم (Ca^{+2}) والماغنيسيوم (Mg^{+2}) والأيونات الذائبة السالبة الكلوريد (Cl^{-}) والعكارة والعسرة ككربونات كالسيوم ($CaCO_3^{-2}$) والكبريتات (So_4^{-2})، وقد أتضح أن معظم مصادر مياه التغذية تحتوي على تركيزات عالية من العناصر الكيميائية وكذلك على تركيز عالى من الأملاح الذائبة الكلية. وبالتالي فإن مصادر مياه التغذية غير ملائمة للشرب من الناحية الكيميائية.

أظهرت نتائج استخدام طريقة التناضح العكسى فى تحليه المياه انخفاض كبيراً في بعض تركيز العناصر الكيميائية وكذلك في كمية الأملاح الذائبة الكلية بعد معالجة مياه التغذية بالمحطات التحلية التجارية المستخدمة للشرب في منطقة الدراسة والتي قد تسبب بعض المشاكل الصحية، وبالتالي فهي غير صالحة للشرب من الناحية الكيميائية من حيث مطابقتها للمواصفات القياسية العالمية والليبية، كما أن احتواء خزانات مياه التحلية على ترسبات وعدم تنظيفها بشكل دوري يجعلها غير ملائمة للشرب، أيضا توصيل مواسير التعبئة ووجود الترسبات عليها من الداخل يجعلها غير صحية.

التناضح العكسى ، و تحلية المياه ،و المواصفات القياسية للمياه

المقدمة

ليبيا جزء من القطاع الجنوبى لحوض البحر المتوسط ، تبلغ مساحتها حوالى 1.760 مليون كيلومتر مربع، وتطل على البحر بساحل يبلغ طوله حوالى 1900 كيلو متر. ويتدرج المناخ فى إطار تقسيم مناخ حوض البحر المتوسط من النطاق الساحلى ذى المطر الشتوى والصيف الجاف الى المناطق الداخلية الصحراوية وهى الجزء الأكبر من البلاد، وليبيا جزء من صحراء شمال أفريقيا. وتقدر الموارد المائية السطحية بحوالى 170 مليون متر مكعب فى العام ، بينما تقدر الموارد المائية الجوفية كوارد سنوى بحوالى 2500 مليون متر مكعب فى العام ،و كمخزون 400000 مليون متر مكعب . يبلغ معدل كمية الأمطار أعلى معدلاته سنويا من 300 إلى 500 ملليمتر فى نطاق الشمال الساحلى (مرتفعات الجبل الأخضر فى الشرق ،و ومرتفعات جبل نفوسة فى الغرب) ، ويقل فى اتجاه الداخل جنوبا حيث يبلغ أقل من 50 ملليمتر. وتقدر أراضى الزراعة المطرية والمروية بحوالى 5% (القصاص ،1999).

ولما كانت المياه السطحية شحيحة و المياة الجوفية غير متجددة ، كان من الضرورى البحث عن مصدر أخر من المياه مثل تحليه مياه البحر أو معالجة مياه الصرف الصحى.

لذا أجريت هذه الدراسة بغرض استخدام عملية التناضح العكسي كإحدى طرق تحليه مياه البحر. ويقصد بها عملية فصل الماء العذب عن محلول ملحي من خلال غشاء شبه نفاذ وذلك بضغط المحلول الملحي بضغط أعلى من الضغط الأسموزي، بهدف تقليل ملوحة المياه وتخليصها من معظم أنواع البكتيريا والفيروسات والمواد الضارة الأخرى. وفاعلية طريقة التناضح العكسي في التخلص من الأملاح ممتازة تصل الى نسبة 99 %.

يهدف البحث الى اختبار كفاءة طريقة التناطح العكسى والتأكد من فاعليتها فى تقليل نسبة الأملاح وتقييم جودة المياه من الناحية الكيميائية فى صلاحيتها للشرب فى بعض المناطق الليبية.

المواد وطريقة البحث

العينات ومواقع تجميعها :

تم أخد عينات مياه من عشر مناطق في مدينة طرابلس لمحطات مياه شرب مختلفة المصدر كما يشاهد فى جدول رقم (1). تم تجميع العينات في زجاجات معقمة ذات سعة 250 مل لتر، لإجراء التحليلات الكيميائية اللازمة والتى شملت الأملاح الكلية الذائبة (T.D.S) وتركيز أيون الهيدروجين (pH) والأيونات الذائبة

الموجبة الصوديوم (Na^+) والبوتاسيوم (K^+) والكالسيوم (Ca^{+2}) والماغنيسيوم (Mg^{+2}) والأيونات الذائبة السالبة (الكلوريد Cl^-) والعكارة والعسرة ككربونات كالسيوم ($CaCO_3^{-2}$) وكبريتات (So_4^{-2}) على التوالى.

جدول (1) يوضح مناطق ومصادر أخذ عينات المياه لمناطق الدراسة.

الرقم	المنطقة	مصدر العينة	الرقم	المنطقة	مصدرالعينة
1	ابوسليم	شبكة	6	11يوليو	بئر
2	الهضبة	شبكة	7	عرادة	شبكة
3	غوط الشعال	بئر	8	السراج	بئر
4	رأس حسن	شبكة	9	السواني	بئر
5	فشلوم	شبكة	10	زاوية الدهماني	شبكة

التحليل الاحصائى:

تم حساب المتوسط الحسابى ± الانحراف القياسى للمقاييس الخاصة بعينات الماء المستخدمة، كما أجرى اختبار ستيودنت – ت (اختبار الفرق بين المتوسطات) للصفات المختلفة لعينات الماء قبل وبعد التحلية بغرض اختبار مدى فاعلية عامل التحلية ومعرفة ما إذا كان الفرق بين متوسط العينتين فرق معنوى أو غير معنوى ، فإذا كان معنوى نستنتج فاعلية العامل . أما آدا كان الفرق غير معنوى فإننا نستنتج عدم فاعلية هدا العامل وان الفرق قد يكون راجعا للصدفة المطلقة أو قد يكون ناتجا من خطأ فى المعاينة (أبو راضي ،1998).

النتائج والمناقشة

نتائج التحليل الكيميائي لعينات مصادر مياه التغذية لمحطات التحلية التجارية في بعض مناطق مدينة طرابلس حيث تستخدم لإغراض الشرب وكانت النتائج المتحصل عليها قبل وبعد التحلية كما في الجداول (2 و3).

يلاحظ من الجدول السابق أن أعلى المناطق فى قيم الكربونات (ALK) 250 ملجم/لتر كانت لمنطقة غوط الشعال ، وأقلها 100 ملجم/لتر لمنطقة أبو سليم . بينما الكربونات (HAR) كانت أعلى القيم 1480 ملجم/لتر لمنطقة الهضبة وأقلهم 500 ملجم/لتر لمناطق كل من عرادة ، و السراج ،و زاوية الدهمانى .

جدول رقم(2): التحليل الكيميائي للعناصر الرئيسية طبقا للمنطقة قبل المعالجة.

Water sample	PH	T.D.S mg/l	Ca^{+2} mg/l	Mg^{+2} mg/l	Na+ mg/l	K+ mg/l	Cl^{-} mg/l	Hco_3 mg/l	So_4^{-2} mg/l	HAR ($caco_3$)	ALK ($caco_3$)
Pond 1	7.61	1615.0	248.0	48.0	184.0	8.8	300.12	122.0	679.0	820.0	100.0
Pond 2	7.61	1628.0	248.0	48.0	184.0	8.9	300.12	152.5	656.0	800.0	125.0
Pond 3	7.39	2358.0	264.0	196.8	210.0	6.2	441.35	305.0	981.0	1480.0	250.0
Pond 4	7.60	1684.0	272.0	38.4	184.0	8.8	300.12	183.0	651.0	840.0	150.0
Pond 5	7.70	1626.0	248.0	52.8	180.0	8.9	300.12	183.0	642.0	840.0	150.0
Pond 6	7.46	2287.0	232.0	100.8	360.0	18.9	815.35	274.5	416.0	1000.0	225.0
Pond 7	7.51	1191	120.0	48.0	182.0	8.5	301.33	213.5	294.0	500.0	175
Pond 8	7.35	1208.0	88.0	67.2	189.0	10.8	301.33	213.5	312.0	500.0	175.0
Pond 9	7.53	2387.0	240.0	105.6	412.0	22.5	815.35	213.5	609.0	1040.0	175.0
Pond10	7.73	1162	128.0	43.2	183.0	6.6	319.05	183.0	285.0	500.0	150.0

فيما يخص الكبريتات كانت أن أعلى القيم 981 ملجم/لتر لمنطقة غوط الشعال ، وأقلها 285 ملجم/لتر لمنطقة زاوية الدهمانى. كانت أعلى القيم للبيكربونات 305.00 ملجم/لتر لمنطقة غوط الشعال وأقلها 122.00 ملجم/لتر لمنطقة أبو سليم. كما كانت أعلى القيم للكلوريدات 815.35 ملجم/لتر لمناطق 11 يوليه والسوانى بينما أقلها 300.12 ملجم/لتر لمناطق أبوسليم ،و الهضبة ،و رأس حسن وفشلوم. . من ناحية أخرى كانت أعلى القيم لعنصر البوتاسيوم 22.50 ملجم/لتر لمنطقة السوانى وأقلها 6.20 ملجم/لتر لمنطقة الهضبة. كما بلغت أعلى القيم لعنصر ا الصوديوم 412.00 ملجم/لتر لمنطقة السوانى وأقلها

180.00 ملجم/لتر لمنطقة فشلوم. وأظهرت النتائج أن أعلى القيم لعنصر الماغنيسيوم 196.80 ملجم/لتر لمنطقة غوط الشعال وأقلها 38.40 ملجم/لتر لمنطقة رأس حسن. من ناحية أخرى كانت أعلى القيم لعنصر الكالسيوم 272.00 ملجم/لتر لمنطقة رأس حسن وأقلها 88.00 ملجم/لتر لمنطقة السراج. كما بلغت أعلى القيم للأملاح الكلية الذائبة 2387.00 ملجم/لتر لمنطقة السوانى وأقلها 1162.00 ملجم/لتر لمنطقة زاوية الدهمانى. و كانت أعلى القيم للآس الايدروجينى 7.73 ملجم/لتر لمنطقة زاوية الدهمانى وأقلها 7.35 ملجم/لتر لمنطقة السراج.

جدول رقم(3): التحليل الكيميائي للعناصر الرئيسية طبقا للمنطقة بعد المعالجة.

Water sample	PH	T.D.S mg/l	Ca^{+2} mg/l	Mg^{+2} mg/l	Na^{+} mg/l	K^{+} mg/l	Cl- Mg/l	Hco3 mg/l	$So4^{-2}$ mg/l	HAR (caco3)	ALK (caco3)
Pond 1	7.22	235.0	24.0	9.6	37.5	1.7	52.96	30.5	80.0	50.0	25.0
Pond 2	7.16	156.0	20.0	7.2	18.0	0.8	26.48	30.5	56.0	80.0	25.0
Pond 3	7.05	197.0	32.0	7.2	16.5	0.4	26.48	61.0	57.0	110.0	50.0
Pond 4	7.16	82.0	4.0	2.4	19.5	0.7	26.48	30.5	Traces	20.0	25.0
Pond 5	6.72	56.0	N I L	N I L	10.0	0.3	8.83	30.5	Traces	N I L	25.0
Pond 6	7.03	217.0	12.8	12.48	39.0	1.4	60.27	24.4	63.0	84.0	20.0
Pond 7	7.13	145.0	4.8	4.8	37.0	0.9	56.72	30.5	8.2	32.0	25.0
Pond 8	7.08	208	11.2	14.4	30.0	2.8	46.09	36.6	60.0	88.0	30.0
Pond 9	7.19	156.0	8.0	8.64	30.0	1.6	49.63	18.3	37.0	56.0	15.0
Pond10	7.01	44.0	1.6	2.88	7.0	0.6	10.46	18.3	Traces	16.0	15.0

يشاهد من جدول رقم (3) التحليل الكيميائي للعناصر الرئيسية بعد المعالجة طبقا للمنطقة، حيث كانت أقل القيم بعد التحلية بطريقة التناضح العكسى للعناصر فى المناطق المختلفة كالتالى: قيمة الكربونات (ALK) 15.0ملجم /لتر فى منطقتى السوانى و زاوية الدهمانى ، الكربونات (HAR) لايوجد فى منطقة فشلوم يليها

بقيمة 16 ملجم /لتر فى منطقة زاوية الدهمانى . كانت أقل القيم فى الكبريتات (آثار منها) لمناطق رأس حسن وفشلوم وزاوية الدهمانى يليها وبقيمة 8.2 ملجم /لتر لمنطقة عرادة. وبلغت أقل القيم للبيكربونات 18.3 ملجم/لتر فى منطقتى السوانى و زاوية الدهمانى . كما وجد أن أقل القيم للكلوريدات 8.83 ملجم/لتر لمنطقة فشلوم . أيضا كانت أقل القيم لعنصر البوتاسيوم 0.3 ملجم/لتر لنفس المنطقة السابقة. بلغت أقل القيم لعنصر ا الصوديوم 7.00 ملجم/لتر لمنطقة زاو ية الدهمانى. كما وجد أقل القيم لعنصر الماغنيسيوم لايوجد فى منطقة فشلوم يليها وبقيمة 2.4 ملجم/لتر لمنطقة رأس حسن. من ناحية أخرى ، بلغت أقل القيم لعنصر الكالسيوم لايوجد فى منطقة فشلوم يليها وبقيمة 1.6 ملجم/لتر لمنطقة زاو ية الدهمانى. أظهرت النتائج أيضا أن أقل القيم للأملاح الكلية الذائبة 44.00 ملجم/لتر لمنطقة زاو ية الدهمانى . وأخيرا كانت أقل القيم للآس الايدروجينى 6.72 ملجم/لتر لمنطقة فشلوم.

يلاحظ من جدول (رقم 4) قيم العناصر قبل تحلية المياه طبقا لنوع المصدر (بئر أم شبكة مياه) . وكما هو متوقع من القيم فى الجدول أن مياه الآبار هى الأكثر تركيزا وأملاحا.مقارنة بالمياه الآتية من الشبكة فيما عدا عنصر الكالسيوم الذى بلغ متوسطه فى مياه الآبار 206.00 ملجم/لتر مقارنة بالقيمة 210.67 ملجم/لتر لمياه الشبكة .أيضا بتطبيق اختبار "ت" وجد أن هناك فروق معنوية بين المصدرين فى عناصر الكربونات الكالسيوم (ALK) ،والبيكربونات، والكلوريد والماغنيسيوم، والآس الايدروجينىpH.

يشاهد فى جدول (رقم 5) القيم للعناصر بعد استخدام طريقة التناضح العكسى فى التحلية والتى توضح الانخفاض الشديد فى قيم العناصر . وبتطبيق اختبار "ت" بعد التحلية للمياه كلن هناك فروق معنوية بين المصدرين (الآبار – الشبكة) فى عناصر الكربونات (HAR)،و الماغنيسيوم ،و الأملاح الكلية الذائبة .

المنـــاقشة

مواصفات مياه الشرب المناسبة للإنسان .

يحتاج جسم الإنسان لنسبة من الأملاح والمعادن لاستكمال حاجة الجسم من هذه العناصر إضافة للمواد الغذائية الأخرى. وهذه الأملاح والمعادن توجد في المياه، ولكي يستسيغ الإنسان شرب الماء وفي الحدود التي لا تضر بالجسم يجب أن يكون نسبة المواد الصلبة الذائبة على سبيل المثال من 100 - 500 ولا تزيد عن 1000 جزء في المليون. و يوضح الجدول التالى المواصفات الليبية ومنظمة الصحة العالمية القياسية لمياه الشرب.

جدول رقم (6): المواصفات القياسية لمياه الشرب طبقا للمواصفات الليبية ومنظمة الصحة العالمية.

الخواص	التركيزات المسموح بها للمواصفات الليبية ملجم/لتر	التركيزات المسموح بها لمنظمة الصحة العالمية WHO ملجم/لتر
الخواص الكيميائية		
المواد الصلبة الدائبة	1000- 500	1000
الماغنيسيوم	150 – 30	150
الصوديوم	200 – 20	200
البوتاسيوم	40– 10	12
الكبريتات	400– 200	400
الكالسيوم	200– 75	100
الكلوريد	250– 200	250
الأس الهيدروجيني		8.5 – 6.5

قد يختلف كثيرا قبول درجة عسرة الماء من مجتمع لأخر تبعا للظروف المحلية . وفي بعض الأحيان يمكن تحمل عسرة للماء تتجاوز 500 ملجم/لتر. وتنتج عسرة الماء عن الشوارد (الأيونات) الفلزية الدائبة المتعددة التكافؤ، وأهمها الكالسيوم، الماغنيسيوم بدرجة اقل. وكثيراً ما يعبر عنه بالكمية المكافئة من كربونات الكالسيوم Ca Co3، وتقع صفة الطعم الشاردة (أيون) الكالسيوم في النطاق 100 -300 ملجم/لتر تبعا للصاعدة Anion المصاحبة . ويحتمل أن تكون عتبة الطعم للماغنيسيوم اقل منها بالنسبة للكالسيوم. وحيث انه من المقترح وضع قيمة مسموحة لإجمالي العسرة، لذلك لم تقترح قيم فردية لكل من الكالسيوم والماغنيسيوم. وقد يكون للماغنيسيوم مع شاردة السلفات، خواص ملينة، إلا إن جسم الإنسان يستطيع أن يتلائم مع ذلك في الوقت المناسب. وعلى أساس التفاعل مع عوامل أخرى مثل الرقم الهيدروجيني والقلوية، فقد يسبب الماء الذي به عسرة تزيد على 200 ملجم/ لتر ، ترسب قشور في شبكة التوزيع، مما يؤدي إلى الإفراط في استهلاك الصابون وبالتالي تكوين <<الغثاء>> Scum . وتنزع المياه العسرة عند التسخين إلى تكوين رواسب قشرية . ومن ناحية أخرى فالماء اليسر Soft الذي تقل عسرته عن 100 ملجم/لتر له قدرة دارئة Buffer Capacity منخفضة، وهو لذلك يؤدى لتأكل أنابيب المياه . والقيمة المسموحة للعسرة هي 500 ملجم/ لتر (في شكل كربونات الكالسيوم) محددة على أساس الطعم واعتبارات الاستعمال المنزلي.

تؤدي التركيزات المرتفعة للكلوريد إلى إكساب الماء والمشروبات طعما غير مستساغ.وتقع عتبات الطعم بالنسبة للكلوريد (كلوريد الصوديوم أو الكالسيوم أو البوتاسيوم) في مدى تركيز ايون الكلوريد البالغ 200-300 ملجم/لتر. وتسبب تركيزات الكلوريد المرتفعة تآكل Corrosion المعادن في شبكة التوزيع وبخاصة في المياه القليلة القلوية ولا تؤدي المعالجة التقليدية للمياه إلى إزالة الكلوريد.

والمصدر الرئيسي لدخول الكلوريد بالنسبة لجسم الإنسان هو الأغذية المملحة، ومتوسط الداخل هو ستة جرامات تقريبا من ايون الكلوريد في اليوم. والقيمة المسموح بها في مياه الشرب هي 250 ملجم /لنر على أساس اعتبارات الطعم.

تتوقف تركيزات الصوديوم في مياه الشرب على عوامل مثل الظروف المائية الجيولوجية والموسم والأنشطة الصناعية. وعادة تكون مستويات الصوديوم في مياه الشرب اقل من 50 ملجم/ لتر، إلا أن هده المستويات قد تزداد أتناء المعالجة وبالأخص عند إزالة عسرة الماء. وربما تتزامن المستويات المرتفعة مع ملوحة التربة. وقد سجلت تركيزات تزيد عن 1000 ملجم/ لتر في بعض مياه الشرب وتعتمد صفة طعم الصوديوم في الماء على الصاعدة (الأنيون) المرافقة ودرجة حرارة المحلول. إما في درجة الحرارة العادية فان صفة طعم الصوديوم في الأملاح الموجودة عادة في مياه الشرب هي حوالي 200 ملجم/ لتر (ايون صوديوم) ، و هى القيمة المسموحة على أساس اعتبارات الطعم .

من المعروف أن إجمالي الأملاح الذائبة الكلية يتكون أساسا من مواد لاعضوية .والمكونات الأساسية لها هي الكالسيوم، الماغنسيوم،الصوديوم، البيكربونات، الكلوريدات، والكبريتات. ومن الجوانب الهامة للأملاح الذائبة من حيث جودة مياه الشرب هو تأثيرها على الطعم، فالماء الذي تقل فيه مستويات الأملاح الذائبة عن 600 ملجم/لتر يعتبر مستساغا بصورة عامة، بينما تقل استساغة الماء إذا زادت هده المستويات على 1200ملجم/ لتر .

بلغ متوسط الأس الهيدروجيني pH قبل المعالجة06 ±7.52، وأصبح 0.03 ±7.09، مما يدل على انخفاضه وقربه من نقطة التعادل، ويتراوح الرقم الهيدروجيني المقبول في مياه الشرب بين 6.5 - 8.5 وهو المدى المسموح به.

وترجع أهمية الرقم الهيدروجيني فى تقليل التآكل وترسيب القشور في شبكة التوزيع نتيجة للعلاقة بينه والمكونات لأخرى مثل ثاني أكسيد الكربون والعسرة ،القلوية ،ودرجة الحرارة. وقد يسبب الرقم الهيدروجيني الأقل من 7 فى تأكل شديد للفلزات في شبكة التوزيع . والمستويات المرتفعة لبعض المواد الكيميائية مثل الرصاص قد تنجم عن تأكل أنواع معينة من الأنابيب ويزداد معدل التآكل بنقص الرقم

الهيدروجيني. وعندما يزيد الرقم الهيدروجيني عن 8 يحدث تناقص فان هذا يقلل بدرجة كبيرة عمليات التطهير بالكلور .

قد تحمي المستويات المرتفعة للعكر الأحياء المجهرية من أثار التطهير، وقد تنشط نمو الجراثيم. وعلى دالك فعند تطهير الماء يجب أن يكون العكر اقل من وحدة واحدة من وحدات قياس الكدر حتى يكون التطهير فعالا.

والقيمة المسموحة هي 5 وحدات من وحدات الكدر أو 5 وحدات من وحدات جاكسون لقياس الكدر، إلا انه يفضل أن تكون اقل من وحدة واحدة للتطهير. والعكر الذي يزيد على 5 وحدات قد يكون ملحوظا وبالتالي مثير للاعتراض.

من النتائج السابقة يتضح التأثير الفعال لعملية المعالجة والتي أدت إلى انخفاض لقيم العناصر السابقة بدرجة كبيرة مما يحسن نوعية المياه، وان كان هذا يجعلها غير صالحة للشرب والاستهلاك البشري، نظراً للانخفاض الشديد في تركيز العناصر الكيميائية المختلفة والاملاح الذائبة الكلية والذي لايطابق المواصفات العالمية والليبية المعمول بها .

التوصيات:

1- النتائج المتحصل عليها للمياه قبل وبعد التحليه تساعد في اكتشاف المشاكل الفنية والتنبيه على اي صيانة يجب القيام بها.

2- المراقبة الدورية المنتظمة لوحدات تحليه المياه، يساعد على اكتشاف المشاكل الفنية وتقييم الماء المنتج ومطابقته للمواصفات الليبية والعالمية، مع مراعاة عدم التأخر في إجراء عمليات الصيانة اللازمة للشبكة.

4- المياه الموجودة في الطبيعة دائما تحتوي على شوائب ذائبة او عالقة، لهذا من الضروري معالجتها قبل إدخالها لوحدات التنقية، حيث أن أتباع طرق المعالجة الأولية الصحيحة تزيد من عمر المحطة.

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Evaluation of Reveres Osmosis Technique in water desalination in some regions of Libyain Tripoli city .

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This study was carried out in some regions that belong to the Libyan Tripoli city to examine the concentration of some elements and evaluate the chemical quality of water which came from different sources (wells and general network) before and after using the Reveres Osmosis Technique.
Data were collected on water samples and information about the region; source of water and date of sample taken were defined.

The water samples were analysed and the concentrations of elements and salts which included T.D.S , pH, Na^+ , K^+ , Ca^{+2} , Mg^{+2} Cl^- , $CaCO_3^{-2}$ and SO_4^{-2} were measured. The results showed that most sources of feed water have high concentrations of chemicals elements and TSD. As a result, this water is unsuitable for human drinking.

From the results of current study ,it can concluded that using Reveres Osmosis Technique attributed to great decrease in some chemicals elements and TDS, which may be cause some healthy problems in some cases due to low salt concentrations as this water may be unsuitable for human drinking according to the world and libyan standard specifications. Also, the sediments in desalination water tanks and connecting tubes made the water unhealthy. However, It is important to clean these tanks and connection tubes of water to prevent the disease causes.

SESSION 5A:
MUNICIPAL WATER MANAGEMENT

Keynotes: Mohamed Abd Rabo, Alexandria University, Economics of Water Resources: cost-effectiveness

Mohamed Abdel Karim Aly Abdrabo received his Ph.D. degree at the University of Liverpool, UK and is currently a professor of environmental Economics, Institute of Graduate Studies and Research, University of Alexandria. He is the executive director of an IDRC sponsored project for the establishment of a center of excellence for adaptation to Climate Change (ARCA) at the University of Alexandria. He is a Leader Author for the upcoming Inter-Governmental Panel on Climate Change (IPCC) Fifth Assessment Report. He worked as Advisor to CEDARE and acted as a consultant to a number of environment-related research projects in a number of countries in the region. His research work in the fields of environmental and urban socioeconomic assessments, economics of the environment and vulnerability and adaptation to impacts of climate change.

Abstract:

Water resources, despite its necessity for human life and most human activities, are among the most undervalued resources in the world. However, the value of water varies among different users and users will typically use water as long as the benefits derived from additional quantity exceed the costs so incurred. Furthermore, the value of water resources depends upon their location, time, quality and quantity. This means that the true economic value of water are linked - not just the price or cost associated with its production – but also the services provided and benefits obtained from these resources.

Despite that most Arab countries are facing water scarcity, the economic value of water resources are still to be taken into account into policy and decision-making. Such a move would require first of all concerted efforts to be made about estimating true economic values of water resources and then integrating these values into policy and decision making systems. There are, for that purpose, a number of economic approaches that could be used to such values.

Managing the Rate of Leaks and Breaks in the Old Water Networks

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Introduction

In Water Networks, a major maintenance expenses go for repairing leaks and breaks of old pipelines, old network apparatus (Valves, Hydrants, etc..), and old service connections. This is beside the fact that during the maintenance of the leaks & breaks, the water service will be interrupted and the customers will not be satisfied which will affect the reputation of the service provider. Implementing water demand and pressure management through optimizing the upstream and downstream parameters of the network and by following advanced pump operating technique can help to minimize the breaks and leaks in the old water networks in an effective way and so in reducing

maintenance costs until the proper time come when a complete replacement projects start and finish. Also it can help to maintain pump efficiency and save water & energy.

By 2002 KAHRAMAA as a first step started to study or put a plan for studying proposals to replace a complete water networks in areas where the networks were installed before 1983. But since it is not possible to finish the study and to start such big replacement projects before 2005 or 2006, KAHRAMAA decided to do something to reduce the leaks and breaks in the old network in order to reduce Maintenances costs, reduce customers complaints, and to keep good reputation for the company until the time come when the replacement projects start and complete..

So from the year 2002 or 2003, KAHRAMAA started implementing water demand/pressure management in a gradual stages by optimizing the upstream and downstream of the water network which affected the rate of leaks and breaks.

KAHRAMAA successfully achieved its target of reducing leaks and breaks in the old network by the year 2004-2005 after which the replacement projects started. This process took three years from

2002 to 2005 to achieve the goal followed by one more step taken from the year 2010 to 2011 . The process can be summarized into five steps on time basis. These steps will be explained in this report and the results will be shown in a hope that other countries may get something from our experience with the old water networks.

Objectives

Implement water demand/pressure management by optimizing the upstream and downstream of the network and also following an advanced pump operating technique which will minimize the rate of breaks and leaks in the network.

Information About KAHRAMAA

KAHRAMAA (or Qatar General Electricity and Water Corporation) was established in July 2000 to regulate and maintain the supply of electricity and water to customers in Qatar. Since its inception, KAHRAMAA has operated as an independent corporation on a commercial basis. Before July 2000 it was a Ministry of Electricity and Water.

KAHRAMAA mission is to provide customers with high quality electricity and water services, whilst creating value for its shareholders.

For the maintenance side of water networks, KAHRAMAA is responsible about all Water Networks Pipelines and Facilities outside the boundary of Desalination/Production Plants. KAHRAMAA water systems consist of the following:

- Transmission mains: They are the Pipelines that are delivering water from Desalination/Production plants to KAHRAMAA Water Reservoirs. KAHRAMAA receives water from 7 Desalination Plants that have total maximum production capacity of 340 MIGD. The Diameters of transmission pipelines ranging from 600mm to 1600mm. Total length is around 714 km. The Material of the Pipes is Ductile Iron Cemented Pipes.

- Water Reservoirs: They are Ground Storage Reservoirs to store the water received from Production Plants via Transmission mains .There are total of 79 reservoirs located at 25 sites in Qatar. Each site have a group of those reservoirs with dedicated pumping station. Total

- Storage Capacity of all reservoirs of Kahramaa together is around 360 MIG. This amount of storage currently represents a contingency stock for 1.3 days. This means in any emergency interruption of water production, KAHRAMAA reservoirs have enough storage to give normal water supply to customers for 1.3 days only. However, at present there are coming projects aimed to increase the storage capacity of KAHRAMAA reservoirs to be sufficient for 7 days normal supply to customers in case of interruption of water production. Such projects are expected to be completed by 2015.

- Pumping Stations: They are stations containing the sets of pumps that are responsible to pump the water from KAHRAMAA reservoirs to the rising mains and to the distribution networks. Pumping stations are always situated near a group of water reservoirs. There are 25 pumping stations in whole Qatar.

- Rising Mains and Distribution Mains: They are the Pipelines that deliver the water from KAHRAMAA pumping stations to the customers service connection. The Diameter ranging from 100mm to 900mm. Total length is around 5,754 km. Pipes' material is Ductile Iron Cemented Pipes. In some limited locations, the Rising mains are supplying Water Towers and those water towers are supplying Tanker Filling Station. Water Towers are no more used to supply distribution network in KAHRAMMA water system.

- Network Appurtenance (or Apparatus): Like Valves of different type, Air Valves of different types and Fire Hydrants. Their present total number in the water networks are around 32,400.

- Service connections: The are Pipelines that deliver water from distribution main to customers. The Diameter ranging mostly from 15mm to 100mm. There are around 200,000 service connections. The pipe materials of the old service connections are mostly Copper. However, recently (since 2004) KAHRAMAA started using MDPE (Medium density polyethylene) pipes for service connections instead of Copper.

- Tanker Filling Stations (TFS): They are Stations containing filling points to fill Tankers. The TFS is always constructed near to a Pumping Station to be supply from it. There is 14 TFS in Qatar.

The problem of Leaks & breaks:

Since its establishment in 2000, KAHRAMAA was concerned about giving quality service to customers and also concerned about the economic side of operating and maintaining the network.

One of the concerns was the relatively high rate of leaks & breaks which occurs mostly due to the age of the water network. With every leak or break, the service to customers is interrupted in order to repair the leak. This is affecting customers and also KAHRAMAA reputation. Moreover, the maintenance cost of the networks increases.

In 2002 KAHRAMAA took one of the strategic decisions to start studying replacing all the very old parts of the water networks in Qatar. But for such study to complete and for such huge project to start it will take some years. And then to be completed it also requires other more years.

Until the time come to complete the replacement of the whole old network, we have to do something to reduce the leaks and breaks in order to better service the customers and to save a lot of maintenance costs until the replacement projects starts and complete. This became one of the targets of KAHRAMAA for the side of water operations and maintenance. KAHRAMA started by 2002-2003 to take steps toward the above mentioned goal. And we were successful to fully achieve our target by
2005.

In this report we will explain the steps taken and the results gained in order to share our experience with other countries.

Pipelines of Kahramaa water network (including Valves, Air Valves, and Fire Hydrants).

When we say Pipelines here in this report we mean altogether the network pipelines (Transmission mains, Rising mains, and distribution mains) and their appurtenance like Valves, Air valves, and Fire hydrants. The diameters are ranging from 100mm to 1600mm. Those pipes are mainly Ductile Iron pipes.

The below figure shows the expansion of the water networks in Qatar from the year 2000 to 2011.

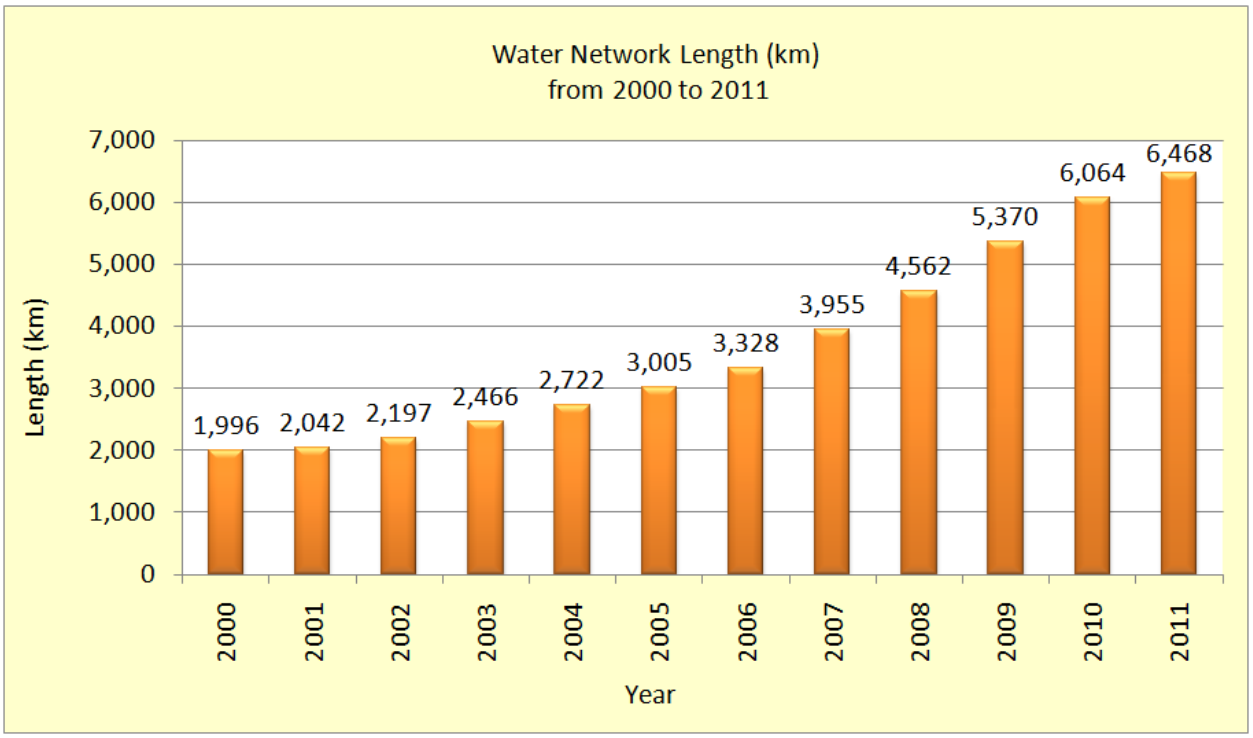

Figure 1: Length of water network in Qatar from the year 2000 to 2011

Methodology or Steps taken to reduce leaks & breaks and the results of each step:

Step-1 (2002 - 2003):

Slightly reduced the pressure in particular portions of the networks (where we have the highest leaks rates) by throttling the feeder pipes for the particular parts of the very old distribution network. We tried to keep maximum 1 bar pressure in those areas.

The Results:

Average leaks & breaks increased from 3 to 3.5 leaks & breaks per day. We will explain later in the analysis section why the leaks & breaks here increased instead of being decreased.

Step-2 (2003 - 2004):

Giving proper training, for the Operators of water reservoirs pumping stations, in the professional way of starting and stopping of the pumps complying with manufacturer recommendation.

by implementing particular pump procedure of start up & shut down (starting/stopping of the pumping) without causing hammering in the old water networks. At that time the pumping was not continuous 24 hours. We were pumping only average from 10 to 16 hours daily depending on the areas supplied. So, the process of Starting/Stopping is a daily practice. And since at that time we have mostly fixed speed drive pumps, we decided that:

1. Before starting the pump we make sure that the delivery valve is closed. Then we start the pumps. Then the delivery valves are opened slowly and gradually for a long period of time (at least half an hour to fully open the valve). This way we saved our old network from sudden pressure increase at the start of the pumps.

2. Before stopping the pumps, the pumps delivery valves should be first closed slowly and gradually for long period of time (at least half an hour) until it is closed 90% then we shutdown the pumps. This way we saved our old network from sudden drop in pressure and changes of flow.

The Results:

Average leaks & breaks reduced from 3.5 to 2.8 per day. (i.e. in 2004 it became 20% less than 2003). **See Figure.2 below.**

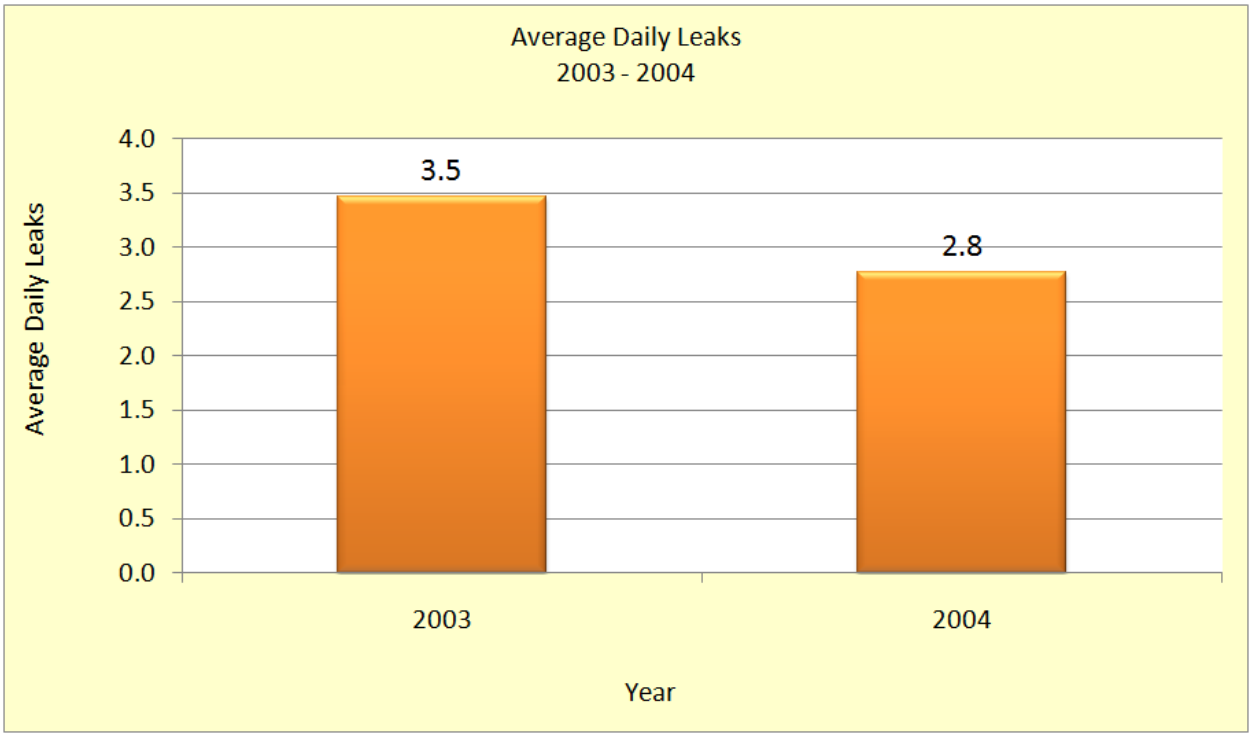

Figure 2: Average Daily Leaks & breaks for the years **2003 to 2004**

Step-3 (2004 - 2005):

Reduce the pressure for the whole water networks to the minimum possible pressure that is adequate to customers. This was done as follows:

1. From our past experience we know that for most customers a pressure of 0.5 bar is sufficient. So, we made our target to give 0.5 bar at the weakest pressure part of each water district/area. This pressure is enough only for those customers who have their own ground storage tank in their houses, which is the case in all Qatar houses which comply with KAHRAMAA rule that their ground storage tank should be near to the water meter and service connection point. Pressure of 0.5 bar can easily fill the ground storage tanks of customer through the period of pumping hours.

2. We started to inform and announce to customers through KAHRAMAA call centre and through other Medias (like Newspapers and Radio) that those customers who do not have ground storage tank in their houses should take immediate action to avoid

any problems in water supply. The capacity of the storage tanks should be sufficient for their use for 48 hours.

3. We started applying the pressure reduction in each water zone separately, one after one considering the higher ground elevation areas and bottle neck locations. Each water zone is supplied by water from one Rising Main or one Water Tower. Each water zone consists of a number of water districts/areas. We apply the reduction on one zone and see the results and customers responses and take required actions. After we complete one zone successfully we proceed to the next zone.

Explaining Water Zones and Water District

The below map is an example to show what is zone and what is districts. All the below areas are supplied from one Reservoirs Pumping Station (RPS). It is Gharrafa RPS. Gharrafa RPS has two sets of pumps. Each set supplying one separate Rising Main. So, we have two rising mains coming our from Gharrafa RPS. The first rising main we call it GRM1 (means Gharrafa Rising Main No. 1). The second Rising main we call it GRM2 (i.e. Gharrafa Rising Main No. 2).

GRM1 is supplying the yellow area on the map. So, we call this yellow area Water Zone of GRM1. It contains two areas (AL Luqtah area + AL Rayyan Al Qadeem Area). We call those two areas Water Districts. So, we have two Water Districts under this yellow Water Zone of GRM1.

GRM2 is supplying the orange area on the map. We call this orange area Water Zone of GRM2. It contains four Water Districts (Al Mesila + Bin Omran + Kulaib + Wadi Al Sail). So, we have here four Water Districts under this orange Water Zone of GRM1.

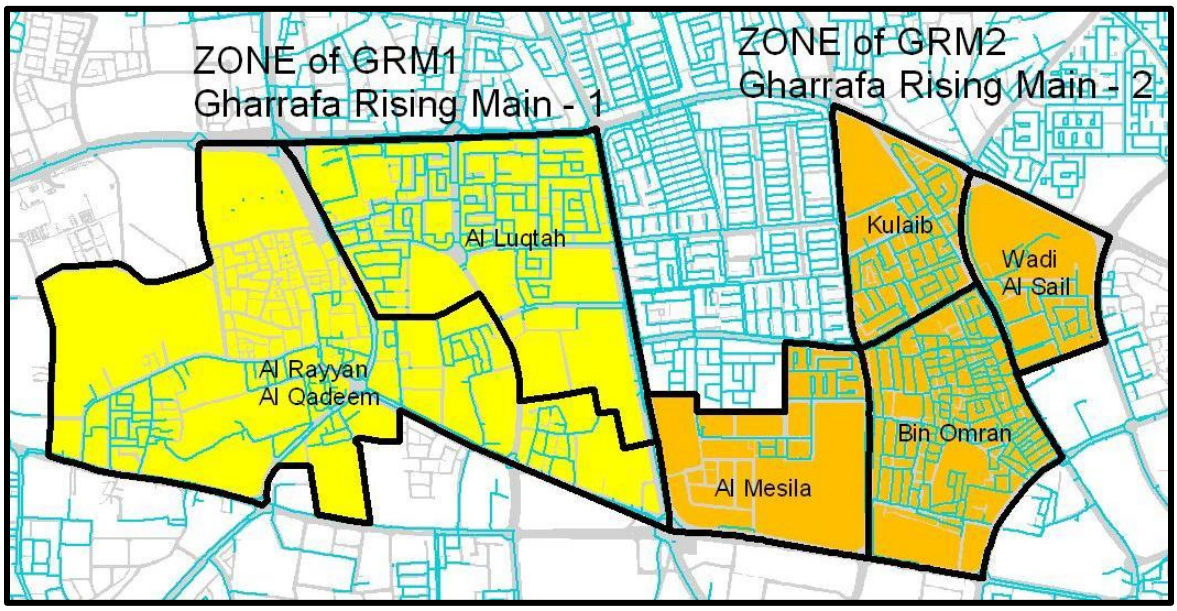

Figure 3: Map showing Water Zones and Water Districts under the Gharrafa Reservoir Pumping Stations.

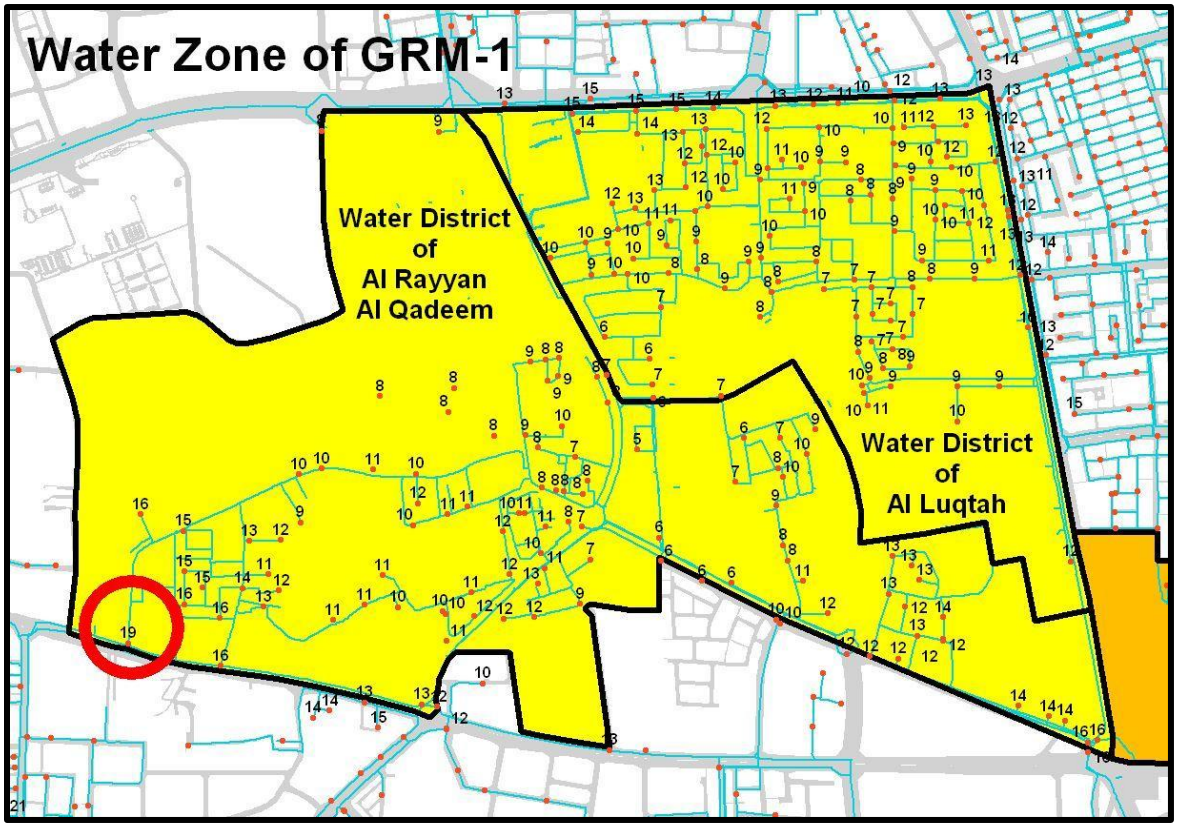

Figure 4: Map showing Elevations of water network above see level for the Water Zone of GRM-1

4. The way we managed the reduction of the pressure in a particular zone is as follows:

- We manually (we have no remote monitoring) monitored the pressure at the weakest pressure points in each zone during the peak demand times and minimum demand times. We select one or two weakest pressure points (reference points) in each water zone. We are taking pressure reading three or four times a day for those points.

  For examples, let us take Water Zone of GRM-1 that we talked about in the previous point. If we looked to the ground elevation (or pipelines elevation) above the sea level (see on the below map the red points and related elevation of each point above the sea level) we will find that our network elevations in this zone are ranging from 5m to 19m above sea level. We took the highest elevation point (see the red circle in figure 4) which is 19m above sea level we took this point as a reference point because it is the **weakest pressure point in the whole Water Zone of GRM-1**. At this point of this zone we are monitoring the pressure repeatedly many times a day and make sure the pressure is always near to 0.5 bar as much as we can.

- For the weakest pressure point (reference point) we try to keep the pressure very near to the minimum acceptable (which is 0.5 bar) the whole period of pumping hours.

- For fixed speed drive pumps we control the pressure from upstream by throttling/controlling the delivery valve of the Rising Main of that water zone until getting the required pressure on the reference point downstream. This way we keep the minim acceptable pressure in each water zone. On the same time we maintain the pump efficiency

- Sometimes to balance the pressure in the zone we have to throttle individual pipelines feeding some districts in that zone. This is because sometime in one zone we have some areas getting higher pressure (due to difference in ground elevation above sea level) and wee need to throttle their particular feeder to reduce the pressure to minimum acceptable.

The Results:

Average leaks & breaks reduced from 2.8 to 2.0 per day. (i.e. 28% less than 2004). See **Figure.5** below.

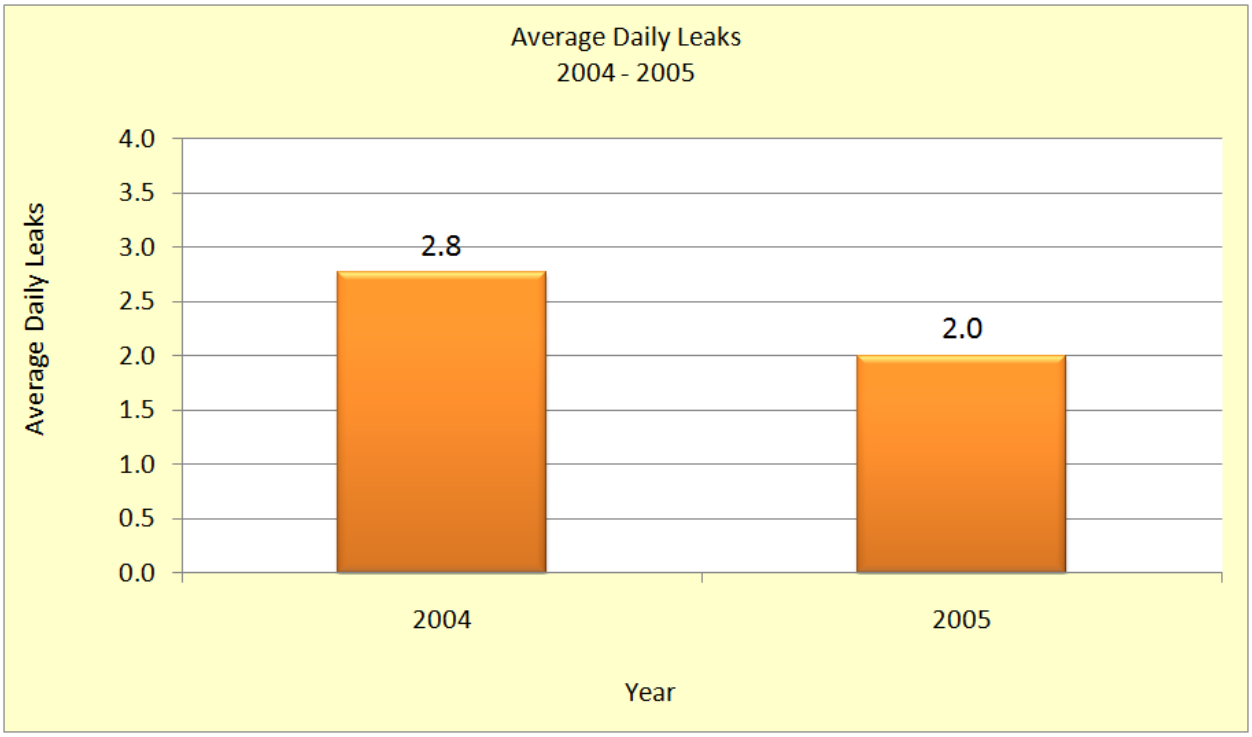

Figure 5: Average Daily Leaks & breaks for the year **2004 to 2005**

Step-4 (2005 - 2010):

With the continuous monitoring of the pressure at the upstream and downstream the number of leaks were reduced further especially with the commissioning of new networks.

Step-5 (2010 - 2011):

Implemented new reliable automatic control technique for water pumps operation that assured a constant network pressure at the minimum accepted pressure point in the network all the time. Moreover the pumps started to always running within the designed operating range as per the manufacturer's recommendations to maintain pump efficiency

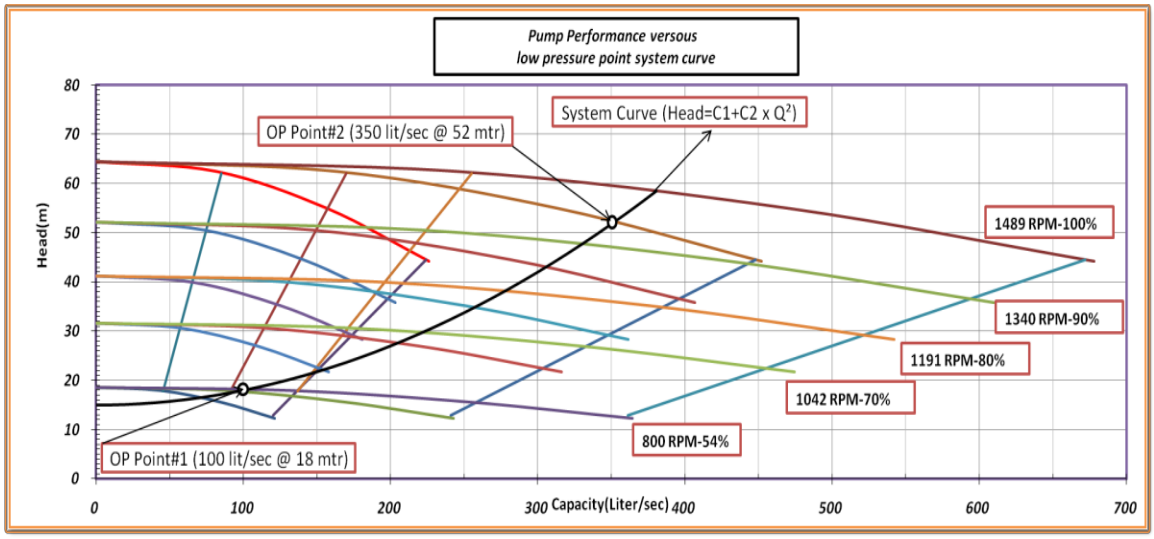

Figure 6: Pump curve vs. System Curve

Two Graphs showing Operating points before and after applying New Technique

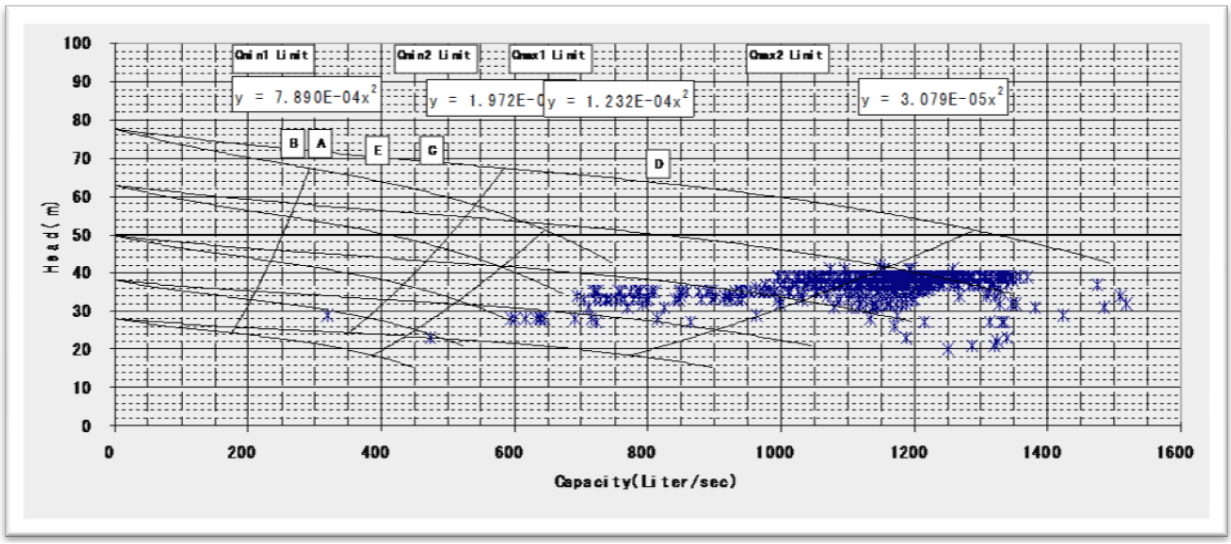

Figure 7: Operating Points before the new operation technique

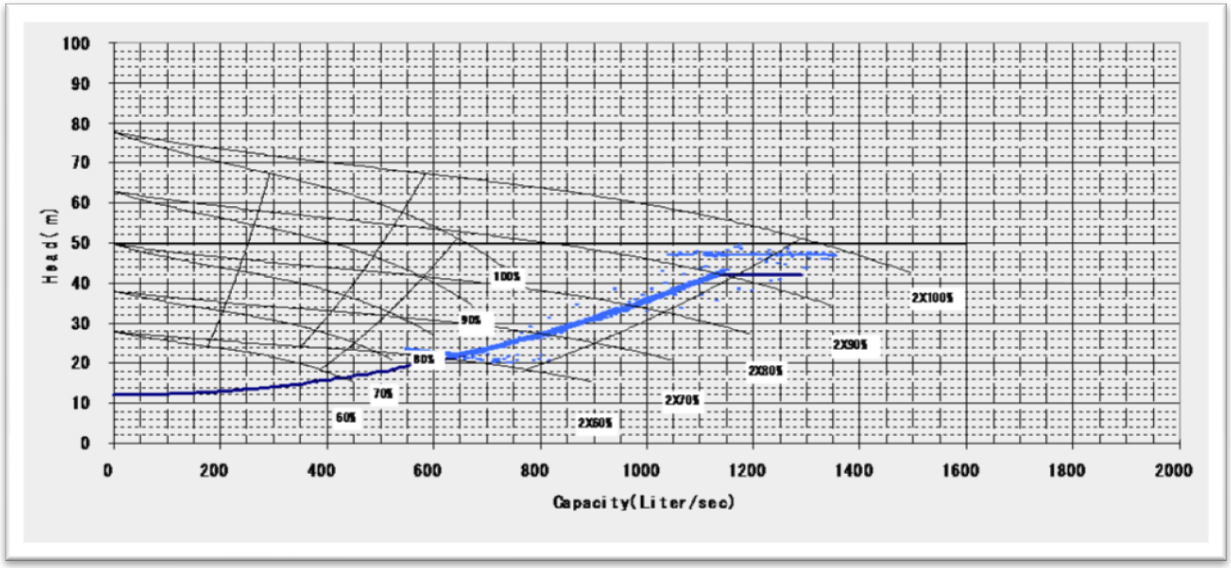

Figure 8: Operating Points After the new operation technique

Analyzing the leaks & breaks data from 2001 to 2011:

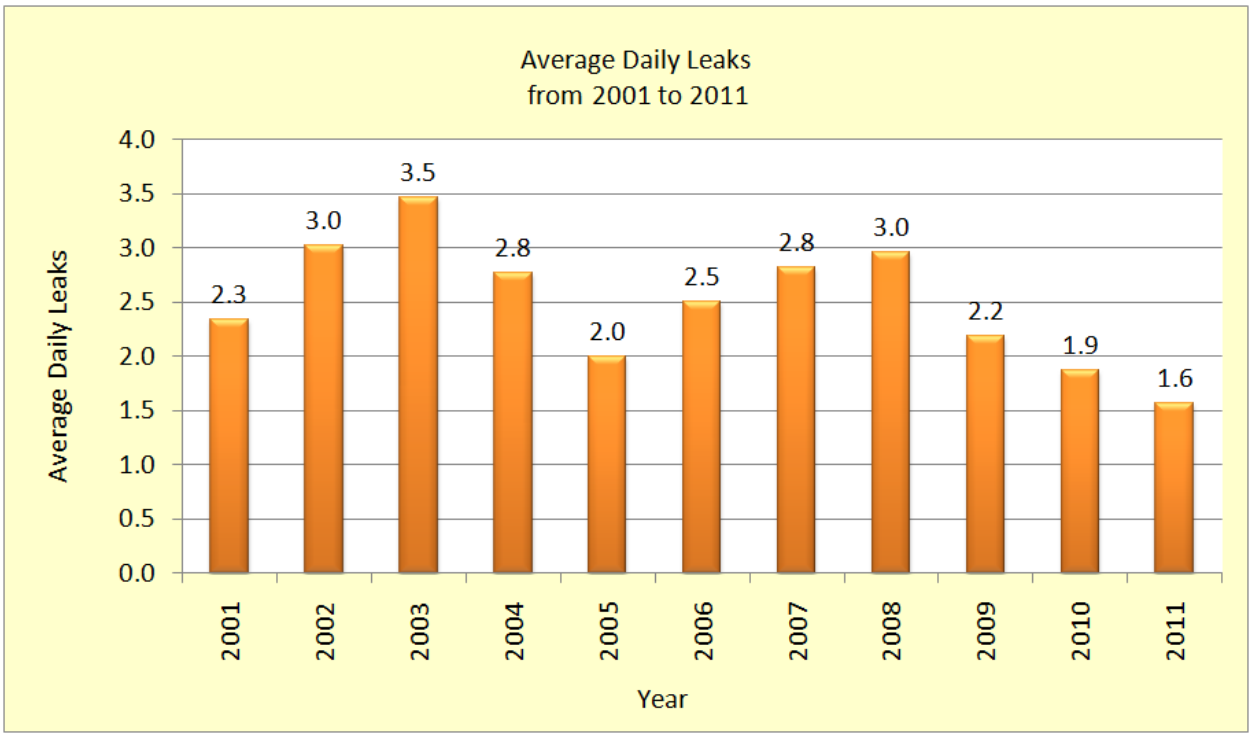

Figure 9: Average Daily Leaks & breaks for the years **2001 to 2011**

For 2001 to 2002

The Average leaks & breaks increased from 2.3 to 3.0 leak&break per day. We were running the network as ordinary as before. No action taken during this period to reduce leaks & breaks.

From 2002 to 2003

The leaks & breaks increased from 3.0 to 3.5 leak&break per day. It reached to the highest rate we reach during the past 10 years. Here although we implemented **Step-1** as explained before of pressure reduction (i.e. Slightly reduced the pressure in the old distribution networks by throttling the main feeding pipelines) but main pipelines leaks & breaks increased. This is because when we throttle the pressure in some very old network portions, the pressure was automatically increased in the surrounding old network areas and caused pipelines leak&breaks to increase on them. However, we overcome this problem in the next two steps that we explained earlier.

From 2003 to 2004

The leaks & breaks decreased from 3.5 to 2.8 leak&break per day (i.e. reduced by 20%). This is because we implemented **Step-2** as explained before (i.e. Training the staff of the pumping stations on better way of operating the pumps).

From 2004 to 2005

The leaks & breaks decreased more from 2.8 to 2.0 per day (i.e. reduced by 28.6 %). This is because we implemented **Step-3** as explained before (i.e. reduced the pressure for the whole water networks to the minimum possible pressure).

From 2005 to 2008 (three years)

Although we continued applying all the steps we mentioned before, yet we notice here gradual increase in leaks & breaks again. From 2005 to 2008 (three years) the leaks & breaks increased from 2 to 3 per day (i.e. Average leaks & breaks where increasing approximately 16% every year). The reasons of this increase are:

1- The replacement projects of KAHRAMAA water networks started in the very old networks areas by the last quarter of 2005. Some of them completed by the end of 2008 and in 2009 but still others are going on until this moment 2011. The problem is that when the contractors of such projects work on the site and start the **excavation near the old pipelines** in order to lay the new pipelines, the vibrations of excavation tools, machines, and vehicles are damaging the vey weak and old pipelines and cause them to leak or break under normal operation pressure.

2- Starting from 2007 we started a new policy of giving 24 hours pumping to customers. Continuous pumping have many advantages for operating the network safely but many of

the invisible leaks & breaks under the ground became visible with the continuous pumping because the ground soil cannot absorb all the continuous leaking water and so the invisible leaks became visible above ground. And they were added to the number of the normal visible leaks.

3- In Qatar so many huge infrastructure projects started since 2005 and 2006. And in all such projects there are a lot of excavations and work around our old pipelines in the site and it happen almost daily that due to contractors vehicles and machines vibrating near to our old pipelines we have a lot of leaks & breaks occurring (the same story with KAHRAMAA water projects mentioned above in point no.1).

Imagine that if we didn't take actions to reduce the leak&breaks from 2003 to 2005 what could happen later?. Let us say that we didn't take any action from 2003 to 2005 and during 2005 we still have 3.5 leaks & breaks per day. This would mean by 2008 the average Daily Leaks & breaks will become 5 leaks & breaks per day instead of 3.5. It is good that we took actions earlier which helped us to avoid worse situation later.

From 2008-2011

The leaks & breaks reduced from 3.0 to 1.6 per day (i.e. reduced by 47%). The reasons for this reduction are:

1- During the years 2008 – 2011, many of the of replacement projects in many old areas were completed. We got rid of many old leaking networks of those areas and so we have no more leaks or breaks in such areas. This helped to reduce the total number of leaks/bursts in the network.

2- From 2008 we put a very strict rules and higher penalty rates on the contractors who are causing damages to our pipelines carelessly and without reasonable and acceptable justification. The contractors working on the different site projects (KAHRAMAA Project and other companies projects) became more careful about our existing networks when they work and excavate near to them because they know that they will pay too much cost for damaging our pipelines carelessly.

3- By the year 2010 we started to implement new reliable automatic control technique for water pumps operation that assured a constant network pressure at the minimum accepted pressure point in the network all the time.

Key Performance Indicator (KPI) for Water Networks Leaks & breaks

The KPI of a Water Network Leaks & breaks is calculated by obtaining the average leak and breaks during a certain period (per year or per month) and dividing it by the total length of the network during that particular period. This will give us average leaks & breaks in each kilometre of that particular network. Then we multiply it by 100 to get the average per 100km of the network.

In Figure.10 below we will see the yearly average of KAHRAMMA water networks leaks & breaks per 100km of network length and compare it with the International Standard. KAHRAMAA were able reduced the Key Performance Indicator (KPI) from 51 to 8 leaks per 100km of network length per year which is lower than the international standard (20 leaks per 100km per year).

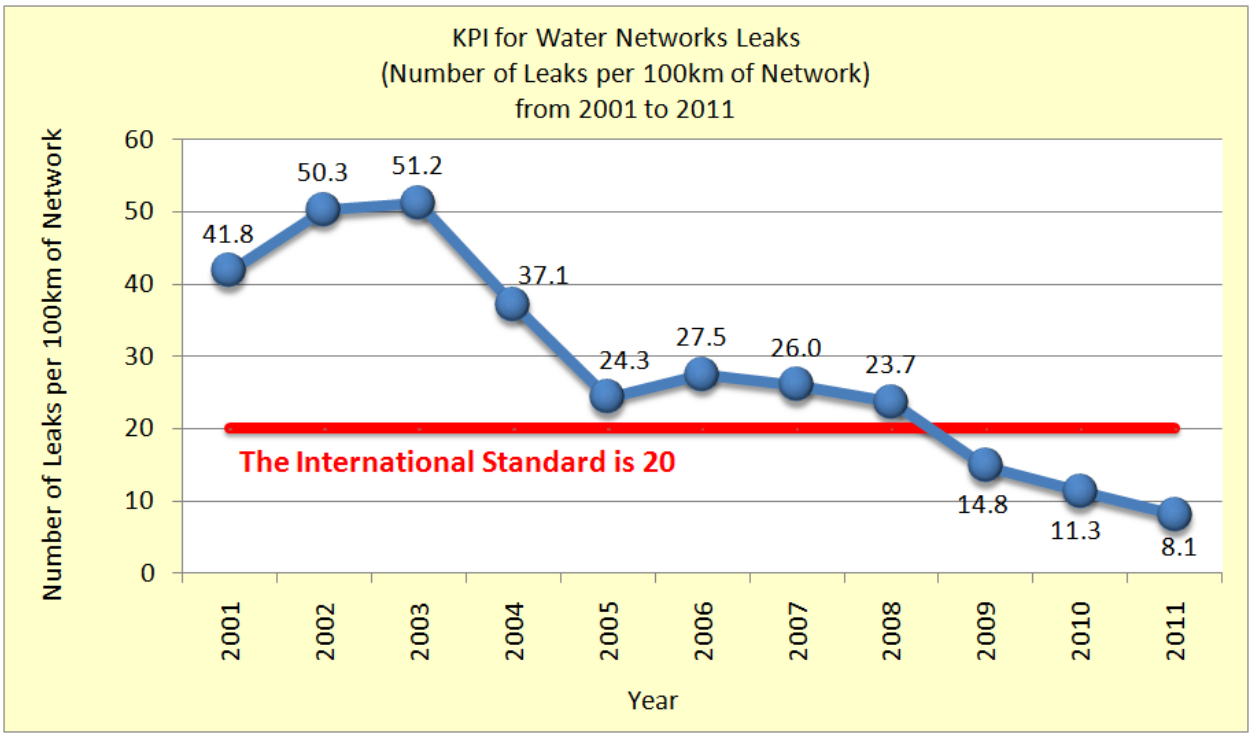

Figure 10: Comparing KAHRAMAA KPI of Networks Leaks & breaks with the International Standard from **2001-2011**

Conclusions from the above chart:

- KAHRAMAA achieved the target of implementing water demand/pressure management that minimized the rate of breaks and leaks in the network.
- Achieving international standards KPI and benchmarking to other utility.
- The solution was efficient and cost effective.
- For the last 10 years we never increased any maintenance attending staff.
- Maintained optimum pump efficiency.
- Reduced Power consumption for pumps.
- Saved a lot of spare parts.

Conclusion

KAHRAMMA achieved good result on decreasing the daily average leaks & breaks from 3.5 to 1.6 per day from the years 2003 to 2011. And will continue improving.

Using Real -Time Telemetry System for Assessing Water Quality and Improving Routine Monitoring

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Abstract

The Ministry of Water Resources and Irrigation (MWRI) represented by the National Water Research Center (NWRC) established the National Water Quality Monitoring Network (routine program) that covers groundwater, Nile water and agriculture drainage water. The sampling frequency of the existing Water Quality Monitoring (WQM) program is based on monthly measurements. However, the methods used to perform WQM have changed dramatically over the last 10 years resulting in improving knowledge and understanding of the relation between water quality and changes in hydrology, geology, and land use. Therefore, NWRC recently initiated an advanced technique for water quality sampling using modern instruments that allow for real-time (continuous) records of concentrations of water-quality variables in water streams. The new WQM technique is applied for some strategic points in the River Nile system. The main objectiveof this study is to assess the current sampling frequency for routine water quality monitoring network based on different time intervals for El-Salam Canal intake (NL39) at Damietta branch at the River Nile using real-time data for selected water quality parameters namely: Total Dissolved Solids (TDS), Dissolved Oxygen (DO), pH and Turbidity (Tur). In addition, the obtained results will help in proposing an optimal sampling frequency for the current routine water quality monitoring network.

Firstly, the analysis started with generating data subsets from the original (measured) water quality data. Secondly, the common statistical representatives for data central tendency and dispersion such as medians and ranges were calculated and then plotted in relation with different proposed sampling frequencies. Finally, visual assessments were carried out for the original data

set in addition to the generated subsets. The result showed that there are narrow changes between both median and range values for the selected water quality parameters in relation with the examined possible sampling frequencies. Therefore, the optimal sampling frequency for the measured water quality parameters is six (6) samples per year. This will significantly reduce the overall cost of the monitoring program facilitating financial resources for better network management.

1. Introduction

Egypt is fortunate to have the River Nile. This main water source adds to economic stability and the quality of life. The water from the Nile is conveyed to users through a vast network of canals. The Egyptian Nile system is tremendous in size and complexity. It consists of the Aswan High Dam, eight main barrages, approximately 30,000 km of public canals, 17,000 km. of public drains, 80,000 km of private canals (mesqas) and farm drains, 450,000 private water-lifting devices (sakias or pumps), 22,000 public water-control structures, and 670 large public pumping stations for irrigation. Throughout this system, approximately 59 billion m^3 of water are distributed annually, not only for cultivated land, but also for municipal and industrial use, for generation of hydro-electricity and for the navigation of freighters and tourist boats on the Nile (Martin H., 1998).

For such a complicated system, water quality can change frequently over time, necessitating frequent, repeated measurements to adequately characterize variations in quality. Therefore, the acquisition of reliable and defensible water quantity and quality data through proper sampling and analytical techniques is often an essential part of the careers for many environmental professionals in Egypt. Moreover, water quality monitoring (**WQM**) will become increasingly important as Egypt tries to meet a growing portion of its future water needs through reuse of water. Technologies exist to do this safely but they require considerable funds and careful management. **WQM** is the integrated activity for evaluating the physical, chemical and biological characteristics of water in relation to human health, ecological conditions and designated water uses (United States Geological Survey (**USGS, 1995**). Therefore, the Ministry of Water Resources and Irrigation (MWRI) represented by the National Water Research Center (NWRC) established the National Water Quality Monitoring Network (routine program) that covers groundwater, Nile water and agriculture drainage water. The sampling frequency of the existing WQM program is based on monthly measurements.

However, the methods used to perform WQM have changed dramatically over the last 10 years resulting in improving knowledge and understanding of the relation between water quality and changes in hydrology, geology, and land use **(Wagner et al, 2006; Khan et al, 2008)**. Therefore, NWRC recently initiated an advanced technique for water quality sampling using modern

instruments that allow for real-time (continuous) records of concentrations of water-quality variables in water streams. The new WQM technique is applied for some strategic points in the River Nile system (**Figure 1**). Both monitoring programs are important decision-support systems for any water quality management plan.

2. Scope and Objective

The high variability in the drainage water quality parameters with low monitoring frequency could lead to misjudgment when the water quality data is analyzed. This is due to the fact that the drainage water is subject to significant changes due to the continuous inflow of wastes from different sources.

The main objective of this study is to assess the current sampling frequency for routine water quality monitoring network based on different time intervals for El-Salam Canal intake (NL39) at Damietta branch at the River Nile using real-time data for selected water quality parameters namely: Total Dissolved Solids (TDS), Dissolved Oxygen (DO), pH and Turbidity (Tur).

In addition, the obtained results will help in proposing an optimal sampling frequency for the current routine water quality monitoring network.

3. Routine Monitoring Program

NWRC has developed extensive monitoring networks for groundwater, Nile water and drainage water. The network includes 300 surface water and 230 groundwater monitoring points and aims at integrating the individual monitoring activities into one coherent and consistent national information system to support decision makers on water quality issues. The monitoring key objectives of the program can be summarized as follows:

- Assess the quality of water entering the Nile Delta and of that released from the Northern Lakes through the drainage system;

- Determine the seasonal variation in water quality along the main water resources (canals and drains) ;
- Quantify the variation in the water quality in relation to the existing pollution sources; and
- Identify the quality and quantity of drainage water reuse in agriculture.

For surface water quality monitoring, the measured parameters can be categorized into four main packages namely:

- Oxygen Budget: Biological Oxygen Demand, Chemical Oxygen Demand, Dissolved Oxygen and Oxygen Saturation.
- Salts (macro-ions): Electrical Conductivity, Total Dissolved Salts, Calcium, Magnesium, Sodium, Potassium, Carbonate, Bicarbonate, Sulphate and Chloride.
- Nutrients: Nitrate, Ammonia, Total Nitrogen, Total Phosphoresces.
- Physical Parameters: Temperature, Acidity, Total Suspended Solids, Total Volatile Solids, Turbidity, Visibility disc, Odor and Color.
- Bacteria: Coliform Total bacteria and Fecal Coliform
- Metals: Cadmium, Manganese, Copper, Iron, Zinc, Nical, Lead and Boron

The NWRC routinely monitors the previous parameters with different sampling frequencies regimes. **Table 1** presents the sampling frequencies for the water body:

Table 1: Sampling frequency for different water body

Water Body	Sampling Frequency (samples/year)
Lake Nasser	2
Nile River	2
Nile Branches	2
Irrigation	12
Drains	12

(Abdel-Gawad et al, 2003).

4. Real-Time Water Quality Monitoring in Egypt

In routine WQM, water samples are typically collected and stored for shipment to a laboratory, where they are analyzed. Problems associated with this practice included ensuring that the samples are transported properly so as to not affect their chemical properties, and the time associated in getting the results back. When the time interval between repeated measurements is sufficiently small, the resulting water-quality record can be considered continuous.

Technological advances in water-quality sampling and recording instruments allow for an almost continuous record of the concentrations of water-quality variables in streams and rivers. A device that measures water quality in this way is called a continuous water-quality monitor. These monitors have sensors and recording systems to measure physical and chemical water-quality field parameters at discrete time intervals at point locations.

These monitors have sensors and recording systems to measure physical and chemical water-quality field parameters at discrete time intervals at point locations. However, the data collected are only as good as the quality assurance and quality control procedures, and the quality assessment measures incorporated into the sampling program. In-stream water-quality sensors provide continuous measurements (typically, every 5-60 minutes) of water-quality conditions that may vary widely over short periods of time due to any natural or anthropogenic threats. When this data is available in real time, water management officials can be notified of these changes and are able to respond by altering treatment (**Khan et al, 2006**).

Additionally, real-time measurements for temperature, conductance, and turbidity can be statistically related with other important properties, such as indicator bacteria that are more costly and difficult to monitor and analyze. Continued development, testing, and deployment of a new generation of real-time sensors for water quality have the potential to greatly increase the level of information available**.** **Figure 1** shows the monitoring locations along the Nile River.

5. METHODOLOGY

5.1. Site Selection

The monitoring location (NL39) is on the Damietta Branch of the Nile River at the intake of the strategically and socio-economically important El Salam Canal. The El Salam Canal itself is also used for fishing and aquaculture.

It is located about two km upstream of the Farasqur dam, where the Damietta Branch discharges into the Mediterranean Sea. The branch width at NL39 is about 220 m and water depths range from 5.25 m at the west point to 11 m at the east point of the section. Agricultural areas are evident on the west bank and at EL-Adleya city which is located on the east bank at NL39 (**Khan, Haseen et al, 2010).**

From a water resources management perspective, this point represents the cumulative impact of several drainage inputs along the Damietta Branch and is a site used for fishing.

It is located about 53 km downstream of the El-Serw drain outlet and also represents the starting water quality of the El Salam Canal which is the primary source of irrigation water for agriculture in the Sinai Peninsula (**Khan et al, 2008)**

The water quality at the previous site is monitored within two monitoring programs National Water Quality Monitoring Network and Real-Time Water Quality Monitoring program and coded as: EI28 and NL39 respectively.

In the real-time network, the monitoring site is provided with devices to measure pH, Dissolved Oxygen (DO), Electric Conductivity (EC), Total Dissolved Solids (TDS), Temperature, Turbidity (Tur.), Nitrate (NO_3) and Ammonium (NH_4) and is adjusted to store readings through

its devices every 15 minutes and take its average; about 96 records are stored each day, through which an average is calculated in order to get a daily record. In this paper the analysis of TDS, DO, pH and Tur. will be presented.

5.2. Statistical Analysis

Sampling frequency is a function of the statistical objective of the monitoring program, which may vary from the determination of means in quality whether daily, annual or seasonal. More measurements will increase the precision, reduce the likelihood of bias, and increase the power of the statistical component of the program but will increase the overall monitoring cost. The study period started at 20 January 2009 till 20 August 2009.

Firstly, the analysis started with generating data subsets from the original (measured) water quality data. Six (6) data subset were developed as following:

- **Subset A** (n= 6 samples/year) measurements started at 20 February 2009.
- **Subset B** (n = 6 samples / year) measurements started at 20 January 2009.
- **Subset C** (n = 12 samples / year) measurements started at 20 February 2009.
- **Subset D** (n = 24 samples / year) measurements started at 20 February 2009.
- **Subset E** (n = 36 samples / year) measurements started at 20 February 2009.
- **Subset F** (n = 48 samples / year) measurements started at 20 February 2009.

Secondly, the common statistical representatives for data central tendency and dispersion such as medians and ranges were calculated and then plotted in relation with different proposed sampling frequencies.

Finally, visual assessments were carried out for the original data set in addition to the generated subsets.

6. Results and Discussion

The real-time water quality data was used to determine the optimal sampling frequency for the routine water quality monitoring network. **Figures 2 and 3** show the histograms for respectively medians and range values of different sampling frequencies for TDS, DO, pH and Tur measurements at Damietta Branch of the Nile River.

The results showed that The TDS medians varied within a relatively small range from 0.266 (gm/L) to 0.279(gm/L). Similarly, DO varied within a relatively small range between 4.53 (gm/L) and 5.09 (gm/L).

Also, pH varied from 7.98 to 8.07 pH unit (slightly basic water) and finally, Tur varied from 11.04 (NTU) to 12.96 (NTU) (**Table 2**).

Similar to what was found for the medians, the TDS ranges varied from 0.068 (gm/L) to 0.080 (gm/L). The DO ranges varied from 4.36 (gm/L) to 5.15 (gm/L). The pH ranges varied from 1.19 to 1.39 pH unit (slightly basic water) and finally, Tur ranges varied from 12.46 (NTU) to 13.60 (NTU) (**Table 3**).

Tables 4 and 5 show the percentage of change for medians calculated for samples measured at different frequencies (6, 24, 36 and 48 per year) compared to those calculated for data measured at 12 samples per year. Similarly, water quality ranges were also presented.

Figures 2 and 3 present the medians and ranges for the examined water quality parameters calculated at different sampling frequencies for the original data set in addition to the subsets generated as explained before.

Visual comparisons between results obtained were carried out. It is clear that there are narrow changes in both median and range values for all the examined parameters in relation with different sampling frequencies.

7. Conclusions and Recommendations

There are narrow changes between both median and range values for the selected water quality parameters in relation with the examined possible sampling frequencies. The final output

obtained proved that the continuous water quality monitoring system is a powerful tool in tracking the water quality status in near real time conditions. The system allows detecting any sudden changes in the quality and permits to have fast reactions based on accurate information.

The optimal sampling frequency for the measured water quality parameters is six (6) samples per year. This will significantly reduce the overall cost of the monitoring program facilitating financial resources for better network management.

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Table 2: The median values of the selected WQPs at NL39

NO	Frequency	pH	DO gm/L))	TDS (gm/L)	Tur. (NTU)
1	6 sample per year (A)	7.98	4.530	0.274	11.43
2	6 sample per year (B)	8.07	4.57	0.271	12.96
3	12 sample per year	8.07	4.84	0.271	11.89
4	24 sample per year	8.03	5.09	0.269	11.79
5	36 sample per year	8.01	5.09	0.266	11.89
6	48 sample per year	7.99	5.02	0.279	11.04

Table 3: The range values of the selected WQPs at NL39

NO	Frequency	pH	DO gm/L))	TDS (gm/L)	Tur. (NTU)
1	6 sample per year (A)	1.19	4.36	0.070	12.46
2	6 sample per year (B)	1.19	4.49	0.068	12.66
3	12 sample per year	1.30	4.71	0.074	13.20
4	24 sample per year	1.35	4.85	0.077	13.50
5	36 sample per year	1.36	5.02	0.079	13.60
6	48 sample per year	1.39	5.15	0.080	13.50

Table 4: % of median changes with different sampling frequencies

NO	Frequency	pH	DO (gm/L)	TDS (gm/L)	Tur. (NTU)
1	6 sample per year (A)	1.12	-6.405	1.125	-3.93
2	6 sample per year (B)	0.00	-5.58	0.000	8.99
3	12 sample per year	0.00	0.00	0.000	0.00
4	24 sample per year	0.50	5.17	-0.738	-0.89
5	36 sample per year	0.74	5.17	-1.845	-0.01
6	48 sample per year	1.05	3.72	2.768	-7.17

Table 5: % of range changes with different sampling frequencies

NO	Frequency	pH	DO (gm/L)	TDS (gm/L)	Tur. (NTU)
1	6 sample per year (A)	-8.74	-7.43	-5.946	-5.61
2	6 sample per year (B)	-8.51	-4.67	-8.108	-4.09
3	12 sample per year	0.00	0.00	0.000	0.00
4	24 sample per year	3.53	2.97	3.514	2.27
5	36 sample per year	4.29	6.58	6.892	3.03
6	48 sample per year	6.67	9.34	8.108	2.27

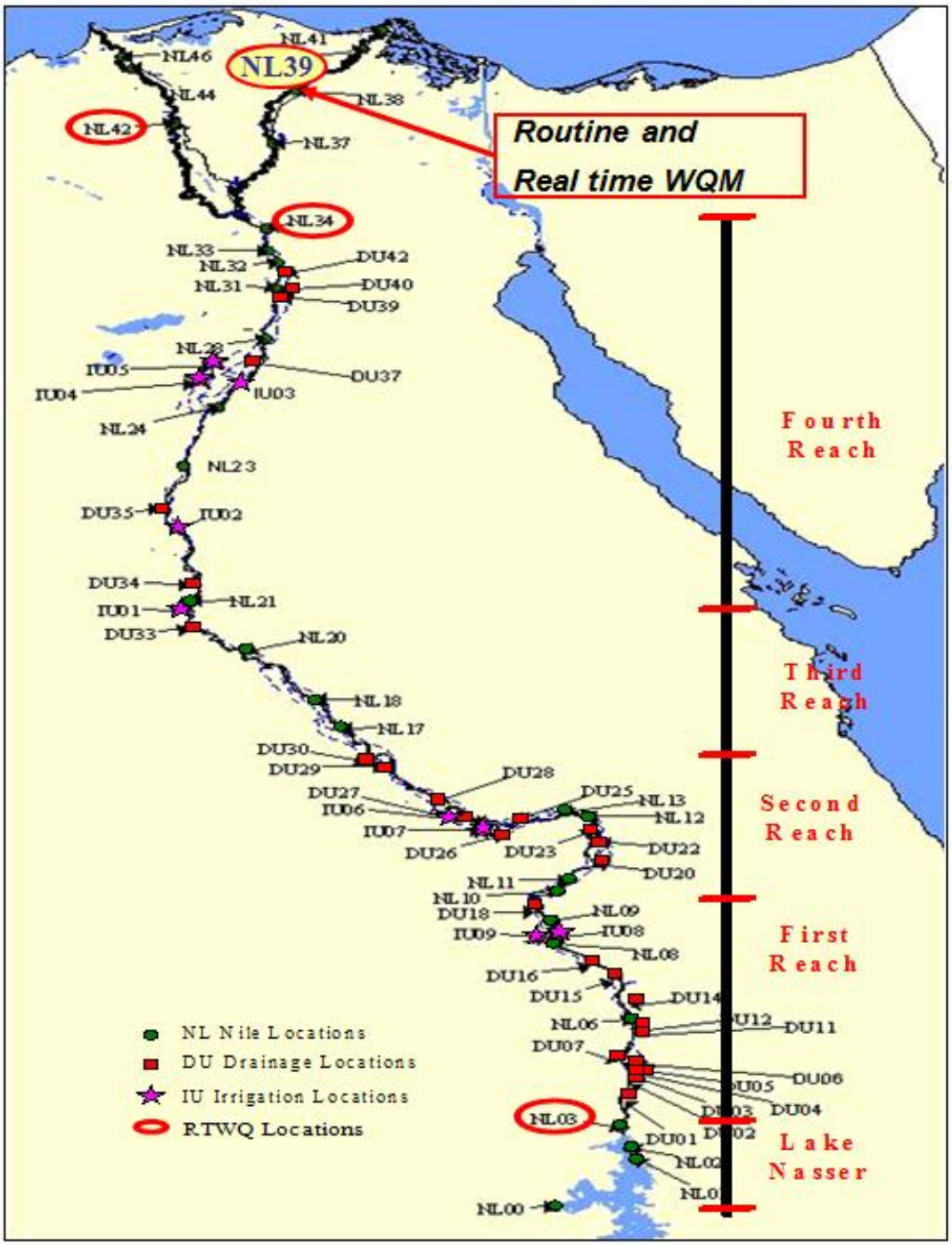

Figure 1: Water Quality Monitoring Sites along the Nile River

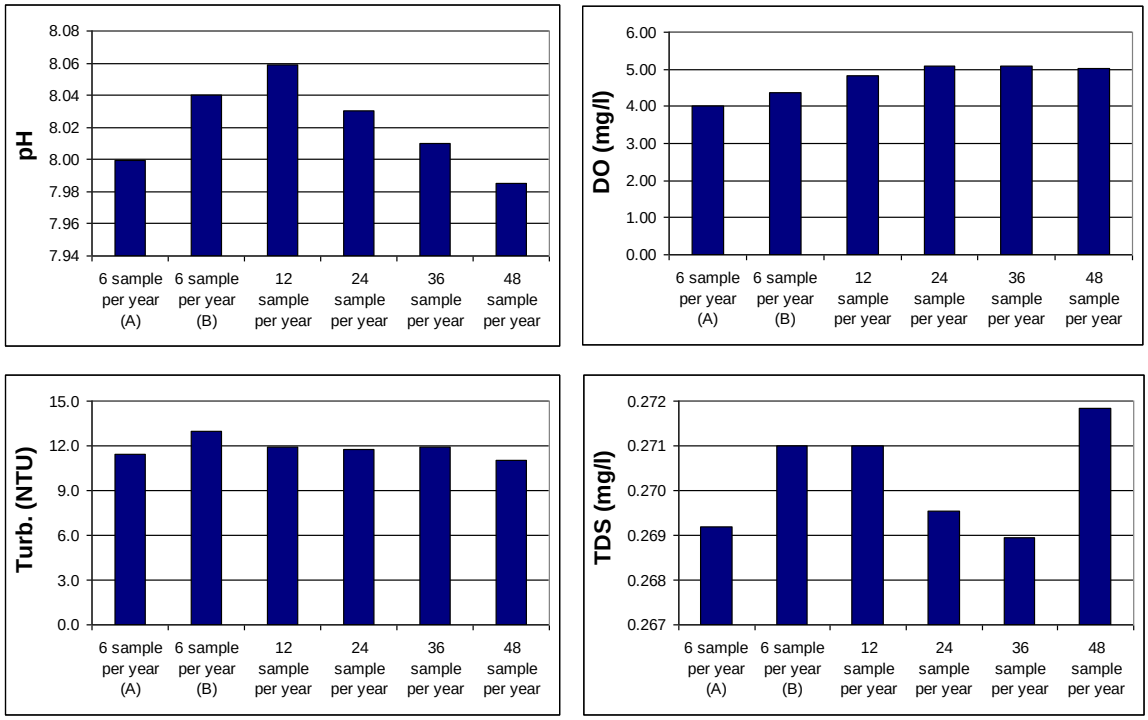

Figure 2: Medians at different sampling frequencies for some WQPs at NL39

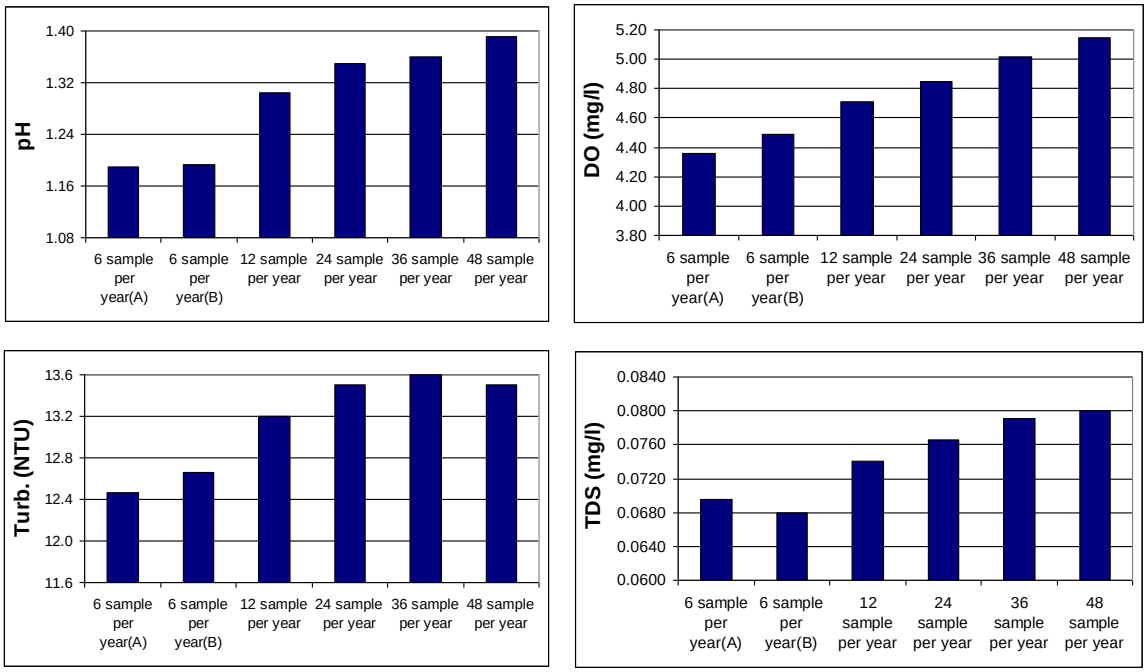

Figure 3: Ranges at different sampling frequencies for some WQPs at NL39

Sustainable Water Supply and Resources Management A Case Study from the town of Hababah, Amran Governorate, Yemen

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Abstract

This paper presents alternative solutions for local communities that find other option for water supply in arid areas to reach sustainable use of water. Hababah town is a part of the District of Thula, one of the twenty districts of the Governorate of Amran. Hababah is suffering from water supply due to the fact that water supply from the public network comes once a month for a few hours. The main thrust of this area is to promote the water supply and management thereby contributing significantly in a sustainable manner and towards poverty reduction. Communities are starting to repair and maintain their previous traditional cisterns and constructing new cisterns in cooperation with the local population and charity men without any support or supervision from the Government or local council. More than fifteen cisterns have been rebuilt and rehabilitated for the sustainable use of water resources. Sustainable use of water has contributed to reduce poverty and improve the bad conditions of the water supply in the area where the poor people are now able to obtain water easily and cheaply. More than seven villages around Hababah town are now relying for water from cisterns. Each year, more than 70,000 cubic meters of water cisterns are being used. More than 1,700 families and 13,000 inhabitants are dependent on water cisterns.

Key words: Water supply, Sustainable, Hababah town, Cisterns, Yemen

Introduction

Yemen faces immense water challenges, such as scarcity of water, low rainfall rate per year. The Yemen Government has identified the water sector as one of the key priorities for government policy. Yemen has been vulnerable to the effect of the climate change. Topographical variations of Yemen give rise to a wide range of climatic conditions. In general, the climate of Yemen can be classified as semi-arid to arid. Averages annual rainfall is 130 millimeters in the western coastal plain Tihama and 127 millimeters in the southern coastal plain Aden. The highest mountainous areas of southern Yemen receive from 520 to 760 millimeters of rain a year (AREA, 2005). Amran Governorate is located north of the capital Sana'a around 40 km and contains twenty districts (Figure 1). Between November and January, temperatures in these mountain areas can drop down to 0 °C particularly in Amran Governorate. Humidity is very high, on the coastal plains up to more than 80%, whereas it goes down toward the high land where it reaches its minimum rate in the desert areas to be around 15%. The hottest season in Amran Governorate is from May to July, and the coldest season is between November and January, with maximum and minimum monthly temperatures in May 33 °C and December 4 °C, respectively. The average monthly humidity in Amran ranges between 35 % in July and 52 % in May. Thula district is one of the Amran Governorate, it is contains six towns, one of these town is Hababah. It is located north west of Sana'a around 40 km.

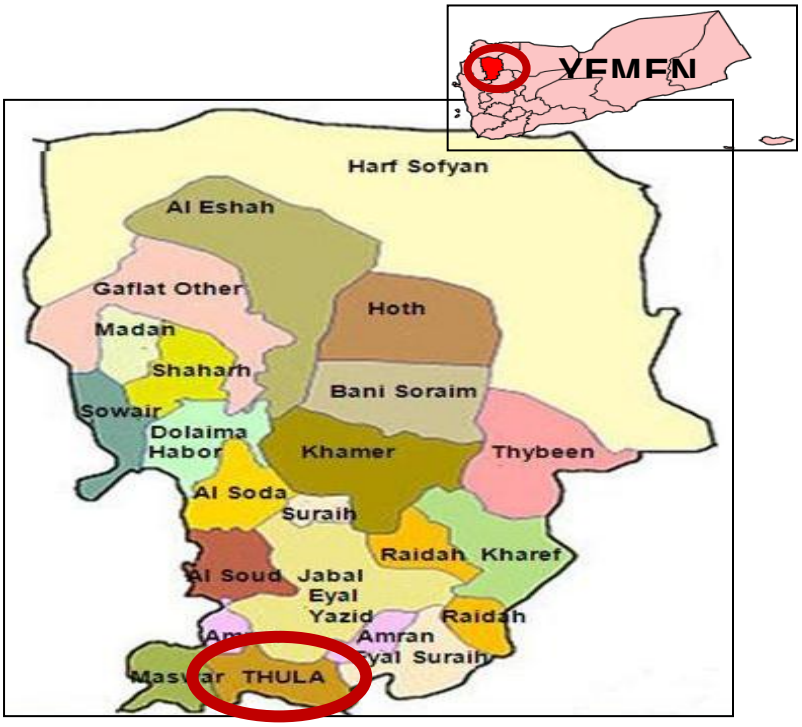
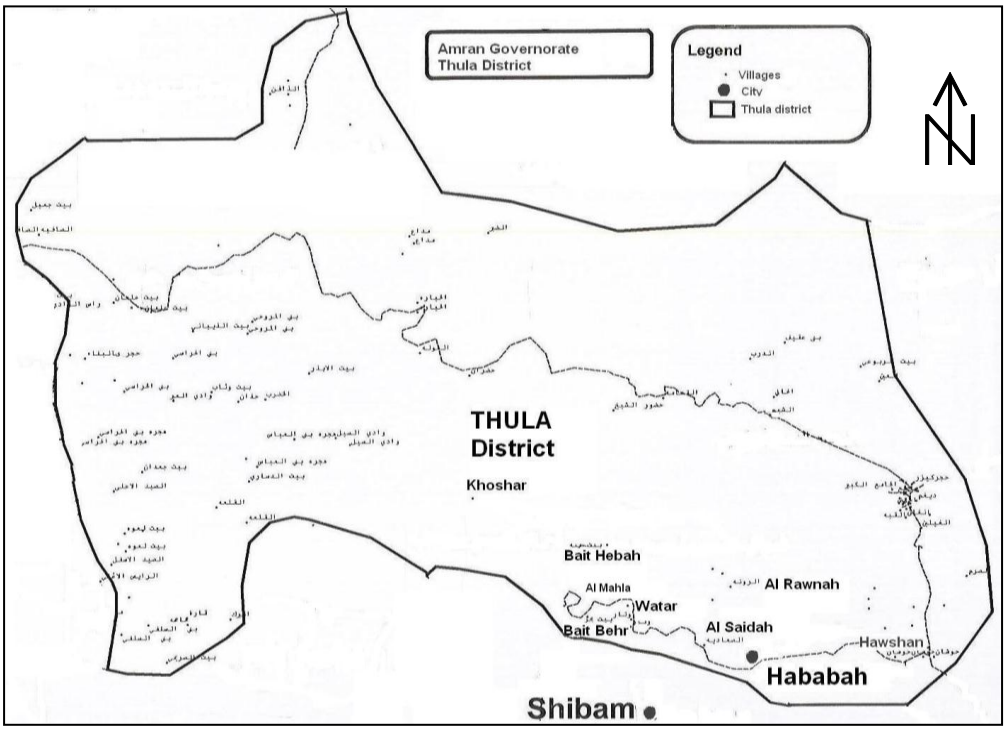


Figure 1: Map of Amran Governorate, red circle is Thula district

Hababah town contains seven villages (Al Saidah, Watar, Bait Behr, Al Mahla, Bait Hebah, Khoshar and Al Rawnah) (Figure 2). The elevation of Hababah is about 2,600 m above sea level. The water resources in Hababah are rain, runoff, surface water e.g. springs and cisterns. The economic activities are agriculture and commerce. Farming mainly relies on the rainy seasons. The priority in this area is water as well as electricity. According to the census (2004), the population in Hababah and the surrounding villages is 13,000 inhabitants and families' number is 1700. The family size is the highest in terms of number of family 8 persons (Table 1).

Table 1: Demographic indicators in Hababah and their villages, Thula district, Amran Governorate (Census 2004)

	Nr. Families	Male	Female	Total (M + F)
Hababah	1174	4333	4232	8565
Al Saidah	108	357	352	709
Watar	108	379	390	769
Bait Behr	44	122	129	251
Al Mahla	131	665	553	1218
Bait Hebah	61	226	230	456
Khoshar	82	390	357	747
Al Rawnah	86	293	282	575



The public water network started in Hababah in the year 1980. This made the people trust the public network for a period of time. As a result communities neglected their traditional cisterns. For the past ten years the public network in Hababah has provided water only one day every two months for a few hours from Shibam city, around 20 km from Hababah. The municipal water utility of Shibam is often unable to guarantee the basic service of water supply and unable to provide people with a continuous drinking water supply due to the growing population and the increasing water demand. The number of hours supply available seems insufficient. The local people believe that water vendors or cisterns could deliver water more reliably than governmental supply. Therefore, rehabilitation the traditional cisterns around Hababah not only to manage the water, but also to help poor families who can not afford to buy water from private water providers. This paper presents the role of community participation on sustainable water supply and resources management and shows how they have helped to improve the conditions in poor rural areas and protected the resource for future generations.

The geological background

The surrounding mountain of Hababah from south and west are Cretaceous Tawilah sandstone whereas Hababah city is located on Jurassic limestone which is part of Amran group that considered to be the oldest sedimentary formation in the region (SAWAS, 1996). The underlying Amran group consists mainly of fossiliferous carbonate (shallow-water limestone and marls) of upper Jurassic with total thickness between 410 and 520 m (Al-Thour, 1997). The Amran limestone is generally considered to be a poor and semi-confined aquifer. Well yields range from 3 to 6 l/s (Rybakov, 2004).

Toward sustainable used

Historically, the region is known for their traditional domestic and drinking cisterns. For centuries, local people in this region have carefully adapted to their local environment and needs. Increasing water demand and lack of access to water resources enable local people to come back to traditional cisterns and undertake activities and responsibilities for the conservation and management of natural resources independent without any support or supervision from the Government. Around two third of the population has no access to water supply in Hababah due to the public network is covering only 30 %. Therefore, the people depended on water vendors and cisterns. The phenomenon of purchasing water from vendors is appearing in Hababah. Vendors bring drinking water from Hawshan village about 10 km to the east from Hababah. The water in Hawshan village based on dug and dug/bore wells.

The repairing cisterns start on 2005 because of the public water supply not sufficient and the cost of water tank truck. The cisterns in Hababah town more than 15 and most of them old and need for rehabilitate (Table 2). The supporting of funding to maintain previous traditional cisterns and built new one come from charity men and local people without any assistance from the Government or local council. Local authorities who are responsible for providing water supply such as General Authority for Rural Water Supply Projects (GARWSP) and National Water Resources Authority (NWRA) are absent in the region. Social Development Fund (SDF) which is support by World Bank built one cistern in Hababah. The cost of this cistern was fife times of other cisterns which fund by charity men. This cistern also has defect in design and construction.

The first stage was repairing Shabar (1) and Shabar (2) which are based on spring water and will be used for drinking water for northern Hababah (Figure 3). Al Hajarn, Mahdi and Al Dalae cisterns are the oldest in Hababah town. These cisterns are cleaned two times per year during runoff and provide the inner town. The second stage was repair Al Safa (1) cistern which is the biggest in the town. The two spring waters in the western part of the town are Al Qasr and Al Sannaf cisterns which have been rehabilitated at the third stage. The last stage which was under construction and rebuild for Al Safa (2), Hejar Al Sood and Al Harawah cisterns. The domestic cisterns filled by rain water during the flooding season and used predominant sources for animals and washing clothes.

Table 2: Names of the cisterns in Hababah town, Amran Governorate

Names of the cisterns	**Area (m2)**	**Capacity (cm3)**	**Location**	**Purposes**
Al Hajarn	1540	10010	Old city	Domestic use
Al Dalae	176	1414	Old city	Domestic use
Shabar 1	774	3870	Northern part	Spring-Drinking
Shabar 2	100	300	Northern part	Spring-Drinking
Mahdi	200	1400	Eastern part	Domestic use
Al Safa 1	5200	41600	Northern part	Domestic use
Al Safa 2	4200	29400	Northern part	Domestic use
Al Qasr	375	1875	Western part	Spring-Drinking
Al Sannaf	510	2805	Western part	Spring-Drinking
Al Harawah	800	4000	Southern part	Domestic use
Hejar Al Sood	512	4096	Southern part	Domestic use

Total capacities for all cisterns are 70,000 cubic meters. Two third of the capacity of fifteen cisterns water have been used each year. More than 1,700 families and 13,000 inhabitants are dependent on water cisterns. The task of water transportation is mainly done by women and children.

Conclusions

The community improved sustainable water use and introduced this approach for other villages using traditional cisterns. The repair of cisterns in Hababah not only improves the management of water, but also helps poor families who can afford to purchasing water. The local people understood the concept of the rebuild the cisterns. It is perfect solution for rural areas that cannot access for public network services. It promotes and create a strong motivation for future generations how to find alternatives for water resources.

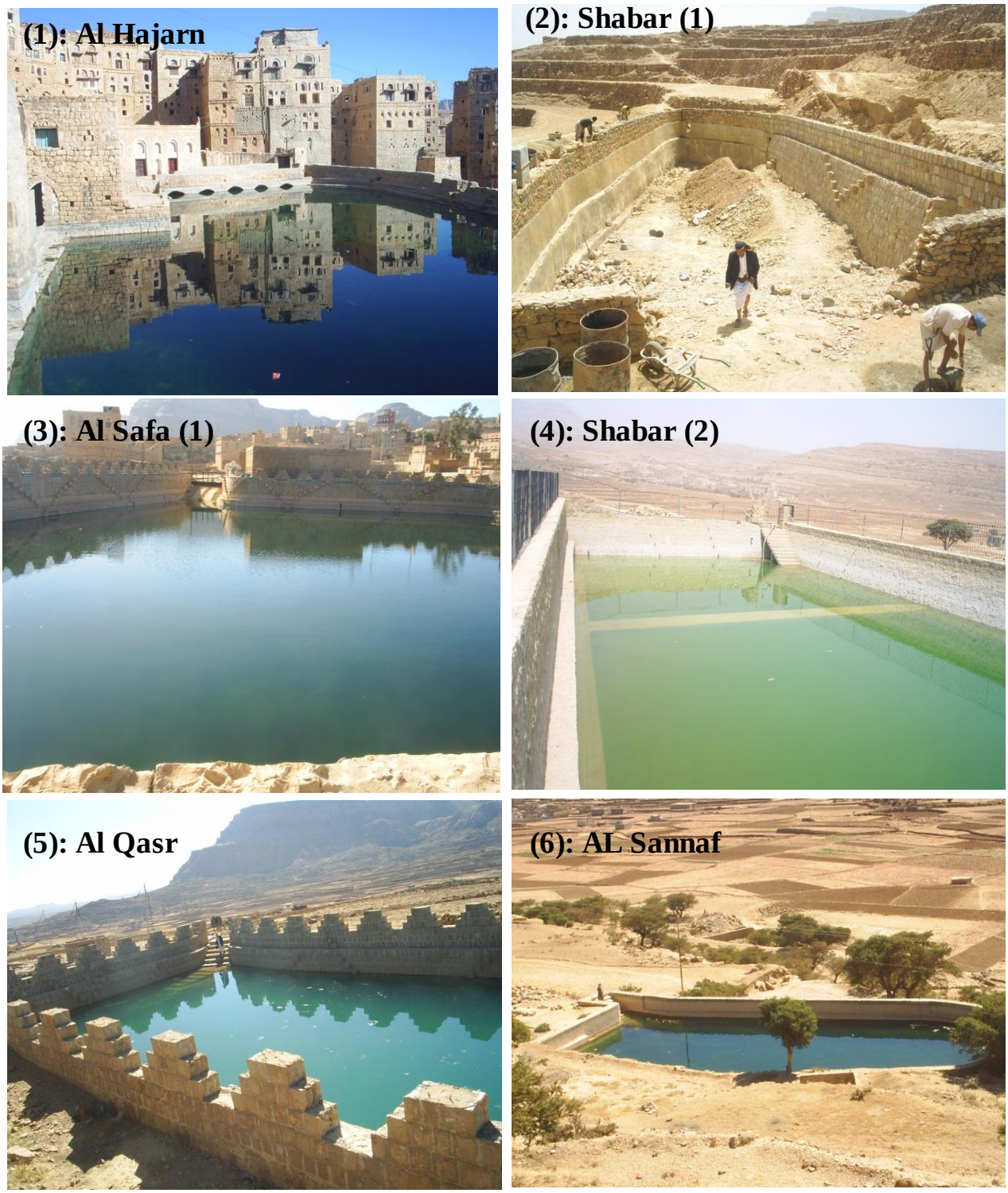


Figure 3: Cisterns in Hababah town, Amran Governorate

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SESSION 5B
MUNICIPAL WATER MANAGEMENT

Keynotes: Slim Zekri, Sultan Qaboos University, Economic incentives and water demand management

Dr Slim Zekri, has an Engineering degree in Major in Agriculture Economics, A Master degree in Environmental Planning and earned his PhD in Agricultural Economics & Quantitative Methods from the University of Cordoba, Spain in 1991. Currently he is Associate Professor, at the Department of Natural Resource Economics, Sultan Qaboos University since September 2003. Dr Zekri published more than 50 papers in International Journals and in International Conferences. Dr Zekri worked as an expert for national and international agencies such as the World Bank, FAO, GTZ, Ministry of Agriculture in Tunisia, Ministry of Municipalities Environment and Water Resources in Oman, Ministry of Agriculture in Oman, ICBA, USAID. His main research and consultancies deal with natural resource economics, agricultural and water management and economics.

Abstract:

Domestic water supplies and sewage service are subsidized in the Sultanate of Oman. Water prices have not increased since 1980 with the of protecting the low-income families. There is a lack of information regarding water price elasticity in Oman and the effect of price increase on different social groups. This paper evaluates the effect of the recent inclusion of sewage services fee on water consumption in a prosperous district in Muscat, capital of Oman. Monthly volume of water used and fee paid were collected from water bills for a period of two years. A random sample of 122 customers was selected and classified into four groups by their average monthly water consumption mimicking income groups. A paired sample T- test was conducted to check the impact of the implementation of the sewage charges on water demand. Results showed that the inclusion of the sewage fee has resulted in 18% decrease in water consumption and a subsequent reduction of subsidy by 16%. The estimated water price elasticity is -0.58 and falls within the range of elasticities found in international studies. This empirical analysis shows that increasing water price can be an efficient way to promote water saving with little impact on low-income groups, reduce public expenditures and postpone the building of new desalination plants.

Excessive groundwater pumping is a global problem which severely affects the dry areas where surface water is scant or inexistent. The coastal areas of Oman are primarily concerned because groundwater over-pumping results in seawater intrusion and causes degradation of the unique renewable water resource. Despite the implementation of several measures, such as the diffusion of water-saving technology, building recharge dams, freezing on drilling new wells, encouraging the re-use of treated wastewater for landscaping and transferring the large producers of Rhodes grass to Nejed area, groundwater levels continue to decline and seawater intrusion is steadily progressing in most of the coastal areas. Groundwater is a common resource pool characterized by the absence of exclusivity and the lack of incentives for farmers to save water due to the open

access nature of the resource. Several experiences around the world have shown that raising farmers awareness, stakeholders' participation, introduction of modern irrigation technologies have very limited impact on the depletion and quality degradation of groundwater. Pricing irrigation groundwater is politically infeasible as is the case of increasing electricity prices. Some countries such the USA, Australia and Jordan have introduced groundwater metering and allocated groundwater quotas to farmers. However, a study done by Zekri (2008) showed that flow water metering is highly expensive and an increase of 250% in electricity price only for the agricultural sector will be necessary to curve down the groundwater pumping. Both above mentioned solutions are considered unfeasible. Given the fact that we have a common resource pool the best solution is to allocate groundwater shares or quota to each farmer according to the farm size and historical cropped area. Zekri (2009) proposed a cost-efficient solution to this problem through the introduction of pre-paid electricity meters and the conversion of the water quota into an electricity quota. The new technological developments allow a better solution due to the availability in the market of Intelligent Energy & Water Meters (Moazedi, 2011). This avoids any conversion of the electricity quota into a water quota. In fact, the new type of meter allows measuring the volume of groundwater pumped.

Water Sustainability and Financial Cost: The Case of Kuwait

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Abstract

The Cooperation Council for the Arab States of the Gulf (GCC) has been experiencing a rapid growth in population. To meet the increase in demand, new projects in the water sector are being planned. These projects are predominately financed with government funding and/or debt, guaranteed by the government.

Most of the water entities in the GCC have a cost recovery system that is not equitable with the reality on the ground. With the high price of oil and gas, most of the countries can afford to provide water services at a price far below cost. The key question is the sustainability of this mode of operation.

This paper will focus on assessing the current trend in population growth in Kuwait, the increasing demand for water and how these are going to impact the financial requirements. The argument will be made, that water supply (mostly desalination) cannot be provided in the long-run by utilizing the traditional methods of project financing and management, in addition to using the same current model of tariffs and cost recovery. In short, the current approach is unsustainable in the medium and long term. Therefore, the major challenge is how to make the system sustainable in both the supply of water resources and the financing of water projects for future generations in Kuwait. In order to have a sustainable water services in Kuwait in the medium and long run, a serious look at the sector is in order. The assessment should focus on the demand side which is being increased tremendously due to the population growth and the government ambitious plans of creating new cities and residential areas. A thorough investigation is needed to identify the actual cost of providing the service. The cost assessment should cover both operational and capital. There is a need to create awareness of the problem of having sustainable supply of water. Also, water users should bear their responsibility in that regard. The government and its citizens are encouraged to agree on the proper methods of sharing. The new proposed Value Added Tax (VAT) along with the trend of engaging the private sector in providing this essential service should provide a more positive outlook going forward. The final thought is, "business as usual" is not sustainable.

Keywords: Cost Recovery, Financing, GCC, PPPs, Population, Sustainability .

1. Introduction

The world global water requirements are expected to grow from 4,500 billion m^3 to 6,900 billion m^3 by 2030[1]. The latest report by 2030 Water Resources Group related the increase to economic growth. The cost of bridging the gap between supply and demand is between $50-60 billion annually. Also, it was estimated that the annual expenditures is between $70 and 90 billion. The conclusion of that report was that population and economic growth are placing water resources under increasing strains, and add to that, the water sector is severely underfunded [2].

The previous paragraph elaborates on the global conditions of water resources' cost and funding. The Middle East and North Africa Region (MENA) and The Cooperation Council for the Arab States of the Gulf (GCC) are no exception. The population in MENA represents 4.52% [3] of the world population. The GCC countries with a population of 42.1 million [4] and increasing rapidly to match the need for labor to help out with the expansion of the economic activities have a combined GDP of $917 billion [5] and noting that one of its members, Saudi Arabia, is a member of the prestigious G-20 group. Needless to say, the economic power of the region being a center of oil, gas and industrial production is attracting manpower from all over the world, from banks executives to, financial managers and retails stores clerk to the unskilled workers.

The increase in population is placing a heavy pressure on services from health to electricity to roads to water and sewage among others. This paper will focus on water provided to municipal, domestic and industrial consumption. Latest statistics show that the GCC is going to experience a noticeable shortage of water which was provided for decades by relying on desalination. Water consumption is around 400 l/c/d, with the exception of the UAE, which is 700 l/c/d [6].

Water projects have been financed mostly through governmental budgets. Recently some projects were financed through public private partnerships and some through private financing. The cost of operations are being subsidized by the government, even thought there is a trend towards having a more reliable and reasonable tariffs by which some of the operating costs will be recovered,

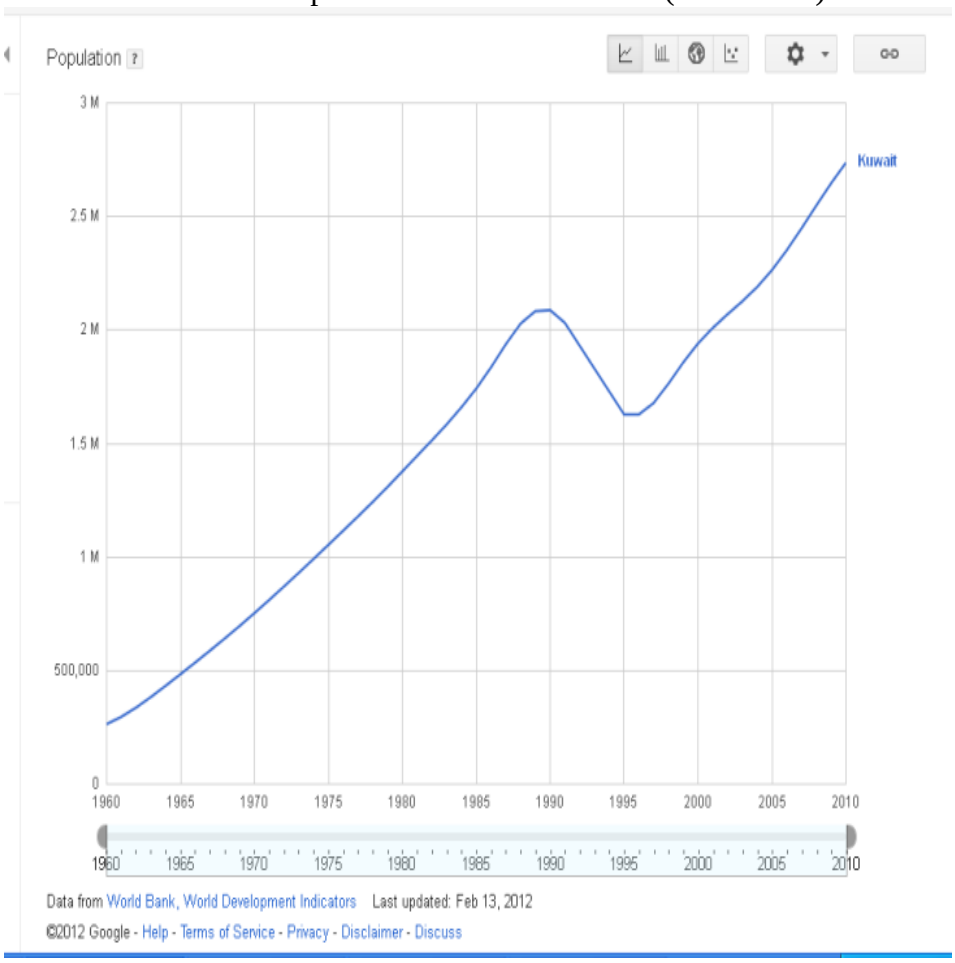
Based on the previous introduction, the question is how to provide sustainable water services to the population in the medium and long-term. The increase in population and the trend for governments to seek more balanced approach in delivering that service is placing a pressure to have a more manageable solution to this problem. The region, meanwhile, is experiencing a rapid economic growth and trying hard to diversify their economies. The economic engine is running on non-renewable resources, which is oil and gas, notwithstanding the serious effort and success of these countries to diversify their economies.

This paper aims to focus on Kuwait to examine some of the possible methods of sustaining water services. In the meantime, some of the lessons could be reviewed for possible implementation in other GCC countries.

2. Population Growth:

Kuwait is a member of the GCC along with Bahrain, Oman, Qatar, Saudi Arabia and United Arab Emirates with a total population of 42.1 million and is expected to reach 55.5 million by 2020 [7]. Kuwait's estimated population is around 2.6 million [8] by which 98% are located in urban areas. The growth rate is 1.99% [9]. The following Table 1 shows the increase in population during the period of (1960-2010). Over a period of 50 years, the population increased from 264 thousand in 1960 to around 2.74 million in 2010. Almost 1.3 million are non-nationals, which means that during unfavorable conditions, there will be a drastic decrease in the population which was the case back in 1990.

Table 1 Population Growth in Kuwait (1960-2010)



For example most nationals live in single family homes with their children, maids, and others. While non-nationals, reside mostly in apartments. This distinction explains the different consumption habits and patterns to meet the increase in demand. Kuwait is planning on building

new cities and residential areas during the coming period, which will add to the requirements and need for future water facilities.

3. Resources:

The majority of the supplied water is provided through desalination plants. Since 1965, six plants were constructed throughout Kuwait. Table 2 below shows the production facilities and the daily production for each of these plants:

Table 2 List of Current Water Plants

Name	Year of Operation	Compound Capacity (000 m3)
Al-Shuweikh Plant	1965	128
Al-Shuaiba North Plant	1965	41
Al-Shuaiba South	1971	137
Al-Doha East	1978	191
Al-Doha West	1983	501
Al-zour Shouth	1988	218
		1216

Source:
http://www.mew.gov.kw/en/?com=content&id=73&act=view
(accessed 1/18/2012)

The above table shows that the latest plan was constructed back in 1988. The total compound capacity is around 1.2 million m^3/day (258 mIG), with a total potable water production from all sources is 366 million m^3 (78,367 mIG). In 1998, the production per person/per annum was increased from 98 m^3 (21,589 IG) in 1988 to 182 m^3 (39,884 IG), in 1997, which is almost 85% increase over a period of 9 years [10].

The plants in question are rather old. The last was commissioned almost 24 years ago. The economic life of water plants is around 30 years. Aside from constructing new plants to meet demand, there is a necessity to upgrade the older system which should be taken into consideration.

Over the years, the attitude was to satisfy the demand side by providing the needed water (the point will be addressed under new projects), with the emphasis on demand, more plants were being provided, but for sure, the impetus was due to the rise in demand only.

4. Completed and Ongoing Projects:

Kuwait has planned for new projects to meet the ever increasing demand. As in other GCC countries, electricity and water projects are combined. Simply put, desalination is energy incentive process, therefore, in most cases, water and electricity projects are executed along with each other. An overview of the planned/completed plants for electricity and water projects are listed below in Table 3 indicate that almost $2.8 billion of projects are completed and $4.2 billion are ongoing:

Table 3 List of Completed and Ongoing Projects

Project Name	Project Value US$	Status
Kuwait MEW - 8 Substations	72,000,000	Completed
Kuwait MEW - Al Zour Water Storage Tanks	250,000,000	Completed
Kuwait MEW - Fintas Z Substation	42,000,000	Completed
Kuwait MEW - Qurain West Substation	70,000,000	Completed
Kuwait MEW - Shuaibah North Power and Desalination	1,270,000,000	Completed
Kuwait MEW - Subiya Desalination Complex Phase 3	262,800,000	Completed
Kuwait MEW - Subiya Water Distribution Scheme Package	62,000,000	Completed
Kuwait MEW - Subiya Water Tanks - C1 Package	50,000,000	Completed
Kuwait MPW - Al Wafra Water Distribution (Phase 3)	85,800,000	Completed
Kuwait MPW - E7 Pump Station	195,000,000	Completed
Kuwait MPW - Kabad Wastewater Treatment Plant	196,000,000	Completed
Kuwait MPW - Sewerage Improvement Project - Phase 9	60,000,000	Completed
Kuwait MPW - Treated Sewage Effluent Lines from DMC	85,200,000	Completed
Kuwait MPW - Umm Ar Rimam lake Treated Water Lines	58,000,000	Completed
Total	2,673,600,000	
KJO - Al Khafji Water Treatment Facility - Phase 3	150,000,000	Ongoing
KNPC - Refineries Effluent Revamp	250,000,000	Ongoing
KOC - Umm Al Aish Camp New Area Substation	11,700,000	Ongoing
Kuwait MEW - Al Zour South RO Desalination Plant	190,000,000	Ongoing
Kuwait MEW - Al Zour Water Complex - Phase 2	190,000,000	Ongoing
Kuwait MEW - Doha East and West Desalination Plants	650,000,000	Ongoing
Kuwait MEW - Doha West Desalination Plant Upgrade	87,000,000	Ongoing
Kuwait MEW - Higher Mutlaa to Site Towers (D20) Water	17,000,000	Ongoing
Kuwait MEW - Medium Mutlaa to Al Jahraa Network	17,000,000	Ongoing
Kuwait MEW - Mina Abdullah 2 water complex to West	133,000,000	Ongoing
Kuwait MEW - Mina Abdullah Water Distribution Complex	257,000,000	Ongoing
Kuwait MEW - Shuwaikh Desalination Plant	320,000,000	Ongoing
Kuwait MPW - Jahra Road Main Sewage Line	101,500,000	Ongoing
Kuwait MPW - Sewerage Improvement Project - Phase 10	64,900,000	Ongoing
Kuwait MPW - Sewerage Improvement Project - Phase 10	19,000,000	Ongoing
Kuwait MPW - Sewerage Improvement Project - Phase 9	57,000,000	Ongoing
Kuwait PTB - Al Zour North IWPP - Phase 1	2,700,000,000	Ongoing
Total	4,245,100,000	
Source:http://www.zawya.com/projects/projectLookup.cfm (accessed 1/23/12)		

A look at some of Kuwait proposed projects for the years 2010-2014, shows those which are labeled as mega because of their high cost. As it was mentioned in the previous section, Kuwait is planning the construction of new cities as mega projects, to meet the demand of its increasing population. For example, "Kuwait has plans to create satellite cities and towns in the outlaying regions mainly in Subiya, Khairan (potentially for 500,000 people), Jaber Al Ahmad City (100,000), Arifjan (up to 100,000) and other smaller city development" [11]. Also, according to the Public Authority for Housing Welfare almost 50,000 residential units will be distributed at the end of the Five-Year Development Plan [12]. The Shuaiba North Power & Desalination Plant is with a combined capacity of 270,000 m^3 of water and 800-MW of electricity. The North Al Zour Desalination Plant with 1,500 MW of power capacity with a combined water capacity of 47,318 m^3 (1.25 m G/d)[13].

5. Financial Requirements:

As in most countries in the GCC countries, the plants in Kuwait are owned and managed by the Ministry of Electricity and Water ("MEW"). Due to ownership, the general expectations of the nationals are that the facilities are there to provide water at reasonable cost and preferably on a highly subsidized basis. Actually the system is run on a highly subsidized basis. Capital cost is provided through budgetary process on a yearly basis, or five-year developmental plan. The operating cost is funded by the government and reduced by the amount of revenue received based on the current tariffs. The tariffs structure covers part of the operating cost.

Kuwait's four-year developmental plan (2010-2014) of $108 billion was approved in 2010. It is to be followed by another 5 plans. It is envisaged that half of the investments will come from the private sector [14]. The current MEW's budget is around $18 billion (KD 5.1 billion). The number of projects to be executed is determined by the allocated budget, therefore, from year to year, the projects in the pipeline may not meet the expected demand. The Public Private Partnerships initiative (PPPs) is expanding. The effort is being assisted by the World Bank as well. The Partnership Technical Bureau which was established in Kuwait is entrusted of implementing the BOT (build-operate-transfer) Law# 7 of 2008, [15]. Actually in the region including Kuwait, there are pending water projects using the PPPs, including Umm al-Hayman wastewater expansion, Az-Zour North IWPP among others.

6. Financing Models.

A proper and suitable method of financing through reliance on revenue received by users is a prerequisite to a sustainable operation. That will be applicable to most public services including water. An assessment of the obligations of the parties concern is crucial. We have the providers and the customers. Each of these parties' duties and responsibilities should be articulated as part of the public discourse. In Kuwait, these issues should be addressed and some kind of consensus should be reached. The fact that should be agreed upon is that "business as usual" is not sustainable. There is a need to have this service to be provided to present and future customers without relying fully on the government budgetary constraints.

The argument here is that, not all expenditures, both capital and operational, should be funded via financing vehicles that are supported by customers. In most countries, the government helps out with the process. For example, in the U.S. the government contributed 70% of the investment for water sector development while the users and the municipalities cover the remaining 30% [16]. The government, however, covers only 50% for the operating costs [17]. In Japan, it is 100% the share of the government for the development, while water users and municipalities cover 100% of the operational costs [18]. It is essential to focus on the cost-recovery principle, but the component of such may vary. Is it operational cost? Operational and capital costs? Operational and operational costs plus proper return on the investment? A decision must be made. In Kuwait, in the initial stage, the focus should be on the operational cost. With a proper time schedule there should be a gradual transition to cover the operational cost and the capital costs as well.

There is a need to have suitable management information system to track all costs associated with the delivery of water to the final customer, starting with the cost of desalination/treatment and all the way to the cost of water at the meter. Including in the cost is the "unaccounted for" due to seepage through the main pipes, meters malfunctioning and the illegal use of water. A detailed cost of maintaining the system should be added to the operational cost.

The capital cost of the on-going projects and the planned projects should be ascertained. With this information, a decision should be made as to the percentage of the capital cost that will be financed by the government and that by the water users. In order to establish a culture of sharing the cost of providing a service in Kuwait, a gradual approach could be worked out by which an initial drastic increase in tariffs should be implemented to send a message to the water users, and then a proper gradual increase of the tariff to reflect the changes in the operational cost structure.

What is needed here is to examine the management efficiency, cutting waste, especially on the administrative side. Most public utilities in the GCC, and Kuwait is no exception, are burdened with heavy payroll expenditures that cannot be justified. Additional crucial point is that," the lack of clarity on the true financial cost of water exacerbates the problem in a further, important way: business, farmers, and households lack sufficiently strong signals and incentives to prompt them to use water more efficiently and productively" [19]

In that regard, a suggested model proposed to charge a price of $1/m3 for water use in excess of a 150L/capita/day allowance and would reduce the demand by about one third, with a range between 20 and 40 percent depending on the model used [20].
Having this in mind, below are some of the suggested vehicles to support the operation:

Operational Costs:

From Year 1 to Year 5:	Users pay 50% of the operating costs. (Start with 10% with an increase at 10% increment)
From Year 6 to Year 10:	Users pay 75% of the operating costs. (Start with 5% with an increase of 5% increment)

From Year 10 going forward: Users pay 100% of the operating costs.

Capital Costs:

From Year 1 to Year 5: New users pay 10% of the capital costs
From Year 6 to Year 10: New users pay 20% of the capital costs
From Year 10 going forward: New users pay 50% of the capital costs

The engagement of the users in paying a certain percentage of the operating cost should be subject to a clear and transparent tariff structure which is debated among users and the government agency in charge. All suggested methods of proper use of water should be intensified. As for the capital cost, a more aggressive system of engaging the private sector should be developed and agreed upon. Initially, partial financing could come via syndicated loans, Islamic Sharia loans and other methods, with the government still supporting the effort until the time by which its role will be a partner and not a sole provider of funds. The point is, "the cost-recovery and user-pays principles are well established in several countries for services linked to water supply [21].

On the macro level, the government of Kuwait is making an effort which is being supported by the World Bank to implement the Value Added Tax (VAT). One of the benefits of this is to increase public revenue. The government could possibly allocate a certain percentage for infrastructure projects [22].

7. Conclusions and Recommendations.

In order to have a sustainable water services in Kuwait in the medium and long-term, a serious look at operation of the sector is in order. The assessment should focus on the demand side which is being increased due to the population growth and the government ambitious plans of creating new cities and residential areas. A thorough investigation is needed to identify the actual cost of providing the service. The cost assessment should cover both operational and capital cost. The plan should take into consideration the cost of rehabilitating the aging current infrastructure as well. Going forward with "business as usual" is not sustainable.

Below are some suggestions/recommendations to consider:

1. Creating a culture among customers to share the cost of providing water services is essential.
2. Formation of policies in regard to funding capital and operation costs is needed. There are precedents in other countries to consider i.e. Japan, Spain and the U.S. The role of the government and that of consumers should be articulated and agreed upon.
3. A reliable assessment of the actual cost of service should be made, with periodic update.
4. Establishing a tariff structure-subject to periodic adjustment- to satisfy the financial requirements of the operation.

5. Creating attractive incentives for the private sector to engage in the services, both on the operational and capital sides.
6. Allocating a portion of the proposed Value Added Tax (VAT) to partially fund infrastructure projects including those in the water sector.
7. It is pertinent to deal with water as an economic resource, by assigning a proper value to charge for providing it.

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New Water Operation Technique

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Abstract

Kahramaa, TDD has implemented new reliable full automatic technique for water operation guarantees a constant network pressure at network lowest pressure point also safe pump operation within manufacturer recommended range of operation and without continuous area pressure monitoring and without stopping pumps when demand deviates out recommended operation range.

Network and pumping operations challenges

We have replaced our old fixed speed pumps pumping to water tower system with modern variable speed pumps supplying directly to the network since our main aim is to get more flexibility on supplying the customers by changing the pumps RPM to fulfill the wide range of customer demand in and expanding country like Qatar and we have succeeded to increase our pumping efficiency and reduced the power cost up to 50% in some stations.

But on the other hand we have faced challenges in controlling pumps considering that old system with pumping to water tower you don't face any change in the operation point unlike when you pump directly to the network. So we have applied the below technique to reach to perfect operation condition in network and pumps.

New Technique Base Line

We have applied the network lowest point's system curve equation to maintain the area pressure considering that system curve is representing the summation of static head " which is required to be constant" and the pressure loss due to friction in a piping system, pressure loss due to friction increases with increasing water flow .

From above definition and since all pressure losses are factor of ($V^2/2g$) we find that system curve can be described via parabolic equation factor of velocity.
And since we are pumping to existing network so the cross-sectional area is constant so system curve equation can be described via parabolic equation factor of flow.

$$\textbf{Pump Head} = C1 + C2 \times Q^2$$

Units:- Pump Head in mtr water
Q is flow in litr/sec

The above equation was integrated in the PLC program so as the flow changes the PLC calculate the required pump head and adjust the pump speed accordingly to maintain the preset area pressure value., also we integrated the operation of throttling valve & recirculation valve to

reduce or increase the flow respectively when operation point out of healthy operation range recommended by the pumps' manufacturer.

Introduction

Kahramaa has replaced old fixed speed pumps pumping to water tower system with modern variable speed pumps supplying directly to the network since our main aim is to get more flexibility on supplying the customers by changing the pumps RPM to fulfill the wide range of customer demand in and expanding country like Qatar and we have succeeded to increase our pumping efficiency and reduced the power cost up to 50% in some stations.

But on the other hand we have faced challenges in controlling pumps considering that old system with pumping to water tower you don't face any change in the operation point unlike when you pump directly to the network. So we have applied the new water operation technique to reach to perfect operation condition in network and pumps.
To explain the need of implementing the new operation technique we have to review below water network challenges.

Direct Pumping to water network challenges

We can brief the challenges in two points listed below

- Difficulty of maintaining constant area pressure considering the continuous change in the flow along the day " day/ night", week " working days/ week end and year seasons " winter / summer"
- Difficulty of keeping operation point within the pump performance curve with the same wide change in the flow considering the rapid development in the State of Qatar

How to tackle operation challenges

1. To maintain constant Area pressure we have gone through three methodologies showing our development in improving our operation technique

A. Changing Pumps pressure manually based on pressure readings taken three times per day "morning, afternoon and night " that pressure readings taken using pressure gauge by field staff. But this method required big number of staff to monitor the network pressure in country various pumping destinations also was not guaranteeing constant area pressure in between the measurements.

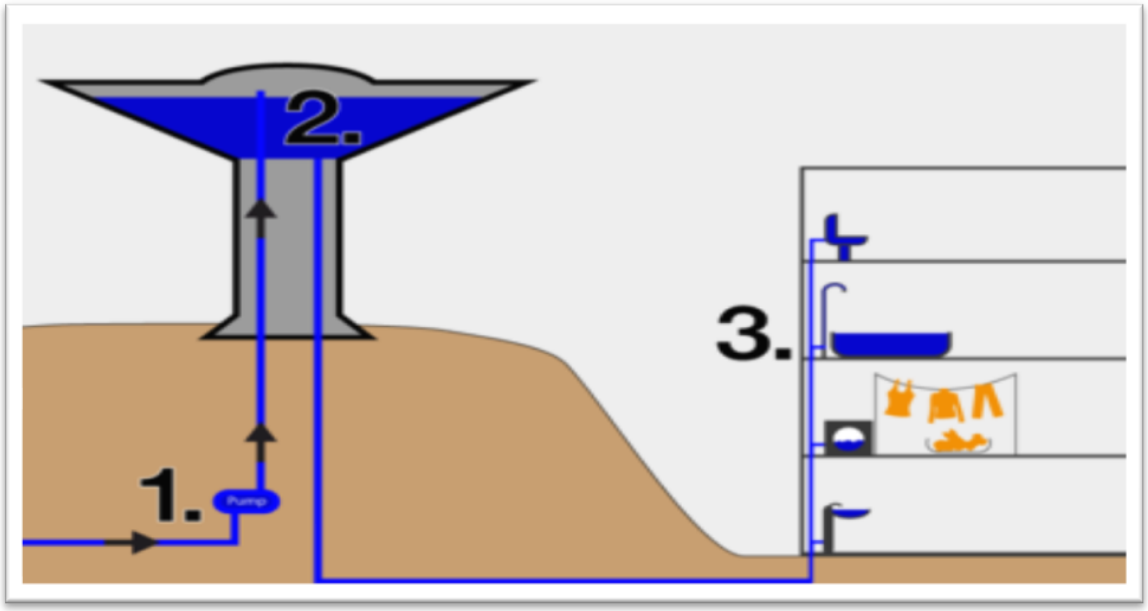
B. Using recorded data measured from the network in different time of the day and programming SCADA PLC using three or four pressure set points.., i.e. one set point for the period from 6am to 12:00pm 2nd from 12:00 pm to 6:00pm 3rd from 6:00 pm to midnight and 4th from midnight to 6:00am. But this method also found inaccurate and can't maintain constant pressure all times since demand is not only changing based on day time but also weekends is different from normal days, summer is different from winter and also holidays are different so we need to change the pressure set points accordingly and that found semi auto operation and our target is to reach to full auto system

C. Finally we decided to integrate system curve equation in the SCADA PLC which fit best describing the required pressure to maintain constant pressure at the network after adding the calculated network headless considering the instantaneous flow causing the losses. that is what we call it new water operation technique and will be elaborated further more in below clause.

New water operation Technique

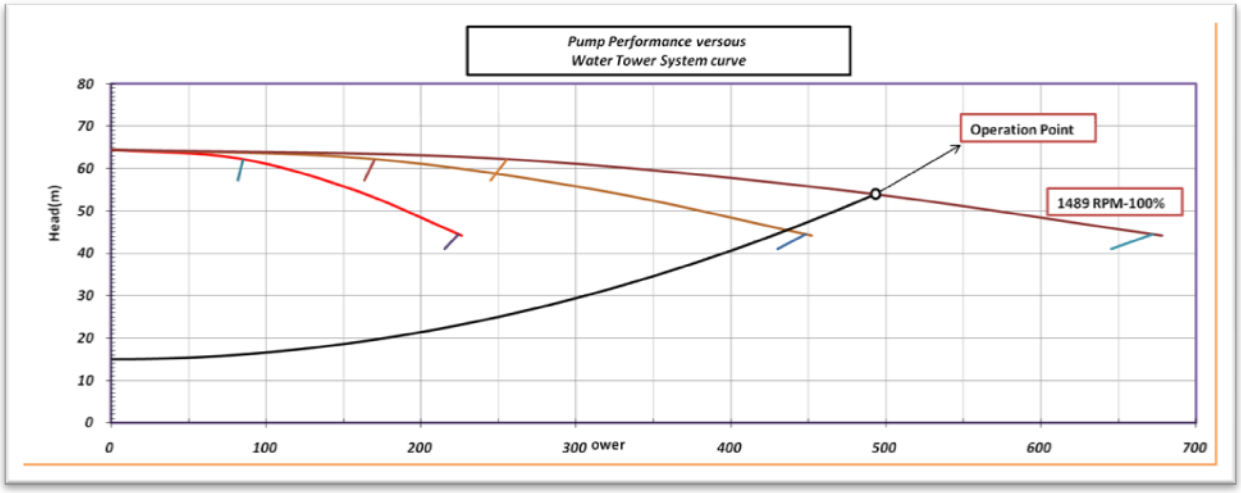
First We need to define what is system curve to explain why we need to use it to maintain constant pressure.

System curve is the total pressure that the pump must produce to move the fluid is determined by the piping system. This total pressure of the piping system is the sum of static head and the pressure loss due to friction. In a piping system, pressure loss due to friction increases with increasing water flow; thus, system curves have positive slopes on pump performance charts. The operating point of a pump is determined by the intersection of the pump and system curves.



1- System curve when pumping to water tower

When we were pumping to water towers we had only on receiving point which is the tower inlet thus we have only one system curve, and that time we were using fixed speed pumps thus we have only one pump performance curve both intersecting in the operating point which will not be changed as shown in below graph.

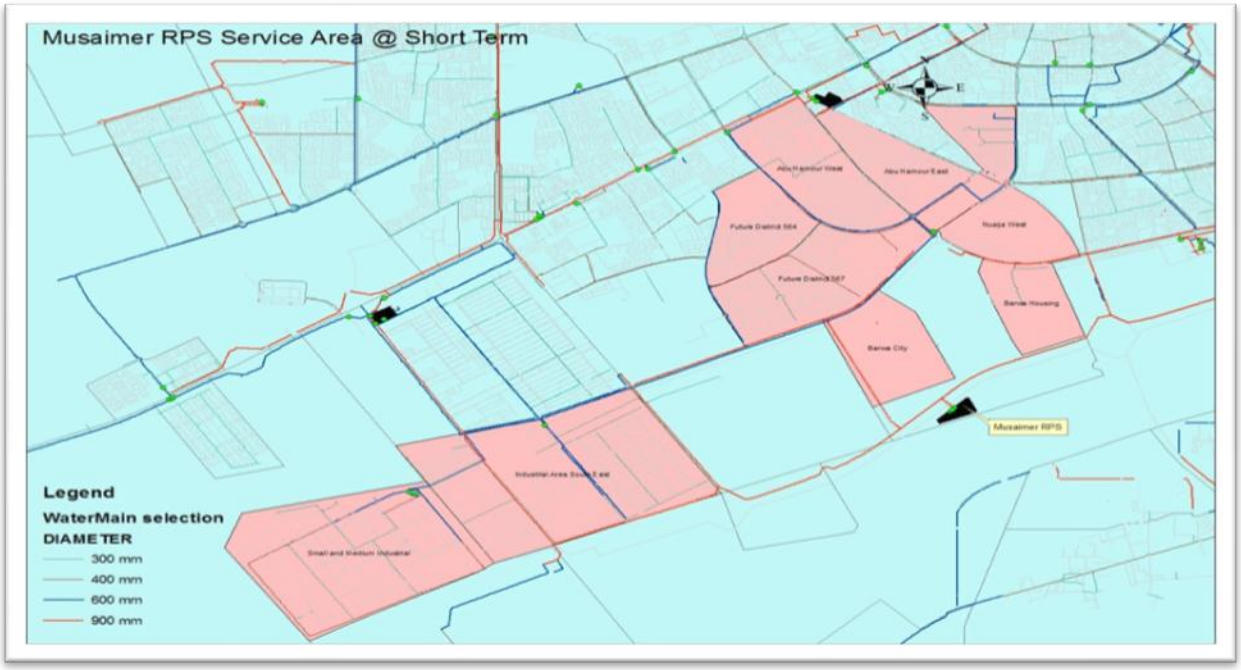


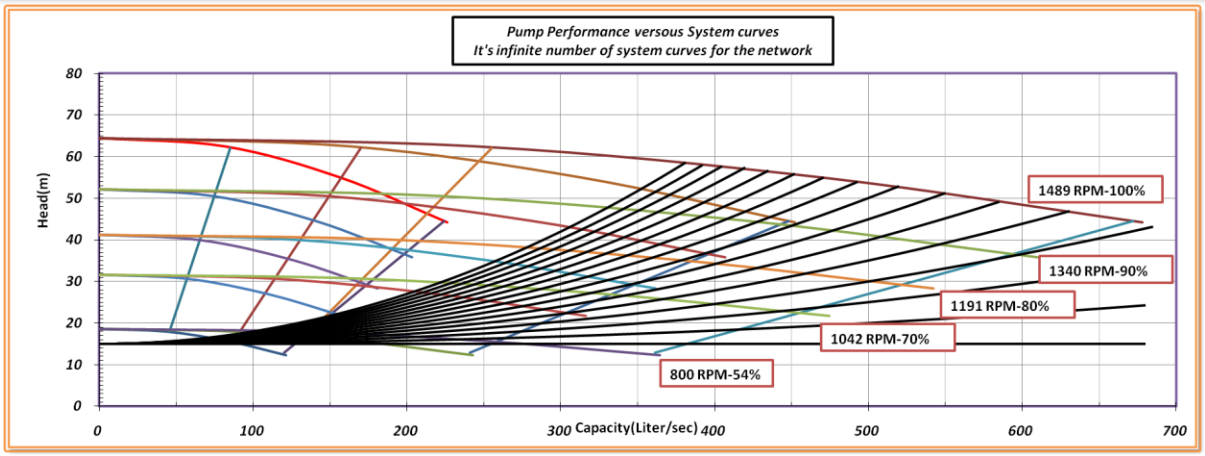
So operator won't worry about change in the flow but just open the valve ,start pumps to fill the tower and stop pump when it's full again will start pump when tower drained to network fill it back any change in the customer demand will be covered by the tower and will not affect the pumping system.

2- System curve when using variable speed pumps and pumping directly to network

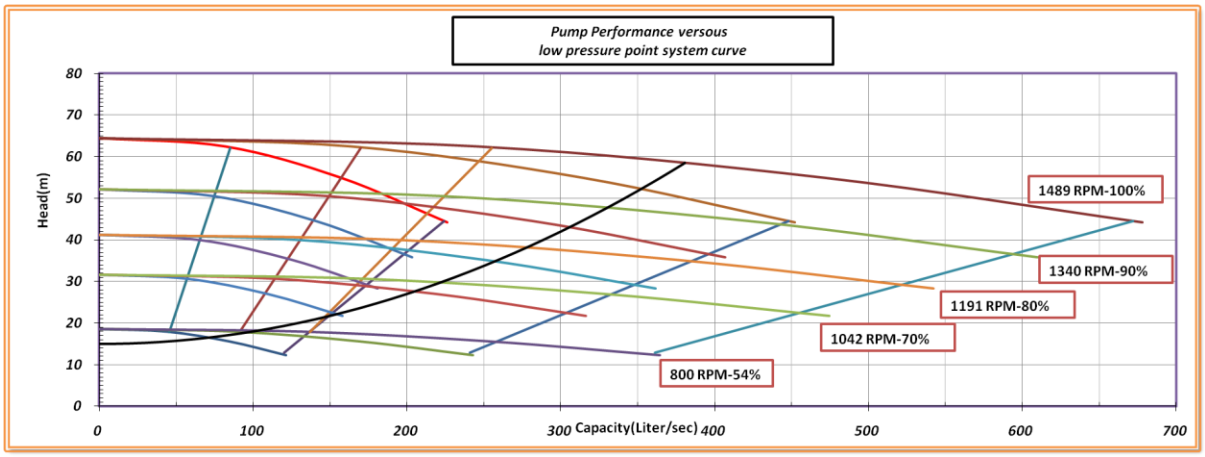
Since operation with water tower it is very difficult to maintain constant pressure in the network due the continuous increase in the demand also we have limitation on building huge number of towers to cover increase in demand in addition to measurable waste of energy when pumping to tower with high pressure while network might require very much less pressure, so we decided to use variable speed pumps as advanced method of operation.

But since we have changed our operation we faced challenge on maintaining the area pressure since we don't have the system curve of the network, considering that network is representing infinite number of water destinations " Customers" and variable speed pumps have infinite number of pump's performance curves .





With this number of system curves we have to decide which system curve represent our pumping best, so we decided to operate on the highest pressure system curve which is the network low pressure point system curve and the only operation curve can move the water to low pressure point with and maintain required static pressure .



Now we know what is the system curve to follow but we need to know how to produce the system curve equation to integrate in the SCADA for operation.

To determine the form of a system curve, consider the equation for total pressure in a piping system. The total pressure caused by a piping system is the sum of the pressure due to inlet and outlet conditions and the pressure required to overcome friction through the pipes and fittings.

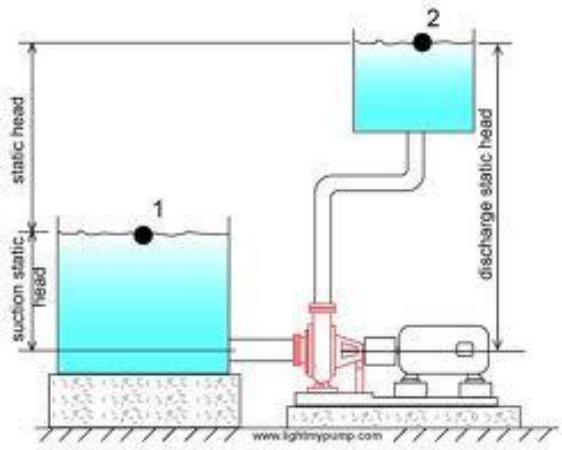
$$\Delta Ptotal = (\Delta Pstatic + \Delta Pvelocity)inlet - outlet + \Delta Pfriction$$

To explain the above equation terms

ΔPtotal :- Is the pump total head " that is the required output from the equation"

ΔPstatic:- Is the difference between required network pressure and suction pressure adding the elevation difference between the two points and that can be represent by a constant value " since our aim is to maintain constant area pressure"

$$\Delta Pstatic = Constant1$$



ΔPvelocity:- Is the difference in velocity head between pump outlet

And the network low pressure point ($\Delta\frac{V^2}{2g}$) and since we are pumping to existing network with fixed pipe sizes i.e. cross- sectional area is constant, that make the above parameter factor of Q^2 ($Flow^2$).

$$\Delta Pvelocity = Constant2 \times Q^2$$

ΔPfricition – is the summation of fittings and pipes head loss

$$Hlfittings = kf \times \frac{V^2}{2g}$$

$$Hlpipes = \frac{f \times L \times V^2}{2D}$$

In the above equations the parameters kf , D , L and f are constants for the same flow route from pump to low pressure point and as cross sectional area is constant we will describe

$$\Delta Pfriction = Constant3 \times Q^2$$

By substitution in main equation we find that

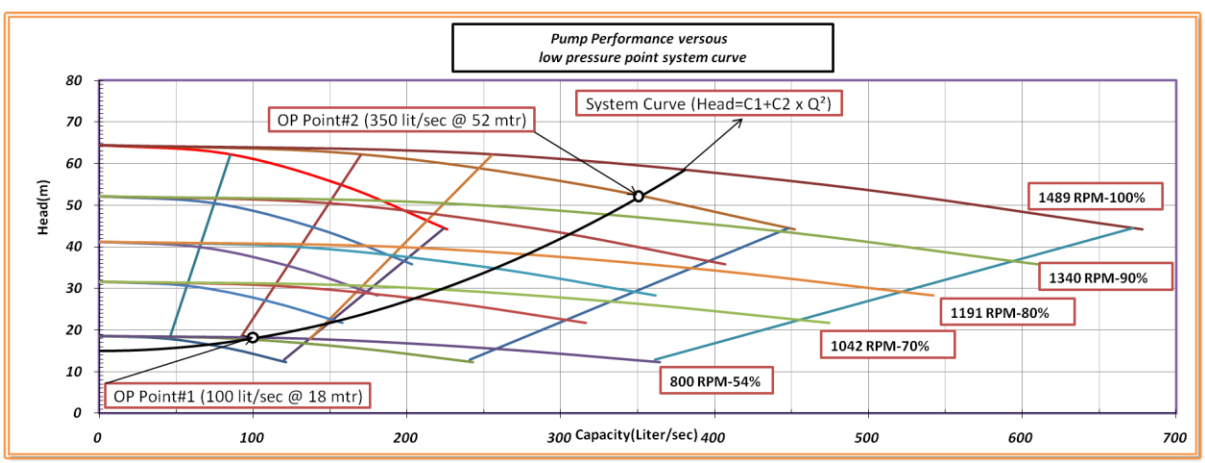
$$\Delta Ptotal = Costant1 + Constant2 \times Q^2 + Constant3 \times Q^2$$

i.e. $\Delta Ptotal = C1 + C2 \times Q^2$

As it's complicated to calculate the network losses for each pipe and fitting we have used the system feed back to calculate the constants C1 and C2

This quadratic relationship can be plotted on the pump curve to show the friction component of the "system curve".

As an Example:- please refer to below system curve, we will monitor the system for two operation points preferred to be during minimum and maximum demand



Let us assume that we want to maintain 15 mtr head at network lowest pressure point, so at low demand period we will increase the pressure manually to achieve the area pressure of 15
That time we will measure the pump flow and pressure " assume our readings was 100lit/sec ($\frac{0.1m^3}{sec}$) @18 mtr head" by substituting in the above formula
We get equation #1 as $18 = C1 + C2 \times 0.1^2$
Once again during the high demand period we will increase the pressure manually to achieve the same 15 mtr at network low pressure point "assume our readings was 350lit/sec ($\frac{0.35m^3}{sec}$) @ 52 mtr" by substituting in the above formula
We get equation#2 as $52 = C1 + C2 \times 0.35^2$
By solving equation #1 and equation #2 we find C1=14.98 and C2=302.2

Then our formula will be integrated in the PLC as

$$\Delta Ptotal = 14.98 + 302.2 \times Q^2$$

$\Delta Ptotal$ *in water mtr head and* Q *in* $\frac{m^3}{sec}$

After integrating the above equation in the PLS it will record the flow every minute and according to flow will calculate pump pressure, if the recorded flow was 200 lit/sec then according to PLC calculation the pump pressure set point will equal $\Delta Ptotal = 14.98 + 302.2 \times 0.2^2 = 27.07$
Accordingly PLC will change pumps speed to achieve the pressure set point, which equals to required area pressure and loss in the network.

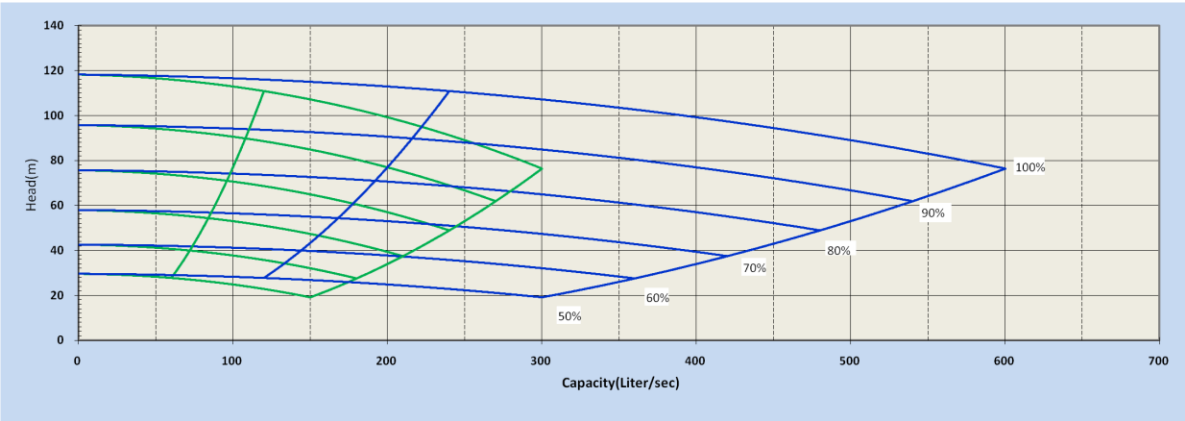
<u>How to tackle operation challenges-Continue</u>

Difficulty of keeping operation point within the pump performance curve with the same wide change in the flow considering the rapid development in the State of Qatar

Next we will show how we control the flow within the healthy operation range

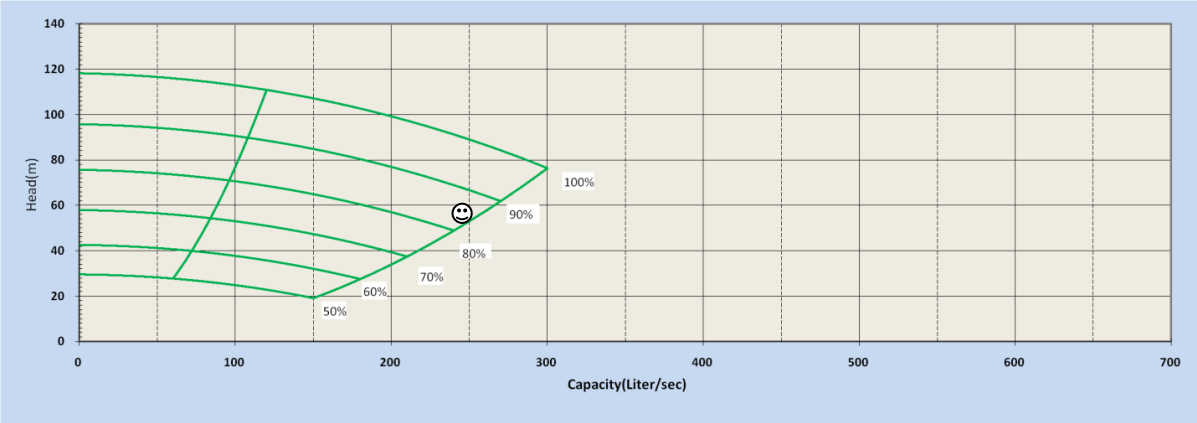
A. Flow should not exceeds pump maximum Flow

Actually we have copied the best practice for manual operation when the flow exceeds the maximum flow of one pump then operator would run the 2nd duty pump to avoid overloading the running pump also when the flow exceeds the two pumps operator will run the 3rd duty pump until reaches the maximum number duty pumps in service and in this case the operator will not be able to run any additional pump so he needs to throttle the rising main valve and that what we have exactly done in the auto operation as will be described below
The PLC is monitoring the flow all time through rising main flow meter and we have fed the PLC with equations calculating the maximum and minimum pump flows factor of RPM which describes the below green and below lines

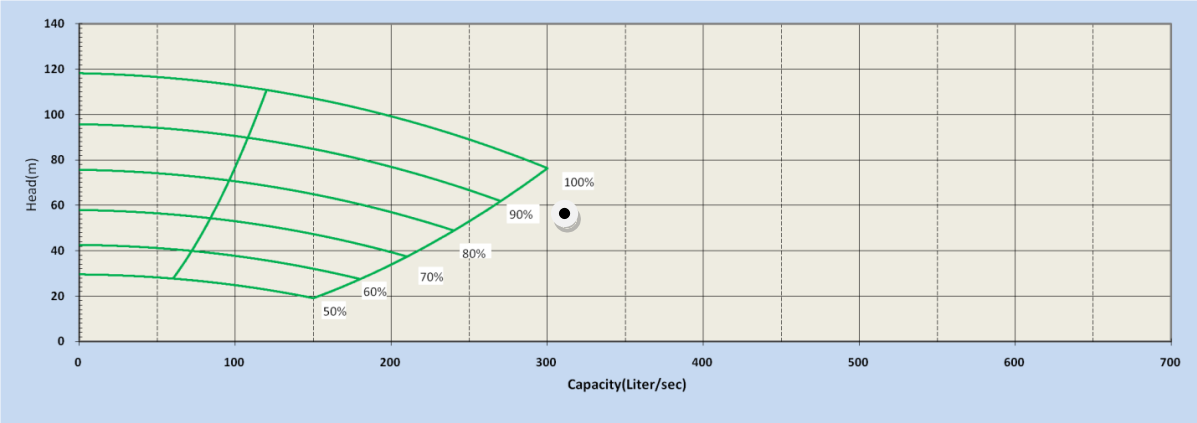


1- When the measured flow exceeds the calculated flow describing our limit for maximum flow of one pump the PLC will launch the 2nd duty point

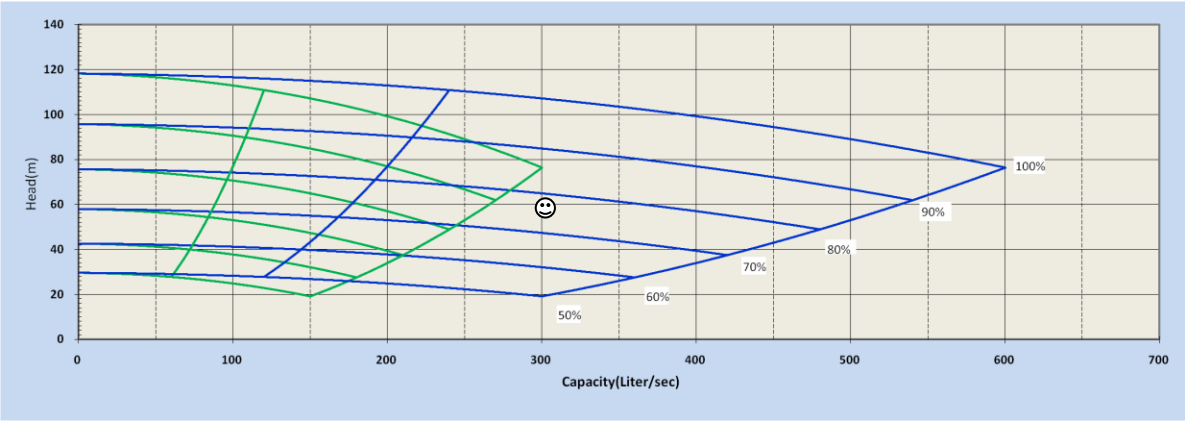
1.1 Graph no.1 one pump healthy operation



1.2 Graph No.2 one pump in over loaded condition PLC action is required,

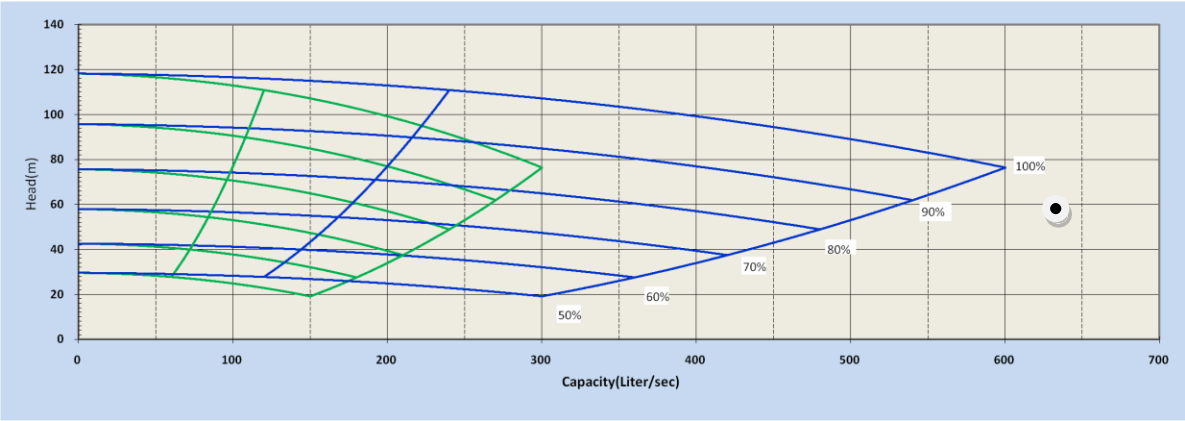


1.3 Graph No. 3 2nd duty pump started and now pumps running in healthy condition

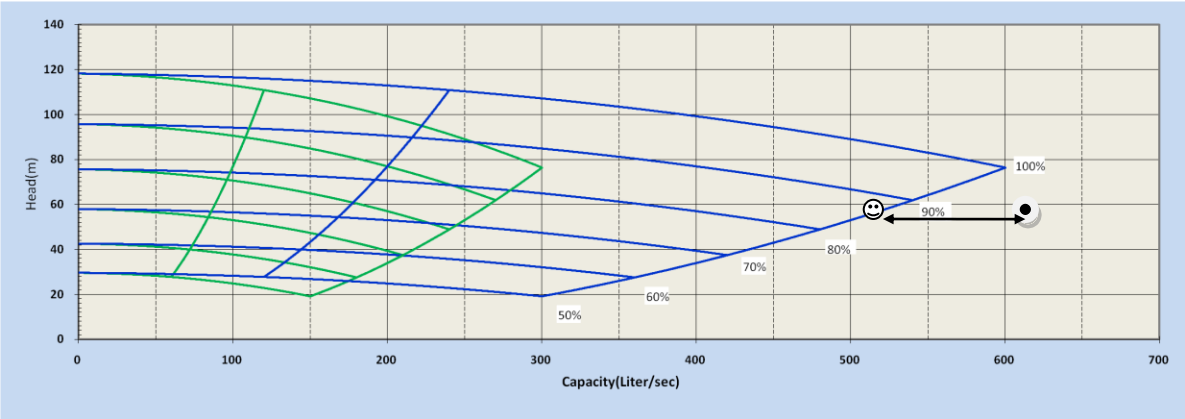


2- When the measured flow exceeds the calculated flow describing our limit for maximum flow of two pumps the PLC will throttle the rising main valve and freezes the pressure set point

2.1 Graph No. 4 shows two pumps running in over loaded condition



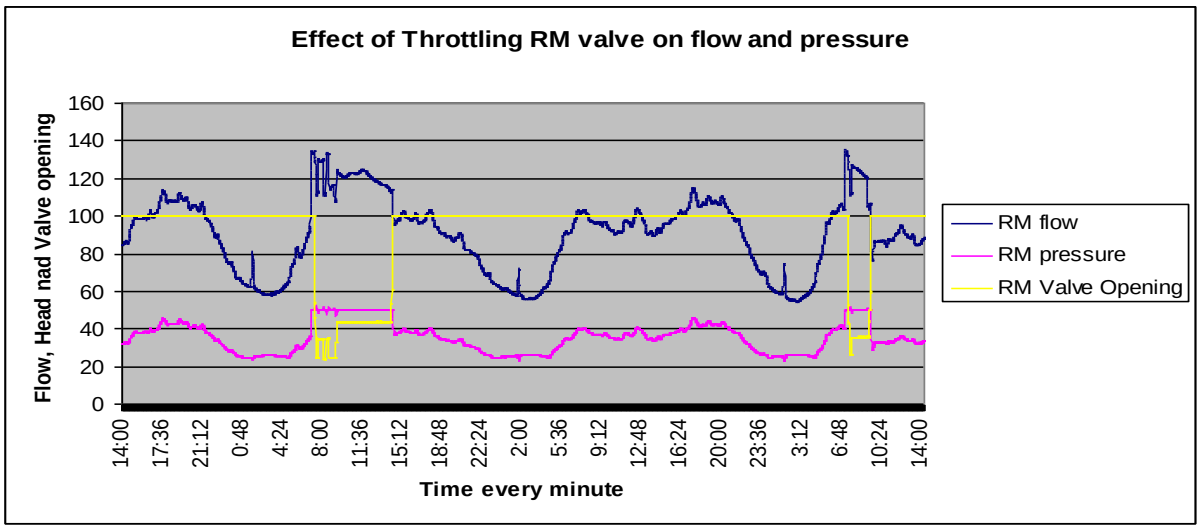
2.2 Graph No. 5 shows how duty point shifted from outside the performance curve to inside the healthy range of operation



As we have seen in Graph No.5 we have reduced the pumped flow by 100 lps to return pump operation within the pump healthy performance curve but still we manage to supply customers with 500 lps but the real advantage of throttling valve that we managed to protect pumps without need to stop the supply but stopping it.

That reduction in flow actually caused by freezing the valve up stream pressure by PLC and in same time when the valve closed that reduces the downstream pressure affecting the flow directly.

After the flow reduces below Qmax with certain amount we open the valve back in steps to make sure pump not over loaded until it's back to full open position.
The below graph shows the operation of throttling valve when the flow increases also when it's back to full open position



2.3 Graph No. 6 shows the effect of throttling RM valve on flow and pressure

B. Flow should not reduce below pump minimum flow

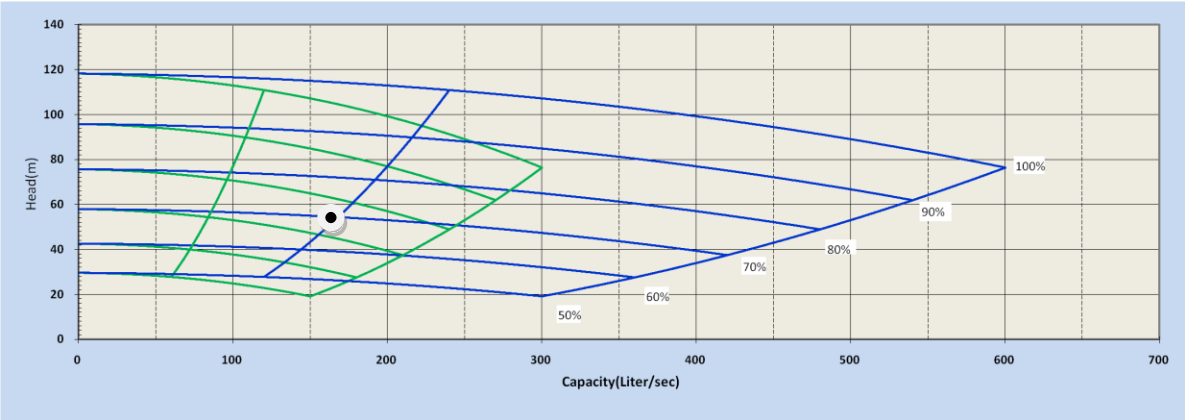
Again we have copied the best practice for manual operation when the flow reduces below the minimum flow of duty pumps ”m” then operator would stop one of the pumps to avoid chocking the running pumps also when the flow further reduces below minimum flow of running pumps ” m-1” operator will stop another duty pump until reaches one pump operation and in this case the operator will not be able to stop any other pump unless he cut the supply to customer.

So we decided to use the recalculation valve to reticulate part of the flow to continue supplying customer by the required flow and in the same time we maintain high flow above the minimum recommended flow of one pump.

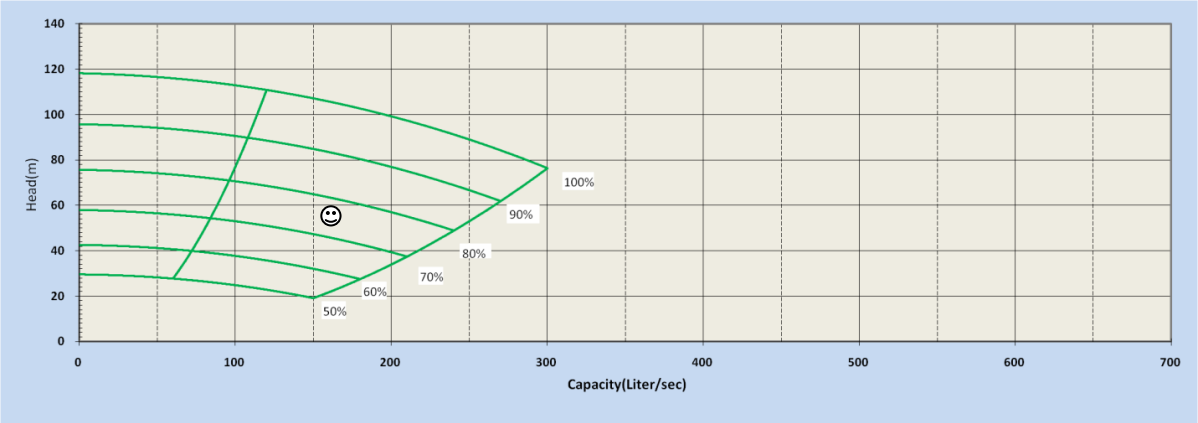
The PLC is monitoring the flow all time through rising main flow meter and we have fed the PLC with equations calculating the maximum and minimum pump flows factor of RPM which describes the below green and below lines

1- When the measured flow reduces below the calculated flow describing our limit for minimum flow of two pumps the PLC will stop the pump with more running hours

1.1 Graph no.7 showing two pumps running in unhealthy operation

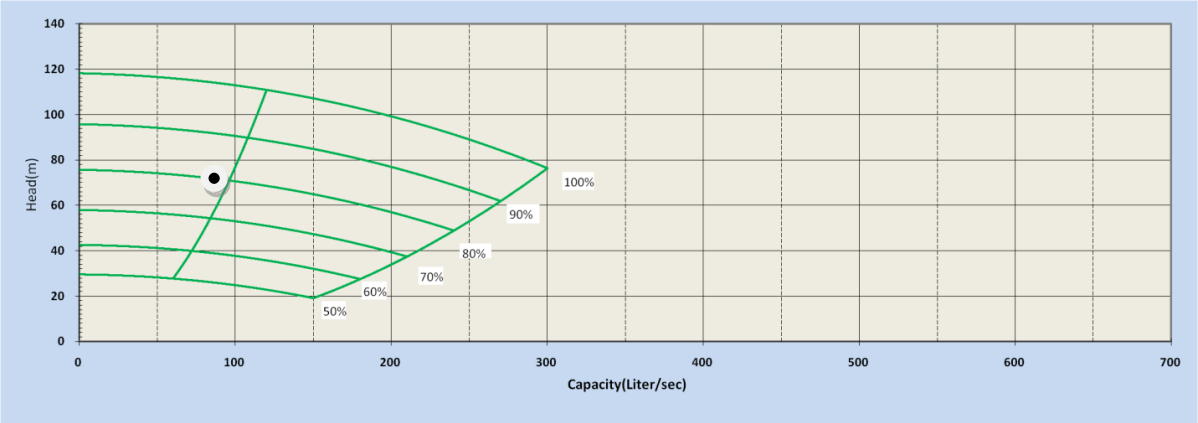


1.2 Graph no.8 showing one pump running in healthy condition after stopping 2nd duty pump

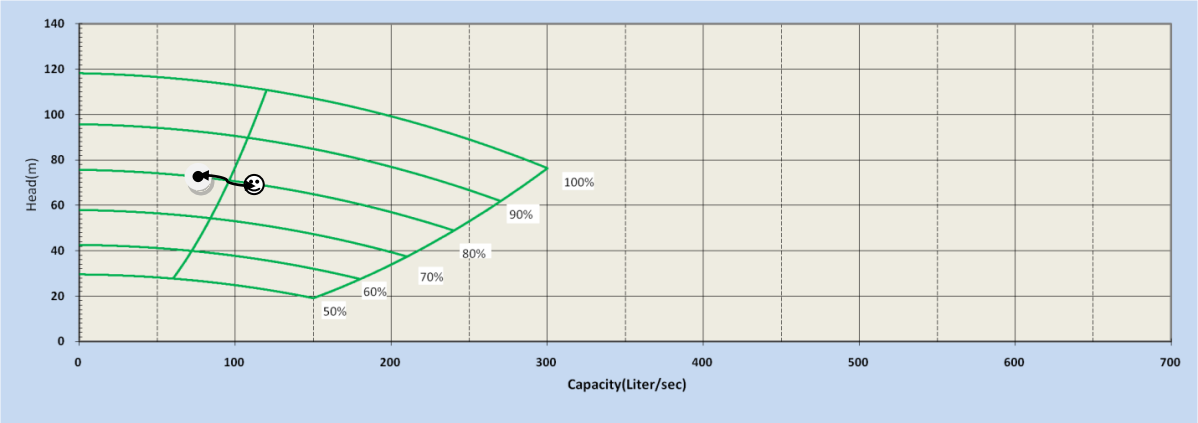


2- When the measured flow reduces further below the calculated flow describing our limit for minimum flow of one pumps the PLC will start open recirculation valve and freezes the RPM to bring the flow back to healthy range

2.1 Graph no.9 showing one pump running in unhealthy condition



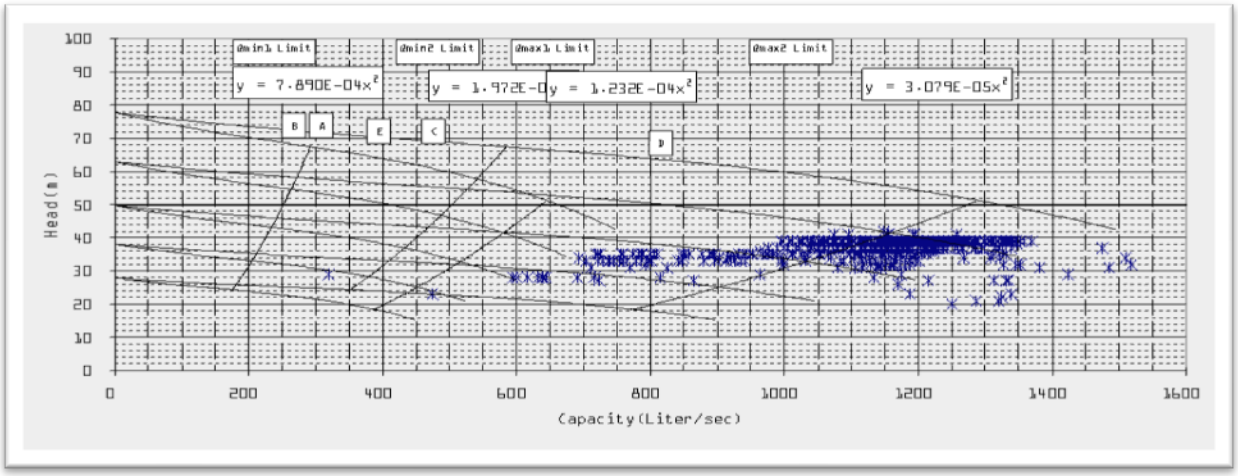
2.2 Graph no.10 showing one pump running in healthy condition after opening recirculation valve



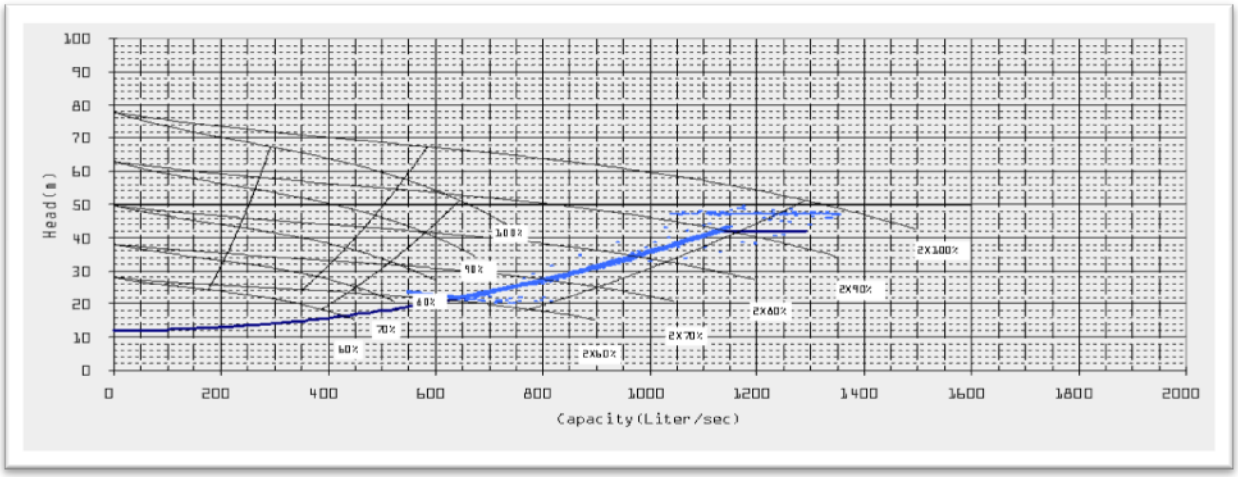
As we have explained in our presentation we have managed to maintain constant pressure in the network regardless of the required demand and also operated pumps within the healthy recommended ranges without stopping pumps.

Below graphs showing the improvement in operation

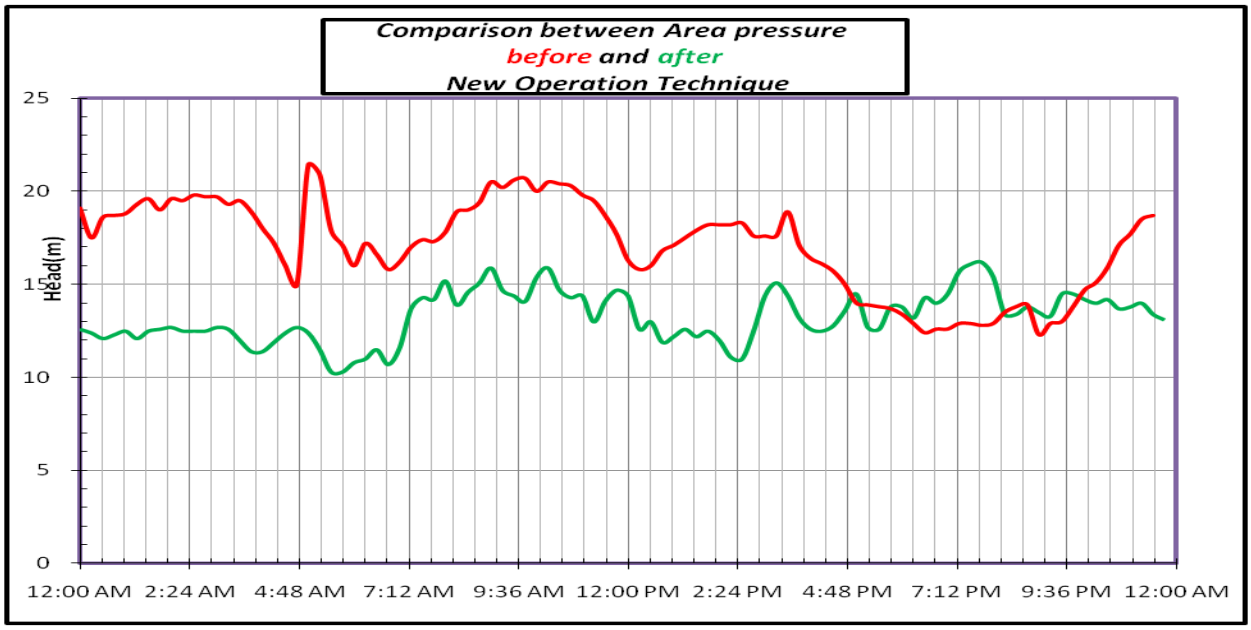
1-Operation Points before implementing New operation techniques



2-Operation Points after implementing New operation techniques



2-Area Pressure Before and After implementing New operation techniques



Restructuring the water tariff to achieve cost recovery: The case of Nablus City, Palestine

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Abstract

In 2009, Nablus municipality (NM) conducted a detailed study on the existing water tariff structure and the prices to find whether the tariff structure and prices cover operation and maintenance costs of the water supply production and distribution or not. The study proved that the existing tariff structure and prices did not cover the operation and maintenance costs of producing and distributing water supply. This is directly reflected on the performance of the water supply department and level of services provided to consumers.

According to the above results NM decided to restructuring the tariff and prices to ensure cost recover of operation and maintenance costs excluding the depreciation costs. The new tariff structure set an affordable price for the basic consumption need of low income households. The customers in this categories (0-10 m3 /month) pay only 85% of the real O&M costs.

The main outputs achieved from implementing the new tariff are:

1. The revenues cover the operation and maintenance costs so that the water department in NM remains financially solvent and able to purchase materials, chemical , pay the staff, etc. By this NM make sure that it can provide its services in proper, sustainable and effective manner and can expand its services to new areas.

2. The low-income households able to afford to pay for their basics needs. Social equity is promoted through a " progressive tariff", when the price/cubic meter of basic needs consumption is less than the price/cubic meter of higher consumption water

3. The new tariff structure set an high price for higher consumption levels to encourage water conservation. This goes with the strategy of NM to focus on public awareness campaigns towards water conservation as one tools in managing water resources.

However, the restructuring of the water tariff does not necessarily increase the fees collection ratio. In this regard, NM is conducting a public awareness campaigns and is coordinating this effort with the German technical assistance (GTZ). The main aims of the campaign are to raise public awareness and education towards water conservation and encourage the willingness of

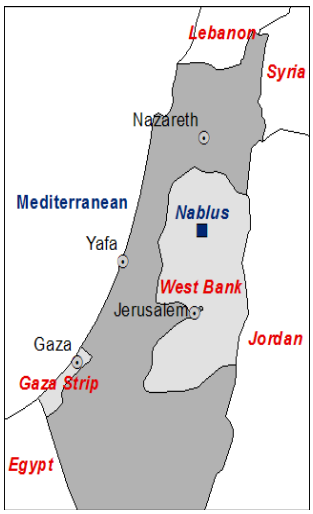
people to pay water bills. Many activities were conducted in the period 2006-2009, which targeted children at school and at summer clubs, teachers, women at home and at women's centers, religious leaders and the public in general. The most important outcomes of the awareness program are: 1) the collection ratio of water bills has increased, 2) many customers have shifted to the lower consumption categories in the tariff structure.

Keywords: cost recovery, tariff restructuring, low-income household, collection ratio, operation and maintenance costs, water conservation, economic price

1) Introduction

According to a study by the Palestinian Bureau Center of Statistics (PBCS) conducted in 2011, around 4 million inhabitants are living in the West Bank and Gaza Strip (see map 1, Map of Palestine). Rainwater is the main source of water and it fluctuates from one year to another. The average yearly amount of rain is 10 thousand million cubic meters, of which 60-70% evaporates, 25% is seepage to the ground, with the remaining amount going directly to the sea. The average annual rainfall ranges from 100 to 650 mm (Maan report, 2008). Ground water is the main water resource in Palestine. Since the occupation in 1967, many environmental and water problems are facing the Palestinian population such as: 1) they do not have access to their water, with Israel controlling over 85% of all available ground water resources in the West Bank. 2) limited resources; 3) inadequate environmental laws and regulations; 4) pollution; 5) high population growth rate (3.5% according to census 2007); 6) poverty ; 7) lack of public awareness.

The current deterioration of the environmental situation in Palestine is a result of deliberate destruction by the Israeli occupation, which includes the systematic destruction of water wells and other water and sewage infrastructure, and hindering the ability of the Palestinian authorities to provide adequate water to the population which has led to a decline in the per capita consumption rate of Palestinians to reach only 25-30 m3 per year compared to the rate of consumption per capita in Israel ranging from 90-100 m3 per year.



In addition to that, water issue is still a thorny issue in the final talks of the bilateral negotiations with the occupying forces. Currently, the Palestinians in the West bank receive drinking water, either from the Israeli water company through a public water network, through the West Bank Water Department's own wells, through water wells belonging to the municipalities, or through collecting the rainwater, and finally some of the communities are supplied by water tankers which is very costly (1 cubic meter cost about 20 US$).

Like other cities and towns in Palestine, the city of Nablus which is considered to be the biggest city in the West Bank, is facing major challenges in managing water sources. Water supply and sanitation services to Nablus city and its vicinity are provided through the Water Supply and Sanitation Department (WSSD) at Nablus Municipality. WSSD provides its services to about 200,000 inhabitants including Nablus city, four refugee camps and nearby villages. To cope with the tremendous increase in population and their increased need for potable water, an efficient management of the limited water resources, with short and long term actions must be undertaken to handle this problem. In addition to that, WSSD suffers from arbitrary fee collection. Consumers are not able to pay there bills. The efforts for encourage them to pay are not sufficient. The bad economic situation in general is the main reason for not paying the bills. According to statistics more than 50% are under the poverty line.

To overcome the above problem, In the short term,

- WSSD is conducting public awareness about water conservation in cooperation with German technical assistance (GTZ). Since 2006 WSSD and GTZ have been conducting a public awareness program . The main aims of this program are:
    1) To raise public awareness and education about water conservation
    2) To strengthen the relationship between the municipality and the communities and encourage the willingness of people to pay water bills.
- Elaboration of an appropriate tariff to secure cost recovery from tariff revenues through socially accepted tariff structures, taking into account local operating expenditures, consumption pattern and affordability aspects.

Restrucruring water Tarrif

Previous Tariff System

The previous water tariff System in Nablus was characterized by:
Three consumption blocks, a minimum charge including a maintenance fee
A progressive structure for domestic and industrial consumers

previous tarrif structure					
Consumer Categories	Tarrif Blocks				
	0 - 10 m^3	**10 1.- 15** m^3	**15.1.- 20** m^3	**20.1 -40** m^3	m^3 **<40**
Domestic	3.72	5.58	7.44	7.75	9.92
Food Industrial	5.27	6.2	6.2	6.2	6.2
Non food industrial	5.27	6.2	6.2	7.75	12.214

New Tariff Structure

Objectives:

Basic objectives focus on the following elements

- The actual operating expenditures should be covered by tariff revenues
- The level of water tariffs should allow low income households a reasonable standard of water consumption
- The structure of tariffs has to considered the potential of internal cross subsidization. Furthermore water consumption levels beyond basic needs should be charged with progressively increasing rates, thus promoting saving of scarce resources.

Components:

The proposed tariff structure considers the following basic data components:

- Updated number of connections and volumes of consumption
- A progressive structure of block consumption rate
- A first consumption block which allows affordable coverage of basic needs
- Different consumer categories
- Fixed minimum charge

The following ranges (blocks) of monthly consumption are proposed:

For Domestic Consumption :

Social block 0-10 m^3

Medium block 10.1-15 m^3

High block I 15.1-30 m^3

High block II > 30 m^3

The following consumer categories will be used:

- Domestic consumers
- Commercial consumers
- Food Industrial consumers
- Non Food Industrial consumers
- Bulk supply consumers

Table 2: 2009 Tariff structure NM

New tarrif structure

Consumer Categories	Tarrif Blocks						
	m^3 **5 - 0**	**10 - 5.1** m^3	**15- 10.1** m^3	**20 -15.1** m^3	**30 - 20.1** m^3	**40- 30.1** m^3	m^3 **40**
Domestic	3.98	3.98	6.70	8.70	8.70	11.50	11.50
Commercial	6.00	6.50	8.00	10.00	11.50	11.50	11.50
Food Industrial	6.00	6.00	6.00	8.00	8.00	8.00	8.00
Non food industrial	6.00	6.00	8.00	8.00	10.00	10.00	12.00
Bulk	3.00						

The proposed tariff structure and level consider

- A socially acceptable tariff level for low income households of NIS 3.98/m3 consuming not more than 10m3/mounth..This tariff level must be subsidies by users, consuming more than 20m3/month.
- An(approx) cost covering tariff of NIS 6.7m3 for medium consumption levels .

- A progressively increasing tariff up to NIS 11.5m3 (NIS 12m3 for industrial consumers) for users, consuming more than 30m3/month

Affordability

The average monthly family income is 2000 NIS and the average bill amount for domestic consumers about 89.66 NIS per month, so the percentage of bill amount from the income is 4.5%.

sewerage Tariffs

New tariff will be developed during 2012 for sanitation so as to cover all the expenses for the provision of sewerage service in terms of maintenance and operation for both the sewerage network and treatment plant. The new tariff will take into account the different categories of water consumption and the ability of citizens to pay. The risk of implementing this step that consumers are not accustomed to regular sewerage tariffs.

Financial Autonomy

Currently Nablus Municipality starts the first steps toward financial and administrative autonomy for WSSD. The water and sanitation accounts are separated from the other municipality services accounts This step will enable the Water and Sanitation Department (WSSD) to determine the actual costs of water service and sewage away from the other municipality costs. Therefore, WSSD can determine the tariff that is covering the actual costs incurred by the WSSD to provide water and sanitation services in high efficient manner.

Public awareness campaign

In the context of the activities of the water awareness program implemented by WSSD in cooperation with the German-Palestinian cooperation program through GTZ, WSSD has conducted several activities in the period

between 2006 - 2009 to achieve its aims of water conservation and encouraging citizens to pay water bills. The following illustrates some of these activities:

1- Summer Camps : The main objectives of these summer camps were: 1) to encourage children to conserve water at home and translate the messages to their families, 2) to form committees of children to spread the message to others (a child to child approach).

2- Conducting several workshops and meeting various target groups: 1) children at different summer camps and at school, 2) employees at various government and NGO institutes. 3) women at women centers, and 4) Imam and preachers (as raising awareness and changing attitudes to water through religion has proved very successful as there is great receptiveness for religions messages).

3- Printed materials
   a. Agenda 2007, 2009
   b. Calendar
   c. Note books
   d. Spots
   e. Posters
   f. Brochure
   g. Bags
   h. Billboards
   i. Other materials

4- Five television spots on raising the awareness of the public about water conservation and on enhancing and encouraging the willingness of people to pay their water bills and on prompting people to maintain and fix their own water and sanitary facilities.

5- Producing song video clips and broadcasting these on TV; within specified deadlines and at regular intervals. The songs are mainly about water and they convey a message to the public.

6- A documentary film about the importance of water, water resources in the city, the problem of water shortage and ways to conserve water consumption. The film is 15 minutes long and has been produced in both Arabic and English.

7- TV interviews: with the Deputy Mayor of Nablus Municipality and with the WSSD manager, which focused on the problem of water shortage and ways to conserve water consumption.

8- A Youth program to direct young people toward solving the problem of water shortage.

9- Conducting several fairs specializing in water and the environment.

10- Competitions among students.

11- Prizes and incentives for people committed to pay their water bills.

12- Building capacity for the staff working and following the awareness program through attending several training courses and visiting other local and regional institutes working in this field to exchange experience.

Outcomes of the awareness program and tariff restructuring

1) An increase in the collection ratio of water bills from 53.4% in 2006 to 79% in 2009. Figure 2 illustrates the collection ratio for the years 2001- 2009.

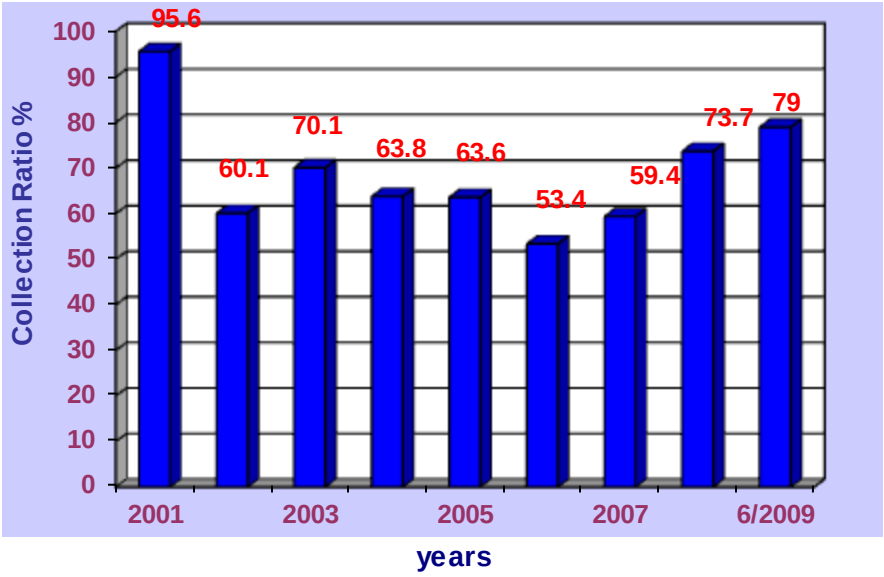


Figure 2 : Collection ratio 2001- 2009

2) Moving the customers to the lower consumption categories in the tariff structure comparing year 2007 with 2008 as shown in table 1.

Table 1: Customers distribution in Tariff structure

Categorizes	2007	2008
0-20 m^3	%87	%87.7
20-40 m^3	%11	%10.6
> 40 m^3	%2	%1.7

3) The result of the evaluation carried out by external consultants showed that public awareness towards water consumption has increased.

4) The WSSD has recently established a division for public awareness. Specialized employees were allied to this division. This division launches public awareness campaigns that target almost all the community groups and sectors.

5) Decision-makers are conscious of the importance of water conservation issues and provide support to the staff carrying out the campaign

Conclusion and recommendation

- Fulfilling the Palestinian water rights and controls there resources.
- Conservation water for current and future generations.
- The resources of energy must be available at suitable prices.
- More efforts for reducing the high UFW.
- Continuing the financial and administrative Autonomy.
- Raising awareness for consumers showing the importance of economical water consumption.

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Multivariate Statistics and Numerical Modeling for Optimizing Water Quality Monitoring Networks

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Abstract

Water-quality monitoring is labour intensive and costly. Therefore, there is a continuous need to optimize the monitoring activities to minimize the cost without substantial effects on the information obtained.

The overall objective of this paper is to introduce a rationalization technique for water quality monitoring networks using an integrated approach that comprises multivariate statistical analysis and numerical modelling. The technique is applied to Edko drain as a case study from Egypt to illustrate its utility in optimizing the number and locations of monitoring sites.

Multivariate Analysis of Variance followed by Multiple Comparisons and then Discriminant Analysis were performed on historical data for the selected parameters measured during the period from August 1999 till July 2010. These parameters are discharges, Biological Oxygen Demand, Cadmium, pH, Total Dissolved Salts and Sodium Adsorption Ratio. Then, the numerical model Qual2k was used to validate the output of the statistical analyses.

The results showed that a substantial consolidation of the monitoring network can be achieved without losing significant amount of information. Five monitoring locations out of thirteen can be closed. This ensures reduction in the total cost of the monitoring activities, a key prerequisite to a sustainable program.

Keywords: Multivariate Statistical Optimization, Water Quality Modeling, Agricultural Drainage, Water Pollution

1. Introduction

Although, Lake Edko (Figure 1) is an important fishing area in Egypt, it receives significant amounts of polluted drainage water. The lake main water sources are drainage water (Kom Belag and Bersik drains) and seawater from Abu Qir Bay. The seawater enters the lake intermittently through the lake-sea connection as subsurface water current under the wind action especially in winter (Abdel-Shafy et al. 2002).

The Kom Belag drain receives its water from three sub-drains; Bosily, Edko and El-khairy where they are connected about 3 km to the east of the lake. Consequently, the information related to water qualities and quantities of these drains plays a vital role in any environmental assessment of the Edko Lake. This information is also essential for deciding whether the drain water is suitable for reuse in agricultural purposes.

The routine work of the National Water Quality Monitoring Network (NWQMN) in Egypt covers these drains to detect their short/long term water quality changes. The monitoring program started in 1977 to monitor a few quantitative and qualitative water parameters (predominantly concerning salinity) in some of the main drains in the Nile Delta.

The main objectives of the current monitoring program are to assess compliance with standards, determine fate and transport of pollutants, make waste-load allocations, and detect possible trends in water quantity and quality with respect to time and space.

In each location, the total number of water quality parameters (WQPs) to be analyzed is 34 parameters, taking into account microbiological, oxygen related parameters, nutrients and extended cations, metals and trace elements as well as the classic parameters i.e. salinity and macro-ions, temperature and pH. The sampling frequency is 12 samples per year for all the monitoring locations. The information obtained from the program is regularly used for planning and managing the reuse of agricultural drainage water for irrigation in the Nile Delta. It also provides an effective overview of those spots where intensified monitoring activities are required (Shaban et al. 2010).

The program was described as "Good Monitoring Program" although the required cost is relatively high (World Bank 2005). Since 1995 the Drainage Research Institute (DRI), as an executing agency, had to expand its monitoring activities to include an ever-increasing number of sampling locations and WQPs as requested by the strategic water resources planning sector (Shaban 2007).

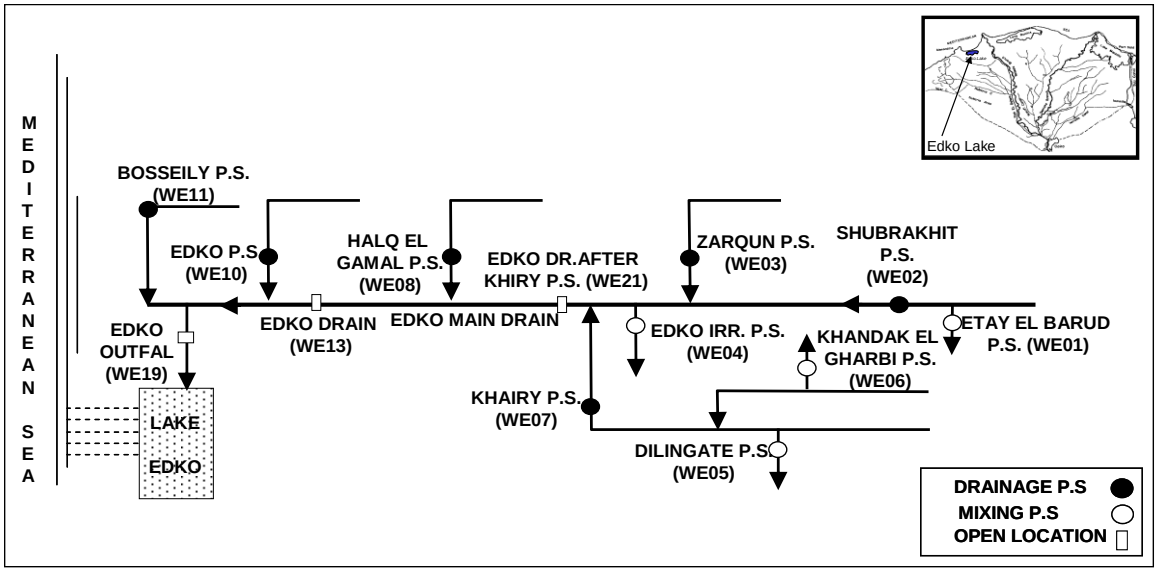

Figure 1: Water quality monitoring locations in Edko drain system

Research was carried out recently to assess the NWQMN in the Nile Delta. The results demonstrated that, in many parts of the system, the network monitors too many parameters at too many locations at too high a frequency (Bahaa Khalil et al. 2010; Bahaa Khalil et al. 2009; Shaban 2007; El-Saadi 2006 and Shaban 2001). In his economic evaluation of the current sampling frequency of the Edko drain-monitoring network, El-Saadi (2006) estimated the monthly cost of one monitoring location between 1000 and 3000 Egyptian Pounds.

The national investment plan for upgrading, operating and maintaining the NWQMN for the period from 2001 to 2012 indicated that the required cost is 292 Million Egyptian Pounds (World Bank 2005). This indicates that both money and experience are intensively required for sample collection, analysis, interpretation and dissemination of information to the various potential users within a short period. These two major perquisites were covered through financial support from the Egyptian Government in cooperation with donor agencies from the Netherlands and Canada. Based on this cooperation, DRI could run the monitoring program for decades. Nowadays, only the Egyptian side has to cover the total cost of the program. Therefore, there is an urgent need to consolidate the monitoring program without losing substantial information.

Therefore, the overall objective of this research is to introduce a rationalization technique for the NWQMN in Edko drain. More specifically, the objective is to determine the number and locations of the monitoring sites by using multivariate statistical methods in combination with numerical water quality modelling. This is mainly to avoid collection of redundant, unnecessary or even useless water quality data.

2. Methodology

2.1. Spatial Analysis

The Edko drain catchment area covers the north-eastern part of the western Nile Delta in Egypt (Figure 1). It is a highly populated area in which the quality of water in the drainage system is deteriorating due to legal and illegal dumping of domestic/industrial wastewaters.

The Edko drain length is around 49 Km starting from Shubra-Kheit and ending at the mouth of Maadia Bougaz (0 Km). It was designed to have a nearly trapezoidal cross section from km 49 to km 14. The bed width ranges from 10 m to 50 m and side slope is about 2:1. The design bed level ranges from (-1.0 m) to (- 5.0 m) above mean sea level.

The drainage system incorporates ten pump stations. Four of these are for official water reuse while the other six stations pump the drainage water into the main drain, then the water flows by gravity to Lake Edko.

The drainage water in the upstream part of the main drain is almost reused by the first three pump stations while the Edko irrigation pump station (WE04) discharges part of the drainage water mixture from Shubra-Kheit (WE02) and Zarqun (WE03) pump stations into Mahmodeya canal. The surplus of the drainage water of both pumping stations flows together with the drainage water of El-Khairy pump station (WE07) towards Lake Edko.

On a monthly basis, water samples are collected from upstream the pump stations (10 locations) as well as three other open locations in the main stream (Figure 1). These 13 locations were divided into four site groups based on the spatial characteristics of the drain system such as geographical position, surrounding environment and the direction of flow. Consequently, the statistical relationships that may be detected among them can be physically explained.

Within each site group, if two sites are found to be statistically similar and produce similar information then one of them can be excluded from the monitoring network.

However, this process limits detecting similarities within each site group and ignores the similarities that may exist between sites that lie in different groups. One cannot easily exclude any of the “statistically” similar sites that are significantly far from each other and/or have different environmental conditions. The selected site groups are as following:

- Site Group 1: includes WE01, WE02, WE03 and WE04.
- Site Group 2: includes WE05, WE06, WE07 and WE21.
- Site Group 3: includes WE21, WE08 and WE13.
- Site Group 4: includes WE13, WE10, WE11 and WE19.

2.2. Multivariate Statistical Analysis

Many publications have used multivariate statistics in assessing and redesigning water quality monitoring networks (Odom 2003; Dobbie et al. 2003; Sigua and Tweedale 2004; Zeng and Rasmussen 2005; El-Saadi 2006; and Shaban 2007). These techniques are capable of distinguishing complex relations among many variables (Spruill et al. 2002).

Multivariate Analysis of Variance (MANOVA) followed by Multiple Comparisons (MCs) and then Discriminant Analysis (DA) were used for the purpose of this study. Figure 2 shows a schematic diagram of the statistical steps carried out using some water quality measurements for Edko drain.

Since many statistical tests assume that data are normally distributed, the analysis started by checking the normality of the examined parameters. The Kolmogorov-Smirnov test statistics (Chakravarti et al. 1967) indicated that most of the examined parameters (monthly measurements) differ significantly from the normal distribution.

The problem of non-normality can be handled through different techniques such as data transformation or even using non-parametric statistical tests that do not require the data to be normal. In some cases, a process of data averaging helps to avoid the non-normality in the original measurements. This process was adopted here with the yearly averages of the WQPs measured at site groups 1, 2, 3 and 4 used to investigate the similarities between the locations in the Edko drain monitoring network.

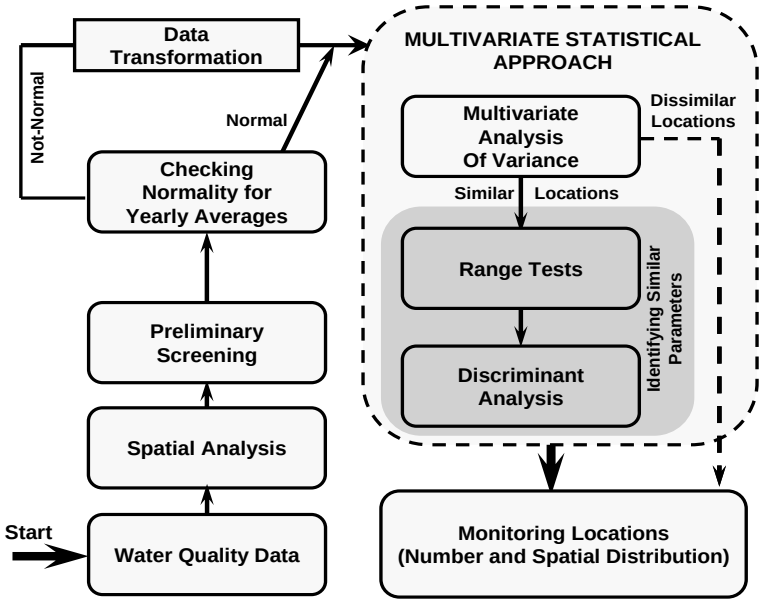

Figure 2: Statistical assessment carried out for the Edko drain WQPs

The analysis started with applying MANOVA followed by MCs and then DA covering the WQPs measured during the period from August 1999 till July 2010. The analysed parameters are

discharges (Q ($M.m^3$/month)), Biological Oxygen Demand (BOD (mg/l)), Cadmium (Cd (mg/l)), pH, Total Dissolved Salts (TDS (mg/l)) and Sodium Adsorption Ratio (SAR).

2.3. QUAL2K Numerical Modelling

For the type of partial differential equations in water quality pollutants transport and fate, the methods of finite differences, finite elements, or boundary elements can be utilized (see, e.g., Abbott 1979, Mohmoud & Yevjevich 1975, Brebbia et al., 1984, Drolc and Koncan 1996, Chaudhury et al., 1998, Ghosh and Mcbean 1998 and Walton and Webb 1994).

In this research, the focus will be on the water quality model QUAL2K that uses a finite-difference method for solving water quality pollutants transport. QUAL2K was developed by the U.S. Environmental Protection Agency (Brown and Barnwell 1987). It is a one dimensional model that assumes well-mixed state in the vertical and lateral directions.

For the purpose of this study, QUAL2K model was used to model the water quality status of Edko drain in two cases (Case A and B). In Case A, the coordinates and hydraulic data for the different drain reaches in addition to the available information concerning the mean WQPs that were collected on monthly basis for the current monitored locations during the period from August 1999 till July 2010 were introduced to the model.

Using the initial boundary conditions, the model was run and the results compared to the field measurements. System coefficients (rates) were appropriately adjusted until reasonable agreement between model results and field measurements were achieved.

Based on the multivariate statistical analysis, similar monitored locations were identified. Consequently, some of these locations can be eliminated. The water quality information related to the eliminated locations was replaced by information related to their statistically similar sites. These new input conditions were used for a second run for QUAL2K (Case B). Finally, the results of cases A and B were then compared to validate the information obtained from the multivariate statistical assessment of the Edko drain locations.

3. Results

3.1. Statistical Evaluation

3.1.1. Site Group 1

This section presents the detailed results of the analyses undertaken on the yearly averages of 6 WQPs (Q, BOD, Cd, pH, TDS and SAR) that were measured at the monitoring locations in Site-

Group 1. The yearly averages of all the examined parameters were found to be normal except TSS which was close to normal. The multivariate tests (Table 1) indicated that the monitoring locations have significant influences on the WQPs (Wilks' Lambda = 0.011 and Sig. = 0.000). The Levene's test of equality of variances (Table 2) indicated that the assumption of equal variances was met for all parameters except Q. However, the failure to meet this assumption is not fatal to MANOVA, which is relatively robust particularly when groups are of equal sample size.

Tests of Between-Subjects Effects (Table 3) indicate that there are significant differences (sig. < 0.05) between the monitoring locations in Site Group 1 due to the differences between Q, TDS and SAR levels measured at these locations.

The objective of the MCs is to identify similarities/dissimilarities between the monitoring locations based on the number of similar/dissimilar WQPs. The focus will be only on the pairs that have direct water flow within the Site-Group.

The MCs results (Table 4) obtained for the locations in Site-Group 1 can be summarized as follows: For the location pair WE02_WE04, the results indicated that all the examined parameters were similar. BOD, TSS, Cd, pH and SAR were similar for the location pair WE01_WE02 where only Q and TDS were dissimilar. Although, all examined parameters, except TDS, were similar for the location pairs WE03_WE04 and WE02_WE03, only the similarity between WE03 and WE04 was considered due to the flow direction condition.

Table 1: Multivariate tests applied for Site-Group 1

Effect		Value	F	Hypothesis df	Error df	Sig.
Sites	Pillai's Trace	1.6	2.07	21	36	0.027
	Wilks' Lambda	0.011	5.33	21	29	0.000
	Hotelling's Trace	39.3	16.22	21	26	0.000
	Roy's Largest Root	38.2	65.46	7	12	0.000

Table 2: Levene's Test of equality of error variances applied for Site-Group 1

	Q (m.m3/month)	BOD (mg/l)	TSS (mg/l)	Cd (mg/l)	pH	TDS (mg/l)	SAR
F	4.38	1.43	0.6	0.63	3.52	0.81	1.54
Sig.	0.02	0.272	0.622	0.609	0.039	0.509	0.243

Table 3: Tests of Between-Subjects Effects applied for Site-Group 1

Dependent Variable	Q ($m.m^3$/month)	BOD (mg/l)	TSS (mg/l)	Cd (mg/l)	pH	TDS (mg/l)	SAR
F	19.7	0.48	0.45	0.3	0.61	13.71	3.74
Sig.	0.00	0.703	0.723	0.826	0.62	0.00	0.033

Table 4: Multiple Comparison tests applied for Site-Group 1

Dependent Variable	(I) Locations	(J) Locations	Difference (I-J)	Std. Error	Sig.	
Q ($m.m^3$/month)	WE01	WE02	-5.710	0.800	0.000	*
		WE03	-4.590	0.800	0.000	*
		WE04	-4.320	0.800	0.000	*
	WE02	WE03	1.120	0.800	0.181	
		WE04	1.390	0.800	0.102	
	WE03	WE04	0.270	0.800	0.742	
TDS (mg/l)	WE01	WE02	-119.110	34.450	0.003	*
		WE03	-218.530	34.450	0.000	*
		WE04	-87.780	34.450	0.021	*
	WE02	WE03	-99.420	34.450	0.011	*
		WE04	31.330	34.450	0.377	
	WE03	WE04	130.750	34.450	0.002	*

* The mean difference is significant at the .05 level.

Table 5 shows the two initial statistics from the DA. The first statistics are the Eigen-values of the discriminant functions. They reflect the importance ratio of the dimensions, which classify cases of the dependent variable. This is because they reflect the percentages of variance explained in this variable, cumulating to 100% for all functions. The first function is the largest and most important, the second is next most important and so on.

The second statistics are the Wilks' lambda statistics that are used to test the significance of the discriminant function as a whole. A small significance value indicates that the locations differ. If the significance value is large, this indicates that they do not differ.

Table 5 shows Wilks' lambda, which has the values (0.011), degrees of freedom (21) and significance value (0.000) for the first function. The values are (0.427), (12) and (0.487) for the second function respectively. The important point to note from Table 5 is that only the first

function is significant. The other functions are not. Therefore, the differences between locations shown by the MANOVA can be explained in terms of one underlying dimension.

The Structure Matrix (Table 6) contains within-group correlations of each predictor variable (WQP) with the canonical function. For each variable, an asterisk marks its largest absolute correlation with one of the discriminant functions. These marked variables are then ordered by the size of the correlation. In general, the independent variables, which have high discriminant function correlations, contribute most to the dependent variable separation.

Table 6 indicates that the WQPs Q and TDS (represented by the first canonical function) are discriminating the monitoring locations in Site Group 1. The main concern here is only the first discriminating function because it is the only significant one. The first discriminant function has highest correlations with these two parameters (Q and TDS).

Table 5: DA output for Site group 1 in Edko drain (Eigenvalues)

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	38.187 [a]	97.14	97.14	0.987
2	0.880 [a]	2.24	99.37	0.684
3	0.246 [a]	0.63	100	0.445

Table 5 Cont.: DA output for Site group 1 in Edko drain (Wilks' Lambda)

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 3	0.011	61.016	21	0
2 through 3	0.427	11.493	12	0.487
3	0.802	2.974	5	0.704

In addition, the relationship between the variates and the grouped factors (locations) is visualized using a Combined Groups Plot (Figure 3). This graph plots the variate scores for each dependent variable grouped by the grouping factor and the average variate scores for each group (centroids). Noting the positions of the centroids in Figure 3, function 1 discriminates the monitoring location WE01 (with largest horizontal distances between centroids). In addition, functions 1 and 2 discriminate the monitoring locations WE03 and WE04 (with relatively large horizontal/vertical distances between centroids).

Table 6: Structure matrix within the DA analysis for Site-Group 1 in Edko drain

	Function				
	1	2		3	
TDS (mg/l)	0.233	-0.747	*	-0.048	
Q (m.m^3/month)	0.298	0.544	*	-0.425	
BOD (mg/l)	0.015	0.280	*	0.223	
pH	0.041	-0.240	*	0.011	
Cd (mg/l)	-0.015	0.231	*	0.041	
SAR	0.120	-0.339		0.465	*
TSS (mg/l)	0.012	0.235		0.347	*

* Largest absolute correlation between each variable and any discriminant function

3.2. Site-Group 2

The MANOVA results indicated that the monitoring locations have significant influences on the WQPs due to the differences between Q and TDS levels. This result was clarified by the MCs analysis, which indicated that only TDS was dissimilar in the location pair WE05_WE07 and only Q is dissimilar for the location pair WE06_WE07. All the examined parameters were similar for the location pair WE07_WE21.

The DA results showed that the differences between locations shown by the MANOVA could be explained in terms of one underlying dimension. Noting the centroid positions in the Combined Groups Plot (Figure 4), it is clear that the first function neither discriminates the monitoring locations WE07 and WE21 nor WE06 and WE07 (with small horizontal distances between centroids).

3.3. Site Group 3

The MANOVA results indicated that the monitoring locations have significant influences on the WQPs due to the differences between Q, TDS and SAR levels. These results were further clarified by the MCs analysis, which indicated that Q, TDS and SAR are dissimilar for the location pairs WE21_WE13. For the pair WE08_WE13, the parameters TSS, Cd, pH and SAR are similar while the other parameters (Q, BOD and TDS) show dissimilarity.

Although only the WQP, TDS, was dissimilar for the location pair WE08_WE21, the similarity between these two locations was ignored due to the direction of flow condition where no flow can reach WE08 from WE21 or vice versa. Noting the centroids positions in the combined groups plot (Figure 5), it is clear that the monitoring locations in this part of the drain

significantly differ. However, one can also recognize that the second canonical function does not discriminate the location pair WE08_WE21.

3.4. Site Group 4

The MANOVA results indicated that the monitoring locations have significant influences on the WQPs due to the differences between BOD and SAR levels. This result was further clarified by the MCs analysis, which indicated that the BOD levels for the monitoring location WE13 differs significantly from the levels measured at WE10, WE11 and WE19. The SAR levels for the location WE10 differ significantly from the levels measured at WE13 and WE19. By contrast, all the other parameters (Q, TSS, Cd, TDS and pH) measured at the monitoring locations in Site-Group 4 have insignificant differences. Although all the examined parameters were similar for the location pairs WE10_WE11 and WE11_WE19, only the pair WE11_WE19 is considered due to the direction of flow condition where no flow can reach WE11 from WE10 or vice versa.

Figure 6 shows that the monitoring locations WE11 and WE19 are similar with smallest horizontal and vertical distances. Although SAR (represented by the second canonical function) seems to discriminate the monitoring locations WE10 and WE19, they can be considered as similar in all parameters due to the fact that the second canonical function is insignificant.

3.5. Summary of Statistical Results

Table 7 summarizes the results of the statistical approach indicating that the discharge and salinity (TDS and SAR) measurements are the main causes for dissimilarity between the monitored parameters in the Edko drain system. Since the locations in Site group 3 were found to be dissimilar, the group was omitted from the table (Table 7).

A simple regression analysis was carried out to describe the SAR levels for the Location Pair WE10_WE19. Figure 7 showed that a strong correlation was found between the SAR levels at WE10 and WE19.

3.6. Validation of Results

QUAL2K model was used to simulate the water quality status of Edko drain in two cases (Case A and B). In Case A (Current Network), the data collected from the current locations were employed while in Case B (Optimized Network), it was assumed that the monitoring locations WE02, WE03, WE07, WE10 and WE11 will be terminated.

Consequently, the data collected from these locations were replaced using data collected from statistically similar locations as presented in (Table 8).

Figure 8 presents a comparison between the QUAL2K simulation results obtained for the WQPs TDS, BOD, pH and TSS estimated for both cases A and B. The simulated parameters were clearly similar indicating that the information collected from the locations WE02, WE03, WE07, WE10 and WE11 are redundant and can be obtained from statistically similar locations (Table 7).

4. Conclusions and Recommendations

One can summarize the activities carried out within the NWQMN in Edko drain to water quality and quantity measurements. These measurements are essential for analyzing the pollutants loads and understanding their movements, nature and trends in the water system. Most of the scientific research in the field of water quality employs these measurements to facilitate proper environmental management. For all the pumping stations within the NWQMN, the Mechanical and Electrical Department under the Ministry of Water Resources and Irrigation (MWRI) collects the basic quantity data namely: water levels at suction and delivery sides, number of operating hours and the electrical power consumption. Then the water quantities can be calculated and delivered to the DRI as an executing institution for the monitoring program.

In DRI, these data are frequently employed to update the discharge-head relations (rating curves) obtained using long series of measurements started in 1994. In general, the cost of generating the quantity data is much lower than the production cost of the water quality data. Therefore, it is recommended that the water quantity measurements (Q) are continued without changes. In fact measuring the TDS levels in the field using simple EC-meters as well as the discharge measurements (Q) at the specified locations in Edko drain may lead to a substantial consolidation for the NWQMN. This reduction may be obtained by excluding the monitoring locations WE02, WE03 (Site-Group 1), WE07 (Site-Group 2), WE10 and WE11 (Site-Group 4). Table 7 shows the similarity results for these locations within each Site-Group.

One can easily recognize that Q and TDS are the reason for the dissimilarity in almost all location pairs presented in the table. Only the SAR was found as dissimilar parameter for the Location Pair WE10_WE19. However, a simple regression analysis was carried out to describe the SAR levels for this pair. The strong correlation found between the SAR levels at WE10 and WE19 supports excluding the monitoring location WE10. The recommended monitoring scheme may ensure significant reduction in the total cost of the monitoring activities. This facilitates a fiscal resource, which is a key prerequisite in developing a successful program. The rescued budget can be redirected to achieve better performance in terms of improving the current monitoring resources. The approach used in this research can be adapted to other parts of the NWQMN. It is based on multivariate parametric statistical tests, which may indicate powerful results and facilitate detailed information about the participated WQPs in relation with the monitoring locations. Firstly, it indicates the significant or insignificant differences between the locations based on these parameters. Then, it identifies which parameters are the reasons of the similarity or dissimilarity. Finally, QUAL2K model can be effectively used to validate the network statistical assessment.

Table 7: Similarity results for some locations within each Site-Group

Location Pair	Water Quality Parameters						
	Q	BOD	TSS	Cd	pH	TDS	SAR
Site-Group 1							
WE02_WE01	1	-	-	-	-	1	-
WE02_WE03	-	-	-	-	-	1	-
WE02_WE04	-	-	-	-	-	-	-
WE03_WE01	1	-	-	-	-	1	-
WE03_WE02	-	-	-	-	-	1	-
WE03_WE04	-	-	-	-	-	1	-
Site-Group 2							
WE07_WE05	-	-	-	-	-	1	-
WE07_WE06	1	-	-	-	-	-	-
WE07_WE21	-	-	-	-	-	-	-
Site-Group 4							
WE10_WE19	-	-	-	-	-	-	1
WE11_WE19	-	-	-	-	-	-	-

(1) indicates that the measurements of this parameter are dissimilar for the related location pair.
(-) indicates that the measurements of this parameter are similar for the related location pair.

Table 8: Locations proposed for termination

Proposed for Termination	Information Replaced from	Remarks
WE02	WE04	All quality parameters were replaced.
WE03	WE04	All quality parameters were replaced except TDS that was obtained from regression analysis.
WE07	WE21	All quality parameters were replaced.
WE10	WE19	All quality parameters were replaced except SAR that was obtained from regression analysis.
WE11	WE19	All quality parameters were replaced.

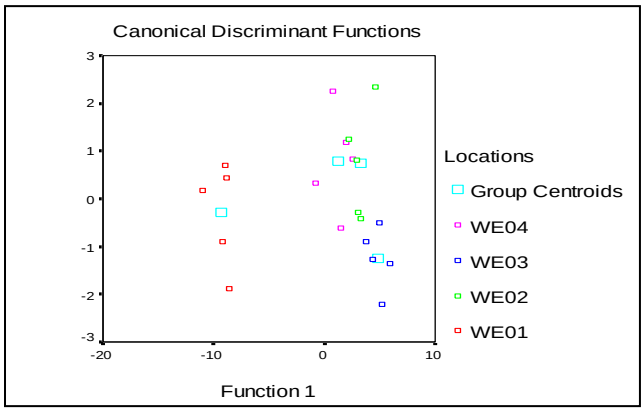

Figure 3: Combined groups plot for Site-Group 1

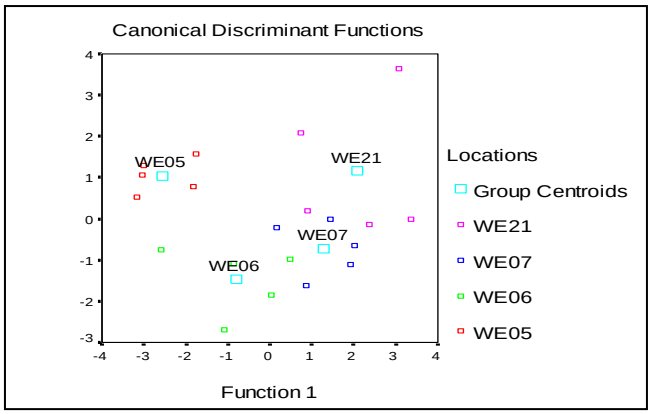

Figure 4: Combined groups plot for Site-Group 2

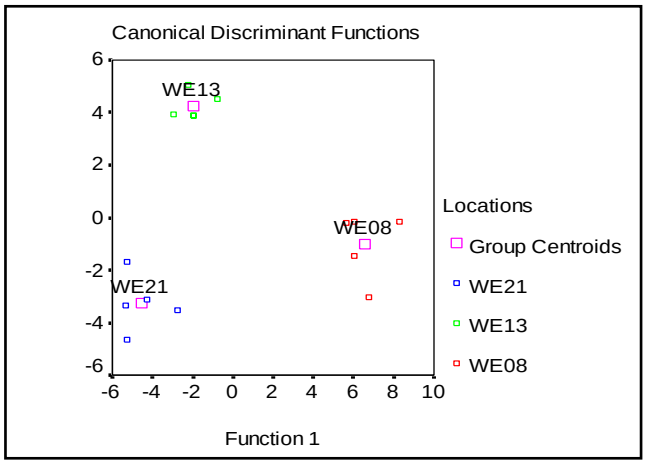

Figure 5: Combined groups plot for Site-Group 3

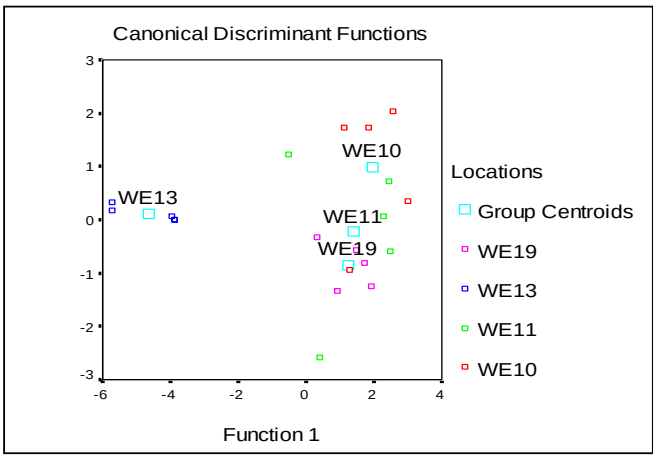

Figure 6: Combined groups plot for Site-Group 4

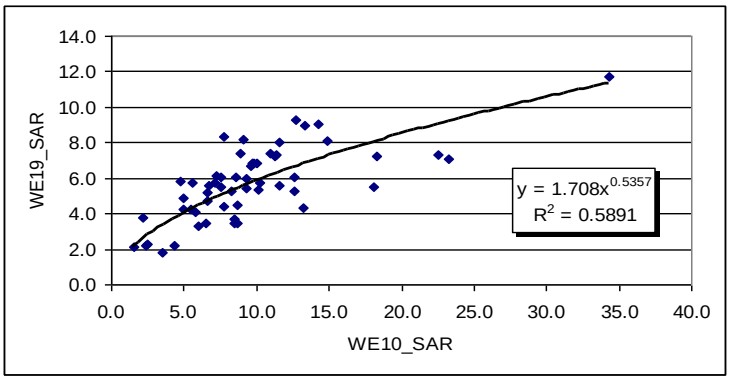

Figure 7: Regression analysis for the SAR levels for Location Pair WE10_WE19

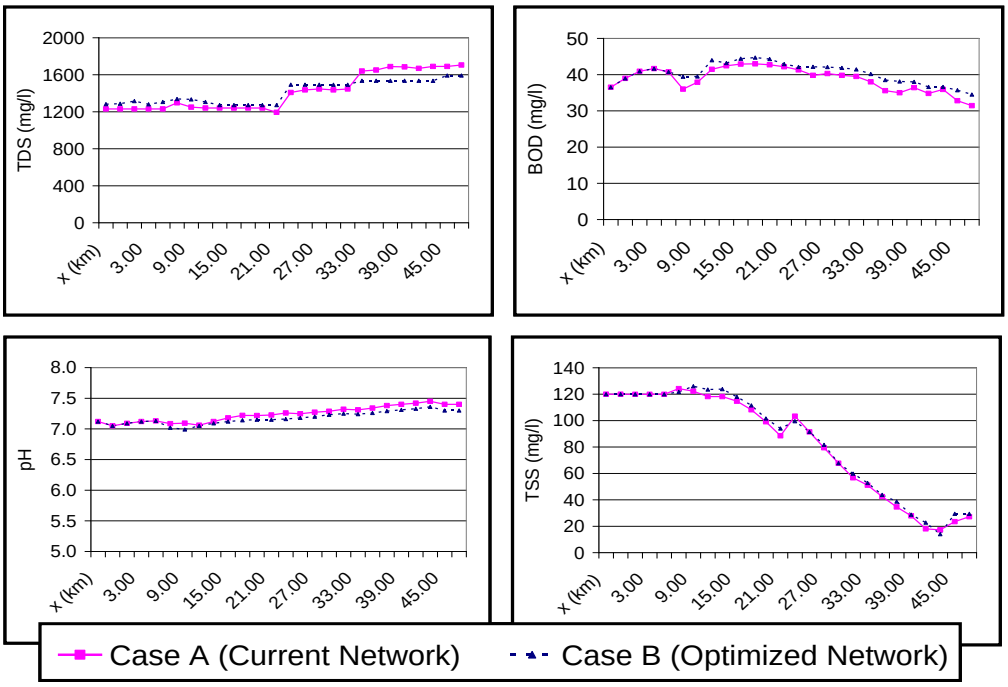

Figure 8: QUAL2K simulation results obtained for WQPs estimated for cases A and B

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الميـــاه المعبـــأة في دولـــــة الكويـــــت

م/ خليفه محمد الفريج

دولة الكويت-وزارة الكهرباء والماء

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ملخص :

تعنى الإدارة المتكاملة لمصادر المياه بجميع أنواع المياه المنتجة والمتوفرة ، كما تعنى بالتكلفة التي تقوم الدولة بتوفيرها على مستوى الفرد بالنسبة لخدمة المياه ومن ضمن هذه الانواع صناعة المياه المعبأة التى ظهرت بشكل متزايد على المستوى العالمى وتقدر قيمة مبيعاتها بحوالي (100) بليون دولار سنويا بزيادة سنوية قدرها 7 % . وبالرغم من ارتفاع قيمة المياه المعباة باكثر من 300 ضعف عن قيمة المياه المنتجة من محطات التحلية بالرغم من تقارب البعض منها من مستوى نوعيتها الا ان استيراد المياه المعبأة مستمرا حيث وصل فى دولة الكويت الى (47) مليون دولار سنويا .

تقوم الدراسة على دراسة الظاهرة وتكلفتها والتوصيات اللازمة لها كما شملت الدراسة ايضا على مقارنة لاكثر من(25) نوع من المياه المعبأة فى الاسواق الكويتية كما قامت الدراسة أيضا بإعداد وتوزيع وتحليل استبيان عن استهلاك المياه المعبأة ومياه الشبكة العامة على مستوى دولة الكويت ، حيث اشتمل على أربع محاور رئيسية ، المحور الأول : بيانات عامة عن المستهلك ويشمل على بيانات العامة للمستهلك من العمروالجنس ونوع العمل ومستوى الدخل ونوع السكن . المحور الثاني : التعرف على وجهة نظر المواطنين في المياه التي تصل إلى المنازل من حيث مدى الاعتماد عليها ومدى معرفتهم عن مصدرها . المحور الثالث : التعرف على وجهة نظر المواطنين للمياه المعبأة واستخداماتها في دولة الكويت . المحور الرابع : الأسباب والدوافع لاستخدام المياه المعبأة ، وقد شمل الاستبيان على نتائج منها ان 40 % من الشريحة يعتمدون فى مياه الشرب على المياه المعبأة فى دولة الكويت .

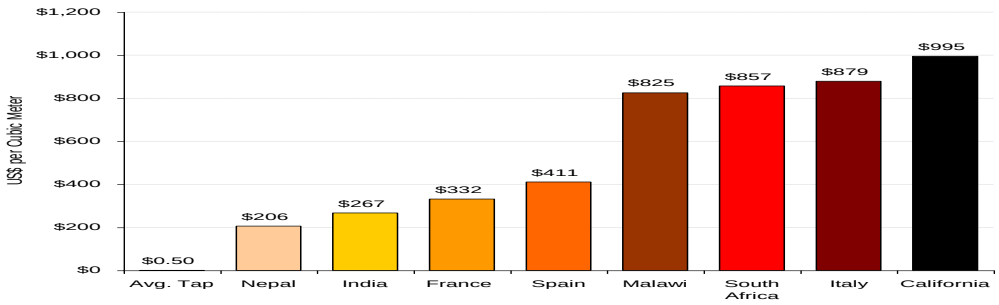
مقدمـــــة

تعتمد دول العالم على مواردها الطبيعية أو الصناعية في مياه تزويد الشرب ، إلا انه ظهر ت صناعات متعلقة بتوفير كميات من المياه تستخدم للشرب وتصنع بأحجام مختلفة للمستهلك ويمكن استيرادها محليا أو عالميا وهى المياه المعبأة . وقد تزايد استهلاك المياه المعبأة في العالم إلى الضعف خلال الأعوام 1996 إلى 2002 وتقد ر قيمة مبيعاتها بحوالي (100) بليون دولار سنويا ، كما أنها تعتبر من الصناعات المتزايدة على مستوى العالم بنسبة نمو سنوي يصل إلى 10 % ، وتصل في بعض الدول الأخرى مثل مصر والولايات المتحدة والكويت إلى 15 %(Gleick، 2004) ، وان كثير من الدول مثل الولايات المتحدة الأمريكية والمكسيك والصين والبرازيل وايطاليا واندونيسيا وألمانيا قد زادت نسبة استهلاك المياه المعبأة ، حيث وصل استهلاك المياه المعبأة عام 2004 إلى 41 بليون جالون وارتفع حتى وصل عام 2009 إلى 53 بليون جالون جدول رقم (1) .

أصبحت قضية مياه الشرب من أهم القضايا المعاصرة والتي تحظى باهتمام متزايد على المستويين الإقليمي والدولي ولا سيما مع إدراك العلاقة الوطيدة بين تلوث المياه والإصابة بالعديد من الأمراض . إن شح الموارد المائية النقية بالإضافة إلى ضعف خدمات توصيل المياه للمواطنين من خلال شبكات توزيع المياه وازدياد درجة تلوث معظم مصادر المياه سواء المياه الجوفية أو المياه السطحية العذبة منها والمالحة وسهولة حمل ونقل المياه المعبأة وسلاسة وصولها إلى موقع ورخص سعرها بالنسبة لأهميتها ، يضاف إلى ذلك تقدم تقنية صناعة المياه المعبأة وسهولة التعامل معها ، ففي الولايات المتحدة الأمريكية نجد أن تكلفة المياه المعبأة تجاوزت 6 بليون دولار عام 2001 بمعدل 5185.3 مليون جالون ووصلت عام 2009 إلى 10.6 بليون دولار بمعدل 8454 مليون جالون جدول رقم (2) ويقدّر حجم الإنفاق العالمي على المياه المعبأة بـحوالي 60 مليار دولار سنوياً، ويصل إجمالي الإنفاق على هذه الصناعة في أستراليا إلى 400 مليون دولار في السنة (على الموعي- صحيفة "نيويورك تايمز الأمريكية "تاريخ 18-07-2009) ، وعلى مستوى دول مجلس التعاون الخليجي تحتل دولة الإمارات العربية المتحدة المرتبة الثالثة من حيث أعلى مستوى لنصيب الفرد من المياه المعبأة وحيث ارتفع نصيب الفرد لديها من 28 جالون عام 2004 إلى 40 جالون عام 2009 . كما احتلت المملكة العربية السعودية المرحلة الثالثة عشر ليصل نصيب الفرد من المياه المعبأة إلى 26.4 جالون عام 2009 . وتأتى قطر في المرحلة السادسة عشر ليصل نصيب الفرد من المياه المعبأة إلى 25.5جالون عام 2009 جدول رقم (3) .

إن تكلفة المياه المعبأة في دول العالم مرتفعة جدا مقارنة مع المياه المنتجة من الشبكة سواء كانت المياه المنتجة ذات نوعية جيدة أم ضعيفة ونجد أن أسعار المياه المعبأة تتراوح من 206 دولار للمتر المكعب في النيبال إلى 995 دولار للمتر المكعب في كاليفورنيا مقارنة بمتوسط تكلفة لمياه الشرب من الشبكة العامة تبلغ 0.5 دولار للمتر المكعب على مستوى العالم شكل رقم (1) .

Bottled Water Prices 2003



شكل رقم (1) أسعار المياه المعبأة في بعض دول العالم مقارنة بمتوسط تكلفة مياه الشرب من الشبكة العامة للمتر المكعب عام 2003 . Gleick et al. 2004

ان التوجه الى النظر فى مياه الشرب المعبأة ادى الى اتخاذ قرارات حازمة نحو عدم تصدير المياه المعباة المنتجة فى بعض دول مجلس التعاون الخليجى ، حيث قررت المملكة العربية السعودية منع تصدير مياه الشرب المعبأة وغير المعبأة الى خارج المملكة العربية السعودية نظرا لشح مصادر المياه الوطنية .(جريدة الرياض العدد 15818 تاريخ 15 اكتوبر 2011)

وفى هذه الورقة يتم تسليط الضوء على ظاهرة المياه المعبأة على ثلاث جوانب رئيسية :

1 – دراسة نظرية عن انواع مياه الشرب فى دولة الكويت

2 – دراسة مقارنة ل (25) نوع من المياه المعبأة والمعدنية فى الاسواق الكويتية .

3 – استبيان لشريحة من المستهلكين حول المياه المعبأة والمعدنية ومياه الشبكة وتحليل بياناته .

المناقشة

1 - تقع دولة الكويت في الجزء الشمال الغربي من الخليج العربي في قارة آسيا على مساحة 17818 كيلومتر مربع ويبلغ عدد سكانها حوالي 3.6 مليون نسمه (الكتاب الاحصائى المائى 2011) ويقع مناخ الكويت ضمن الإقليم الصحراوي الجاف ويمتاز فصل الصيف بأنه أطول فصول السنة حيث يمتد من شهر ابريل إلى شهر سبتمبر وهو فصل حار تصل فيه الحرارة إلى 50 درجة مئوية .

يوجد في دولة الكويت بشكل عام نوعين لمياه الشرب هما :

أ – مياه التحلية : وهى المياه المنتجة بواسطة وزارة الكهرباء والماء (محطات التحلية) ويتم إيصالها للشبكة العامة للمستهلكين من خلال شبكة المياه العامة .

ب – المياه المعبأة : وهى مياه معبأة تباع فى الاسواق التجارية إما طبيعية أو معالجة وتختلف طرق المعالجة لها .

أ - تحلية مياه البحر (المياه المقطرة)

لقد كانت مهمة توفير المياه العذبة الصالحة للشرب واللازمة للتوسع العمراني من أولى المهام التي اهتمت بها دولة الكويت ، ولهذا فقد قامت دولة الكويت بالتوقيع على أول محطة تقطير تعمل بطريقة الأنابيب المغمورة عام 1953 وفى نفس العام تم تشغيل أول محطة تقطير في الشويخ بسعة إنتاجية قدرها مليون جالون إمبراطوري يوميا ، واستمرت جهود تعزيز وتوسيع والبحث والتطوير لطرق تحلية مياه البحر عن طريق التقطير الوميضي متعدد المراحل وتم تطوير تلك الطريقة حلال الفترة السابقة لزيادة كفاءة المقطرات المنتجة لمياه المقطرة لتزداد سعة المقطرات من نصف مليون جالون إمبراطوري في اليوم الى مليون جالون إمبراطوري في اليوم ثم مليونيين جالون إمبراطوري فى اليوم فأربعة ملايين جالون إمبراطوري في اليوم وسبعة ملايين جالون إمبراطوري في اليوم حتى وصلت حاليا إلى 12.5 مليون جالون إمبراطوري في اليوم . وقد تم اعتماد تقنية التطاير الفجائي متعدد المراحل (MSF) لتحلية مياه البحر منذ أكثر من 50 عاما ، وتوجد حاليا توجد ست محطات تقطير تعمل معظمها بطريقة التطاير الفجائي متعدد المراحل وهم موضحة كالتالي :

- محطة الشويخ :

من أول محطات التقطير التي أنشئت في عام 1953 توجد حاليا ثلاث وحدات تقطير بسعة إجمالية 19.5 مليون جالون إمبراطوري في اليوم .

- محطة الشعيبة الجنوبية :

بدا تشغيل محطة الشعيبة الجنوبية عام 1971 ، وتتكون المحطة من ست وحدات تقطير سعة كل منها خمسة ملايين جالون إمبراطوري في اليوم بسعة إجمالية 36 مليون جالون إمبراطوري في اليوم .

- محطة الدوحة الشرقية :

بدا تشغيل محطة الدوحة الشرقية عام 1978 ، وتتكون المحطة من سبع وحدات تقطير سعة كل منها ستة ملايين جالون إمبراطوري بسعة إجمالية 42 مليون جالون إمبراطوري في اليوم

- محطة الدوحة الغربية :

بدا تشغيل محطة الدوحة الغربية عام 1983 وتتكون المحطة من 16 وحدة تقطير وتتكون من مرحلتين المرحلة الأولى تتكون من أربع وحدات سعة كل منها 6 مليون جالون إمبراطوري في اليوم بسعة إجمالية 24 مليون جالون إمبراطوري في اليوم ، المرحلة الثانية تتكون من 12 مقطرة تعمل على بسعة 7.2 مليون جالون إمبراطوري يوميا بإجمالي 86.4 مليون جالون إمبراطوري في اليوم لتصبح السعة الإجمالية للمحطة 110.2 مليون جالون إمبراطوري في اليوم.

- محطة الزور الجنوبية :

بدا تشغيل محطة الزور الجنوبية عام 1988 وتتكون المحطة من 16 وحدة تقطير بسعة 7.2 مليون جالون إمبراطوري في اليوم بسعة إجمالية 115.2 مليون جالون إمبراطوري في اليوم .

-محطة الصبية :
بدأ تشغيل محطة الصبية عام 2006 وتتكون المحطة من 8 وحدات تقطير سعة كل وحدة 12.5 مليون جالون إمبراطوري في اليوم بسعة إجمالية 100 مليون جالون إمبراطوري في اليوم .

تتم عملية تصنيع المياه العذبة في محطات تسمى محطات الخلط والضخ وهذه المحطات تكون قريبة من ناحية الموقع من محطات التقطير وهي موزعة جغرافيا حسب التالي :

- محطة الخلط والضخ في الشويخ .
- محطة الخلط والضخ في الدوحة .
- محطة الخلط والضخ في الشعيبة .
- محطة الخلط والضخ في الزور .

- محطة الخلط والضخ فى الصبية

وهـي محطات وظيفتها مكملة لعمل محطــات التقطير حيث أنها تعمل على تعديل نوعيـة المياه المقطـرة المنتجـة من محطـات التقطيـر وجعلها مياها عذبـة صالحـة للاستعمـال الآدمـي حسب المواصفات العالمية وذلك بخلطها بالمياه قليلة الملوحة المنتجة من آبار المياه الجوفيـة في كل من الشقايا والصليبية والوفرة وأم قدير بنسب معينة لتحسين طعمها وإضافة ما يحتاجه الجسم من أملاح لها وكنتيجة لهذه الإضافة تزداد كمية ما يتم إنتاجه من مياه الشرب كما يتم تطهير هذه المياه بإضافة مادة الكلورين لتعقيمها واوضحت بعض الدراسات ان نوعية مياه الشرب من الشبكة العامة ذو قيم متوسطة مقارنة بالمياه المعبأة (الفريج واخرون ، 1999) .

جدول رقم (4): تطورا لاستهلاك الكلي للمياه العذبة ومعدل استهلاك الفرد للمياه في دولة الكويت

السنة	السكان	جملة الاستهلاك في السنة (مليون جالون)	استهلاك الفرد في اليوم (جالون / فرد / يوم)	(لتر / فرد / يوم)
1995	1721968	61577	98	447
2000	2231908	88452	108	492
2005	2991189	111507	102	454
2010	3582054	134153	102.6	456

ب - الميـــــاه المعبـــــأة والمعدنية

المياه المعدنية الطبيعية هي مياه جوفية طبيعية تحتوى على الأملاح المعدنية الذائبة بها طبيعيا ولا تجرى عليها أي عمليات كيميائية و يتم الحصول عليه من الينابيع أو الآبار الارتوازية أو من الطبقات الحاملة للمياه الجوفية ، ولا ينبغي تعديل هذا النوع من الماء بخلطه بماء من مصدر أخر أو بإضافة أو إزالة الأملاح الذائبة باستثناء ما يتعلق بالفلترة والتطهير بالأوزون أو بالأشعة فوق البنفسجية . أما بالنسبة لمياه الشرب المعبأة فهي تلك التي تستهلك كبديل لمياه الشبكة ويتم تنقيتها بصورة خاصة من مراحل الترشيح (

الفلترة) أو التحلية (عمليات التناضح العكسي أو زوال التأين بتبادل الايونات) أو عملية التطهير (بالأوزون أو الأشعة فوق البنفسجية) وتضاف إليها معقمات حتى تكون آمنة للشرب " وبالنظر إلى مصادر ونوعية المياه المباعة حاليا في الأسواق فإننا سنجد أن معظمها عبارة عن مياه بحر أو مياه جوفية شبه مالحة ، تقوم شركات تعبئة المياه بتحليتها – وفى الغالب – باستخدام محطات تناضح عكسي وتعقيمها بالكلور أو بالأوزون أو بالأشعة فوق البنفسجية ومن ثم تعبئتها وتوزيعها في الأسواق ، ويلاحظ أن القليل منها هو مياه طبيعية (أي مياه ينابيع أو جوفية) ومع ذلك يتم تسميتها تجاوزا ولأسباب تجارية مياها معدنية وتتراوح نسبة الملوحة في المياه المعبأة من 100 -500 مليغرام في اللتر أي تصل نسبة الملوحة منها إلى اقل من ثلث مستوى الأملاح في الشبكة الحكومية وقد يكون ذلك من أهم المبررات لتفضيلها على مياه الشبكة على الرغم من سعرها العالي " . (الزبارى ، 2008) ، كما توجد اثار بيئية لصناعة المياه المعبأة من حيث صناعة العبوات البلاستيكية والتخلص منها يحتاج الى تكاليف باهضة توازى تكلفة الوقود اذا اخذ بالاعتبار الطاقة المستخدمة لتعبئة وتسليم واعادة تدويرها ، كما ان رمى الفراغات البلاستيكية فى المكبات يوفر لها استمرارية قد تصل الى الف سنة قبل تحللها البيولوجى الكامل .

وفى دولة الكويت تعتبر مياه شركة الروضتين من أول الشركات المحلية والوحيدة (شركة مساهمة كويتية مقفلة) التي وفرت المياه المعدنية الطبيعية وتوجد في حقل الروضتين وأم العيش وقد بدأت أول عمليات الضخ عام 1962 ويقدر المخزون الطبيعي من هذين الحقلين 40 ألف مليون جالون . وقد توقف الإنتاج في حقل أم العيش بعد الغزو العراقي الغاشم، أما بالنسبة لحقل الروضتين فتقدر الطاقة الإنتاجية في الحالات الاعتيادية بحوالي مليون جالون يوميا ، وعدد الآبار المنتجة 14 بئرا ويتم استغلاله تجاريا في إنتاج المياه المعبأة (مياه الروضتين) و تتراوح نسبة الملوحة من 400 - 1000 جزء في المليون (الكتاب الإحصائي للمياه ،2010) _وقد تكونت مياه حقل الروضتين في صخور عصر النيوجين / البللستوسين من تكوين الدبدبة في مجموعة الكويت الجيولوجية ويمتاز بمياهه ذات الخواص المعدنية والتي تجمعت عبر ملايين السنين من مياه الأمطار والسيول والشعاب وتغذت بالمعادن الضرورية للجسم عبر ملايين السنين حتى تجمعت في مصفاة طبيعية ضخمة في أعماق ارض الكويت (www.alrawdatain.com) ، كما تعتبر مياه شركة بيريه من أوائل ماركات المواد الاستهلاكية الخارجية التي دخلت الكويت وتحديدا في عام 1963 عندما كانت تستورد للأجانب في شركات النفط ثم لقيت رواجا كبيرا وإقبالا من قبل المواطنين . وقد بلغ حجم الاستهلاك السنوي للمياه المعدنية والمعبأة إلى 180 مليون لتر في 2007 بزيادة بلغت أكثر من 28 % عن عام 2006 إذ بلغ الاستهلاك حوالي 129 مليون لتر وبلغت قيمة الاستهلاك المحلى في 2007 (13) مليون دينار تقريبا . واستحوذ الإنتاج المحلى على 47 % من السوق المحلى فيما ذهب الجزء الأكبر من النسبة المتبقية للمياه المستوردة من السعودية والتي تحتل المرتبة الأولى بين الدول المصدرة للمياه المعدنية والمعبأة في الكويت ، حيث تشكل المياه السعودية 75 % من المياه المستوردة فيما تشكل المياه الإماراتية 15 % من المياه المستوردة ، أما المياه المستوردة من الدول الأوربية كفرنسا وايطاليا وسويسرا وبلجيكا وبلدان أخرى فلا تشكل مجتمعة أكثر من 10 % . وقد بلغت إجمالي سوق المياه المعبأة في الكويت 25 مليون دينار كويتي بمعدل استهلاك الفرد السنوي 90 لتر . (جريدة القبس العدد 2518 تاريخ 6 ابريل 2008)

2 - **قامت الدراسة** على جمع ومقارنة اكثر من 25 نوع من المياه المعبأة والطبيعية المتوفرة فى الاسواق الكويتية المختلفة ، وقد اخذت البيانات والمكونات الكيميائية الموضوعة لكل نوع بالاضافة الى سعر

بيعها فى الاسواق الكويتية جدول رقم (5) حيث لوحظ فى تلك الانواع ان نسبة الاملاح الذائبة تتراوح من 43 الى 309 مليجرام / اللتر . كما لوحظ ان دول المصنعة للمياه المعبأة التى شملتها الدراسة هى الكويت ، السعودية ، الامارات ، الاردن ، تركيا ، النرويج ، المانيا ، ايطاليا ،فرنسا والبوسنة والهرسك . ، كما بلغت قيمة اجمالى تكلفة المياه المستوردة إلى دولة الكويت 13 مليون دينار كويتي عام 2008 (بيانات الإدارة العامة للجمارك الكويتية) بكمية تقدر 400 بليون لتر.

تكلفة مياه الشبكة العامة والمياه المعبأة فى دولة الكويت :

بلغت إيرادات مبيعات المياه العذبة 38 مليون دينار كويتي عام 2009 (الكتاب الإحصائي السنوي للمياه ، 2010) حيث تعتمد تكلفة إنتاج مياه الشبكة العامة على عدة عوامل منها عوامل الوقود المستخدم في الغلايات مصدر تسخين مياه البحر وتشغيله والصيانة والمواد الكيميائية المستخدمة للمعالجة وغيرها ولهذا يختلف سعر إنتاج المياه من فترة إلى أخرى بسبب تباين سعر الوقود وتقدر معدل إنتاج وتوزيع المياه 8.418 دينار كويتي / 1000 جالون و يدفع المستهلك كدعم حكومى (0.8) دينار كويتي / 1000 جالون (0.17 دينار / للمتر المكعب = 0.22 فلس / لتر) اما قيمة قنينة المياه المعبأة أو المعدنية في الأسواق الكويتية تتروا ح من 100 فلس إلى 650 فلس لكل لتر كما هو مبين في جدول رقم (4) . وباحتساب قيمة المياه المعبأة بالقيمة الادنى فان الفرق بين قيمة مياه الشبكة العامة لمياه الشرب والمياه المعبأة فى الاسواق يتجاوز اكثر من ثلاثمائة ضعف فى دولة الكويت .

3 - **قامت الدراسة أيضا** على إعداد وتوزيع وتحليل استبيان عن استهلاك المياه المعبأة ومياه الشبكة العامة على مستوى دولة الكويت ، حيث تم في البداية إعداد محاور الاستبيان والمشتملة على أربع محاور رئيسية:

- المحور الأول : بيانات عامة عن المستهلك ويشمل على بيانات العامة للمستهلك من العمر والجنس ونوع العمل ومستوى الدخل ونوع السكن .
- المحور الثاني : التعرف على وجهة نظر المواطنين في المياه التي تصل إلى المنازل من حيث مدى الاعتماد عليها ومدى معرفتهم عن مصدرها . ويشتمل على نوعية مياه الشرب التي يستخدمها المستهلك ومدى الرقابة عليها .
- المحور الثالث : التعرف على وجهة نظر المواطنين للمياه المعبأة واستخداماتها في دولة الكويت : ويشتمل على مدى استخدام المياه المعبأة وكمياتها والأنواع المفضلة والحجم المناسب والقيمة الشهرية لشرائها والرقابة على نوعيتها والعبوات المناسبة للاستخدام .
- المحور الرابع : الأسباب والدوافع لاستخدام المياه المعبأة : ويشتمل على أسباب استخدام المياه المعبأة و الجوانب المختلفة لاستخدام مياه الشرب من الشبكة العامة .

وقد تم توزيع 100 نسخة من الاستبيان روعي فيه جميع شرائح مستهلكي دولة الكويت وأنواع السكن ومستوى الدخل والعمر والجنس . وبعد الانتهاء من الاستبيان تم تحليل البيانات واستخراج النتائج منها .

وفيما يلي تحليل المحاور الأربعة للاستبيان :

أ – المحور الأول البيانات العامة :

تنوعت شريحة الاستبيان على البيانات العامة للشريحة كالتالي :

مثلت الشريحة على 51 % من الذكور و 49 % من الإناث شكل رقم (3)، كما شملت على 59 % متزوج و 41 % أعزب شكل رقم (4) .كما شملت على التنوع في سنوات العمر حيث شملت الشريحة على الفئة الأولى (50 سنة فما فوق) 8 % والفئة الثانية (25 -50 سنة) 55 % والفئة الثالثة (15 – 25) سنة 37 % شكل رقم (5) .كما تنوعت الشريحة على المستوى التعليمي حيث شملت الشريحة على 7 % مستوى فوق الجامعي و 72 % المستوى الجامعي و التعليم الثانوي 16 % ومرحلة التعليم المتوسط 5 % شكل رقم (6) . ومن حيث العمل شملت الشريحة على 59 % يعملون في العمل الحكومي و 6 % يعملون في المؤسسات شبه الحكومية وفى القطاع الخاص 6 % والذين لا يعملون في الشريحة يمثلون 29 % شكل رقم (7). وعلى مستوى دخل الفرد في الشريحة تمثلت الشريحة على الفئة الأولى (اقل من 500 دينار) 35 % والفئة الثانية (500 -1000 دينار)28 % والفئة الثالثة (1000 -1500 دينار) 13 % والفئة الرابعة (1500 – 3000 دينار)والفئة الخامسة (أكثر من 3000 دينار كويتي) 5 % شكل رقم (8) . وعلى مستوى السكن مثلت الشريحة عل بيت 78 % وشقة 22 % شكل رقم (9).

ب – المحور الثاني :التعرف على وجهة نظر المواطنين في المياه التي تصل إلى المنازل من حيث مدى الاعتماد عليها ومدى معرفتهم عن مصدرها :

- نوع المياه التي تستخدم للشرب حيث مثلت الشريحة 40 % منهم يستخدم مياه شرب معبأة وان 54 % من الشريحة تستخدم مياه شرب باستخدام الفلتر المنزلي وان 6 % فقط تستخدم مياه شرب مباشرة من دون فلتر شكل رقم (10) .
- الاعتماد على مياه الشرب التي تصل إلى المنزل بينت الشريحة أن 61 % يعتمدون عليها وان 26 % أحيانا يعتمدون عليها وان 13 % لا يعتمدون علي مياه الشرب التي تصل للمنزل شكل رقم (11).
- وفى رأى الشريحة في نوعية المياه التي تصل إلى المنزل تمثلت بان 38 % ممتازة و 47 % جيدة و 10 % رديئة و 5 % لا يعلمون شكل رقم (12) .
- أما بالنسبة إلى الرقابة الرسمية على نوعية مياه الشرب التي تصل للمستهلكين فتمثلت ب 44 % نعم و 26 % أحيانا و 10 % لا و 20 % لا اعلم شكل رقم (13) .

ج - التعرف على وجهة نظر المواطنين للمياه المعبأة واستخداماتها في دولة الكويت

- وعن استخدام المياه المعبأة أو المعدنية للشرب فقد بينت الشريحة أن 44 % يستخدمون المياه المعبأة وان 49 % أحيانا يستخدمونها وان 7 % فقط لا يستخدمون المياه المعبأة أو المعدنية شكل رقم (14) .
- كما بينت الشريحة أن 45 % يؤيدون أن المياه المعبأة او المعدنية ذات نوعية افصل من المياه التي تصل للمنزل من الشبكة وان 18 % لا يؤيدون وان 37 % لا يعلمون شكل رقم (15) .
- وأوضحت الشريحة أن 50 % يفضلون بعض أنواع المياه المعبأة والمعدنية للاستخدام المستمر وان 50 % الآخرين لا يفضلون شكل رقم (16) .
- إن 92 % من استخدام المياه المعبأة أو المعدنية يكون بغرض الشرب وان 3 % يكون للطبخ وان 5 % يكون لأغراض أخرى شكل رقم (17) .
- أوضحت الشريحة أن 47 % لديهم معرفة بالمحتويات المعدنية للمياه المعبأة أو المعدنية وان 33 % ليس لديهم معرفة وان 20 % أحيانا ولديهم بعض المعرفة شكل رقم (18) .
- وبالنسبة للأنواع المفضلة من المياه المعبأة وجد أن المياه المعبأة محليا تمثل 58 % والخليجية 11 % والعالمية 31 % شكل رقم (19) .
- وبالنسبة إلى القيمة الشهرية التي تصرف على المياه المعبأة وجد أن 38 % فئة (1- 5 دينار كويتي) وان 20 % فئة (5 – 10 دينار كويتي) وان 10 % فئة (10 – 15 دينار كويتي) وان 2 % فئة 15 دينار كويتي فما فوق وان 15 % لا يعلمون وان 15 % لا يوجد شكل رقم (20) .
- أوضحت الشريحة أن 47 % يقرئون حين الشراء تاريخ انتهاء صلاحية المياه المعبأة وان 20 % أحيانا وان 33 % لا يقرئون شكل رقم (21) .
- إن 16 % من الشريحة لا يعلمون أن هناك رقابة على نوعية المياه المعبأة التي تباع بالأسواق وان 36 % يعلمون وان 48 % لا يعرفون .أن هناك رقابة أم لا .
- وجد أن 88 % يفضلون المياه المعبأة ذات العبوات التي لا يعاد تعبئتها بمختلف أحجامها وان 12 % يفضلون عبوات سعة 20 لتر والتي يعاد تعبئتها شكل رقم (22) .
- أوضحت الشريحة أن 73 % يعتقدون أن قناني المياه المعبأة بعد استعمالها تضر بالبيئة وان 10 % لا يعتقدون وان 17 % لا يعلمون أنها تضر أم لا شكل رقم (23)

د - الأسباب والدوافع لاستخدام المياه المعبأة

- وبالنسبة للدوافع لاستعمال المياه المعبأة نجد أن 34 % يرجعون السبب إلى سهولة الحصول على المياه المعبأة بينما 21 % يرجع السبب إلى عدم تقبل طعم أو رائحة مياه الشبكة العامة لمياه الشرب كما يعتقد 20 % بان السبب يرجع إلى عدم نظافة خزانات المياه بالمنزل و 16 % إلى التخوف من عدم جودة مياه الشبكة العامة لمياه الشرب و 5 %يرجع السبب إلى التأثر بالحملات الإعلانية و 4 % إلى عدم توفر مياه الشبكة العامة بانتظام شكل رقم (25) .

- أسباب استخدام المياه المعبأة
- أوضحت الشريحة أن أسباب استخدام المياه المعبأة -أكثر سلامة للصحة -14 % وافق بشدة ، 42 %وافق ، 29 % لا يدرون ،10 % لا يوافق 5 % لا يوافق بشدة شكل رقم (26).
- كما أوضحت الشريحة أن أسباب استخدام المياه المعبأة بسبب استخدام الأسرة لها وجد أن : 76 % وافق ، 2 % وافق بشدة ، 4 % لا يدرون ، 11 % لا يوافق ، 7 % لا يوافق بشدة شكل رقم (27).
- أسباب استخدام المياه المعبأة – يستخدمها الأصدقاء وجد أن 56 % وافق ، 10 % وافق بشدة ، 21 % لا يدرون ، 8 % لا يوافق ، 5 % لا يوافق بشدة شكل رقم (28) .
- أسباب استخدام المياه المعبأة – عدم الثقة في جودة مياه الشبكة العامة لمياه الشرب وجد ان 28 % لا يوافق ، 11 % لا يوافق بشدة ، 23 % لا يدرون ، 22 % موافقين ، 16 % موافقين بشدة شكل رقم (29).
- أسباب استخدام المياه المعبأة – عدم تقبل طعم ورائحة مياه الشبكة العامة وجد أن 35 % غير موافقين ، 18 % غير موافقين بشدة ، 13 % لا يدرون ، 21 % موافقين ، 13 % موافقين بشدة شكل رقم (30) .
- أسباب استخدام المياه المعبأة – القلق من خلط مياه الشرب بمياه الصرف الصحي وجد أن 23 % لا يوافقون بشدة ، 33 % يوافقون ، 11 % لا يدرون ، 25 % موافقين ، 8 % موافقين بشدة شكل رقم (31) .
- أسباب استخدام المياه المعبأة – القلق من احتمال وجود ميكروبات في مياه الشرب وجد أن 27 % لا يوافقون ، 16 % لا يوافقون بشدة ، 21 % لا يدرون ، 22 % موافقين ، 14 % موافقين بشدة شكل رقم (32).

- أسباب استخدام المياه المعبأة – القلق من احتمال وجود مخلفات كيميائية في مياه الشرب وجد أن 33 % غير موافقين ، 17 % غير موافقين بشدة ، 17 % لا يدرون ، 17 % موافقين ، 16 % موافقين بشدة شكل رقم (33) .
- أسباب استخدام المياه المعبأة – بديل للمشروبات الغازية وجد 52 % موافقين ، 17 % موافقين بشدة ، 17 % غير موافقين ، 8 % غير موافقين بشدة ، 6 % لا يدرون شكل رقم (34) .
- أسباب استخدام مياه الشرب من الشبكة العامة
- مياه الشرب من الشبكة العامة آمنة وجد أن 36 % موافقين ، 23 % موافقين بشدة ، 27 % لا يدرون ، 11 % غير موافقين ، 3 % غير موافقين بشدة شكل رقم (35) .
- الخشية على الصحة من استعمال مياه الشرب من الشبكة العامة وجد أن 32 % غير موافقين ، 11 % غير موافقين بشدة ، 11 % لا يدرون % ، 36 % موافقين ، 10 % موافقين بشدة شكل رقم (36).
- استخدام فلاتر لتصفية مياه الشبكة العامة يجعله آمنة للشرب وجد أن 46 % موافقين ، 30 % موافقين بشدة ، 10 % لا يدرون ، 10 % غير موافقين ، 4% غير موافقين بشدة شكل رقم (37).
- بصفة عامة هناك احتمال كبير بالمرض عند استخدام مياه الشبكة العامة وجد أن 30 % غير موافقين ، 19 % غير موافقين بشدة ، 34 % لا يدرون ، 13 % موافقين ، 4 % موافقين بشدة شكل رقم (38)
- طعم ورائحة مياه الشبكة العامة بما تحتويه من مواد التعقيم غير صالحة وجد أن 27 % غير موافقين ، 14 % غير موافقين بشدة ، 34 % لا يدرون ، 16 % موافقين ، 9 % موافقين بشدة شكل رقم (39)

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الاستنتـــــــــاج

1 – صناعة المياه المعبأة فى تزايد مستمر على المستوى العالمى .

2- سعر المياه المعبأة فى دولة الكويت يفوق سعر مياه الشبكة العامة باكثر من ثلاثمائة ضعف .

3- تتراوح اسعار المعبأة فى الاسواق الكويتية من 100 الى 560 فلس / اللتر .

4 – تترواح نسبة الاملاح الذائبة فى عينات المياه المعبأة المختلفة التى جمعت فى الدراسة من الاسواق الكويتية من 43 الى 309 مليجرام / اللتر .

5 – يقدر اجمالى سوق المياه المعبأة فى دولة الكويت 25 مليون دينار كويتى فى السنة .

6- من خلال الاستبيان تبين ان 92 % من استخدام المياه المعبأة فى دولة الكويت يستخدم

للشرب فقط .

7 – من خلال الاستبيان تبين ان 85 % يعتمدون على مياه الشبكة باستمرار اواحيانا .

8 – من خلال الاستبيان تبين ان 64 % لا يعتقدون وكذلك لا يعلمون بوجود رقابة على المياه المعبأة .

9 – من خلال الاستبيان وجد ان 88 % يفضلون المياه المعبأة ذات العبوات التى لا يعاد تعبئتها بمختلف احجامها .

التوصيـــــــــــــات

- توعية المواطنين بالمياه المعبأة وأثرها ونوعيتها والتقارير المتعلقة بها .
- إنشاء موقع في شبكة الانترنت يتضمن قاعدة معلومات عن جميع أصناف المياه المعبأة المتوفرة في الأسواق المحلية ونتائج اختبارات الجودة الدورية التي تجريها الجهات المختصة وأية تحذيرات أو معلومات عن جودة الأصناف المختلفة .
- إنشاء جهاز رقابي خاص للمياه المعبأة يعنى بمراقبة نوعية المياه المعبأة المستوردة والمحلية .
- توجيه مصانع المياه المعبأة بذكر المعلومات التالية على عبوات المياه :مصدر المياه المعبأة ونوعية المعالجة المستخدمة والمستويات المسموح بها لمياه الشرب المعبأة لمعايير الجودة المذكورة على العبوة.
- اعتبار المياه المعبأة من ضمن أنواع وموارد مياه الشرب المستخدمة والمتزايدة وادراجها ضمن الخيارات المتعددة في حال التخطيط الشامل والاستراتيجى لتوفير مياه الشرب .

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جدول رقم (1) : معدل استهلاك الفرد من البلدان الرائدة خلال عامي 2004 &2009

GLOBAL BOTTLED WATER MARKET
Per Capita Consumption by Leading Countries
2004 – 2009

2009 Rank	Countries	Gallons Per Capita 2004	Gallons Per Capita 2009
1	Mexico	44.5	61.9
2	Italy	48.5	50.7
3	United Arab Emirates	27.9	40.1
4	Belgium-Luxembourg	39.1	36.7
5	Germany	33.0	34.5
6	France	37.4	33.8
7	Lebanon	26.8	31.8
8	Spain	36.1	31.4
9	Hungary	20.1	29.3
10	United States	23.2	27.6
11	Slovenia	21.2	27.1
12	Thailand	20.2	26.4
13	Saudi Arabia	23.2	26.4
14	Switzerland	26.3	26.0
15	Croatia	18.1	25.6
16	Qatar	20.6	25.5
17	Cyprus	24.3	24.5
18	Austria	21.7	23.5
19	Czech Republic	23.0	23.3
20	Hong Kong	15.4	21.9
	GLOBAL AVERAGE	6.4	7.9

Source: Beverage Marketing Corporation

جدول رقم (2) حجم وإجمالي تكلفة المياه المعبأة في الولايات المتحدة الأمريكية خلال الفترة من 2001 إلى 2009

U.S. BOTTLED WATER MARKET Volume and Producer Revenues 2001 – 2009				
Year	Millions of Gallons	Annual % Change	Millions of Dollars	Annual % Change
2001	5,185.3	--	$6,880.6	--
2002	5,795.6	11.8%	$7,901.4	14.8%
2003	6,269.8	8.2%	$8,526.4	7.9%
2004	6,806.7	8.6%	$9,169.5	7.5%
2005	7,538.9	10.8%	$10,007.4	9.1%
2006	8,255.0	9.5%	$10,857.8	8.5%
2007	8,757.6	6.1%	$11,551.5	6.4%
2008	8,669.3	-1.0%	$11,178.5	-3.2%
2009	8,454.0	-2.5%	$10,595.0	-5.2%
Source: Beverage Marketing Corporation				

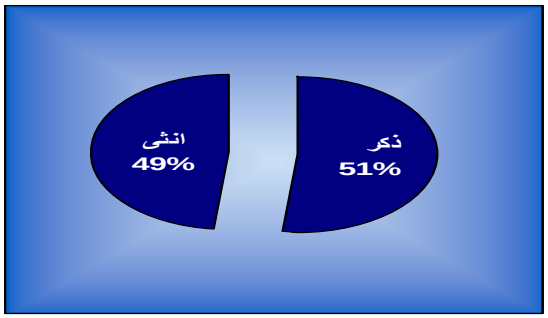
جدول رقم (3) : معدل استهلاك الفرد من البلدان الرائدة خلال عامي 2004 &2009

GLOBAL BOTTLED WATER MARKET Per Capita Consumption by Leading Countries 2004 – 2009			
2009		Gallons Per Capita	
Rank	Countries	2004	2009
1	Mexico	44.5	61.9
2	Italy	48.5	50.7
3	United Arab Emirates	27.9	40.1
4	Belgium-Luxembourg	39.1	36.7
5	Germany	33.0	34.5
6	France	37.4	33.8
7	Lebanon	26.8	31.8
8	Spain	36.1	31.4
9	Hungary	20.1	29.3
10	United States	23.2	27.6
11	Slovenia	21.2	27.1
12	Thailand	20.2	26.4
13	Saudi Arabia	23.2	26.4
14	Switzerland	26.3	26.0
15	Croatia	18.1	25.6
16	Qatar	20.6	25.5
17	Cyprus	24.3	24.5
18	Austria	21.7	23.5
19	Czech Republic	23.0	23.3
20	Hong Kong	15.4	21.9
	GLOBAL AVERAGE	6.4	7.9
Source: Beverage Marketing Corporation			

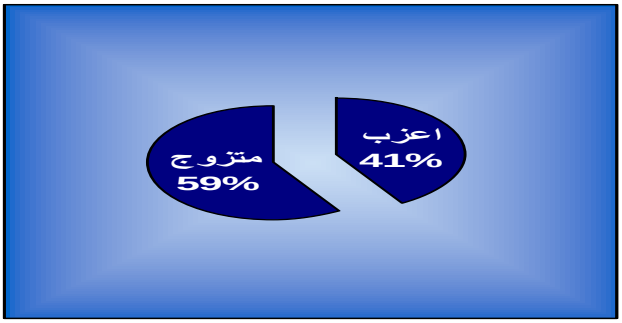
جدول رقم (4) أنواع المياه المعبأة في الأسواق الكويتية وبعض محتوياتها مقارنة بأسعارها

	الاسم	البلد	السعة لتر	معدني /معبأة	مجموع الأملاح مليجرام/اللتر	السعر فلس
1	الروضتين	الكويت	0.33	معدنية	-	50
2	أبراج	الكويت	0.300	معبأة	-	40
3	اكوافينا	الكويت	0.6	معبأة	110	65
4	أروى	الكويت	0.5	معبأة	120	55
5	ABC	الكويت	0.33	معبأة	105	50
6	جودة	الكويت	0.330	معبأة	105	30
7	هنية	السعودية	0.6	معبأة	125	55
8	دلتا	السعودية	0.330	معبأة	43	150
9	هالي	السعودية	0.330	معبأة	110	75
10	حياة	السعودية	0.33	معبأة		45
11	دلتا	السعودية	0.33	معبأة	43	155
12	الهدا	السعودية	0.33	معبأة	109	35
13	جمان	السعودية	0.33	معبأة	125	50
14	هنا	السعودية	0.330	معبأة	127	45
15	حلوة	السعودية	0.6	معبأة	210	60
16	صفا	السعودية	0.33	معبأة	100 - 150	40
17	بامبينى	السعودية	1.5	معبأة	43	395
18	الإمارات	الإمارات	0.15	معبأة	120	30
19	العين	الإمارات	0.5	معدنية	110	60

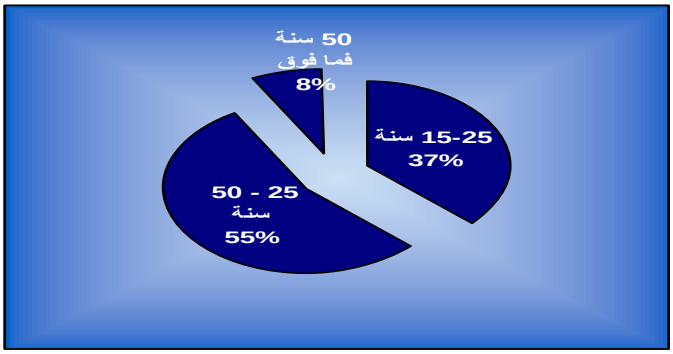
20	غلفا	الإمارات	0.6	معدنية	120	60
21	مسافي	الإمارات	0.5		120 - 180	60
22	الترا	الأردن	0.5	معبأة	-	180
23	بينار	تركيا	0.5	معدنية	118	85
24	سرايفكا	البوسنة والهرسك	0.33	معدني	-	105
25	ASBRE	النرويج	1	معدني	4	650
26	VIO	ألمانيا	0.5	معدني	150	255
27	SAN BENEDETTO	ايطاليا	0.5	معدني	6	320
28	فولفيك	فرنسا	0.5	معدنية	130	225
29	ايفيان	فرنسا	0.50	معدنية	309	225



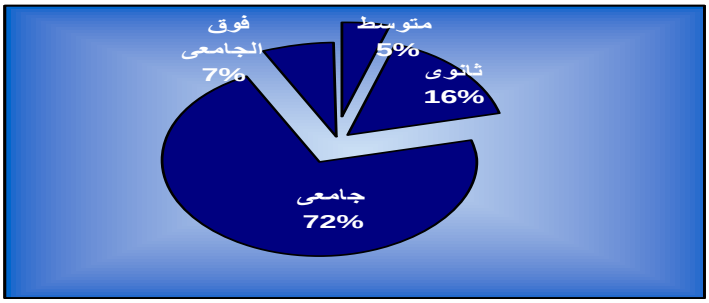
شكل رقم (3) بيانات عامة عن الشريحة - الجنس



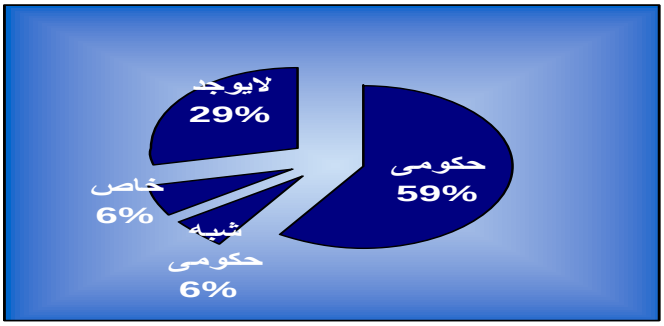
شكل رقم (4) بيانات عامة للشريحة- الحالة الاجتماعية



شكل رقم (5) بيانات عامة عن الشريحة- أعمار الشريحة

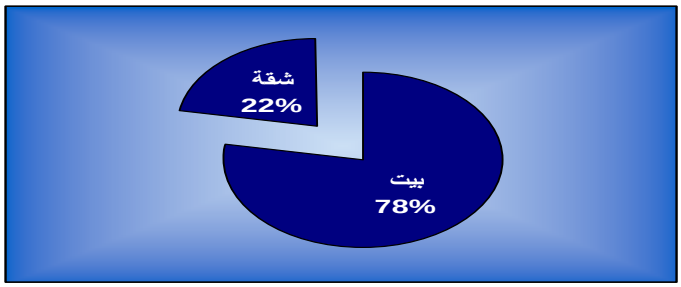


شكل رقم (6) بيانات عامة عن الشريحة – المستوى التعليمي

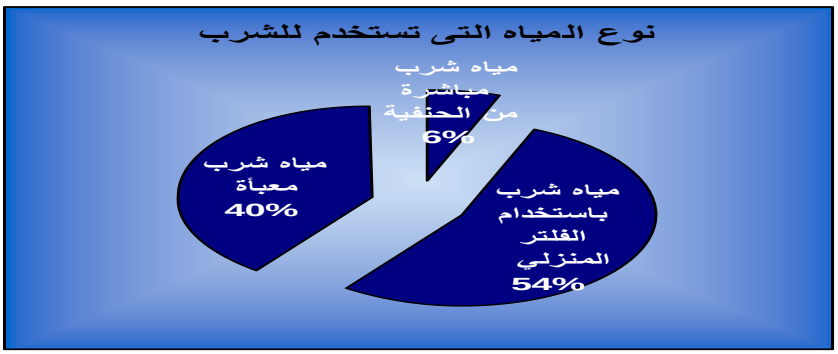


شكل رقم (7) بيانات عامة عن الشريحة – عمل الأفراد

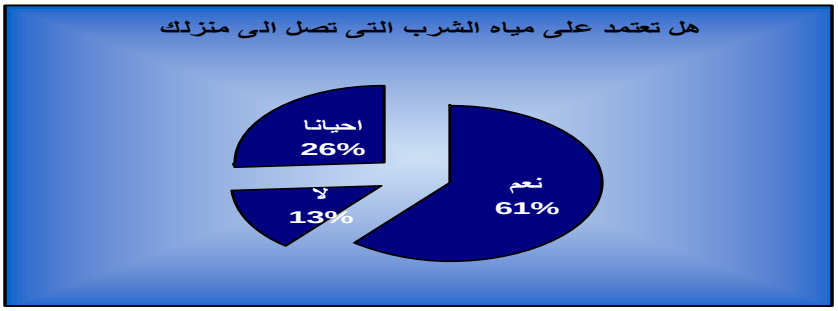
شكل رقم (8) بيانات عامة عن الشريحة –مستوى الدخل



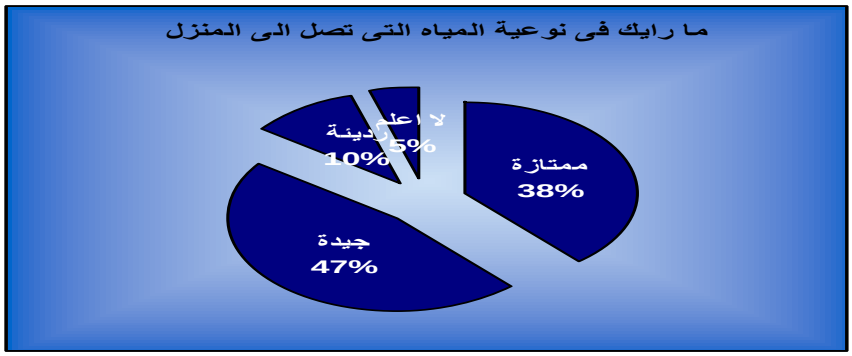
شكل رقم (9) بيانات عامة عن الشريحة – نوع السكن



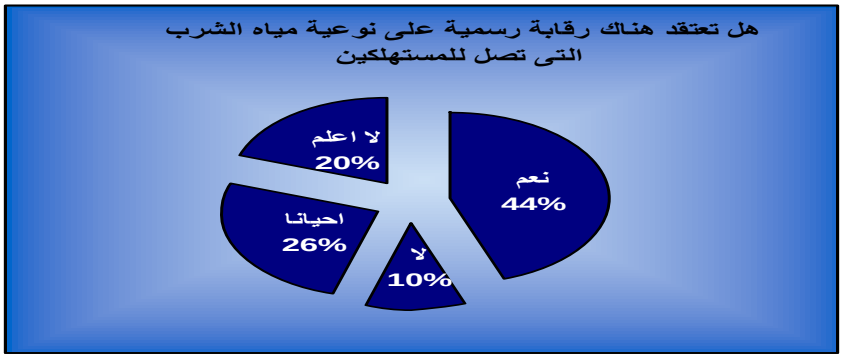
شكل رقم (10) نوع المياه التي تستخدم للشرب



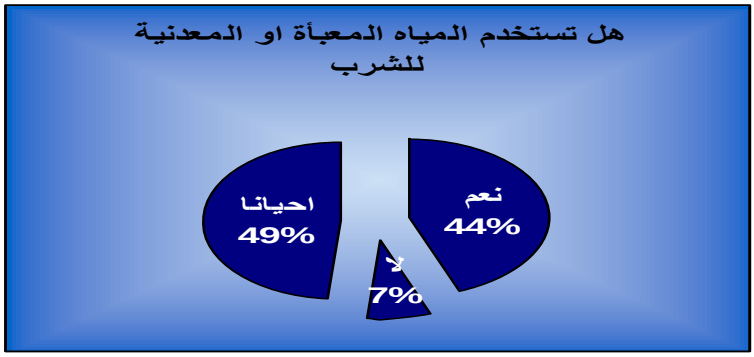
شكل رقم (11) الاعتماد على مياه الشرب**1**



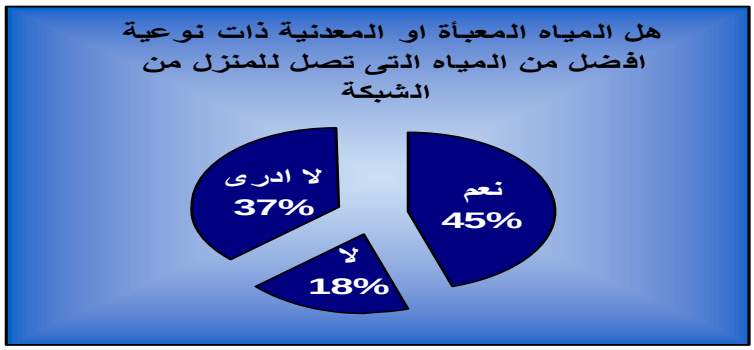
شكل رقم (12) معرفة نوعية مياه الشرب



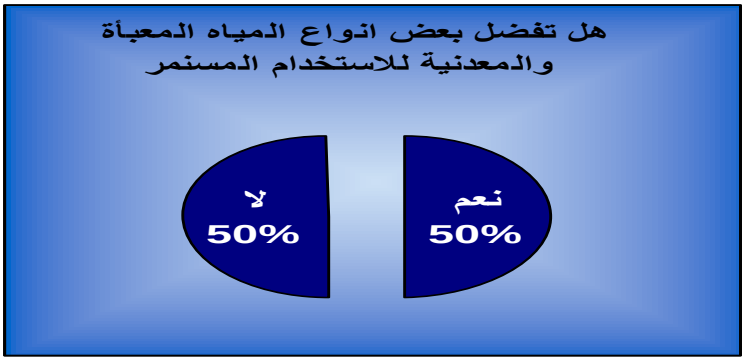
شكل رقم (13)الرقابة الرسمية على نوعية مياه الشرب من الشبكة العامة



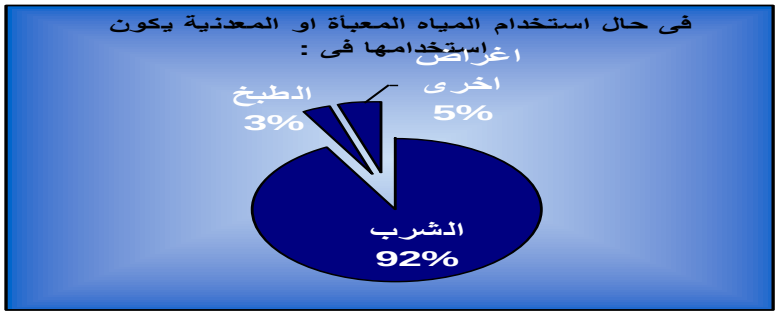
شكل رقم (14) استخدام المياه المعبأة



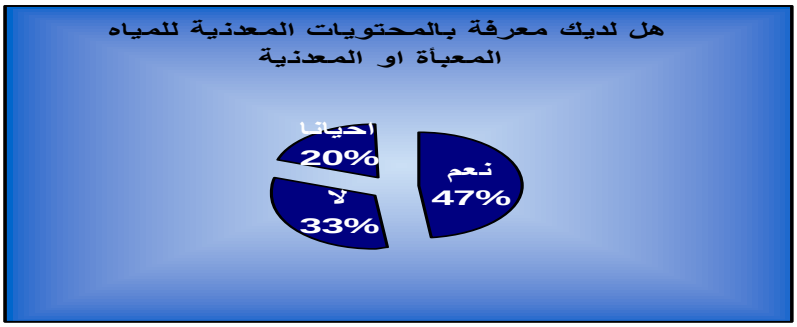
شكل رقم (15)مقارنة نوعية المياه المعبأة



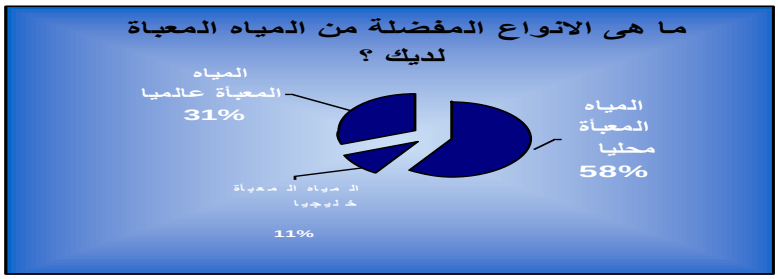
شكل رقم (16) استخدام بعض أنواع المياه المعبأة



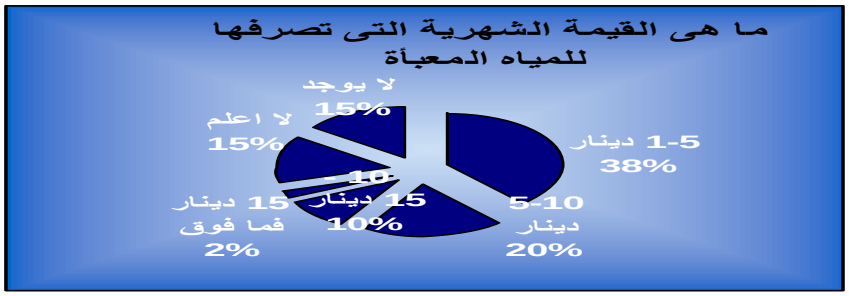
شكل رقم (17) استخدام المياه المعبأة



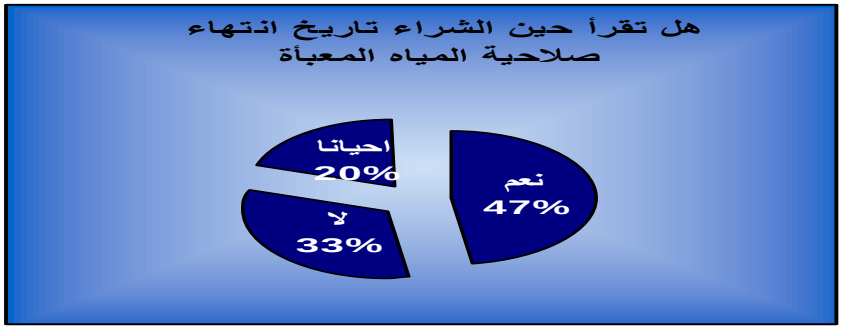
شكل رقم (18) معرفة محتويات المياه المعبأة



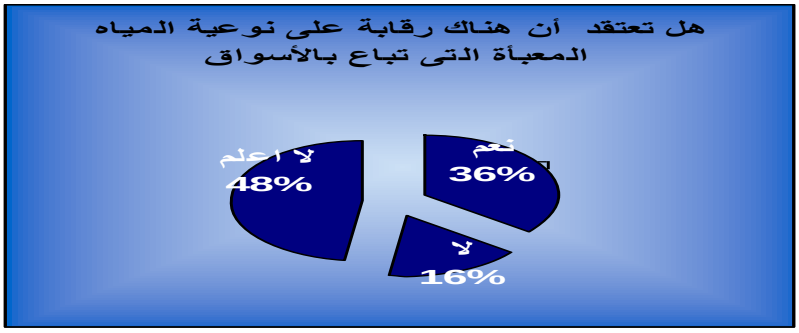
شكل رقم (19) معرفة الأنواع المفضلة من المياه المعبأة



شكل رقم (20) التكلفة الشهرية لاستخدام المياه المعبأة

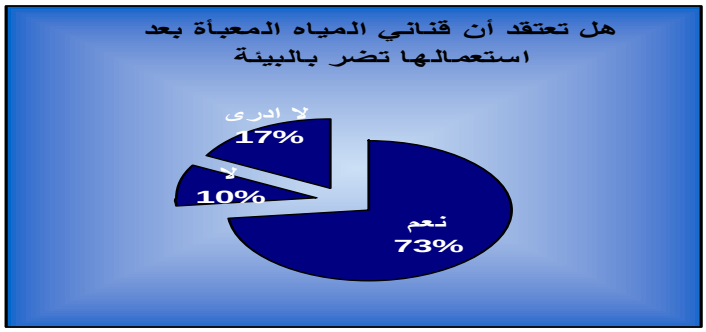


شكل رقم (21) معرفة تاريخ انتهاء صلاحية المياه المعبأة حين الشراء

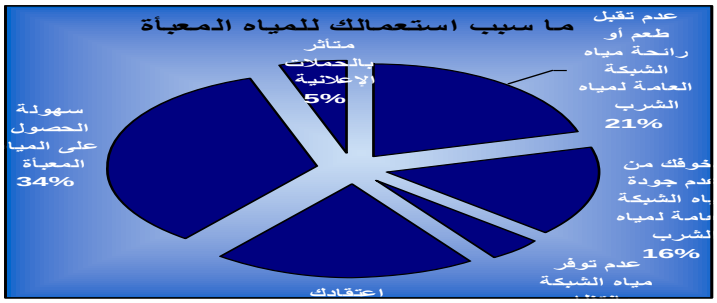


شكل رقم (22) الرقابة على نوعية المياه المعبأة

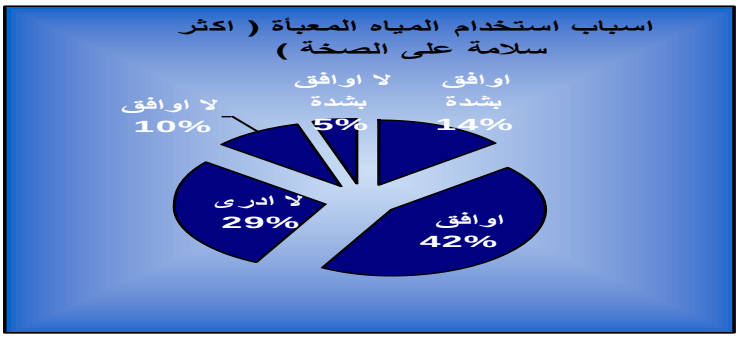
شكل رقم (23)حجم العبوة المستخدمة



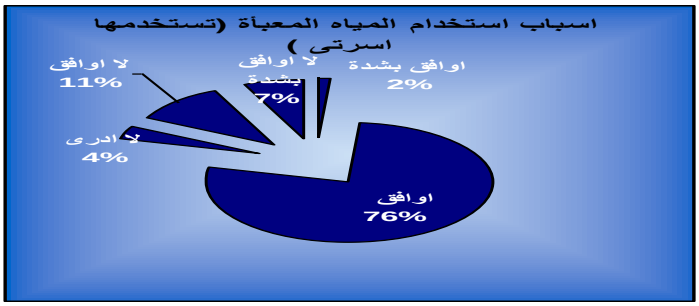
شكل رقم (24)معرفة ضرر القناني بالبيئة



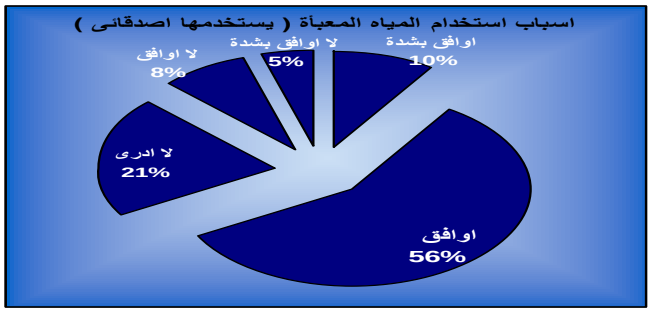
شكل رقم (25) أسباب استعمال المياه المعبأة



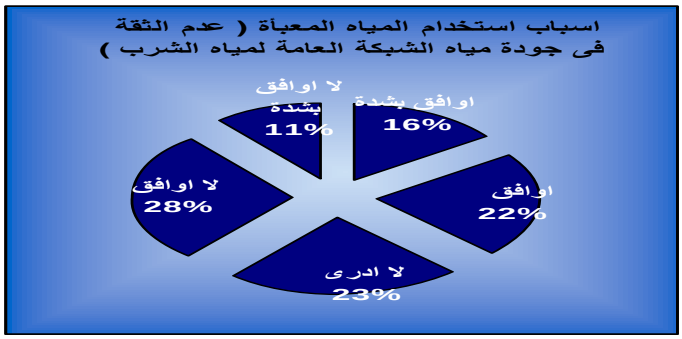
شكل رقم (26) تابع..أسباب استخدام المياه المعبأة



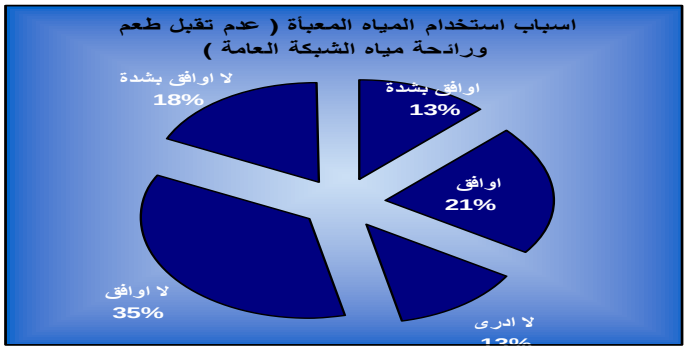
شكل رقم (27) تابع..أسباب الاستخدام المياه المعبأة



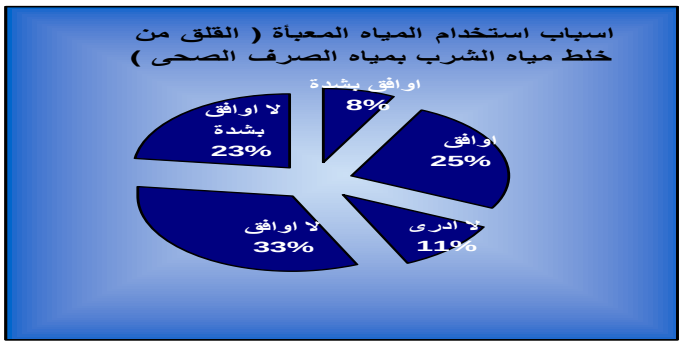
شكل رقم (28) تابع..أسباب استخدام المياه المعبأة



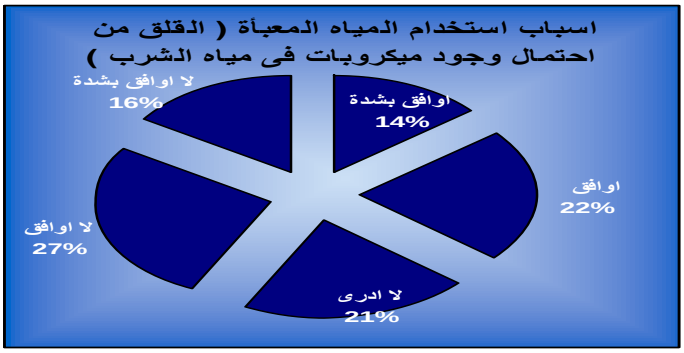
شكل رقم (29) تابع..أسباب استخدام المياه المعبأة



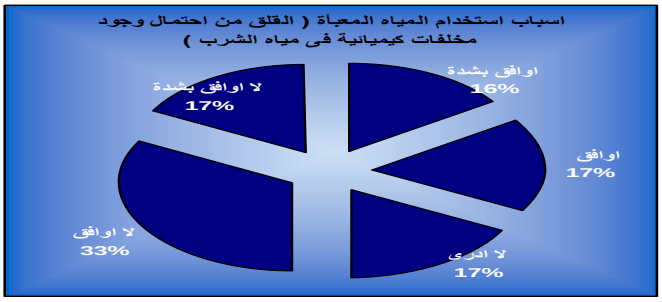
شكل رقم (30) تابع..أسباب استخدام المياه المعبأة



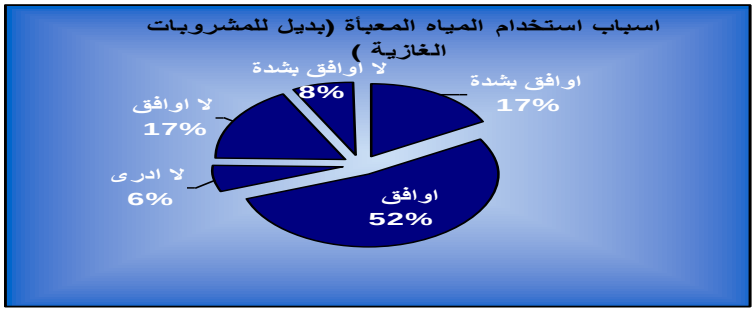
شكل رقم (31) تابع..أسباب استخدام المياه المعبأة



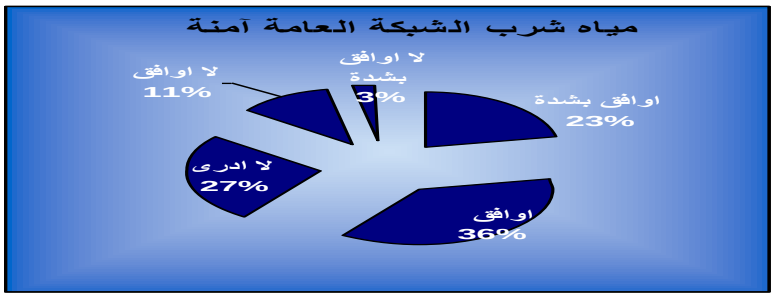
شكل رقم (32) تابع..أسباب استخدام المياه المعبأة



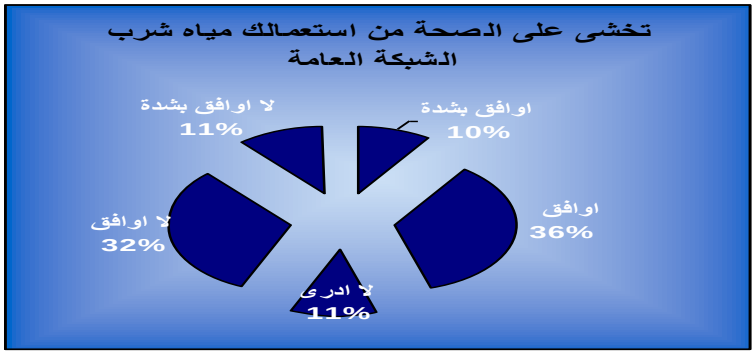
شكل رقم (33) تابع..أسباب استخدام المياه المعبأة



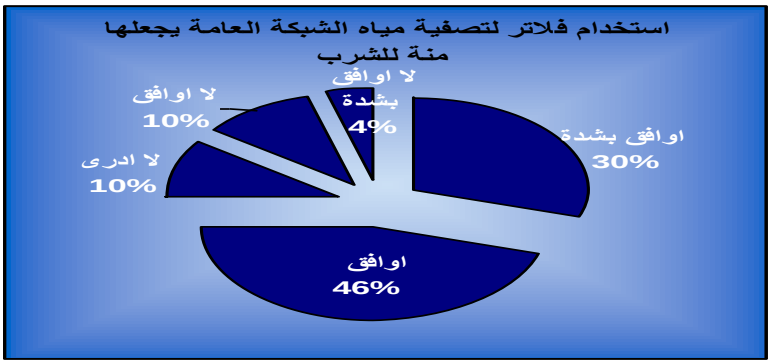
شكل رقم (34) تابع..أسباب استخدام المياه المعبأة



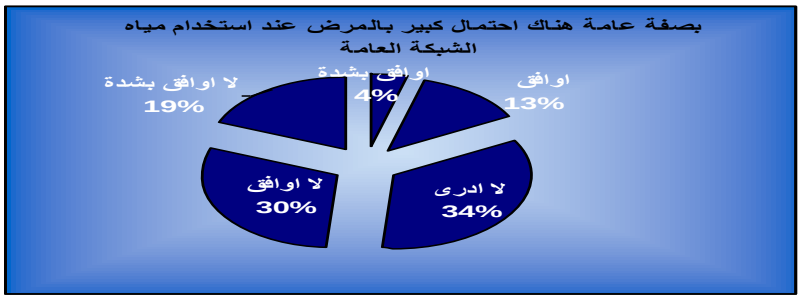
شكل رقم (35) الجوانب المختلفة لاستخدام مياه الشرب من الشبكة العامة



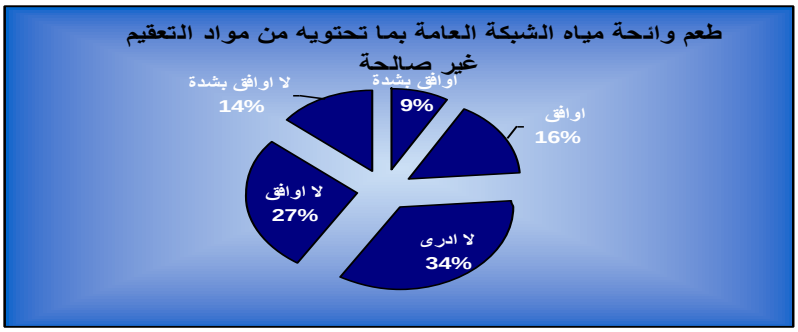
شكل رقم (36) تابع..الجوانب المختلفة لاستخدام مياه الشرب من الشبكة العامة



شكل رقم (37) تابع..الجوانب المختلفة لاستخدام مياه الشرب من الشبكة العامة



شكل رقم (38) تابع..الجوانب المختلفة لاستخدام مياه الشرب من الشبكة العامة



شكل رقم (39) تابع..الجوانب المختلفة لاستخدام مياه الشرب من الشبكة العامة

DAY THREE
Sunday, 24 April, 2012

SESSION 6:
WASTEWATER SECTOR MANAGEMENT AND REUSE

Keynote: Radoune Choukrallah, Institut Agronomique et Vétérinaire Hassan II, Sustainable Wastewater Management and Reuse in the Arab Region

A horticulturist and water environmental expert with more than 25 years of experience in coordinating and managing field-based projects and technical teams involved in site specific activities. Has extensive experience on protected culture particularly soilless culture, as well as the use of saline water and pre-treated sewage in agriculture, and soil and ground water pollution prevention.

As a senior level professor at the Institute of Agronomy and Veterinary Hassan II, has designed and taught classes on the use of pre-treated sewage and saline water in agriculture. He served as president of several International Conferences on the use of unconventional water in Agriculture. Received a Fulbright Scholarship to study at the Environmental Research Laboratory in Tucson, Arizona and has written numerous authoritative texts in his field.

He also served as a technical coordinator of a 12 Million project, financed by USAID on the water resources sustainability in morocco. In this project he coordinated the feasibility study, the planning, the engineering, the implementation, and the monitoring of a wastewater treatment plant of a small rural community.

Abstract:

Water resources scarcity, accessibility, and environmental degradation are the major challenges facing most of the Arab region. This region has already run out of renewable freshwater decades ago, and is unable to meet their food requirements using the available water resources. Several Arab countries have exhausted their natural water resources and must begin looking seriously at other alternates to meet future demands. Treated and re-used sewage water is becoming a common source for additional water in many Arab states (Tunisia, Jordan, Palestine, Morocco, and GCC) and many of these countries have included wastewater re-use in their water planning. Proper wastewater management is now being increasingly required in the Arab region countries to ensure a sustainable environment through protecting public health, maintaining aquatic ecosystems, and improving and protecting water resources. In fact, the perception of wastewater management in most Arab countries has generally shifted from its conventional objectives of health and environmental protection, to be considered as a valuable resource where treated effluents are utilized to increase national water resources. Therefore, adequate treatment, and/or appropriate soil-water-crop management strategies are needed for using treated wastewater for irrigation. The Arab states are currently producing 10.85 km^3/year of wastewater, of which 59.8% are treated and 2.17 billion m^3/year of the treated effluent (20% of the total generated wastewater) is reused, and not only for agricultural uses, but also for landscape irrigation, golf courses, cooling, and maintaining ecological flows.

The main objective of this review is to conduct a diagnosis of the current situation of the wastewater treatment and reuse in the Arab states, identify issues limiting the reuse in the Arab

region, and evaluate the Arab States of current wastewater policies, and propose Solutions to be environmentally acceptable, cost-effective toward sustainable use of reclaimed water resources, providing economic benefit, and supporting community development. Many examples of water reuse practices in different Arab countries will be presented including agriculture uses, golf course, landscaping, industries, and groundwater recharges.

Keynote: Numan Mizyed, Palestine, Treated Wastewater Reuse in The West Bank: Prospects, Challenges And Constraints

Education:

- Doctor of Philosophy, Colorado State University, Fort Collins, Colorado, 1990. Major: Agricultural Engineering/ Water Resources Systems Analysis.
- Master of Science, Colorado State University, Fort Collins, Colorado, 1988. Major: Irrigation and Drainage Engineering / Agricultural Engineering.
- Bachelor of Science, University of Jordan, Amman, Jordan, 1984. Department of Civil Engineering. Major: Civil Engineering

Current job and title: Currently head of the Civil Engineering Department at An-Najah National University. A department with more than 900 students and 30 staff members. At the same time, associate professor of water resources teaching graduate and undergraduate civil, water resources and environmental engineering classes. Also, currently registered as a Professional Engineer with the Board of Engineers of the State of Colorado, USA. TREATED WASTEWATER REUSE IN THE WEST BANK: PROSPECTS, CHALLENGES AND CONSTRAINTS Numan Mizyed, An-Najah University, Nablus, West Bank

Abstract:

This paper presents the prospects, challenges and constraints of treated wastewater agricultural reuse in the West Bank. The paper evaluates the potential areas and potential crops that could be utilized in treated wastewater reuse in addition to current strategies, regulations and bylaws available in the West Bank. The paper also evaluates public concerns and farmers acceptance regarding treated wastewater reuse in the West Bank. These evaluations are based on field investigations at different villages and localities in the West Bank. The field evaluations utilized meetings and interviews with farmers and officials in addition to collecting data using questionnaire designed to assess farmers response to treated wastewater reuse.

Based on the field investigation and analyses of available data regarding the subject it was found the treated wastewater reuse has a good potential in the West Bank if careful planning and enough public awareness were utilized in the design and implementation of such process. The reuse will improve agricultural income, provide new jobs for the growing population and improve the sustainability of irrigated agriculture in the West Bank. Farmers interviewed in many areas of the West Bank indicated a strong willing in reusing treated wastewater. The concerns expressed by farmers were related to marketing and worries about the quality of treated wastewater supplied to them. The current regulations and bylaws in the West Bank are

comprehensive and cover most aspects of reuse. There will be a need to develop farmers associations/cooperatives to be in charge of operating and managing treated wastewater systems.

Public Works Authority Apply Sustainable Developments Concept with Sewerage Works, Qatar

Khaled El Emadi [a], Ghazi Abdel Kerim [b], Hassan El Emadi [c]
gabdulkareem2@ashghal.gov.qa

[a] Manager of Quality,& Safety Department, PWA*, Doha 22188, Qatar.

[b] Environmental Expert, Prof. of Environmental Engineering, PWA*, Doha 22188, Qatar.

[c] Head of Environmental Section, PWA*, Doha 22188, Qatar.

Abstract:

The United Nations announced, through both the first Earth Summit in Rio de Janeiro, 1992 and the second Earth Summit in Johannesburg, 2002, Agenda 21, covered the key aspects of sustainability. Accordingly, all nations announced that decade 2005 – 2015 is considered the sustainable development decade for all nations, where all nations are required to settle programs to cover their communities needs towards sustainable development.

Accordingly, his Excellency Deputy Emir of Qatar declared law no. 1 year 2004 to establish Public Works Authority (PWA) to manage & develop Public Building and infrastructure systems. In year, 2009, his Excellency Deputy Emir of Qatar announced law no. 44 to organize PWA and develop its terms of reference. Since then PWA started planning, designing and implementing infrastructure projects depending on professional consulting offices as well as international contracting companies. Since 2011, PWA has been launched its strategy that deliver and manage state-of-the-art, sustainable world class infrastructures that fulfill the Qatar Vision 2030 for sustainable developments. During the first and second five years plans 2005 – 2010 & 2012 – 2016, PWA has been managing consultancy and contracting services to design, build and operate sanitary drainage works that not only achieve environmental protection, but also to sustain the environment and increase non-conventional water resources.

This paper presents regional and international treated water reuse criteria, that the PWA proposed and future treated effluent design standards. The proposed PWA design standards of Treated Sewage Effluent (TSE) are developed to cover pH, BOD5, TSS, COD, Ammonia, Phosphate, Residual Chlorine, Dissolved Oxygen, Turbidity, Dissolved Solids, Total coliform, Fecal coliform, Nematodes Eggs, Enteric Viruses and Gardia cysts. Moreover, it describes

current PWA sewage treatment work projects, which have been constructed and operated during the first and second five years plans 2005 – 2010 & 2012 – 2016, its design capacities and treated effluent criteria. The treated effluent quality is expected suitable for different reuse applications. In addition, it presents TSE demand and distribution in Qatar and current reuse applications. Furthermore, it describes developments of monitoring programs and developments of emergency storage lagoons and emergency TSE disposal Plan. Finally, it presents PWA pilot trial studies to extend TSE reuse in other applications to consider sustainable development concept with sewerage works in Qatar.

Key words: Wastewater, Treatment, Reuse, Sustainable, Development, Qatar.

Introduction:

Qatar is now under fast urban development including infrastructure, industry, tourism as well as agriculture, which will cause water supply needs to increase dramatically to match the fast moving development. Due to dry weather condition in state of Qatar and rarity of water resources, planning is essential to find out new water resources other than water desalination works to cover needs for current expansion and urban development. Treated Sewage Effluent (TSE) generated from sanitary drainage services is now considered an important water source to strength water resources management in state of Qatar.

PWA plans to develop the existing sanitary drainage services including sewage treatment works to produce TSE suitable for reuse for unrestricted irrigation. In the same time, PWA plans for further upgrade the STW projects to extend TSE reuse applications behind irrigation. TSE reuse applications could be in construction activities (earth works, block manufacturing and concrete works) as well as in cooling purposes (District Cooling). Recently, TSE is being planned to be used for District cooling (Qatar Cool, Barwa Financial District and Mesherib District) as well as building works, road works, and industrial applications.

Aim of the Work:

- To set proposed criteria for treated sewage effluent reuse.
- To evaluate the condition of existing sewage treatment works.
- To identify PWA needs regard to TSE reuse strategy in Qatar.
- To plan, design, implement and operate drainage extension & upgrading Projects.
- To develop monitoring programs of drainage works.

Material and Methods

- PWA Environmental Section (PWA-ES) carried out literature review regarding to international, regional and local criteria for TSE reuse.
- Proposed TSE design criteria of PWA treatment facilities are settled.
- PWA Infrastructure Affairs (PWA-IA) started planning, designing and implementing sanitary projects, producing treated water suitable for different reuse applications.
    - Current operation conditions of existing STWs are assessed.
    - Data collection of current served population, STWs capacities, and TSE design quality are conducted.
    - Population forecast for years 2010, 2020 and 2030 are estimated.
    - Essential needed drainage works extension and upgarding projects are identified to fullfill the proposed TSE design criteria.
- PWA Quality & Environment Department established developments of monitoring programs of drainage works.

- PWA Asset Affairs conducted developments and rehabilitation of emergency storage lagoons and emergency TSE disposal plan.
- PWA conducted feasibility pilot study regarding the application of Reverse Osmosis as tertiary treatment stage in STWs.
- The basic requirements to atchive PWA future vision regard to TSE reuse are idntified.

Since 2004, Public Works Authority (PWA) has been established by declared law no. 1 settled by his Excellency Deputy Emir of Qatar. PWA set up their organization and announced a 5 year plan 2004 – 2009 regarding developments and upgrading the drainage works in all municipalities except industrial areas related to Qatar Petroleum (QP). The main outcome of the 5 year plane is: (1)Upgrade the existing main sewage treatments works such as Doha South, Al Siliyah, Al Khore, Doha Industrial Area, Al Khreeb, Al Shamal and Um Sallal. (2) Upgrade and extend the associated sewerage systems, surface groundwater networks, TSE distribution networks and related pump stations. (3) Develop design, implement and operate long term contract with private qualified contractors such as Doha North STWs contract, as well as Al Siliyah STWs contract. (4) Develop operation & maintenance long term contract with private qualified contractors such as Doha South & Doha Industrial Area STWs contract. (5) Develop monitoring programs of current PWA drainage projects to assess their performance and efficiencies respect to contract conditions and terms of references. At the end of the 5 year plan the performance of PWA was evaluated respect to project progress and its advantages and disadvantages.

As a result, in year, 2009, his Excellency Deputy Emir of Qatar announced law no. 44 to organize PWA and develop its terms of reference, in order to upgrade their performance regarding the implementation of the next 5 year plan. Since then PWA launched its strategy that delivers and manages state-of-the-art, sustainable world class infrastructures that fulfill the Qatar Vision 2030 for sustainable developments.

During the coming five year plan 2012 – 2016, PWA is managing consultancy and contracting services to design, build and operate sanitary drainage works that not only achieve environmental protection, but also to sustain the environment and increase non-conventional water resources.

Literature Review:

Literature review is carried out with regards to international, regional and local criteria for TSE reuse. This review covers microbiological, chemical, other Physico-chemical properties, trace elements and Agronomical Aspects, for Wastewater Reuse

Microbiological Quality for Wastewater Reuse:

With respect to microbiological standards for wastewater reuse, WHO guidelines made recommendations for microbiological standards in 1989. The WHO limits for MPN of Fecal Coliform is 100/100 ml for irrigation of crops likely to be eaten raw, sports fields and public parks. With respect to landscape irrigation with unlimited public access, WHO limits for MPN of Fecal Coliform is 200/100 ml. Furthermore, WHO sets limits for Intestinal Nematode to be less than 1 Helminth egg/ liter [18].

In 1978, California set more strengthened microbiological standards for wastewater reuse. California limits of MPN total Coliform for spray and surface irrigation of food crops and high exposure landscape irrigation to 2.2 /100 ml and 23/100 ml respectively. Furthermore, Wastewater reuse regulations adopted by the state of Arizona contain enteric virus limits; wastewater is not to exceed 1 plaque forming unit (PFU) per 40 litre for application such as spray irrigation of food crops. In 1992, US EPA has set recommendations for microbiological standard for wastewater reuse. The US EPA limits of MPN Fecal Coliform for surface or spray irrigation of any food crop including crops eaten raw and restricted irrigation are 14/100 ml and 200/100 ml respectively [11] [17].

Other countries such as Italy, Cyprus and Andalusia have also set guidelines of microbiological quality for wastewater reuse. Italy set more strengthened microbiological standard for wastewater reuse. Italy limits of MPN total Coliform for unrestricted and restricted irrigation are 2.0/100 ml and 20/100 ml respectively. On the other hand, Cyprus set less strengthened microbiological standards. Cyprus limits of MPN Fecal Coliform for unrestricted and restricted irrigation are 100/100 ml and 200/100 ml respectively. Furthermore, Cyprus limits of Intestinal Nematode for unrestricted and restricted irrigation are 0.0/l and 0.0/l respectively. While Andalusia set more less strengthen standard of microbiological quality for wastewater reuse. The Andalusia limits of MPN Fecal Coliform for irrigation of vegetable eaten raw and sports fields and parks with public access are 200/100 ml and 1000/100 ml respectively. Furthermore,

Andalusia limits of Intestinal Nematode for unrestricted and restricted irrigation are 1.0/l and 1.0/l respectively [11] [17].

Chemical Quality and Agronomical Aspects for Wastewater Reuse:

In addition to standards for the microbiological quality of the effluent to protect the public health, other parameters including Salinity, Exchange Ions (Na, Ca, Mg), Boron and Trace Metals (Cd, Cu, Hg, Ni, Mo, Pb, Zn) are also important to determine the suitability of the treated wastewater for irrigation in agriculture and agronomic point of view, to protect soil and crops. Other physical-chemical parameters including, pH, TSS, BOD, COD, and DO are also important.
A number of different irrigation water quality guidelines have been proposed. The guidelines were set on the basis of the long term influence of water quality on crop production, soil conditions, and irrigation techniques. The Food & Agriculture Organization (FAO) published in 1985 revised guidelines for water quality used for irrigation in agriculture [11]. These guidelines were developed by the University Of California Committee Of Consultants. The guidelines were set taken into consideration four categories of potential management problems associated with water quality: (1) Salinity, (2) specific ion toxicity, (3) water infiltration, and (4) miscellaneous effects.

PWA Proposed Design Standards:

Adoption of more stringent regulations is required to protect an already high standard of public health by preventing, at any expense, the introduction of pathogens into the human food chain. The PWA Infrastructure Affairs (PWA-IA), with cooperation with PWA Environmental Section (PWA-ES), established proposed design standards for Treated Sewage Effluent (TSE) for the new domestic sewage treatment works in 2004, see table (1). PWA-ES proposed to add to the microbiological quality, the limits of other parameter such as Intestinal Nematode, Virus as well as gardia. Accordingly, all new projects are designed according to this proposed standards as indicated in column No. (2). Keep in mind that the basis of compliance is as indicated in column No. (4). The new treatment works, which would be in operation during the coming five year plan 2012 – 2016 , must follow these proposed standards in normal operation condition [5] [4] [1].

Table (1) Proposed Standard Sewage Treated Effluent For Reuse (Drainage Affairs, Ashghal, 2004)

Standard Effluent Criteria	Proposed Standard	Future Standard	Basis of Compliance
Suspended Solids	5 mg/l	5 mg/l	90%
BOD	5 mg/l	5 mg/l	90%
COD	50 mg/l	50 mg/l	90%
P H	6 – 9	6 - 9	90%
Ammonia	1 mg/l	1 mg/l	90%
Phosphate	*1/2 mg/l	2 mg/l	90%
Total Nitrogen	10 mg/l	5 mg/l	90%
Dissolved Oxygen	2 mg/l (min)	2 mg/l (min)	90%
Chlorine (Free Residual)	0.5 – 1.0 mg/l	0.5 – 1.0 mg/l	90%
Turbidity	2 NTU	2 NTU	90%
Total Dissolved Solids	2000 mg/l	500 mg/l	90%
MPN of Faecal Colifrom per 100 ml	0.0	0.0	90%
Intestinal nematodes (no. of eggs per 1 litre)	< 1.0	0.0	95%
Enteric Viruses (no. of plaque forming unit (PFU) per 40 liters)	< 1.0	<1.0	90%
Guardia (no. of cysts per 40 liters)	< 1.0	<1.0	90%

*Phosphate limit is based on applied treatment technology (Chemical/Biological).

The PWA Environmental Section reviewed the proposed standards with reclaimed wastewater quality for irrigation. PWA-ES recommend considering other parameters regarding reuse of TSE for irrigation. These parameters are trace metals as well as important parameters, which determine the suitability of the treated wastewater for irrigation in agriculture and agronomic point of view, to protect soil and crops. These are covered by FAO recommendations for water irrigation in agriculture, and Recommended Maximum Concentrations of Trace Elements in Irrigation Water [(11)].

Overall suitability of water for irrigation is normally determined using the guidelines for water quality recommended by FAO which cover the chemical characteristics that may adversely affect soil properties and crop growth. The guidelines are reproduced, where the FAO guidelines have been revised for use for desert sandy soil [17]. The only departure from FAO recommendations is that the allowable salt content of the water has been increased substantially.

PWA Future Design Standards:

PWA plan to extend the opportunity of TSE reuse applications as well as reduce TSE reuse impacts on soil condition and plant growth. This would need to upgrade the water quality to comply with new requirements. Accordingly, PWA plan to study the feasibility of applying further reverse osmosis technology to reach the future standard as indicated in Table (1), column No. (3) [5] [1] .

PWA Reverse Osmosis Pilot Plant Study:

In order to support the future design standards, PWA –IA implemented a pilot plant to provide indicative performance data for the types of advanced wastewater treatment (AWWT) technology including pretreatment and reverse osmosis units [5]. The pilot plant studied applied on reliable water quality data for the TSE from existing main sewage treatment works plants at Doha South STWs & Al Sailiyah STWs.

Current served and Projected population:

The Current population in the State of Qatar has been recorded since the year 1977. Furthermore, existing sewage treatment works current operation capacities has been reviewed. The Population served by sanitary services is estimated considering 270 l/cap.d as wastewater dischare per capita as taken by Draiange Affairs design department. Table (2) presents the summary of wastewater generated quantities and estimated population served up to yeat 2004. It indicates that the percentage of served population by sanitary services is 70% during year 2004 [12].

Table (2) Quantities of Generated Wastewater and Population Served During the Period 1977 - 2004

Year	Wastwater Generated m3/d	Wastewater Generated m3/year	Popoultion Served	Population Estimate by Municipality	% Served
1977	18000	6570000	66667		
1987	60000	21900000	222222	384327	58
1997	93300	34054500	345556	522023	66
2004	140800		520641	744029	70

Projected population has been estiamted by a consultant as well as by The Planning Council, General Secretarate, Statistics Department, Population Statistics Division [13]. Furthermore, the population estimate has been carried out by arithmatic and geometric methods. Fig. (1) Presents a summary of population forecast up to the year 2030. Furthermore, PWA consider that fast urban development which have been taken now in Qatar, including infrastructures, industry, tourism as well as agriculture will attract great numbers of non residents, which will increase the population dramatically during the next decades. Examples of these developments are Lusail, Barwa residence and commercial projects, and the Mesherib District project.

PWA Sewage Treatment Works Projects:

Since year 2004, PWA has been taken responsibility to upgrade the existing sewage treatment works to achieve the settled TSE standards for unrestricted reuse for irrigation. In the same time, PWA plans for further upgrade the STW projects to extend TSE reuse applications behind irrigation. Table (3) presents summary of PWA Extension and Upgrading Sewage Treatment Projects. The outcome of these projects during the coming five year plan 2012 – 2016 would extend the capacity up to 634860, 790410 and 819410 m3/d in the years 2013, 2016 and 2030 respectively. Furthermore, the TSE quality will be improved for unrestricted reuse for irrigation as well as behind irrigation. As a result of the commission of drainage projects during the coming five year plan, the distribution of drainage services implemented by PWA, Private Sector, and QP per population would be 80 %, 18% and 2% respectively, see figure (2). Moreover, the transportation of crude sewage from dwellings by tanker service would be diminished.

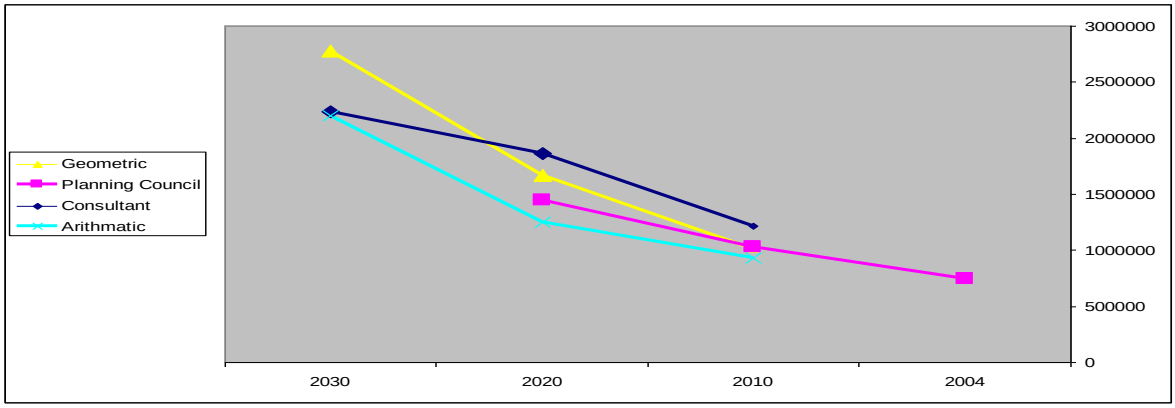


Fig. (1) Population Forecast up to year 2030

Table (3) PWA Sewage Treatment Works Projects

STW	Com. year	Design Flow Capacity, m3/d	Com. year	Design Flow Capacity, m3/d	Com. year	Design Flow Capacity, m3/d	Com. Year	Design Flow Capacity, m3/d
Sailiyah	2008	135000	2013	175000		175000		175000
Naijah	2006	106000	2013	180000		180000		180000
Industrial Area	2006	12000	2013	24000	2016	48000		48000
Al Khore	2008	5000		5000	2016	10000		10000
Al Dhakhirah		1600	2013	3200	2019	42000	2030	56000
Doha North			2013	243000	2016	324000		324000
Al Shamal		150	2013	750	2015	7500	2030	22500
Jumeliyah		540	2014	2020		2020		2020
North Camp		300	2014	540		540		540
Shahaniyah		810	2013	1350		1350		1350
Al Khareeb	2005	60						
Aum Sllal	2006	1500						
Total				**634860**		**790410**		**819410**

* AS : Activated Sludge SBR: Sequencing Batch Reactor

AS EA : Activated Sludge Extended Aeration Com.: Commission

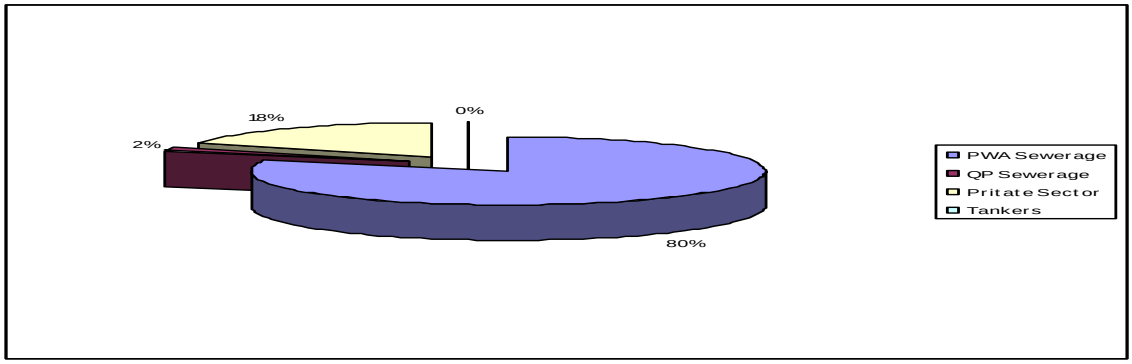


Fig. (2) Distribution of Drainage Services per Population, Qatar 2020 (3208963)

Doha West (Sailiyah) STW:

The Sailiyah STW is situated on the western outskirts of the capital City of Doha. An extension and upgrading project of Sailiyah STW has been contracted in year 2006. The contract included designing, building and operating to add capacity of 135000 m3/d with design year 2020, [4]. The project's main components include the following: 1. screens with screening washing and dewatering facilities, 2. vortex grit removal units with associated classifiers, 3. activated sludge tanks. The activated sludge process is designed to have full nitrification, 4. The process is supported by anaerobic zone, where phosphorus is removed by biological means, Furthermore, the anaerobic zones followed by anoxic zones in which denitrification will take place [11] [15], 5. The tertiary treatment processes includes sand filters followed by ultra filtration (membrane filter) [3] [6] [16] , 6. Disinfectant of final treated effluent is carried out by both Ultraviolet Radiation followed by chlorination [19] [20] . The treatment processes are designed to produce an effluent with the proposed design criteria as indicated in table (1). Due to the rapid increase of generated wastewater received in Sailiyah STW's, additional project has been contracted to include design, build and operate to add capacity of40000 m3/d to the current operated project at Sailiyah STW.

Doha South (Naijah) STW:

Doha South STW is situated on the southern outskirts of the capital City of Doha. During years 2005/2006, an extension project of Naijah STW has been implemented to add capacity of 110000 m3/d, with design year 2013. The treatment process at Doha South components include the following: 1. Inlet works consisting reception chamber, screening, and hydro-dynamic grit

removal plants with associated classifiers. The inlet works is covered and ventilated to a three stage chemical scrubber. 2. A flow distribution chamber that splits the flow between existing activated sludge AS plant and the new Sequencing Batch Reactor (SBR) plant. Both the exiting AS and the new SBR designed to achieve a fully nitrified effluent. The two schemes are followed by tertiary treatment, comprising of rapid gravity sand filters and Chlorine Disinfectants. The treatment processes at Naijah are designed to produce an effluent with the following quality BOD5: TSS: Ammonia of 10:10:1 mg/l. Due to the rapid increase of generated wastewater received in Al Naijah STW, an additional project has been contracted to include design, build and operate to add capacity of 65000 m3/d to the current operated project at Al Naijah STW, considering the proposed design criteria as indicated in table (1).

Doha Industrial Area STW:

In year 2006,a new STW was commissioned to treat domestic wastewater generated from Doha industrial area. The design capacity was 12000 m3/d with design year 2015. The project's main components include screening, grit removal, activated sludge Sequencing Batch Reactors, followed by tertiary treatment, comprising of rapid gravity sand filters and chlorination. The treatment processes are designed to produce an effluent with the following quality: BOD5: TSS: Ammonia: Total Coliform of 10:10:1 mg/l and 23 MPN/100 ml respectively. Due to the rapid increase of generated wastewater in Doha Industrial Area, additional project has been contracted to include design, build and operate to add capacity of 33000 m3/d to the current operated project at Doha industrial area STW, considering the proposed design criteria as indicated in table (1).

Al Khore STW:

Al Khore STW is situated on the Northern outskirts of Al Khore City, commissioned in 2008. The treatment processes at Al Khore STW employs activated sludge extended aeration process designed with Ammonia removal followed by tertiary treatment, comprising of rapid gravity sand filters and UV/Chlorine Disinfectants. The treatment processes at Al Khore STW is designed to produce an effluent, considering the proposed design criteria as indicated in table (1). Due to the rapid increase of generated wastewater received in Al Khore STW, an additional project has been contracted to include design, build and operate to add capacity of 5000 m3/d to the current operated project at Al Khore STW.

TSE Demand and Distribution in the State of Qatar:

Full use of TSE is a governomental policy in the State of Qatar**. First:** The two main users of TSE are: **(1) City irrigation,** where it covers all uses of TSE where public access is avialable such as roads and golf courses (Doha City, Dukhan Road, Salwa Road, North Road, Doha Expressways, Doha Golf Clup, and university of Qatar. **(2) Agriculture,** where TSE is used to irrigate agriculture crops. The crops grown at present are livestock fodder crops. (Al- Rakhiyya Farm, Al Refaa Farm) [12]. **Second:** The secondary user of TSE are: **(1) Sand washing** (Sahara Sand Factory & Al Rakia Sand Factory). **(2) District cooling** (Qatar Cool, Barwa Financial District and Mesherib District).

Based on population forecast and generated treated water analysis, it is expected that TSE availability would be 542250 and 836750 m3/d during summer in years 2015 and 2020 respectively. In comparison with theoretical TSE demand year 2020, there would be excess TSE with approximate of 67155 and 367918 m3/d in summer and winter respectively. Moreover, in year 2030, the excess TSE would increase to 432193 and 779018 m3/d summer and winter respectively, see fig. (3).

Accordingly, a great effort should be directed toward further upgrade sewage treatment works and increase TSE reuse applications during 2020 – 2030 to cover the gap between projected generated wastewater, TSE availability and theoretical TSE demand especially during the summer time. Moreover, excess TSE management should be arranged during winter time by arranging temporary TSE demand in different applications. In addition, emergency TSE storage lagoons might be considered to balance between the gap.

TSE Application in PWA Construction Works:

In 2008, PWA initiated a demonstration pilot project including upgrading of one sewage treatment work (Al Dhakhirah STW) by ultra filtration UF & reverse osmosis RO units in order to reuse TSE for construction works in two major projects: Doha North STW Project and Al Shamal Road Project [21]. The outcome of this pilot project direct PWA plan to extend TSE reuse into other applications behind irrigation. These TSE reuse applications could be in building works, road works, and construction industry.

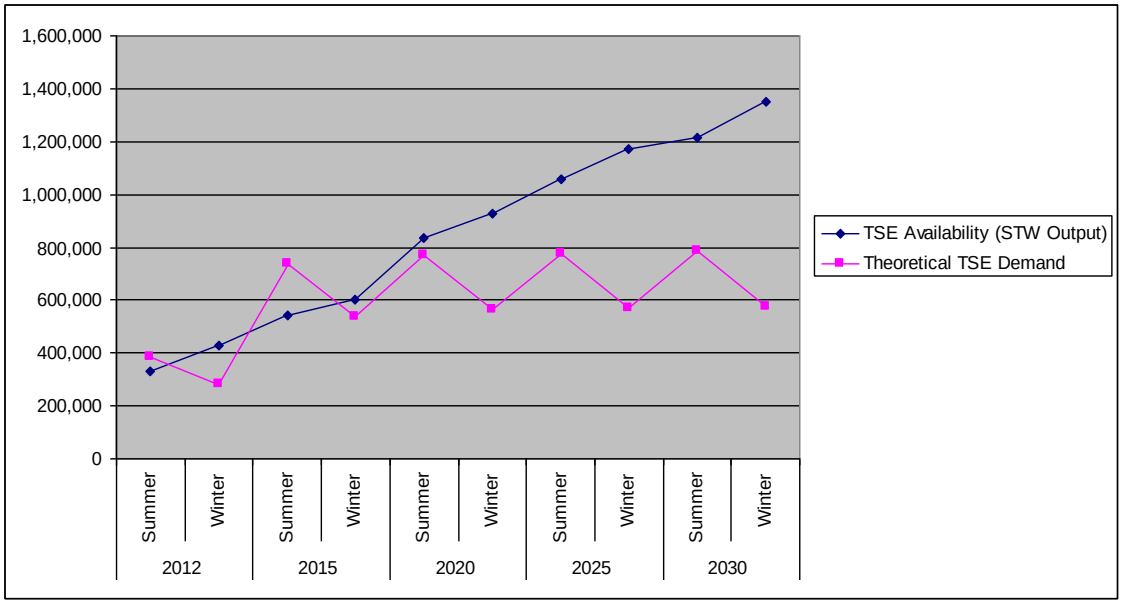


Fig. (3) Projected TSE Availability and TSE Demand, Qatar

Developments of Monitoring Programs:

In 2004, monitoring of PWA drainage facilities was carried out by only one identity such as laboratory belonging to PWA quality section. Daily as well as weekly reports were generated to be used as guide to drainage facilities operators to assess the performance of these facilities respect to the required output based on its design criteria.

In 2005, PWA Environmental section asked drainage operators to initiate their own monitoring tools, to as self monitor programs and to assess drainage facilities performance respect to both design criteria and Qatar environmental law. In 2006, PWA Quality section initiated evaluation tools of local private laboratory respect to their performance towards quality control and quality assurance. The laboratory evaluation tools were initiated by setting laboratory quality manual and quality laboratory evaluation team.

In 2007, PWA drainage facilities operators developed professional contracts with private drainage operator's contractors to take over the responsibility towards operation and maintenance as well as self monitoring of drainage facilities performance respect to both design criteria and Qatar environmental law. During 2008 and 2009, PWA harvested the efforts done during the last three years through settlement professional contracts with private drainage operator's contractors as well as approved private laboratories. Accordingly, monitoring of

PWA drainage facilities was extended to be carried out by not only PWA laboratory quality section but also by approved private laboratories.

In 2010 PWA Environmental section applied 6712FR refrigerator auto samplers on treated water quality effluent generated from main treatment plant facilities. The refrigerator auto samplers are supported by remote monitoring instruments based on: (1) YSI 600 Sonde with pH, Dissolved Oxygen, Conductivity, and Temperature, Total Suspended Solids (TSS), and Ammonia, Probes, (2) 2105G Network Interface Module with built-in GSM/GPRS cellular modem, and includes external magnetic mount antenna.(3) Flowlink Pro software, Stores data in a Microsoft SQL or Oracle central database. The Flowlink Server operates on Windows Server 2003. The remote monitoring instruments support PWA Environmental section by real time daily, weekly and monthly treated water quality reports, which are made available to all PWA concerned parties. Moreover, PWA Quality section developed evaluation tools of local private laboratories considering their certification process regarding achievements of ISO 9001 and ISO 17025 as basis for laboratories approval within PWA laboratories approval list.

Developments of Emergency Storage and TSE Disposal Plan:

During the first year plan 2005-2010, PWA was in development stage of drainage infrastructure, there was still a urgent need to emergency storage lagoons for both crude sewage as well as excess treated sewage effluent generated from sewage treatment works. Accordingly, PWA designed, implemented and operated emergency storage lagoons allocated beside the existing sewage treatment works as well as emergency TSE deep groundwater injection. During the second five year plan (2011-2016) , PWA are in process to rehabilitates three temporary storage lagoons. One lagoon, Abu Nakhla, is allocated by PWA to receive excess treated effluent, while other two lagoons, Al Khore and Karaana, are allocated by municipalities to receive crude sewage transported by tankers. Furthermore, PWA currently is in process to design, implement and operate two temporary package treatment plants (PTPs) in two storage lagoons. The PTPs are distributed in Karaana and Um Barka with design capacities 10000 m3/d each. These PTPs are designed to produce treated effluent comply with environmental law respect reuse for irrigation of forest and trees allocated around the vicinity of these locations. Finally, PWA is in process to design, implement and operate demonstration wetland treatment plant with design capacity 5000 m3/d. The main purpose of the above mentioned projects are not only to protect the environment form pollution attributed to direct disposal of crude sewage, but also to improve the surrounding environment by enhancing the distribution of wetland system, local trees and native vegetations.

Conclusion & Recommendations:

PWA has been taken responsibility to upgrade the existing sewage treatment works to achieve the settled TSE standards for urestricted reuse for irrigation. In the same time, PWA plan for further upgrade the STW projects to extend TSE reuse applications behind irrigation. During these decades, the capacity of STWs will be extended up to 634860, 790410 and 819410 m3/d in years 2013, 2016 and 2030 respectively. The TSE quality will be improved to the higher quality standard to extend the reuse application behind irrigation. In year 2020, it is projected there would be excess TSE with approximate of 67155 and 367918 m3/d in summer and winter respectively. Moreover, in the year 2030, it is projected that the excess TSE would increase to 432193 and 779018 m3/d summer and winter respectively

Further upgrade sewage treatment works and TSE reuse applications should be carried out in parallel to developments of monitoring programs as well as developments of Drainage Master Plan. There are needs to extend TSE reuse in other applications such as building works, road works, and industrial applications as well as cooling purposes. Moreover, excess TSE management plan should be arranged during winter time by arranging temporary TSE demands in different applications. In addition, emergency TSE storage lagoons supported by natural wetland treatment system might be considered to balance the gap.

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المعالجة اللاهوائيه لمياه الصرف الصحي بصنعاء باستخدام محطة تجريبية بنظام مفاعل UASB

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1. الملخص

أدت شحة المياه في مدينة صنعاء إلى زيادة تركيز المواد العضوية في مياه الصرف الصحي الواصلة إلى محطة المعالجة حيث ارتفعت من 500 مجم/لتر سنة 1983 م إلى 1100 مجم / لتر سنة 2000، مما أثر على كفاءة المعالجة رغم أن المحطة فقط قاربت للوصول للحمل الهيدروليكي التصميمي (50000 م3/يوم). هذا التركيز العالي يدفعنا إلى التفكير بإدخال معالجه لاهوائيه تسبق المعالجة الهوائية لتقليل الكلفة. تهدف هذه الورقة -التي استخلصت من بحث الماجستير- إلى دراسة كفاءة المعالجة اللاهوائية لمياه الصرف الصحي باستخدام مفاعل UASB كمحطة تجريبية تمثل المرحله الإبتدائيه لتخفيف الحمل العضوي و تقليل كلفة المعالجة التي تتم حاليا بطريقة التهوية الممتدة للحمأه المنشطة. يعتبر مفاعل UASB أحد أنظمة المعالجة اللاهوائيه لمياه الصرف الصحي الذي يتم فيه تقليل التراكيز العالية للمواد العضوية في مياه الصرف الصحي من خلال مرورها من أسفل المفاعل إلى أعلاه خلال طبقات من الحمأه الغنية بالبكتيريا اللاهوائيه التي تعمل على هضم المواد العضوية الموجودة في مياه الصرف الصحي و ينتج عن هذه العملية تصاعد غاز الميثان الذي يمكن استغلاله كطاقة. و من مميزات هذا النظام اقتصاديته في الإنشاء و التشغيل والصيانة حيث لا يحتاج إلى ميكنة و طاقة بل ينتج طاقه ويستخدم هذا النظام في معظم دول العالم لمعالجة مياه الصرف الصحي ذو التراكيز العالية خاصة في التجمعات السكانية الصغيرة. تم تصميم مفاعل UASB كمحطه تجريبيه من الحديد المجلفن وتشغيله في محطة معالجة مياه الصرف الصحي بمدينة صنعاء، الجمهورية اليمنية كمرحلة ابتدائية تسبق الأحواض الهوائية. تم إضافة الحمأة البادئة كخميرة لتنشيط البكتريا اللاهوائيه من مشروع إنتاج الغاز الحيوي من مخلفات الأبقار في المعهد البيطري بصنعاء. تم تشغيل مفاعل UASB على مراحل لمدة 83 يوم، المرحلة الأولى لمدة 45 يوم بتطبيق جريان مستمرقدره 23.46 لتر/ ساعه مع فترة مكوث 24 ساعة بغية الوصول إلى حالة الاستقرار ثم تم تشغيله كمرحله ثانيه لمدة 38 يوم في الفترة من 8 أغسطس إلى 14 سبتمبر 2009م على ثلاث فترات مكوث (HRT) مختلفة: 24, 12 و6 ساعات والتي نتج عنها ثلاث سرعات صعود الماء في المفاعل قدرها: 0.073 م/ ساعة , 0.146 م/ ساعة و 0.292 م/ساعة، على التوالي. تم أخذ عدد 23 عينة مياه صرف صحي من المدخل و نفس العدد من المخرج لمفاعل UASB وذلك لقياس COD خلال فترات المكوث الثلاثه. كما تم أخذ عينتين من الحمأة من أسفل مفاعل UASB لقياس المواد الصلبة الكلية و الذائبة و المتطايرة عند فترة مكوث 24 ساعة. تم فحص عينات مياه الصرف الصحي و الحمأه في المختبر التابع للمحطة طبقا للطرق القياسية المتبعة. تراوحت كفاءة إزالة COD للمفاعل (8 ± 61)% عند فترة مكوث 24 ساعة و (7 ± 50)% عند فترة مكوث 12 ساعة و (4 ± 45) % عند فترة مكوث 6 ساعات. أما عينات الحمأة فقد كانت نتائجها: TS=56.4±8.5g/L , TVS= 38.8±7.5g/L , TFS=17.6±1.0g/L مما يعني أن الحمأه تحتوي أكثر من 50% منها على

مواد بكترية.كما ظهرت فقاعات غاز الميثان في السطح العلوي لمياه الصرف الصحي داخل مفاعل UASB أثناء التشغيل كمؤشر لتصاعد الغاز. هذه النتائج تمكننا من الاعتماد على هذا النظام في تقليل كلفة معالجة الصرف الصحي بصنعاء. يوصي الباحثون بالاستمرار في دراسة كفاءة المفاعل التجريبي لإزالة COD و BOD وذلك للحصول على نتائج أكثر في مرحلة استقرار المفاعل. كما يجب توفير جهاز قياس غاز الميثان لمعرفة كمية الغاز الناتجة عن المعالجة وجدوى استخدامه كطاقة وتطبيق هذا النظام في المناطق الحضرية والريفية في اليمن.

مفاتيح كلمات: UASB، معالجه لاهوائيه، صنعاء، فترة مكوث، سرعة صعود

2. المقدمة

أدت شحة المياه في مدينة صنعاء إلى زيادة تركيز المواد العضوية في مياه الصرف الصحي الواصلة إلى محطة المعالجة حيث ارتفعت من 500 مجم/لتر في سنة 1983 م إلى 800 مجم/لتر في عام 1995 م و بلغت 1100 مجم / لتر في سنة 2000 م [1]، مما أثر على كفاءة المعالجة رغم أن المحطه فقط قاربت للوصول إلى الحمل الهيدروليكي التصميمي (50000 م3/يوم). هذا التركيز العالي دفع المؤسسة المحلية للمياه و الصرف الصحي بصنعاء إلى التفكير بإدخال معالجه ابتدائية على شكل احواض ترسيب ابتدائيه تسبق المعالجة الهوائية لتخفيف الحمل العضوي على المرحله الهوائيه. كما يعتبر إدخال نظام مفاعل UASBأيضا حلا مثاليا لتخفيف تركيز الحمل العضوي وإنتاج طاقه يمكن الاستفادة منها. ومن ضمن المميزات أن نظام مفاعل UASB يحتاج لإنشاءه إلى مساحة أقل من احواض الترسيب مما يوفر على الدولة صرف تعويضات عن الأراضي المستخدمة كما تحتاج إلى شراء مولد لتوليد كهرباء لتشغيل المحطة لاحقا وكذلك صيانة مستمرة للأجهزة الميكانيكية للمحطة و ذلك بواسطة مهندسين متخصصين.[2]. تطورت نظم المعالجة اللاهوائيه لمياه الصرف الصحي واستحدث نظام مفاعلUASB تتم المعالجة في المفاعل UASB بواسطة بكتيريا لاهوائيه تقوم بتحليل المواد العضوية إلى غازات (CO_2,CH_4) تستخدم كطاقة بنسبة (90 - 95%) وحمأه (Sludge) بنسبة(5- 10%) تستخدم كسماد[3] وبالتالي تعتبر طريقه المعالجة اللاهوائيه UASB من الطرق المتقدمة لمعالجه المواد العضوية في مياه الصرف الصحي و هذه الطريقة لا تحتاج إلى الطاقة والميكنة بل على العكس نحصل منها على طاقه من غاز الميثان المتصاعد . بدا استخدام نظام مفاعلUASB في عام 1970م من قبل العالم Gatze Lettinga واثبت كفاءة في تخفيف تركيز المواد العضوية (COD, BOD) بنسبه كبيره لذا تم إدخال هذا النظام للمعالجة في مناطق مختلفة من العالم. لذا اعتبر نظام المعالجة اللاهوائيه باستخدام المفاعل UASB جزء هام من منظومة المعالجة لمياه الصرف الصحي لتخفيف تركيز المواد العضوية (BOD) وكذلك تخفيف العوامل الممرضة .و يتحقق التلامس الجيد بين مياه الصرف المراد معالجتها والحماه التي تحتوى على البكتيريا اللاهوائيه النشطة بـأي غذاء يتوزع بشكل منتظم أسفل المفاعل والاضطراب الذي يحدث بسبب الغاز الطبيعي المنتج وسرعة الصعود الكبيرة .عند ضخ مياه الصرف من أسفل الخزان صعود المياه إلى أعلى الخزان بسرعة محدده وتمر خلال طبقة الـ (sludge) الموجود فيها البكتيريا اللاهوائيه فتقوم باستهلاك المواد العضوية وينتج غاز الميثان وغاز ثاني أكسيد الكربون [4].

يتميز مفاعل UASB عن بقية الأنظمة بمعالجته لمياه الصرف ذو التراكيز العالية و بكفاءتة العالية في إزالة الملوثات كما أنه لا يحتاج إلى ميكنة و بالتالي فهو ذو تكلفة بناء و تشغيل و صيانة منخفضة و معدلات التحميل العضوي أعلى بكثير من أنظمة المعالجة الطبيعية مما يجعلها تحتاج إلى مساحات أقل بكثير من طرق المعالجة الطبيعية كما ينتج عن المعالجة غاز (CO_2 + CH_4) كمصدر للطاقة و يخفض الحمأه (sludge) و لا يحتاج إلى إضافة أكسجين لعملية المعالجة . لا يحتاج إلى عمالة مدربة (تدريب عالي) [4].

المعايير التصميميه لمفاعل UASB:

- سرعة صعود المياه Vup < 3 m/h ,و سرعة الخروج Vout < 3 m/h
- تتم المعالجة في خزان (reactor) يصمم على فترة مكوث للمياه من hr (6-24) وعمق الخزان (2.5m) وفى أسفل الخزان طبقه من الأوحال بها بكتيريا لاهوائيه نشطه (sludge) .

3. الهدف من البحث :-

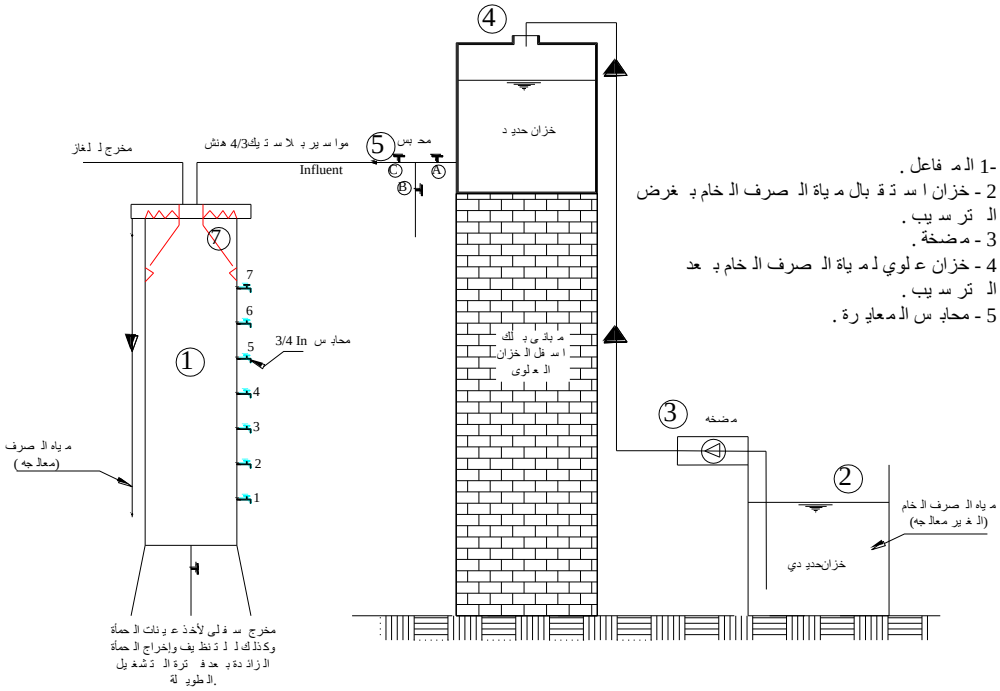
دراسة كفاءة المعالجة اللاهوائية لمياه الصرف الصحي بصنعاء باستخدام محطة تجريبية بنظام مفاعل UASB .

4. منهجية البحث

4- 1 : مرحلة تصميم مفاعل (UASB) و ملحقاتة :-

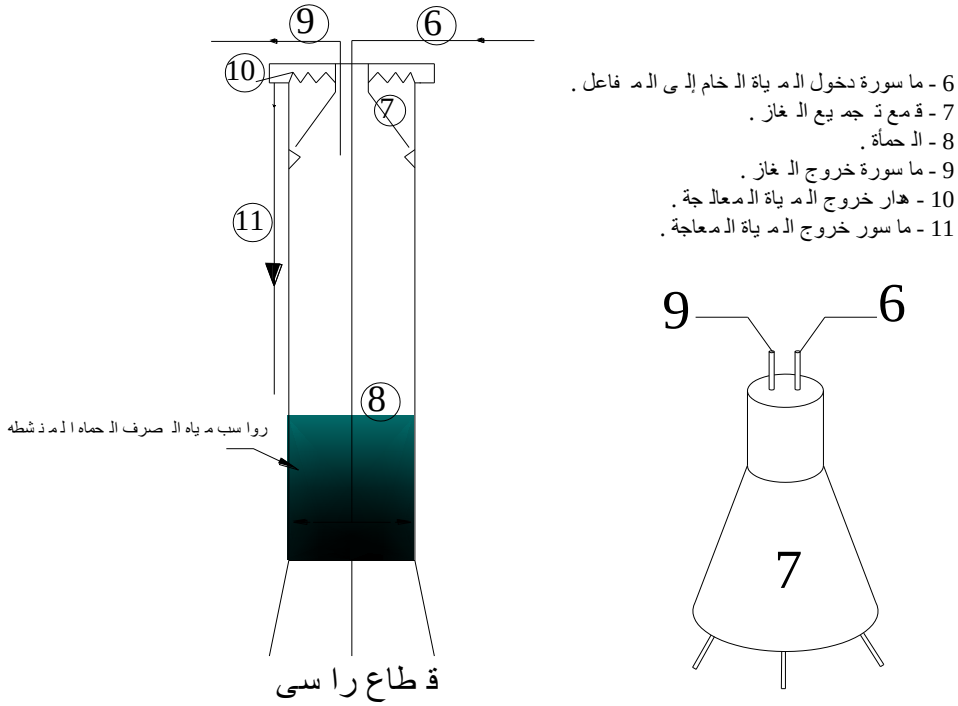
تم أخذ شكل ال (Reactor) من تصاميم العالم الهولندي (Lettinga)
الذي بداء فكرة المفاعل عام 1970 م .
وتم صنع المفاعل لهذا من مادة الحديد المجلفن فى ورشه للحديد تقع على شارع الستين الشمالي – صنعاء – الجمهورية اليمنية بالمقاسات التالية :

- القطر = 64 cm .
- الارتفاع = 250 cm .
- قطر القمع = 54 cm .
- المسافة بين مسند القمع و القمع = 5cm بواسطة 6 ركائز طولها 5 cm .



شكل (1) يبين مكونات المحطة التجريبية ل (UASB Reactor)

صورة (1) مفاعل UASB مع ملحقاته



شكل (2) يبين مكونات ال(UASB reactor)

5-1- مرحلة تصنيع و إنشاء مفاعل UASB اللاهوائى:

1-تم تجهيز المفاعل مع الملحقات و تركيبة بحسب الشكل1 و الصورة 1

2-تم نقل المفاعل إلى محطة المعالجة الرئيسية بأمانة العاصمة و تم وضعة جوار مدخل مياه الصرف الصحي الخام إلى المحطة تم بناء قاعدة للخزان العلوي بارتفاع 3.6 م من مباني بلك 15 سم الغرض من ذلك أن يتم دخول الماء للمفاعل بالجاذبية الأرضية .

3-تم توريد وتركيب خزان علوي بحجم 1 م 3 وخزان سفلي بحجم 1 م 3 .

4-تم تركيب دينامو قدرة ½ حصان لرفع الماء من الخزان السفلي إلى الخزان العلوي وتجهيز أعمال السباكة و توصيل المواسير و تركيب المحابس و المضخة بين الخزان السفلي و الخزان العلوي و بين العلوي و المفاعل و بين المفاعل و مدخل المحطة (للمياه الخارجة من المفاعل بعد المعالجة) .

5- تم توفير مضخة كبيره لرفع المياه الخام من المدخل إلى الخزان السفلي و توفير رافعة و توفير وايت للمياه العذبة لتنظيف الخزانات و المفاعل و تعبئة المفاعل بالمياه النقية عند بدء التشغيل (هذه المعدات تابعة لمحطة المعالجة).

5-2- تجهيز و تشغيل نظام مفاعل UASB :-

تجهيز الحمأه :-الحمأة : هي عبارة عن الترسبات الناتجة عن تركيز وترسيب مياة الصرف و تم تحضيرها بالطريقة التالية :-

1) تم تعبئة ال (Reactor) بمياه الصرف الخام و تم ترك الخزان لمدة يوم كامل وفي اليوم التالي تم فتح المحابس جميعها ماعدا الفتحة السفلية لل (Reactor) .
2) تم تكرار العملية السابقة في اليوم الثالث تم فتح جميع المحابس ما عدا المحبس رقم 1 من الأسفل و تكررت العملية بنفس الطريقة حتى المحبس رقم 3 بحيث أنة تم ملئ أكثر من ثلث ال (Reactor) من الحمأة .
3) تم أخذ 10L من الحماة الغنية بالبكتيريا اللاهوائيه من المعهد البيطري – (مشروع إنتاج الغاز من مخلفات الحيوان) (خميرة للحمأه الموجودة) لإنتاج بكتيريا الميثان داخل ال (Reactor) وتم إضافتها للحمأة الموجودة.

صورة (2) إضافة الحمأه (الخميرة) في المفاعل

4) لدخول مياه الصرف الخام المراد معالجتها إلى داخل المفاعل بالتدفق المطلوب تم وضع خزان معدني سعة1m3 فوق بناء من البلك فى منسوب اعلي من منسوب المفاعل بمقدار (0.2m) ليحدث تدفق ذاتي (بالجاذبية الأرضية) .
5) تم تعبئة الخزان العلوي بمياه الصرف من الخزان السفلى بواسطة مضخة كهربائية .
6) الخزان السفلى يعبأ بمياه الصرف بواسطة (مضخة كبيرة) تابع للمحطة تقوم بشفط المياه من مدخل المحطة وضخها إلى الخزان السفلي .
7) تم توصيل الخزانين السفلى والعلوي بمواسير بلاستيك و مضخة كهربائية.
8) تم توصيل الخزان العلوي مع المفاعل بمواسير بلاستيك مع المحابس لمعايرة دخول مياه الصرف إلى المفاعل بالتدفق المدروس .
9) تم تشغيل المفاعل وعلى فتره المكوث التصميمية (36h) بعد احتوائه على الكميه الكافية من الحمأه الفعالة وبارتفاع لا يقل عن 1/3 ارتفاع المفاعل.

صورة (3) معايرة التدفق (Q) حسب فترة المكوث المطلوبة وكذلك أخذ عينات للمياه الداخلة للمفاعل

10) مرحلة الاستقرار :- تم ضبط التدفق للمفاعل على فترة مكوث (36) ساعة و تمت التعبئة للمفاعل من مياه الصرف الخام و استمرت تعبئة الخزانات بانتظام لمدة شهر كامل حتى تتكون البكتيريا اللاهوائيه .
11) تم تعبئة المفاعل بمياه نقية ثم بمياه صرف مخففة بمياه نقية لمدة أسبوعين ثم بمياه الصرف الصحي (فترة المكوث 36 ساعة) .
12) تم تشغيل المفاعل على فترات مكوث 24 ,12 ,6 ساعات
13) تم أخذ عينات لاختبار COD لعينات الداخل و الخارج من المفاعل و ذلك بعد شهر (الوصول إلى حالة الاستقرار و التفاعل الطبيعي لبكتيريا الميثان) .
14) تم اخذ النتائج و عملها في جداول و رسوم بيانية .

5-3-1- حساب كميه التدفق المطلوب تدفقها الى المفاعل (Q) (التصميمية) .

المساحة السطحية للمفاعل A= 0.322m2 , حجم المفاعل V= 0.804m3

الحجم الفعلي Vac=0.563m3, نفرض فتره المكوث HRT3=6 ,HRT2 =12hr ,HRT1=24hr

* كميه التدفق(Q) :

Q3= 93.83L/hr, Q2= y=46.92L/hr, Q1=V/HRT2 =23.46 L/hr

* سرعه التدفق المطلوبه(v)

V3 = 0.292 m/hr, V2 = 0.146 m/hr, V1 =Q/A= 0.073 m/hr <3m/hr (Safe)

مساحه مقطع ماسورة التغذية (قطر 4/3) هنش = 2.85 سم2

المساحة السطحية للخروج مابين جدار المفاعل و محيط القمع (A2) :

قطر المفاعل = 64cm, قطر القمع = 55cm

A2= (0.64^2-0.55^2)*3.14/4=0.094m2

سرعه الخروج: V1-2=0..257m/hr , V2-2=0.514m/hr , V3-2=1.028m/hr < (2-3) Ok

3-5- التحاليل المعمليه:-

1- قياس كميات المواد الصلبه الكليه Total Suspended Solid (TSS)

الحمأه : العينه الماخوذه 25ml من أسفل المفاعل.

2- قياس كميات المواد الصلبه الكليه (المتطايره والذائبه والعالقه) TS

الحماة :-العينة الماخوذه 50ml من أسفل المفاعل :

3- قياس كمية المواد العضوية الكلية COD

1) بعد وصول المفاعل إلى حالة الإستقرار تم أخذ العينات يوميا من المياه الداخلة للمفاعل من المحبس

(B) ما بين الخزان العلوي و المفاعل .

2) و تم أخذ العينات للمياه الخارجة من المفاعل من انبوب الخروج يوميا و كان يتم مراجعة (HRT) يوميا بواسطة انبوب مدرج مع ساعة إيقاف و تصحيحه بطريقة المحاولة و الخطاء .

3) تم أخذ العينات عند فترات مكوث مختلفة (24 , 12 , 6) ساعات .(عينات من المخرج و المدخل)

5. النتائج

1- كمية المواد الصلبه الكليه Total Suspended Solid (TSS)

1- الحماه :-العينة الماخوذه 25ml من أسفل المفاعل .

W1(ورقة الترشيح)	W2(ورقة الترشيح +المواد الصلبه)	W2-W1)/25*10^6 (TSS
0.3336g	0.4618g	5128mg/L

2- من المياه الخارجة المعالجة :-

العينة الماخوذه 25ml من أعلى المفاعل: يتم عمل نفس الخطوات السابقة

W1(ورقة الترشيح)	W2(ورقة الترشيح +المواد الصلبه)	W2-W1)/25*10^6 (TSS
0.346g	0.35518g	204 mg/L

2- قياس كميات المواد الصلبه الكلية (المتطايرة والذائبة والعالقة) TS

1 - الحماه (من اسفل المفاعل):-العينة الماخوذه 25 ml

W1 (الجفنه فارغة)	W2 (الجفنه +المواد الصلبة)	W3 (الجفنه +المواد الصلبة الغير متطايرة)	TS=(W2-W1)/ 25 *10^6 الكلية	TVS=(W2-W3)/ 25 *10^6 الذائبة	TFS=(W3-W1) / 25 *10^6 المتطايرة
45.6447g	46.8461g	46.0628g	47908 mg/L	31292 mg/L	16616 mg/L

$$TVS= \frac{31292}{47908} *100\% = 65.3\%$$

2- الحماه (الخميرة): العينة الماخوذه 10 ml

(الجفنه W1 فارغة)	(الجفنه W2 +المواد الصلبة)	(الجفنه W3 +المواد الصلبة الغير متطايرة)	TS=(W2-W1)/ 10 *10^6 الكلية	TDS=(W2-W3)/ 10 *10^6 الذائبة	TFS=(W3-W1) / 10 *10^6 المتطايرة
0.3437g	0.9929g	0.5300	64920mg/L	46290mg/L	18630mg/L

$$TVS= \frac{46290}{64290} *100\% = 71.3\%$$

3- الحماه (من ال (Thickener):- العينة الماخوذه 10 ml

(الجفنه W1 فارغة)	(الجفنه W2 +المواد الصلبة)	(الجفنه W3 +المواد الصلبة الغير متطايرة)	TS=(W2-W1)/ 10 *10^6 الكلية	TVS=(W2-W3)/ 10 *10^6 الذائبة	TFS=(W3-W1) / 10 *10^6 المتطايرة
0.3454g	0.7674g	0.3955	42200mg/L	37190mg/L	5010mg/L

$$TVS= \frac{37190}{42200} *100\% = 88.1\%$$

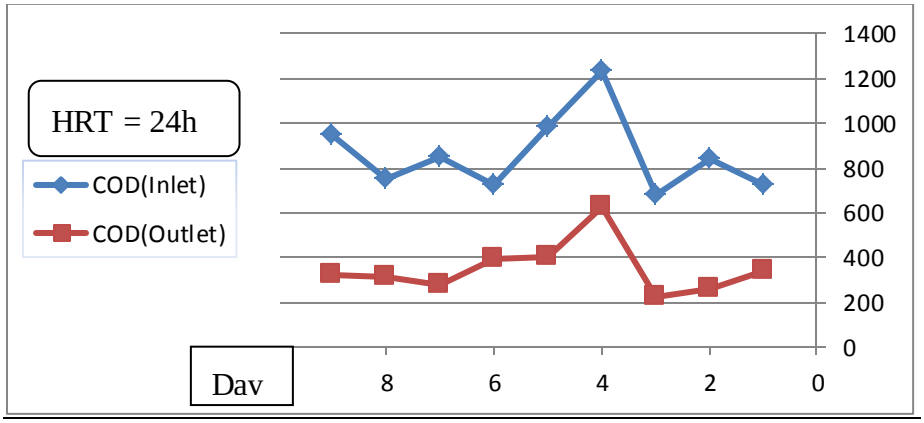
3- قياس كميه المواد العضويه الكليه COD:-

جدول (1) يوضح قيم(COD) لمياه الصرف قبل و بعد المعالجة في المفاعل

م	HRT	Inlet COD)	Outlet (COD)	كفاءة المعالجة
1	24	720	340	52.78%
2	24	840	260	69.05%
3	24	680	224	67.06%
4	24	1236	628	49.19%
5	24	984	404	58.94%
6	24	720	395	45.14%
7	24	850	280	67.06%
8	24	750	315	58.00%
9	24	950	325	65.79%

جدل (1) يوضح قيم COD للعينات التي تم فحصها لفترة مكوث 24 ساعة

COD Value mg/l

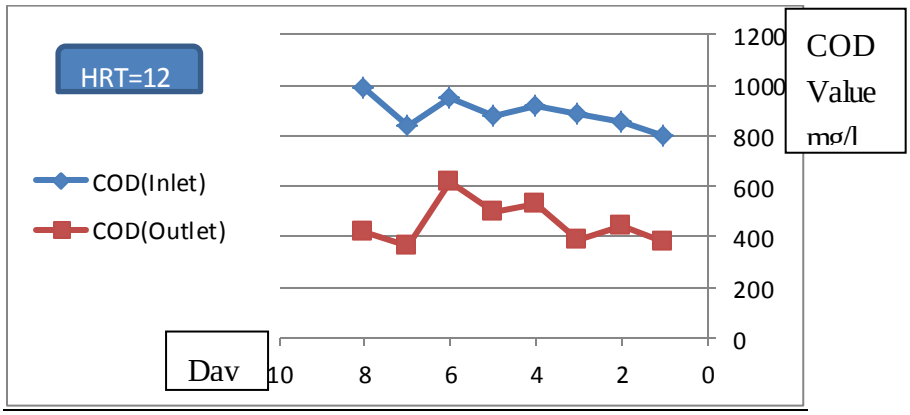


الشكل (3) رسم بياني لقيم CODللعينات التي تم فحصها لفترة مكوث 24 ساعة

فترة المكوث (12) ساعة

م	HRT	Inlet COD)	Outlet (COD)	كفاءة المعالجة
1	12	800	380	52.50%
2	12	856	440	48.60%
3	12	884	388	56.11%
4	12	920	528	42.61%
5	12	880	500	43.18%
6	12	950	620	34.74%
7	12	840	368	56.19%
8	12	990	420	57.58%

جدل (2) يوضح قيم COD للعينات التي تم فحصها لفترة مكوث 12 ساعة

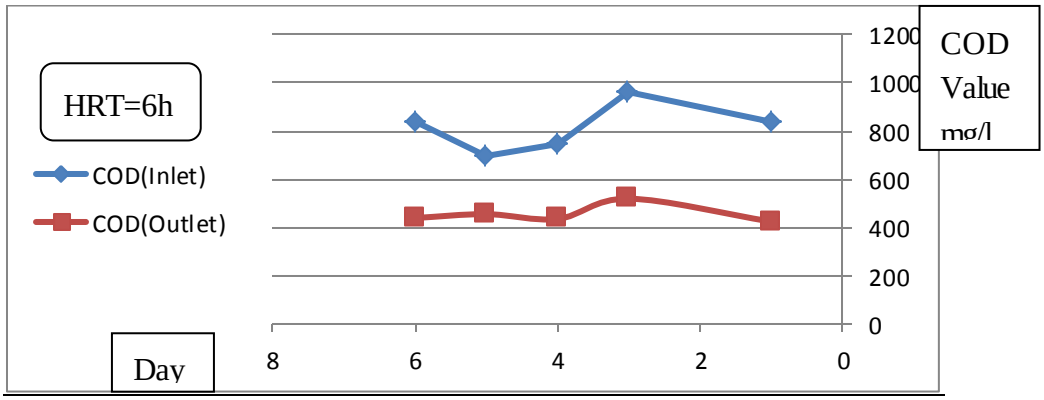


الشكل (4) رسم بياني لقيم COD للعينات التي تم فحصها لفترة مكوث 12 ساعة

فترة المكوث (6) ساعات

م	HRT	Inlet COD)	Outlet (COD)	كفاءة المعالجة
1	6	835	425	49.10%
2	6	960	520	45.83%
3	6	750	436	41.87%
4	6	700	456	34.86%
5	6	840	440	47.62%
6	6	835	425	49.10%

جدل (3) يوضح قيم COD للعينات التي تم فحصها لفترة مكوث 6 ساعات



الشكل (5) رسم بياني لقيم COD للعينات التي تم فحصها لفترة مكوث 6 ساعات

3 – ظهور فقاعات من غاز الميثان (الغاز الحيوي) حول القمع المجمع

صورة(4) توضح القمع مع فقاعات الغاز المتصاعد (CH4)

6. المناقشة والاستنتاج

1) تم مشاهدة فقاعات الغاز الحيوي الناتج من التفاعلات البيولوجية داخل المفاعل و لكن لم يتم قياس كمية الغاز الناتج عن المعالجة داخل المفاعل (غاز الميثان) لعدم توفر الجهاز المطلوب.
2) من خلال النتائج في الجداول (1 , 2, 3) وجد أن كفاءة المفاعل من 34% - 67 % و هذه نتيجة مشجعة لتطبيق هذا النظام في معالجة مياه الصرف الصحي .
3) استخدام مفاعل UASB منتشر في جميع الدول و يستخدم لمعالجة المياه للتجمعات السكانية الصغيرة حيث لا يحتاج إلى طاقة بل و ينتج طاقة و لسهولة التشغيل و الصيانة و لعدم وجود ميكنة , يستخدم لمعالجة المياه الصناعية و كذلك يستخدم لمعالجة المياه ذو التراكيز العالية ل COD.
4) تمت مقارنة التجربة بتجربة مماثلة في إيران [5] نظرا للتشابه الكبير بين التجربتين من حيث حجم المفاعل و درجة الحرارة وفترة المكوث و بحسب الجدول التالي :

وجه المقارنة	نتائج تجربة إيران	نتائج تجربة هذا البحث
حجم مفاعل UASB(م3)	0.848	0.804
HRT(ساعة)	2,4,6,8,10	6,12,24
درجة الحرارة (درجة مئوية)	صيفا 26 , شتاءا 22	21 درجة مئوية متوسطة لفترة البحث
متوسط COD inlet عند فترة مكوث 6 ساعات	406	820
متوسط COD outlet عند فترة مكوث 6 ساعات	260	450
متوسط كفاءة المعالجة	36%	45%

جدول (4) مقارنة بين بيانات التجربة في إيران و التجربة في هذا البحث

من خلال الجدول (4)يوضح أن كفاءة المعالجة في هذا البحث أكبر من كفاءة المعالجة في نتائج التجربة الإيرانية مما يبين أن كفاءة مفاعل UASB قد تزيد بزيادة تركيز COD في مياه الصرف الصحي الداخل للمفاعل حيث أن متوسط COD inlet عند فترة مكوث 6 ساعات للتجربة الإيرانية هو (406 mg/l) بينما متوسط COD inlet عند فترة مكوث 6 ساعات للتجربة اليمنية هو (820 mg/l) .

5) تمت ايضا مقارنة التجربة بتجربة مماثلة في الهند [6] بحسب الجدول التالي :

وجه المقارنة	نتائج تجربة الهند	نتائج تجربة هذا البحث
حجم مفاعل UASB(م3)	0.001	0.804
HRT(ساعة)	24	6,12,24
درجة الحرارة (درجة مئوية)	---	21 درجة مئوية متوسطة لفترة البحث
متوسط COD inlet عند فترة مكوث 24 ساعات	1200	820
متوسط COD outlet عند فترة مكوث 24 ساعات	310	352
متوسط كفاءة المعالجة	74%	61%

جدول (5) مقارنة بين بيانات التجربة في الهند و التجربة في هذا البحث

من خلال الجدول (5) يوضح أن كفاءة المعالجة في هذا البحث أقل من كفاءة المعالجة في نتائج التجربة الهندية مما يبين أن كفاءة مفاعل UASB قد تزيد بزيادة تركيز COD في مياه الصرف الصحي الداخل للمفاعل حيث أن متوسط COD inlet عند فترة مكوث 24 ساعة للتجربة الهندية هو (1200 mg/l) بينما متوسط COD inlet عند فترة مكوث 24 ساعة لتجربة هذا البحث هو mg/l (820) .

6) تمت ايضا مقارنة التجربة بتجربة مماثلة في البرازيل [7] بحسب الجدول التالي :

وجه المقارنة	البرازيل	تجربة بحثنا
حجم مفاعل UASB(م3)	67.5	0.804
HRT(ساعة)	7	6,12,24
درجة الحرارة (درجة مئوية)	16 شتاءا, 23 صيفا	21 درجة مئوية متوسطة لفترة البحث
متوسط COD inlet عند فترة مكوث 24 ساعات	793	820
متوسط COD outlet عند فترة مكوث 24 ساعات	311	450
متوسط كفاءة المعالجة	56%	45%

جدول (6) مقارنة بين بيانات التجربة في البرازيل و التجربة في هذا البحث

من خلال الجداول و المقارنات مع تجارب اخرى فانه يعطي دلالة على أن ما تم عمله في هذا البحث يعتبر خطوة جيدة للاستمرار في البحث للوصول إلى نتائج أفضل كي يمكن تطبيقها بمحطات معالجة واقعية ذو اقتصادية أعلى و كلفة أقل .

7) استخدام مفاعل UASB منتشر في جميع الدول و يستخدم لمعالجة المياه للتجمعات السكانية الصغيرة حيث لا يحتاج إلى طاقة بل و ينتج طاقة و لسهولة التشغيل و الصيانة و لعدم وجود ميكنة

7. التوصيات

1) ضرورة الاستمرار في أخذ العينات و التدقيق على المدخلات حتى نصل إلى نتائج أدق لإمكانية تطبيق هذا النظام و الاستفادة من مميزات هذا النظام و التقليل من عيوبه ومعالجتها .
2) نوصي بتطبيق هذا النظام في معالجة مياه الصرف الصحي في المناطق ذوات درجة الحرارة العالية والإشعاع الشمسي الكبير حيث أن هذين العاملين يسرعان في عملية المعالجة و زيادة كفاءتها و كذلك إنتاج طاقة من غاز الميثان الناتج من عملية المعالجة داخل المفاعل .
3) ضرورة تصنيع مفاعل آخر للمقارنة مع المفاعل الحالي .
4) ضرورة التعديل في طريقة عمل المفاعل حتى يكون أقرب للواقع وذلك بالخطوات التالية :
   a) استبدال الخزانات العلوي والأرضي بمضخة صغيرة مخصصة لمياه الصرف بحيث تعطي التدفق المطلوب لمياه الصرف الصحي الداخلة للمفاعل و تمنع وقوع الانسداد في الأنابيب للمياه الداخلة .
   b) عدم الضخ من المدخل إلى المفاعل مباشره بل يتم الترسيب وحجز الرواسب والرمال أولا .
5) الاهتمام بعمل البحوث في هذا المجال من قبل جامعة صنعاء (مركز المياه والبيئة) و وزارة المياه و البيئة و الجهات ذات العلاقة لإيجاد تقنية أفضل و أقل تكلفة في معالجة مياه الصرف
6) ضرورة إشراك القطاع الخاص في هذه البحوث و ذلك لمعالجة مياه الصرف الصناعية بهذه التقنية القليلة الكلفة كما في البلدان الأخرى .
7)

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Reusing Treated Wastewater in Muscat: Social Survey

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Abstract

Currently, about 70,000 m^3/day of treated wastewater is produced in Muscat, Oman by Haya Water Co.. Muscat Municipality is partially utilizing the treated effluents (TE) in landscape irrigation. However, disposing of the remaining TE in an environmental friendly way is a major concern for Haya Water and relevant authorities. Furthermore, reusing excess TE produced from the current treatment plants and the future ones in sustainable, economical and environmental friendly ways is very important since TE is considered as an important water resource in this region due to scarcity of natural water resources. The main objective of this research project is to implement a comparative study on potential reuse options for the treated wastewater produced by Haya Water Co.. These options include: urbane reuse, agriculture reuse, industrial reuse, groundwater recharge, and energy generation. The guiding goal for this project is to promote the conservation of the country's water resources by recycling treated municipal wastewater for different potential uses, which should lower demand on finite water resources, support business and growth, and introduce reliable and potentially lower cost water sources for industry in the long-term. A Social survey was conducted to collect the opinions of people living in Muscat. About 115 houses chosen randomly to cover different regions in Muscat were included in this study. The results showed that the public have a general understanding about the different water and wastewater terminologies. Also, the results indicated a gap of knowledge that might affect the public's perspective towards wastewater nature, treatment and reuse. However, the respondents were very positive to support any potential reuse option that helps in either or all the following aspects: prevent pollution, protect human health, be a long term solution, energy efficient, financially sound, protect wild life or has low green house emissions. The majority of the respondents were positive about the reuse of the treated effluent in irrigation purposes and urban practices followed by groundwater recharge and industrial reuse. The least preferred reuse options were irrigation agricultural crops, discharge to marine environment and reuse as drinking water.

Keywords: treated wastewater, social survey, reuse wastewater, sustainable environmental management

Introduction

The reuse of wastewater in domestic and agricultural applications has been ongoing since historical times. However, planned reuse has attracted importance during the past two or three decades as the demands for water dramatically increased due to technological advancement, population growth, industrialization, and urbanization, which put great stress on the natural water cycle. Consequently, a number of wastewater professionals are calling for more proper and planned reuse of treated wastewater as they found it to be a viable and reliable alternative water source, in future. Several pioneering studies have provided the technological confidence for the safe reuse of treated effluents for beneficial uses. Although, initial emphasis was mainly on reuse for agricultural and non-potable reuses, recent trends have proven that such effluents can be used in industry, energy production, restoration of saline aquifers, potable reuses and many other direct reuse opportunities to applications closer to the point of generation.

In Oman, "Haya Water Co." is a government company that is responsible for building, operating, and managing wastewater projects in Muscat Governorate. It is expected that by the year 2018, 80% of Muscat households be connected by sewer network with state-of-the-art treatment plants. Accordingly, tremendous amounts of generated treated wastewaters that may reach several millions of cubic meters is anticipated by Haya Water (more than 100,000 m^3/d by 2012 and 160,000 m^3/d by 2020). Therefore, the company is exploring the best options for disposing or reusing such large volumes of treated wastewater. Although, wastewater effluent is typically discharged to a receiving stream or a land application system, wastewater effluent can also be beneficially used for a variety of purposes. This study aims at exploring and comparing different options for reusing and recycling of treated wastewater in Muscat area. In particular, the study will concentrate on six possible options for reusing the effluents from wastewater treatment plants: urbane reuse, industrial reuse, agricultural reuse, groundwater recharge, power generation, and potable reuses. Furthermore, this paper is providing results obtained from a social survey study.

Possible Wastewater Reusing Options

A brief review the applications of treated effluents mentioned in the above options is provided below.

Urban reuse

The reuse of treated wastewater is common in urban settings. Many countries around the world, including some in the Middle East, had adopted methods to maximize the urban reuse of wastewater (Lu and Leung, 2003). Typical urban reuse of wastewater applications includes

irrigation of public lands such as parks, golf courses, athletic fields, highway medians and shoulders, landscaped areas for commercial properties and landscaping for residential areas. Other applications could include vehicle washing facilities, laundry facilities, fire protection, toilet flushing in commercial building, decorative water features such as street fountains and reflecting, street sweeping, dust control and for construction projects (Lu and Leung, 2003). In certain regions such as southern Europe and the Mediterranean region, most such projects are designed to compensate for local and occasional water deficiencies, and to preserve the quality of the environment (Lu and Leung, 2003). Furthermore, urban non-potable reuse (irrigation of green areas, waterfalls, fountains, road cleaning, car wash, toilet flushing and fire fighting) is developing quickly and is becoming an important element in integrated water management (IWM) policies in high-density urban areas in the United States, Japan, Egypt, Tunisia, Morocco, and the UAE (Bouwer, 2000; Lazarova *et al.*, 2001).

Agricultural reuse

Almost two thirds of the world water use, including all the water diverted from rivers and pumped from underground, is used for irrigation purposes. Hence, if the world is facing a water shortage then it is facing a food shortage as well (Kretschmer *et. al.*, 2003). Critical situation is particularly clear in the Middle East and North Africa as most of the conventional water resources have already been exploited in Saudi Arabia, the United Arab Emirates, Oman, Qatar, Kuwait, Bahrain, Yemen, Jordan, Palestinian Territories and Libya and it is predicted that it will be fully exploited in a number of other countries within the next decade (Kretschmer *et. al.*, 2003). For Oman and other semi-arid and arid regions where current fresh water reserves are at a critical limit, recycled wastewater is the only affordable alternative water resource for agricultural purposes (Kretschmer *et. al.*, 2003).

Therefore, planning and management of wastewater for agricultural reuse projects need to consider institutional and legal, socio-economic, financial, environmental, technical and psychological aspects (Lazarova et al., 2001). Many countries that are implementing agricultural reuse of wastewater or working on implementing it in the future need to study in more details the aspects they require in order to develop appropriate strategies and qualified bodies for local management of wastewater treatment and reuse projects. A major disadvantage in implementing agricultural reuse of wastewater in developing countries is often the lack of the institutional settings and guidelines or measures to be able to implement and plan the wastewater reuse projects (Valencia et al., 2011).

Industrial reuse

It is estimated that industries consume almost 10% of the world's water use, and this figure is expected to increase, especially in developed countries, where industries are continuously expanding to meet the demands of the market. The industries that produce metals, wood and paper products, chemicals, gasoline and oils are all demand huge amounts of water. In fact, almost all manufactured product uses water during some part of the production process (Angelakis and Bontoux, 2001).

The large water demands of power facilities for cooling water and other needs makes them an ideal facility for reuse. Furthermore, because re-circulating evaporative cooling water systems consume water (versus the once-through cooling water system that has no evaporation), they are the most common industrial system using reclaimed water (Rebhun and Engels, 1988). Reclaimed water is also used as process water for a number of applications at petroleum refineries, chemical plants, metal working, pulp and paper mills, and other production facilities (Miller, 2006). Other industries with a potential to use reclaimed water are industries using water for washing or wetting requirements, such as laundries and sand and gravel washing operations (Miller, 2006).

Groundwater recharge

The natural recharge rates give an estimation of the safe amounts of water that can be pumped from groundwater aquifers without depleting the resources and maintaining a sustainable usage of the groundwater (Asano and Cotruvo, 2004). In many areas of the world, especially in the drier regions, groundwater is considered the main water resource and often the pumping rate exceeds the recharge rate, so the underground water levels are gradually declining. Water resource specialists have a big concern, that the wells in these areas will go dry and no other fresh water sources will be available (Asano and Cotruvo, 2004). Aquifer recharge with reclaimed water is considered among the most promising avenues for augmenting water supply with treated wastewater in dry regions, especially if advanced reclamation treatments become cheaper. Furthermore, groundwater recharge using reclaimed wastewater has been used to reduce saltwater intrusion in coastal potable and non-potable aquifers, and to prevent ground subsidence (Durham *et al.*, 2002). In Oman, groundwater recharge with treated effluents is in practice in the southern region (Salalah) for several years now.

Power generation

In recent years wastewater started to be recognized as a valuable energy source, and has been used successfully as renewable source of energy to produce electricity through geothermal power plants, Microbial Fuel Cell (MFC) technology, and hydro-electric energy. In geothermal application, treated wastewater is pumped into long pipelines that transport it into the geothermal field where the treated water is distributed to specially designed and strategically located wells, and injected into reservoirs. That water is then heated to produce steam, which is tapped by production wells that supply steam directly to turbines that generate electricity (Goyal and Conant, 2010).

The chemical energy extracted from wastewater carbohydrates has the potential to convert wastewater treatment plants from power users to sources of electrical power. The MFC technology is predicted to have radical positive effects by providing energy to huge energy consuming industries all over the world. The technology of using wastewater to generate energy has the potential to generate sufficient power to operate a host treatment facility without adding or requiring additional energy. In short, it would have the potential to achieve environmental goals in an energy self-sufficient manner (Du et al., 2010).

The hydro-electric energy is produced by using energy from treated wastewater and water flows through generators designed to capture energy from the flows of water or treated wastewater travelling through a pipe. The hydro-electric generator at North Head Wastewater Treatment Plant is the first of its kind in Australia generating power from treated wastewater. The combined capacity of both the cogeneration and the hydro-generator at North Head is about 3.4 megawatts. These plants will generate about 20,000 megawatt hours of electricity each year, providing over 40% of the Plant's own power (NSW, 2010).

Potable reuse

The reuse of treated wastewater for potable purposes have been developed and practiced around the world as direct and/or indirect potable reuse. An example of direct potable wastewater reuse production is the Windhoek plant in Namibia in which 25% recycled water, diluted with natural resource water. According to Travet *et. al.* (2008), no negative impact of this type of water on human health has ever been reported. Indirect reuse of treated wastewater might occur either planned or unintentionally, where the treated wastewater is disposed into a receiving body of water that is used as a potable source of water (Lu and Leung, 2003).

Social Statistical Survey

A random sample of 115 people from muscat/ oman city were surveyed to determine their responses to the concept of reusing treated wastewater in the different applications "haya water" suggested (irrigation , urban reuse , industrial reuse, potable water, underground water recharge and energy generation). the questionnaire included nine questions that were divided into two sections that provided the following information:

- Demographic information, age, educational level, occupation etc.
- General information regarding knowledge of the respondents about wastewater and wastewater treatment; and their knowledge about the local water authority laws and regulations regarding this matter.
- Acceptance level for various wastewater reuse application including irrigations,
- Portable use, industrial use etc.
- Fear factors regarding wastewater and wastewater reuse of the respondents.
- Level of trust towards "haya water co." realizing a wastewater reuse scheme and for the qualitatively/safety, monitoring and control of the application.
- The preferred communication method to provide information to the citizens.

Results and Discussion

Table 1 presents the demographic information of the respondents to the questionnaire which includes, gender, age occupation, education level; number of years lived in Muscat and the number of children in each household if any. The results help in determining the population composition, which is an important parameter in effecting the public acceptance towards the idea of wastewater reuse.

Table 1: Demographic records of the social study respondents.

	Percentage		Percentage
Gender		**Occupation**	
Male	62.1 %	Engineer	28.8 %
Female	37.9 %	Doctor	9.9 %
		Employee	29.7 %
Age Ranks		Technician	12.6 %
20-29 years	54.8 %	Student	10.8 %
30-39 years	26.1 %	Others	8.2 %

40-49 years	11.3%
50+ years	7.8%

Educational Level	
Under high school	5.3%
High school	11.4%
College graduate	65.8%
Others:	17.5%

Number of Children in household(s)	
No children	43.9%
0-5 years	27.2%
6-10 years	5.3%
1-15 years	6.1%
16+	16.7%

Living in Muscat	
0-1 years	2.6%
2-5 years	18.4%
6-10 years	12.3%
11+ years	65.8%

Note: n= 115

Figure 1 shows that only 32 % of the respondents in Muscat are well informed about wastewater and wastewater treatment, while 34 % of the respondents have general knowledge about wastewater and wastewater treatment. The remaining respondents have no knowledge about the subject of wastewater or wastewater treatment.

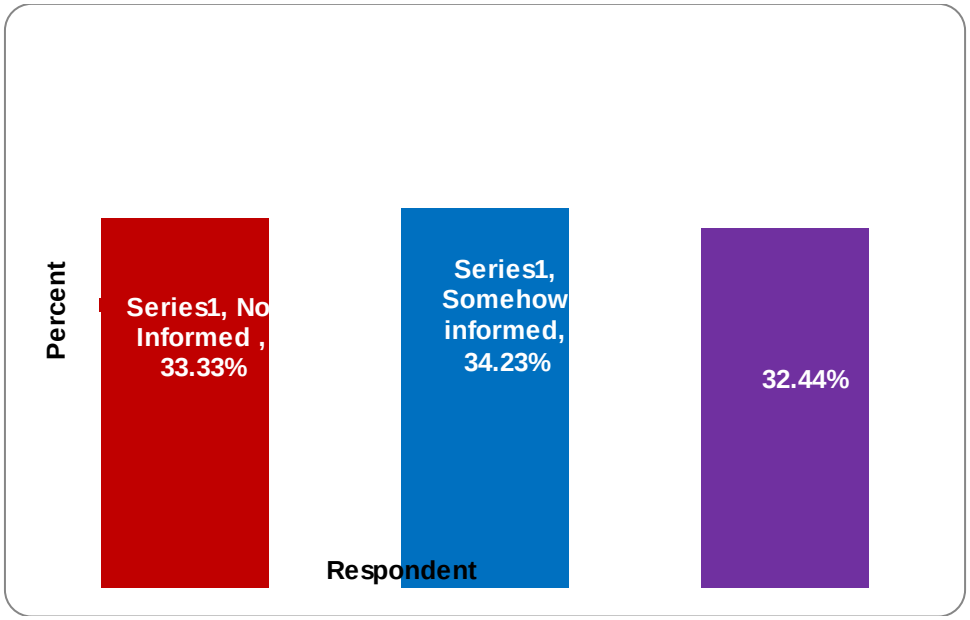

Figure 1: Knowledge of the respondents about wastewater treatment.

Table 2 presents the knowledge of the respondents about the different water and wastewater terminologies that might be used in media or through other public informative sources. About 81% of the respondents are well informed about the meaning of potable water, 54% are well informed about wastewater, 51% are informed about recycled wastewater and 28% are informed about grey water. The results show that the public have a good general understanding about the different water and wastewater terminologies, and this is probably due to the continuous water shortage problem in Muscat/Oman that the public is aware of.

Table 2: Respondents knowledge about water and wastewater terminologies.

erms	Not Informed	Moderately Informed	Well Informed
Portable Water	11.32%	7.50%	81.18%
Waste Water	18.09%	27.52%	54.39%
Grey Water	55.31%	16.49%	28.10%
e Recycled water	34.04%	14.89%	51.06%
l Effluent	36.27%	16.67%	47.05%

Figure 2 shows that 39% of the respondents believe they have no impact on policy and decision making regarding wastewater reuse. Around 34% believe they have moderate impact and 26% believe they have a strong impact on policy and decision making. The results show that there could be more efforts to put in public involvement that would recognize the real users' needs and community goals for health, safety, ecological concerns and costs.

Figure 3 shows that more than 57 % of the respondents are not aware about any Omani wastewater reuse and discharge laws and regulations. This shows that there is a gap of knowledge that might affect the public's perspective towards wastewater nature, treatment and reuse. Information about the exact required quality by the government of the treated or discharged effluent should be provided during the implementation of any future wastewater reuse schemes.

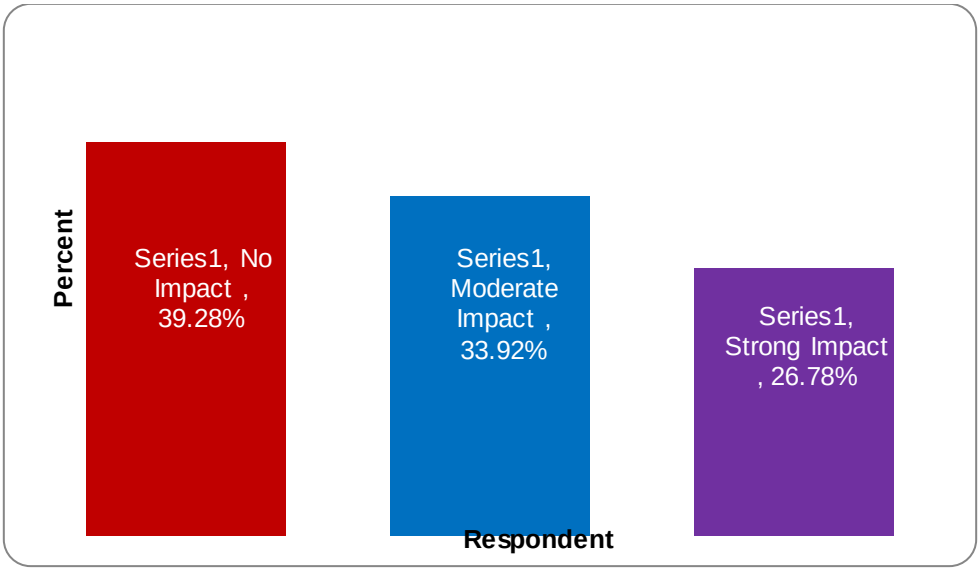

Figure 2: Perspective of respondents about their individual impact on policy making regarding wastewater reuse.

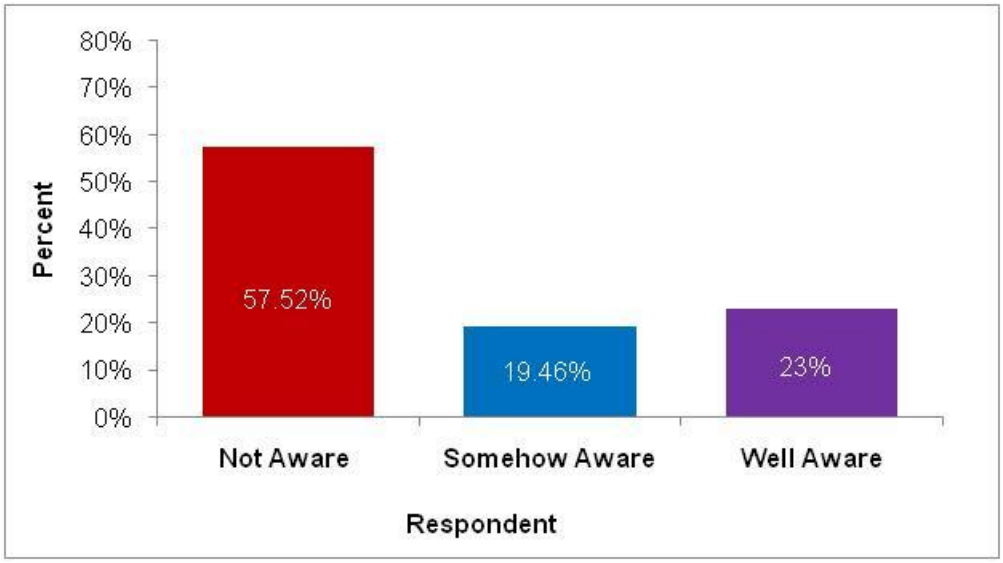

Figure 3: Knowledge of respondents about Omani wastewater reuse and discharge laws and regulations.

Table 3 shows the factors that might impact the public's choice towards choosing an appropriate reuse option. The results showed that the respondents are very positive to support any potential reuse option that helps in either or all the following aspects: prevent pollution, protect human

health, be a long term solution, energy efficient, financially sound, protect wild life or has low green house emissions.

Table 4 shows the preferred reuse options of the treated effluent. Percentages reveal that the majority of the respondents are very positive about the reuse of treated effluent to irrigate non-edible crops, school parks, public parks, golf courses or business areas. The majority of the respondents were also very positive about the reuse of the treated effluent in urban practices such as; fire hydrants, toilette flushing, car washing and building cool. The public also supported the reuse of treated effluent for underground recharge and industrial reuse, but to a lesser degree than that for urban reuse and irrigation of non-edible crops and green landscape.

Table 3: When choosing an appropriate reuse option it is dependent on the following factors.

	Not Important	Important	Very Important
Prevent pollution	14.81%	12.03%	73.14%
Protect human health	13.39%	9.82%	76.78%
A long term solution	8.57%	14.30%	77.14%
Energy efficient	14.15%	19.81%	66.03%
Financially sound	14.95%	14.95%	70.09%
Protect wildlife	14.29%	23.80%	61.90%
Low green house emissions	20.20%	29.29%	50.50%

Table 3: The most preferred reuse option according to the respondents:

Option	Not preferred	Somehow preferred	Well preferred
Irrigate golf courses	15.23%	12.40 %	72.37%
Irrigate landscapes in business areas	17.47%	6.81%	75.72%
irrigate parks in public areas	19.79%	9.38%	70.83%

Irrigate School Grounds	18.18%	12.13%	69.69%
Irrigate non-edible crops	12.64%	8.66%	78.70%
Ground Water recharge	29.51%	23.78%	46.71%
Irrigate agricultural crops	49.12%	22.57%	28.31%
Industrial processes	24.78%	26.72%	48.57%
Cool building	14.14%	11.36%	74.52%
Toilet flushing	20.20%	12.50%	67.30%
Fire Hydrants	12.36%	12.24%	75.47%
Car wash	21.73%	14.12%	64.15%
Discharge TE in marine environment	50.48%	16.52%	33.00%
Reuse as drinking water (direct/indirect)	74.26%	16.26%	9.48%

More than 50 % of the respondents didn't support the discharge of treated effluent in marine environment. Almost 50 % of the respondents didn't support the reuse of wastewater to irrigate edible crops. More than 74 % of the respondents didn't support the reuse of treated effluent as potable water. The results show that the public might be reluctant to accept any kind of reuse that is directly or indirectly related to food and drinking.

Figure 4 explains the level of trust, satisfaction and responsiveness or the respondents towards "Haya Water Co.". About 40% of the respondents trust Haya water, while 41% of the respondents have limited trust and 19% have no trust. These results reveal that more serious

effort should be put by all the people and agencies involved in the wastewater treatment and reuse schemes to put out public and transparent information including trusted audits on the treated effluent and its various reuse applications. All benefits of the practice should be clearly and publicly stated and adequate scientific information should be available and easily provided.

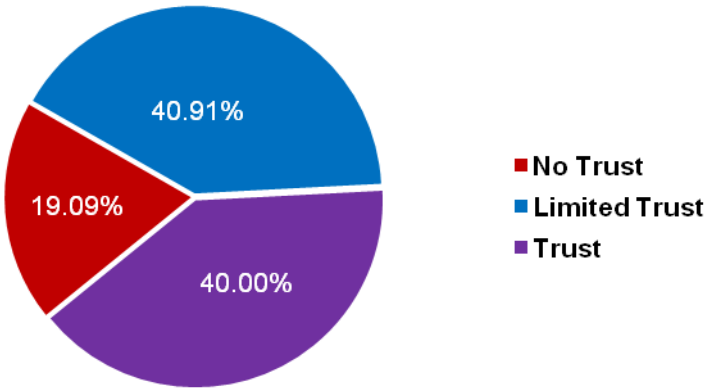

Figure 4: People's trust in "Haya Water" to serve the Community and Protect environment.

Figure 5 shows the level of effort that is being put in order to involve the citizens of Muscat in promoting the idea of wastewater reuse. About 36% think there is no effort being made, while the 38% think there is moderate effort being made whereas 26% think there is significant effort being made. The results show that certain target groups are being involved and continuously informed about wastewater reuse and its benefits while others are neglected. Public involvement should be on a larger scale, where students, farmers, industries, public and private sectors etc. should all be informed and involved.

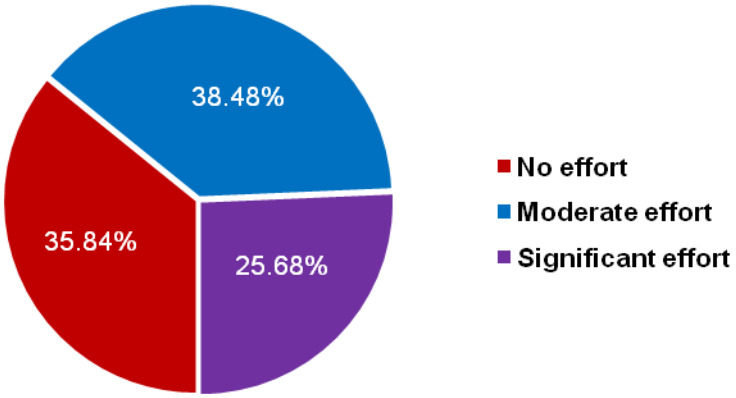

Figure 5: The degree of effort put to increase citizen participation in regards to improving wastewater reuse.

Table 4 shows the views of the respondents to ways of communication with Haya Water Co. The respondents thought that news paper articles, national television and radio channels are the best way to communicate with the citizens and to provide information about wastewater treatment and reuse.

Table 4: respondents' choice about the best way for "Haya Water" to communicate with citizens.

The Ways	Percentage of peoples
Article in the newspaper	47.82%
Mailed informational pamphlets	13.04%
Focus groups/workshops	17.39%
Presentations at clubs or other meetings	18.26%
Public meeting	21.73%
Informational booths at community events	20.89%
Television and radio programs	46.08%
Others: (, E-mail, Facebook, Twitter, etc)	11.30%

Conclusions

A random sample of 115 people from Muscat city were surveyed to determine their responses to the concept of reusing treated wastewater in the different applications (irrigation , urban reuse , industrial reuse, potable water, underground water recharge and energy generation). The results can be summarized:

- One third of the respondents have no knowledge about the subject of wastewater or wastewater treatment,
- The public have a good general understanding about the different water and wastewater terminologies,
- More efforts are needed to put in public involvement in order to recognize the real users' needs and community goals for health, safety, ecological concerns and costs.
- There is a gap of knowledge that might affect the public's perspective towards wastewater nature, treatment and reuse,
- The respondents are very positive to support any potential reuse option that helps in either or all the following aspects: prevent pollution, protect human health, be a long term solution, energy efficient, financially sound, protect wild life or has low green house emissions,
- The public might be reluctant to accept any kind of reuse that is directly or indirectly related to food and drinking,
- Public involvement in wastewater reuse should be on a larger scale, where students, farmers, industries, public and private sectors etc. should all be informed and involved.

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Somatic DNA and male-specific RNA coliphages as viable Indicators for Reuse of Wastewater Effluents in Irrigation.

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The reuse of wastewater effluents in irrigation is expected to increase dramatically for the next five years. Therefore, the health aspect of this practice is a major concern. Health risks associated with recycled wastewater are usually controlled using microbiological monitoring systems such as indicator organisms. The soundness and viability of such systems depend on the successful design of proper microbial monitoring system.

In this study, the resistance of five microbial indicators (faecal coliforms, faecal streptococci, *Clostridium perfrengens*, somatic DNA coliphages and male-specific RNA coliphages) were tested against different stresses; namely filtration and UVR disinfection. It is hoped that the results will be utilized to design a proper and new microbial indicator model as a tool to mitigate health risks, evaluate treatment effectiveness, and assess effluent quality. For this purpose, a prolonged pilot-scale experiment were run using actual wastewater in attempt to reduce seasonal variations as well as simulate full scale practices.

The results showed that *Clostridium perfrengens* are highly resistant to filtration and UV disinfection followed by both coliphages. The study suggests the use of *Clostridium perfrengens* and male-specific RNA coliphages as key indicators.

In particular the investigation propose, for the first time, the use of the fRNA coliphages (which can be easily detected in only 18hrs) limits of 20 PFU/100 ml and 50 PFU/100 ml as new guidelines for unrestricted and restricted irrigational reuse of wastewater effluents, respectively.

1. Introduction

The Kingdom of Saudi Arabia (KSA) is the largest country in the world without running surface water due to severe aridity with annual rainfall of only 100 mm (Ukayli and Husain, 1988). It is probably one of the most affected countries by water shortage. Increased population, high evaporation and evapotranspiration rates coupled with the introduction of intensive agricultural techniques have generated a gap between demand and supply causing a serious deficit in the water budget (Mohorjy, 1988). Water shortages are becoming a severe problem facing agricultural and industrial developmental plans (Arar, 1991; Al-Turbak, 1998). This is manifested in a gradual depletion of fossil ground water which provides about 80% of the water supply annually due to over-exploitation (Mohorjy, 1988); while agriculture is the largest water sink (80% of TWD).

Agriculture can accept water with marginal quality, such as wastewater effluents. It is estimated that at least 1.54 Mm^3/d of treated effluents of domestic origin was produced in 1995. This amount is steadily increasing and expected to double by the year 2020. Although it is governmental policy to reuse all available wastewater effluents in irrigation by the year 2000, only 34% have been utilised. The reuse of treated effluent in Saudi Arabia is anticipated to be large-scale application to include most of the plants around the country. These facts call for the use of sound microbial indicator system.

2. Significant of Microbiological Bioassay

Background

Many pathogens are continuously present in wastewater as a result of being excreted in large numbers by people. Some pathogenic bacteria may even multiply in wastewater treatment plants. They may survive conventional biological treatments and some may pass tertiary filtration. Pathogens are grouped into bacteria, viruses, protozoa, and helminths, and they may survive from several days to several months in water, irrigated soil and/or crops even in hot climatic conditions (Arar, 1986; Ali 1987b). In a general sense, the microbiological survival capability in wastewater, soil and crops are reported to follow the order protozoa < bacteria < viruses < helminths (van der Leeden *et al.*, 1990). Therefore, helminths may pose the greatest risk in reuse projects especially in hot climates (Pescod, 1994).

2.1 Possible health hazards associated with reuse projects

The main diseases associated with wastewater reuse are listed below (Cairn cross, 1993).

Amoebic dysentery (P)
Campylobacter enteritis (B)
Cholera (B)
E. coli diarrhoea (B)
Giardiasis (P)
Cryptosporidium (P)
Rotavirus diarrhoea (V)
Salmonellis (B)
Shigellosis (bacillus dysentery) (B)
Yersiniosis (B)

Typhoid and paratyphoid (B)
Poliomyelitis (V)
Hepatitis A (V)
Leptospirosis (B)
Ascariasis (H)
Trichuriasis (H)

(B) bacteria (P) protozoa (V) virus (H) helminth

Infections of the upper pulmonary system and lungs via are also possible via breathing aerosols from downwind mists of a sprinkler system, as discussed earlier.

Bacterial diseases

The major bacterial diseases associated with the faecal-oral route are the Gram negative bacteria of the family *entertobacteriaceae*, causing typhoid and paratyphoid fevers, salmonellosis, as well as shigellosis, cholera and others belonging to this family. Some pathogens in this category, notably *Campylobacter*, *Salmonella*, and *Yersinia* are also passed on in the faeces of animals (Cairncross, 1993).

Viral diseases

Viruses are present in large numbers in both effluents and sludges. Half of all water-borne diseases are caused by contaminated groundwater (Gerba and Bitton, 1984) probably due to high mobility of viruses. The number of viral diseases related to water has increased drastically to reach 50% of all gastroenteric diseases in the world.

Parasitic helminths

The third and most important pathogenic groups are parasites. They can be subdivided into protozoan parasite and helminths (worm) parasites. Parasitic helminths associated with the reuse of effluent are classified by WHO as high risk, high incident agents. These disease agents enter the human body via the mouth-route from the consumption of poorly prepared agricultural products irrigated with inadequately disinfected effluents (Satchwell, 1986).

2.2 Reduction of health risk

Success in the elimination of a health risk depends on the means to control, contain, and /or mitigate health-hazard agents generating the risk. This depends largely on an integrated approach which combines disciplines such as engineering, management, medicine, chemistry, and agriculture. Health risk reduction will not be possible without high level control which involves regulating; monitoring and the enforcement of measures (control) (Arar, 1987; Pescod, 1994).

2.3 Bacterial indicator organisms: Their detection and enumeration

Detection of pathogens is not only a time consuming and dangerous procedure but also expensive and require certain skills and laboratory equipment. Therefore, direct pathogenic detection or isolation is considered totally unfeasible and completely impractical although they represent the ultimate indication.

Coliform groups are considered standard indicators and their detection methods have been approved by many agencies such as WHO and the 1988 Standard Method Committee of APHA.

Bacterial indicators appear to be especially fit to represent pathogenic bacteria which are less sensitive and have lower death rates than them. They are also considered suitable to reflect treatment processes efficiency (especially disinfection). However, they cannot be relied upon as sound indicators for viruses and other parasites (Bitton *et al.,* 1986; Sim *et al.,* 1995). The usefulness of these classified indicators have been debated as a result of doubts to meet criteria set for ideal indicators set by Bond (cited by Haas *et al.,* 1985), which are included in the National Academy of Science of the USA (N.A.S., 1977), which outlined the features of an ideal indicator as:

1. Present whenever a pathogen is present and at larger numbers
2. Has a greater survival time and is more resistant than pathogens
3. Correlated with the amount of pollution

4. Easily detected with cheap and rapid methods
5. Has no after growth (no replication)
6. Harmless to man
7. Has constant characteristics
8. Absent from unpolluted water environments
9. Applies to all kinds of water

The normal human intestinal bacteria flora consists of organisms like *E. coli*, faecal streptococci, and faecal clostridia. All these organisms are found in large numbers in human excreta and even a small degree of faecal pollution can easily be detected by their presence. Furthermore, their number is similar or higher than the pathogens in an infected person and their survival rate in the environment outside the human body is higher than that of pathogens. Therefore, their presence in water or effluent samples indicates the pollution by municipal wastewater of domestic origin (Sebastian and Nair, 1984).

The bacterial organisms which have been found to fulfil most of these criteria are: the total coliform, faecal coliform (*E. coli*), faecal group D Streptococci, and *Clostridium perfringens* (Evison and James, 1985). For viruses, bacteriophages have been used (Grabow, 1986). Up to date, there is no single ideal indicator but rather each of these indicators can satisfy a given condition. Yet, their uses as an ideal indicator for viral and other parasites have been argued. In many instances, reports exist that describe the detection of viruses and protozoa in microbio-logically proved waters (Bitton *et al.*, 1986; Borrego *et al.*, 1987; Borrego *et al.*, 1990; Sim *et al.*, 1995). IAWPRC Study group (1983) reported that this fact is confirmed by at least six different researchers at different time and regions.

Treatment processes designed on bacteriological criteria do not necessarily protect against the risks of viral infection simply because they are more persistent in water environments than bacteria (Havelaar *et al.*, 1993).

2.4 Viral indicators: Detection and enumeration

Viruses themselves differ widely in morphology. They are classified to two main groups: isometric and anisometric. The first group includes crystalline forms while the second non-crystalline group is subdivided into bacillus-like bodies, rigid rods, long flexible threads, and brick-like shapes. Many types have been found pathogenic to man, animal or plants. Some are very virulent and fatal whereas others are rather harmless.

Significance of viral indicators

According to Funderburg and Sorber (1985), coliform groups are not good indicators for viral presence because of differences between these two different microbial classes. These main differences include:

I) Viruses are a cellular (non-cellular) entities which give them a higher resistivity to environmental stress and treatment processes including disinfection.

II) They are much smaller than bacteria and they behave like colloids carrying a charge. Hence, the distributions of viruses and bacteria are different.

III) Viruses tend to adsorb to minute solids more than bacteria, and thus will be more protected from inactivation than bacteria.

Other differences include that for the virus's dormancy and latency last longer and that the factors affecting multiplication, growth, die-off rate, and transport are different than for bacteria. According to APHA (1989), the use of virus analysis or its indicators is very important in the reuse of wastewater effluents.

Bacteriophages and coliphages

Bacteriophages or "phages" are distinguished from other viruses by their host range as they infect certain type of bacteria. Infection of the host bacteria occurs in two phases in sequence: adsorption to specific sites in the cell wall followed by the transference of genetic material to inside the cell by a syringe-like mechanism. As low as 1 - 2 PFU are capable of causing infection of the cell (Gerba and Rose, 1989). Bacteriophages take control of metabolism activity and multiply in the infected bacteria. This results in lysis of the bacteriophage cell and release of new phage particles to infect adjacent cell (APHA, 1989).

Bacteriophages are of two types: Somatic (F- bacteriophages) that infect host cells via receptor molecules in the cell wall and male-specific (F+ bacteriophages) that infect the host cell via f-type conjugational system (sex pili) (Palmateer *et al.*, 1991; Rhodes and Kator, 1991; Rajala-Mustonen and Heinonen-Tanski, 1994). The two types can be differentiated by size. Somatic are in the size range of (200 nm) while the male-specific are much smaller (30 nm).

Based on the following justifications several authors proposed bacteriophages as EV indicator:

1. They outnumber EV in water environments by thousands folds (IAWPRC Study group, 1983; Bitton *et al.*, 1986; Castillo and Trumper, 1991).

2. They are more resistant to environmental stress treatments, and disinfection than bacterial indicators (IAWPRC Study group, 1983; Bitton *et al.*,1986; Borrego *et al.*, 1990; Aulicino *et al.*, 1996).
3. Their detection methods are simple, reliable, economical, and obtained in a short time (IAWPRC Study group, 1983; Bitton *et al.*, 1986; Dutka *et al.*, 1987; Ratto *et al.*, 1989; Borrego *et al.*, 1990; Hernandez-Delgado *et al.*, 1991).
4. They are constantly present in sewage (Kott, 1992; Morinigo *et al.*, 1992).
5. They correlate to viral pathogens (Bitton *et al.*, 1986; Morinigo *et al.*, 1992).
6. They do not replicate in sewage (APHA, 1989; Kott, 1992; Morinigo *et al.*, 1992)

Even though coliphages seem to be good indicators of a health risk their use as sole indicators for polluted water and wastewater has not yet been accepted by the various legislative agencies (Dutka *et al.*, 1987; Kott, 1992).

Detection of coliphages

Coliphages can, however, be detected using many simple and rapid methods such as:

1. Double agar layers (DAL) described by Adams in 1959 (cited by Rajala-Mustonen and Heinonen-Tanski, 1994).
2. Single agar layer (SAL) (APHA, 1989). Modified by Grabow and Coubrough (1986) and detection limit 1 PFU/ 100 ml.(suitable for wastewater assays)

It can be concluded that no one organism alone has been found to fulfill all the requirements for an ideal indicator. An IAWPRC Study group (1983) wrote: "A single universal indicator which behaves identical to enteric viruses under all possible conditions will probably never be found. There is sound evidence that a practical indicator system for the reliable monitoring can be established. Such a system will most likely include different indicators for different purposes". They add that in case of the reuse of wastewater in irrigation the need for a broad spectrum of indicator organisms including

3. Method And Materials

In this investigation, wastewater effluent was collected before and after filtration and before and after UV disinfection. The major part of this study was performed at the end line of a secondary wastewater treatment plant to simulate field conditions and to avoid changes of wastewater quality due to transportation. The resistances to sand filtration and UVR were evaluated by enumerating five microbial indicator organisms, namely faecal coliform (FC), faecal streptococci or enterococci (FS), *Clostridium perfringens* (CP), and somatic DNA (P706) as well as male-specific fRNA (P597) coliphages before and after filtration.

The UVR unit was equipped with a single low pressure mercury UV lamp (LPML) which emits a peak intensity of 253.7 nm WL. This model was calibrated to provide a dose in excess of 36000 $\mu Ws/cm^2$ (36 mWs/cm^2).

Samples for microbiological analysis were collected in autoclaved sampling bottles, placed in a cooling box, protected from sunlight, and transported to laboratories to be refrigerated at 4 °C and analyzed within 3 - 5 hours after collection. The mean elapsed time between sampling and the start of microbial analysis was about 2 hours. Analyses were done in accordance to the Standard Methods for Examination of Water and Wastewater (APHA, 1989).

Microbiological analysis

Bacteriological analyses were performed using the membrane filter (MF) method for the enumeration of FC, FS, CP with a minimum detection limit less than 1 CFU/100 ml (colony forming units). Results were obtained in CFU with the aid of colony counter apparatus.

Faecal coliforms (FC) were enumerated according to the standard method by APHA (1989) by using m-FC agar medium and an incubation period of 24 ± 4 hours at 44 ± 0.5 °C in a water bath.

Faecal streptococci (FS) were enumerated according to the standard method by APHA (1989) by incubation in KF- streptococcus agar medium for 48 ± 4 hours at 44 ± 0.5 °C in a water bath. Suspected colonies were tested for confirmation using a catalase test utilising H_2O_2 according to Finnish standards SFS 3014. FS are catalase-negative and thus will not degrade H_2O_2 and produce oxygen bubbles.

Randomly selected plates and suspected colonies have been confirmed for FS using bile-esculine-azide agar. FS was inoculated on to this medium using sterile disposable plastic tips and incubated

for an additional 24 ± 4 hours in 44 ± 0.5 °C and positives were confirmed by the production of black or brown color along the streaks.

Detection and enumeration of spores of sulphite-reducing anaerobes (*Clostridium perfringens*) were done according to European standard EN 26461-2:1993 part 2 (which is identical to the international standard ISO 6461-2:1986). The plates were incubated using an anaerobic jar for 24 ± 4 hours in 37 ± 1 °C. This incubation could continue for up to to 48 hours.

Coliphage viruses were assayed using *E. coli* as the host bacteria. ATCC 13706 and ATCC 15597 strains to detect and enumerate somatic DNA and male-specific FRNA coliphages, respectively (Rajala-Mustonen and Heinonen-Tanski, 1994). The single agar layer method of Grabow and Coubrough (1989) was used which is a modification of method 9211D in APHA (1989) and has a detection limit 1 of PFU/100 ml (plaque forming units) instead of 5 PFU/100 ml. The incubation time was 18 hours at 35 - 37 °C. In many instances results were readable after 8 hours of incubation. Pyrex glass trays, described by (Rajala-Mustonen and Heinonen-Tanski, 1992), have been used in half of the analysis as an alternative to 19 cm disposable petri-dishes to be save costs and time. The obtained results were also reported in PFU/100 ml.

4. Results

4.1 Microbiological resistant to filtration

The resistances to sand filtration was evaluated by enumerating five microbial indicator organisms, namely faecal coliform (FC), faecal streptococci or enterococci (FS), *Clostridium perfringens* (CP), and somatic DNA (P706) as well as male-specific fRNA (P597) coliphages before and after filtration. Their numbers followed a consistent sequential order in the form FC > FS > P706 > P597 > CP for both the influent and effluent. Microbiological reductions after filtration are presented in Table 1 and compared with effluents that we have collected and analyzed from a rapid sand filter (RSF) used as tertiary treatment.

Table 1. Reduction percentages of indicator micro-organisms in SSF and RSF.

Indicator	SF (mean, n=25); **%**	RSF (mean, n=5); **%**
FC	72	46
FS	82	36
CP	62	25
P706	74	35
P597	72	34

4.2 Results of microbiological resistance to UVR Disinfection

The five microbiological indicators were assayed to evaluate their relative resistance to UVR. The results were compared and summarized in Table 2.

Table 2. Comparison between microbial reductions after each treatment scenario (T1 to T5); reported in percents, means.

	Unit	SF only n = 25	SF + 1VR n = 10	1UVR n = 5	2UVR n = 2	SF+ 2UVR n = 4
FC	CFU/100ml	71.65%	99.999%	95.89%	99.99%	98.14%
FS	CFU/100ml	81.87%	99.98%	98.82%	99.63%	99.50%
CP	CFU/100ml	61.62%	93.01%	85.45%	97.77%	97.61%
P706	PFU/100ml	73.7%	99.90%	99.90%	99.96%	99.86%
P597	PFU/100ml	71.4%	99.57%	99.88%	99.89%	99.999%

<u>The relative resistance of microbial indicators</u>

For the purpose of selection of the best fit organisms to the proposed indicator system, the microbial resistances based on survival concept were compared after each treatment scheme T1 to T5. The inactivation rate constant K was calculated according to equation (1) below. The results are presented in Table 3.

$$\mathbf{N = N_0\, e^{-KD}} \qquad (1)$$

Table 3. The inactivation rate constant (K) in m^2/J for the 5 indicator organism groups after 4 types of treatments.

Group	T3	T4	T2	T5
CP	0.0003	0.0044	0.0064	0.0072
FC	0.0040	0.0088	0.0138	0.0101
FS	0.0028	0.0057	0.0117	0.0115
P706	0.0068	0.0065	0.0123	0.0125
P597	0.0059	0.0046	0.0108	0.0116

single disinfection. T2: after SSF + single disinfection.
le disinfection. T5: after SSF + double disinfection

5. Discussion

5.1 Microbial correlations and relative resistance

The present work demonstrated that bacterial indicator organisms, which are widely used in practice, if used alone proved to be inefficient indicators. Cross-correlations, when existed, between the bacterial and coliphage groups were observed to be lower than that within each group and generally were less statistically significant. Strong evidence also exists in the literature against the use of bacteria as sole indicator organisms (Grabow, 1986; Gerba and Rose, 1989; Hernandez-Delgado *et al.* 1991; Castillo and Trumper, 1991; Korhonen *et al.* 1996). This is supported by the fact that coliphages were detected in the absence of coliforms especially after UV disinfection of filtered effluent (Table 2).

Furthermore, upon examining microbial data of the current work, different inactivation results and seasonal occurrences of the assayed bacterial and coliphages indicators were observed. It is clear that the two groups behaved differently to SF and UVR (Tables 1 and 2). For example, it was found in the present work that pH values correlated negatively with FC and FS, whereas it correlated positively with both assayed coliphages ($R > 0.6$, $p < 0.05$). Similarly, It has been reported that the two groups behave differently as well in different environments and are affected differently by seasonal changes (e.g. in soil and water) (Castillo and Trumper, 1991; Sinton *et al.*

1997; Rajala and Heinonen-Tanski, 1998). This indicated that the two groups may not represent each other and that coliphages were more reliable indicators for viral presence than bacteria which correspond well with reported similar work (Funderberg and Sober, 1985; Grabow, 1986; Borrego *et al.* 1990). Although counts from both groups, bacteria and coliphages, were highest during the summer period, the estimated increase was 50% and 10% for bacteria and coliphages, respectively. Estimates from other sources were found to be 15-25% lower (Rajala and Heinonen Tanski, 1996). Hence, the seasonal pattern of both groups was found to be different. Moreover, their removals after SF were also observed to be different. The lower removal of phages than bacteria in winter may infer that viruses are more resistant in winter, or that SF is less efficient in lower tempratures. This is manifested by existence of higher correlation coefficients within members of each group than that found between members of each group (i.e. bacteria vs. coliphages).

Nevertheless, no single specie fulfilled ideally the indicator criteria presented earlier (P 6). However, the inclusion of both groups is a step towards rather an ideal indicator-system. This is logical because the fate of coliphages, being acellular organisms, was expected to be different than that of cellular bacterial indicator organisms.

Therefore, as reuse of effluent practices increase in arid countries and because of the extreme low infection dose of viral pathogens compared to that for bacteria, the need for an inclusion of a viral indicator is superimposed especially in a country like Saudi Arabia where large-scale reuse programs are anticipated. Any technical standards regulating irrigation reuse based on only a single specie may prove unreliable. Several health-related investigations suggested virological assays be carried out as well (Borrego *et al.* 1987; Palmateer *et al.* 1991; Cornax *et al.* 1991; Morinigo *et al.* 1992).

Statistically significant correlation existed between the occurances of the somatic (P706) and the fRNA (P597) coliphages in the influent and effluent as well as in terms of reductions ($p < 0.01$). This called for the selection of either one of these coliphages. But since the fRNA morphotype showed much higher resistance (lower inactivation rate, K) to the UVR treatments (Table 3) and to the SF process (Tables 1,2), it was selected as a reliable viral indicator in the proposed system. The fRNA phage proved to be highly resistant organism to environmental stresses and UVR in other studies (Grabow, 1986; Toranzos, 1991; Havelaar *et al.* 1993; Rajala-Mustonen and Heinonen-Tanski; 1995). This may be due to its extremely small size (smaller than somatic phage by 7 fold, 30 nm and 200 nm, respectively), its high association with submicron particulates (Cairns, 1992), and most importantly due to its poor adsorption to surfaces (Gerba,

1987). Furthermore, it has been reported to correlate with enteric viruses more than any assayed indicator organism (Borrego *et al.* 1987, 1990; Cornax *et al.* 1991; Lewis 1996).

5.2 Selection of Proper Indicator System

From the bacterial group, FC seems to be the most appropriate indicator because of its abundance compared to other assayed microorganisms. It is also suggested as a reliable indicator in large numbers of literature (Schwebach *et al.* 1988; Castillo and Trumper, 1991; EPA, 1992). Moreover, FC is recognized as a more health-related as total coliform group (Borrego *et al.* 1987), which is suitable for assessment of treatment efficiency.

FS showed good correlation with both of the coliphages used in this study. It has been suggested as reliable indicator in polluted waters because their relationship to viruses more than any bacterial group (Bitton *et al.* 1986; Cornax *et al.* 1991). However, this argument is invalid with the inclusion of a true viral indicator, the fRNA, as suggested above. Moreover, in some cases, FS were found to be of a limited value in assessing irrigation water quality with respect to gastrointestinal illnesses (Goyal *et al.*, 1984; Schwebach *et al.* 1988). In the present work, they showed similar removal as coliphages in winter, however, their resistant fell drastically in summer. Similar observations were made by Castillo and Trumper (1991). This may indicate that FS may not a suitable choice in hot climates such as Saudi Arabia. This is supported by results of FS assays in tropical areas (Evison and James, 1985). Futhermore, the time required for FS detection is considered a primary draw-back for their selection as an ideal indicator. Therefore, they were excluded from the proposed indicator system.

The significance of CP is manifested in its being the highest resistant specie to UVR and SSF among the assayed microbial species (Tables 1, 3). This is in agreement with similar research (Kawamura *et al.*, 1986; Quals *et al.*, 1989; Savolainen, 1991). More importantly, they have been reported to be highly correlated to cysts, oosysts, and ova of parasitic protozoa and helminths (Hurdy and Hurdy, 1992). Therefore in addition to its persistence, it is at least arguable that CP can provide a relevant comparative index as an added safeguard for the presence of these extremely important parasites. Hence they should be included in the propsed indicator-system.

There are sufficient evidences from the above arguments that adopting an indicator-system consisting of FC, CP, and P597 in reuse projects is necessary, because it is much closer to an ideality than single species due to the abundance of FC, the resistivity of CP, and viral nature of the P597.

A guideline or a limit for the fRNA phages for reuse does not exist in literature. This significant issue warrants serious consideration because these indicators are increasingly recognised. For example, the State of California regulations require a viral fRNA inactivation of 5 logs as a prerequisite for unrestricted reuse (Jolis *et al.*, 1995). However, enteric virus limits have been reported for several purposes. For example, De Leon *et al.*, (1986) proposed a 1.2 PFU/ 40 liters limit of enteric viruses for unrestricted reuse, while the states of Arizona and Hawaii impose a maximum of 1 PFU/ 40 liters for unrestricted irrigation using wastewater effluents (EPA, 1992). Moreover, Havelaar (1993) indicated that the European limit for recreational water for enteric viruses is 4 PFU/ 40 liters. However, the direct detection methods of enteric viruses and the large sample size needed for its assay pose a limitation on the adoption of such a proposal and strongly suggest the use of reliable surrogate indicator such as fRNA phages or equivalent as suggested earlier. For the purpose of estimating fRNA limits to be used as guideline for effluent irrigation regulation, a stochastic model was used to predict the possible limits for the fRNA from FC guideline limits which was statisically significant ($p < 0.01$); (Table 5.13). The correlation coefficient was in the reported ranges in polluted marine water (Duttka *et al.*, 1990; O'Keefe and Green, 1989). The model was validated on the present data using randomly selected values and gave a good prediction. Using this technique the following limits are proposed:

1. For unrestricted reuse: 20 PFU/100 ml for P597 or equivalent phage.

2. For restricted reuse: 50 PFU/100 ml for P597 or equivalent phage.

The proposed limit for unrestricted reuse found to be similar to that proposed by Dutka *et al.*, (1987) for recreational water (swimming beaches).

6. Conclusion

Where raw or treated wastewater is reused, health risks may arise from exposure to pathogens, including bacterial, helminths, protozoa and enteric viruses. In several studies of reuse projects, viruses were detected in a bacterial free samples indicating no correlation between the two species due to differences in their nature and their responds to environmental stresses. In addition, standard bacterial indicators proved to be poor in representing parasites which are known to be resistant to conventional treatments and disinfection.

The investigation indicated that microbial reductions of faecal coliforms (FC), faecal streptococci (FS), *Clostridium perfringens* (CP), somatic coliphages (host *E. coli* ATCC 13706;

P706), and male-specific (host *E. coli* ATCC 15597; P597) were 5.0, 3.7, 1.15, 3.0, and 2.4 $\log_{10}$ units, respectively, after UV disinfection of filtered effluent whereas disinfection of the unfiltered effluent yielded only 1.4, 1.9, 0.84, 2.95, and 2.90 $\log_{10}$ units reductions, respectively. Their resistance to UVR decreased in the order CP>P597>P706>FS>FC and that to the sand filter CP>P597>FC>P706>FS. It is reliable and practical for the evaluation and monitoring of UV disinfection efficiency and treatment assessment as well as safety effluent quality within 24 hours of sampling. Thus, a combination of a bacterial indicator coupled with a bacteriophage may serve as an ideal indicator system for the purpose of microbiological effluent quality assessment.

From the health point of view, the study strongly suggested the use of the fRNA P597 coliphage as a primary indicator in conjunction with the usual bacterial indicator guidelines. The investigation proposed the limit of 20 PFU/100 ml and 50 PFU/ 100 ml fRNA phage counts as new guidelines for unrestricted and restricted irrigation reuse, respectively. The turbidity showed a statistically significant association with most parameters. It can be used as a potential surrogate for several parameters that require long and complex procedures. Therefore, the study suggested the use of turbidity, FC, CP, and P597 which can be obtained in less than 24 hours as key indicators for the assessment and monitoring of effluent quality that to be used for irrigation.

On The Sustainability of Rural Wastewater Management Systems In Small Communities in the Palestinian Territory

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Background:

Water supply and demand management along with access to water resources as well as wastewater treatment and reuse in the Palestinian territory were and still are negatively affected by the Israeli military occupation; these have shaped the under development of the occupied Palestinian territory ever since. This practice has resulted in poor capacity building in the water sector, limited rural development, poor if not negative economic growth, an increase in poverty, poor health and sanitation conditions, and physical and environmental deterioration. At present, mainly due to political constraints, water needs exceed the available water supply. The gap between water supply and water needs is growing, emphasizing the need for the adoption of the integrated water resources management approach and the mobilization of any additional conventional and non-conventional water resources, thus helping to solve part of the existing problems of the water sector.

The wastewater sector status in the Palestinian territory is characterized by poor sanitation, different wastewater quality, insufficient treatment, unsafe disposal of untreated or partially treated wastewater and the use of untreated wastewater in some areas to irrigate edible crops. Wastewater management in Palestine has been a neglected issue over the past years. No comprehensive data on wastewater characteristics and amounts discharged are yet available. The effectiveness of the existing urban sewage collection and treatment facilities is usually constrained by limited capacity, poor maintenance, process malfunction, poor maintenance practices, and lack of experienced or properly trained staff. Raw or partially treated wastewater is discharged into the valleys where it is used for irrigation purposes.

The situation of the sewerage system is extremely critical. Approximately, 60% of households in the urban cities are connected to the sewerage system. In some urban and all semi-urban areas as

well as all rural communities, collection systems are rarely used and wastewater is discharged into percolating pits or septic tanks. The septic tanks emptied by vacuum trucks and disposed of either in the treatment plant or just in the valleys. In villages, no sewage network exists, and wastewater is discharged into percolating pits.

Better management of the water and wastewater sector could reduce total water demand, reduce the pressure on the water supply system, and address health and environmental issues. Improving wastewater treatment and reuse in the Palestinian territory is a high priority because these are highly water-stressed areas. Water quality suffers from pollution and over abstraction. Wastewater treatment plants, which currently exist, are either not functioning properly, or are overloaded, so some wastewater is discharged without treatment. In rural areas, water and money are not available to provide centralized conventional wastewater services. So, application of decentralized management approach within the water cycle and the use of low cost sewerage are more suited to the socio-cultural and environmental circumstances.

As stated above, water consumption is very low in the Palestinian territory due to the lack of adequate and regular water supply and high water rates. Wastewater is mainly of domestic origin. But since water consumption is very low, wastewater is concentrated and its strength, in some locations, is comparable to that of industrial wastewater. Light industries are prevailing in the West Bank, which means that heavy metal contamination is not probable. At present, the situation is changing, but still there is no enforcement of rules and regulations. This leads to a discharge of wastewater that has high pH value, high temperature, high content of chemicals, or high content of inert suspended solids. Complied by Al-Sa'ed (2000).

Decentralized wastewater management systems should be an integral part of any rural sanitation policy. This will ensure public health protection, reduction in aquatic environment degradation and save costs of treatment and biosolids. Furthermore, privatization might play a key role in solving some of the sanitation problems of rural communities. The advantages lay in reduction of capital investments, private sector responsibility of risk for planning, investment and operation, enhance the economical efficiency and project management. However, the experience gained in Europe on privatization of municipal services indicated that privatization was not always the best option for public owned utilities (Nisipeanu, 1998).

Key factors to success in formulating rural community wastewater management programs should include public acceptance and local political support, funding availability and reasonable costs, visibility and accountability of local leaders. Also capability and skills of local technical and field staff, availability of creative and professional advisors, clear and concise authority, regulations and enforcement mechanisms are key issues (EPA, 1994).

Objective:

The main goal of this paper is to develop a sustainable wastewater management for small communities. This paper is limited to those Palestinian rural communities, who have a population number of equal of less than 5000 residents taking into account the environmental and socio-economical aspects of the residents in the small communities. This main goal can be achieved by evaluating the present status of rural sanitation in the West Bank with special emphasis on existing onsite sanitation systems, assessing available alternative options on adequate sanitation technologies, and developing a sustainable approach for rural wastewater management.

Methodology:

A decentralized system employs a combination of onsite and/or cluster systems and is used to treat and dispose of wastewater from dwellings and businesses close to the source. Decentralized wastewater systems allow for flexibility in wastewater management, and different parts of the system may be combined into "treatment trains," or a series of processes to meet treatment goals, overcome site conditions, and to address environmental protection requirements.

Managed decentralized wastewater systems are viable, long-term alternatives to centralized wastewater treatment facilities, particularly in small and rural communities where they are often most cost-effective. These systems already serve a quarter of the population nationwide and half the population in some states. They should be considered in any evaluation of wastewater management options for small and mid-sized communities.

Many options now exist for wastewater treatment and disposal in rural areas and small communities. Each technology has advantages, as well as limitations, so a treatment technology must be selected specifically to meet local conditions and treatment objectives. Similarly, every community's own financial, physical, and regulatory factors must be evaluated to find the best technology for their circumstances.

Onsite systems now include a number of alternatives that surpass conventional septic tank and drainfield systems in their ability to treat wastewater. Alternative onsite processes, such as sand filters, peat filters, aerobic treatment units, pressure distribution systems, drip irrigation, and disinfection systems, can be employed in a wide range of soil and site conditions. Alternative systems require more monitoring and maintenance, making a strong case for these systems to be managed.

Small satellite treatment plants or soil absorption systems that have low-cost collection sewers are called cluster systems. Cluster systems treat wastewater from a group of dwellings and/or businesses and are most appropriate in moderately populated areas. These systems serve two or more dwellings (but not usually an entire community) and are located near the buildings they serve.

The wastewater from each dwelling or business flows into its own interceptor (septic) tank to settle out and allow solids to break down. From the tank, the effluent is able to travel through smaller diameter, therefore less expensive, collection pipes.

These pipes are buried at a shallower depth than full sewers and run relatively short distances to smaller, less maintenance-intensive treatment and disposal units. These units often use soil absorption fields or effluent recycling rather than discharging the treated wastewater into surface waters.

Progressive view of decentralized systems

Decentralized systems include small, medium and large flow systems using basic and advanced on-site technologies. Medium flow, on-site systems (designated here as systems with design flows between 0.5 m3/d and 2.0 m3/d), and large flow on-site systems (> 15m3/d design flow)

include those serving individual commercial facilities and cluster systems serving multiple homes in a community. Monitoring of the cumulative impacts of on-site systems on the ecological resources in a watershed area, as well as monitoring the performance of each individual or cluster system in the community, closes the loop for on-site systems (Figure 1). Once monitoring is in place, these on-site systems can be repaired or upgraded as needed to protect public water supplies as well as ecological resources such as ground water resources and surface water resources including nutrient sensitive waters and shellfish harvesting waters.

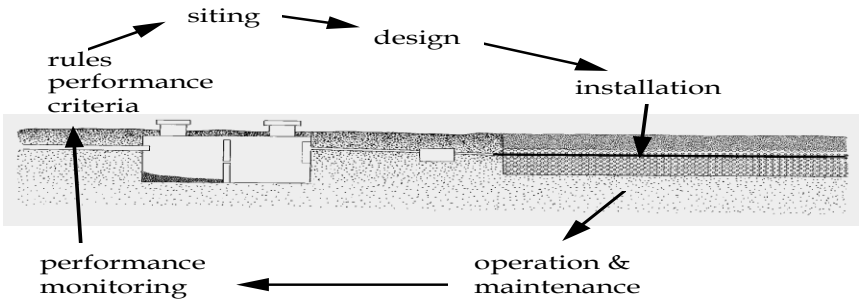

Fig 1: Siting and design of on-site systems with long term monitoring.

In a progressive regulatory structure, closely monitored and maintained advanced on-site systems are allowed on otherwise unsuitable soils to remediate existing failing conventional septic systems and ineffective cesspools. These advanced systems must meet specific treatment performance standards so as to:

- Protect personal family health at the site,
- Protect the public health in the surrounding community,
- Protect and preserve the environment including important ecological resources, and
- Be affordable to communities.

System performance is measured and assessed relative to the applicable treatment performance criteria. Resource impact monitoring identifies early on any potential for environmental degradation (such as eutrophication) before it happens. This facilitates upgrading the treatment performance requirements for technologies used within that subwatershed area if necessary to protect the public water supply or resources.

I. Individual (on-site) treatment systems

These service individual sections or lots (Fig 2), where all waste produced on-site are treated on-site. Generally the treated waste re-enters the ecosystem on site. This means the ability of the soils to absorb the treated waste will determine whether this kind of system can be used.

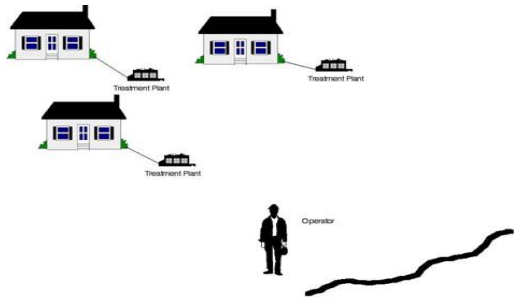

Fig 2: Onsite wastewater management - builds small treatment systems for each home (Graf, 1990)

The nature of local groundwater systems, including the level of the water table in different seasons, will be important. Sometimes underground water (aquifers) can be affected by wastewater trickling though the soils and polluting the water. This water may find its way into a local stream, or bores may bring it to the surface for household use.

Some soils will not be suitable. Others may require a larger area for absorption. In many ways the absorption ability of these soils will have been a major factor in originally deciding the density. Deciding whether or not to stick with on-site systems will be a 'crunch' soils to absorb wastes at all, or to absorb increased amounts, will be a deciding factor for the system you choose.

On-site systems use biological processes that need to be carefully managed and protected. People can find this tiresome, and some visitors to teach communities may know little about how to deal with them. There are ways the community can come together to manage the separate on-site systems. In other words, individual systems do not have to mean private management. The modern approach to managing on-site systems involving system monitoring and operation and maintenance inspections can ensure the long life of the system while protecting the investment in the system hardware. The cost of this managed approach can, when spread out on an annual basis, equate to the sort of charge that councils levy as sewerage charges in urban residential areas.

Treatment systems can also be designed to deal with different kinds of wastewater. For example, on-site systems can deal with a combination of graywater and blackwater, just graywater, or just blackwater.

II. Cluster treatment

The focus here is on relatively small treatment plants designed to serve a group of houses or businesses (Fig 3). More than one plant may be needed to serve the whole community. They provide considerable flexibility. For example, your community may decide that it wants to continue with on-site treatment and the densities of settlement that this brings. At the same time, it may be prepared to allow a one-off development of a certain size that cannot be serviced by on-site systems. Provided the development has its own cluster system, it can proceed.

On the other hand, it may be that your community is on a centralized system. To allow more growth would require a bigger system – not just the treatment plant but the pipes as well. This can be expensive. More development might be possible if a small cluster system is used. It is therefore a useful tool for allowing some growth and change to occur without shifting to a centralized system that might bring pressure for even more growth. Often a cluster treatment system utilizes land disposal. The number of dwellings serviced by the cluster system needed will determine the area of land. At the same time, a cluster system can allow a more managed land-based ecosystem re-entry because the volumes of waste treated will be relatively small.

Cluster treatment can also be linked to a centralized system. For example, some technologies allow the wastewater, by hooking up to wastewater mains pipes and removing some of the wastewater for processing. This mining can provide reclaimed water for re-use and contribute to reducing the amount of wastewater going to a centralized plant.

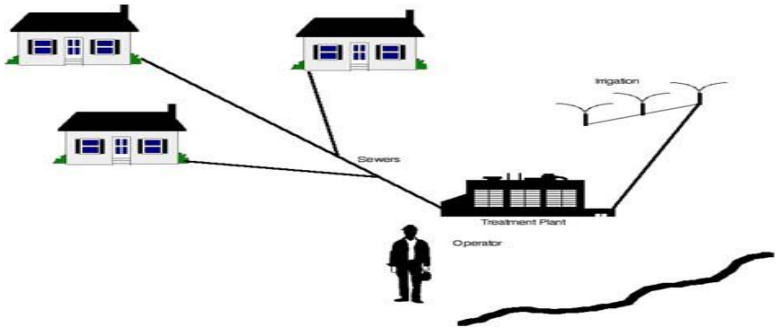

Fig 3: Collect wastewater and treat before reuse through irrigation (Graf, 1990)

Scenarios for sound practices

General scenarios can be sketched based on population density to illustrate integration of technology, environmental, economic and social factors. For a low population density and where land is available around dwellings, on-site systems with on-site reuse provide householders with options, which are a function of water availability, toilet type and desired reuse of blackwater and graywater. Use of a double vault composting toilet and graywater for subsurface irrigation is shown in Figure 4. Maintenance requirement will be emptying the vault (say, every 6 months), windrow composting the content with garden waste and diverting blackwater from a full vault to the one just emptied. Irrigation system for graywater needs to be checked weekly.

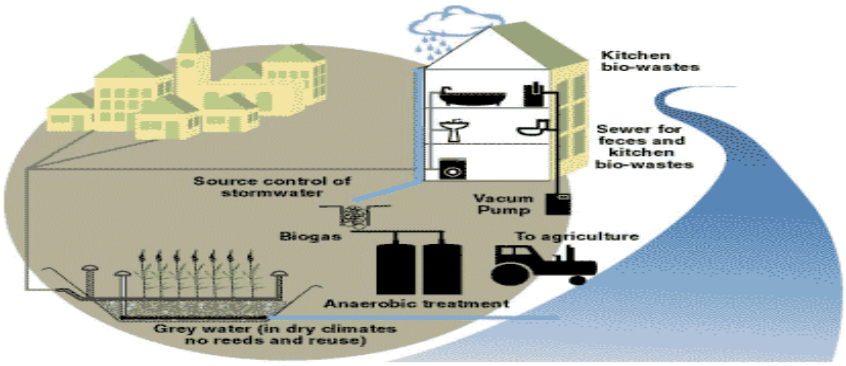

Fig 4: Composting toilet for blackwater and sub-surface irrigation of graywater (Otterpohl and Lange, 1997)

A system requiring less householder maintenance is a septic tank with an inverted leach drain or evapotranspiration trench. The septic tank needs to be de-sludged every 3 to 5 years. This is done

by calling a sludge contractor. This service should be available in the community for this option to operate satisfactorily including the safe disposal of the sludge by the contractor.

For a high population density, community ablutions blocks with payment for use can work well. The wastewater can be conveyed to a location where land is available for land-based treatment and reuse through grazing grasses irrigated by treated wastewater. The operator of the ablutions facilities needs to ensure public health requirements for the wastewater reuse are met.

Toilet facilities in individual dwellings are an option with wastewater collected using simplified sewerage. This can be condominial sewers or with street connections depending on community choice. Collected wastewater is treated using a series of lagoons, with the final lagoon employed for aquaculture. Depending on land use downstream of the lagoons, wastewater can be reused further for agriculture, horticulture or tree plantation.

The requirement of planning a sewerage system within a catchment basin (to use gravity flow), the environmental requirement for reuse of wastewater nutrients (to prevent pollution), the economic requirement of balancing economy of scale of treatment and the cost of the sewer pipes, and the social requirement for community consultation point to planning for a community-scale collection, treatment and reuse of wastewater. The optimum size of the population served for a community-scale systems will depend on local conditions, which in turn are determined by local geographical (topography, climate, soil), environmental, economic and social/institutional considerations.

A useful tool that can help towards achieving integrated waste management is the waste management hierarchy. It has been used to direct waste management towards achieving environmentally sound practice. The waste management hierarchy in its most general form is shown in Table 1. In using this tool for waste management we systematically go down the list to see if step 1 (Prevent or reduce waste generation) can be implemented, before considering the next step (2) and so on. Only when steps (1) to (5) have been fully considered that we consider disposal of the waste (step 6).

Table 1: The waste management hierarchy

1. Prevent or reduce waste generation
2. Reduce the toxicity or negative impact of the waste
3. Recycle waste in its current form
4. Reuse waste after further processing
5. Treat waste before disposal
6. Dispose in an environmentally sound manner

We cannot prevent the production of human excreta or stormwater, but we can prevent other materials from being disposed with human excreta, or solid waste with stormwater. We can use less water to achieve the same purpose (e.g. flushing toilet) and hence produce less wastewater. We can avoid toxicity of wastewater by preventing toxic household or industrial wastes to be disposed with biodegradable organic wastes. A reuse example is the use of urine as a liquid fertilizer, while composting can convert human excreta into a soil conditioner. It should be recognized that all waste management practices have costs as well as benefits. The application of the waste management hierarchy therefore needs to consider economics as well as other factors (e.g. some culture may not allow reuse of human wastes).

Environmentally sound practices in wastewater and stormwater management are practices that ensure that public health and environmental quality are protected. A range of technologies exist that can achieve this objective.

Common to all sound technologies is that there is a scientific basis for the physical, chemical and biological processes for the removal of pathogens and pollutants from the water. These processes are largely akin to the purification and recycling processes taking place in nature. Properly designed, constructed, maintained and operated these technologies can achieve protection of public health and the environment, and can recycle water and nutrients, which are beneficial to sustaining ecosystems and life.

Associated with each technology hardware is a philosophical basis or approach, e.g. separation of waste components (dry conservancy), or conveying all wastes away with water (water based conveyance) minimizing capital cost, minimizing maintenance requirement; or maximizing reuse

maintenance and operational requirements, which are the software associated with the technological hardware, and therefore level of skills required to operate the hardware and software, and consequently training requirements for personnel.

Social impact and criteria selection

Sustainable development must be environmentally friendly, socially acceptable and financially viable. It is widely agreed that progress towards sustainable services requires the integration of these three elements into the decision making process. Multi-criteria analysis is different from multi-objective decision making, as the former has a single objective, which includes several criteria. There is a need to improve the quality of decisions. The adoption of transparent and stakeholder sensitive decision making processes will be crucial for future changes to water service provision. Decision makers insist they take sustainability into account but it is not so in reality, because it is difficult to consider all the aspects.

Economical aspects

Cost is an important consideration in the selection of technology. Decision makers need to know about the relative costs of technologies, so that a decision to select a particular technology can be based on sound financial and economic considerations. Cost alone should, however, not be the sole determining factor in the selection of technology. Environmental impact of the technologies, such as contamination of groundwater, should also be considered. Appropriateness of the technology in the context of the availability of skilled personnel to operate and maintain it, as well as other social and cultural factors need to be taken into account.

The costs of managing onsite wastewater treatment systems are mostly determined by the local soil conditions and the corresponding types of wastewater treatment technologies used. In areas with deep, permeable soils, septic tank-soil absorption systems can be used. In areas with shallow soils to a limiting condition, very slowly permeable soils, or very highly permeable soils (such as sand), more complicated onsite systems will be required. The cost of management is directly related to soil limitations and the complexity of the necessary treatment technology. Most of the costs come from the salary and benefits provided for the operator. All systems will

require periodic septic tank pumping and for some systems worn out pumps and other parts must be repaired or replaced.

The Palestinian territory is one of the developing countries with limited financial, technical and natural resources. Despite recent capital investments the water and sanitation services in both urban and rural communities are still poor. To date significant national and foreign funds have been invested, but more have to be spent.

Operations and Maintenance

Proper operation and maintenance of onsite systems are essential to avoiding system failures. For certain types of onsite systems with electrical or mechanical components, maintenance is often regulated through operating permits. These permits need to be renewed periodically with maintenance as a condition of renewal. In some cases, homeowners can perform system maintenance, but health officials or other qualified professionals usually must perform inspections.

Maintenance of conventional septic systems is not specified in great detail in most regulations, and although it is in homeowners' best interests to operate and maintain systems correctly, many do not know how to maintain their systems, where their systems are located, or even what types of systems they have. Yet, homeowners can be held liable for systems that pose a threat to public health and the environment.

Conclusions

Sustainable development incorporates social, economic, and environmental factors into the evaluation and selection of wastewater management options. The sustainability of various wastewater management options can be compared when criteria are identified and weighted and performance measures selected that fit the specific conditions. The criteria used to assess sustainability are unique to the specific application. A site-specific definition must be developed for each application. The site-specific definition for a particular application is achieved by adjusting the weighting factors for the individual criteria. As new and improved onsite wastewater treatment technologies are developed, more wastewater management options will

offer greater sustainability. These management options will improve the sustainability of onsite systems even further through increased reliability and flexibility.

Recommendations

From the information viewed in this paper, it is recommended to promote best practice in sanitation and environmental health in rural areas, emphasis should be placed on developing sanitation projects that will validate low-technological innovations that are powered by natural processes. These pilots should include a cost benefit analysis component resulting in data that can support decision-making process and educate planners and municipal-level officials regarding the potential benefits of low technology and naturally based treatment and recovery systems.

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SESSION 7A:
WATER, HEALTH, AND ENVIRONMENT

Keynote: Odeh AlJayoussi, Jordan Royal Scientific Society, Water and Environment

Odeh R. Al-Jayyousi is the vice president for science and research at the Royal Scientific Society since Sept. 2011. He worked as the regional director for IUCN – The International Union for Conservation of Nature - West Asia / Middle East regional office during (2004-20011). He was a university professor in water resources and environment during (1993-2004). He was an academic director for MBA Programme in transformational management in UK. He has diverse skills in knowledge management, strategic planning, public policy analysis, and sustainable development.

He has over twenty years of experience in various planning activities in Chicago at the Department of Planning-City of Chicago, and University of Illinois at Chicago, Center of Urban Economic Development- Chicago. He facilitated workshops, focus groups, and meetings. He developed and carried out training courses in leadership skills, knowledge management, economic development, urban planning, and water planning.

He worked as a consultant with EU, ESCWA, World Bank, GTZ and USAID. He worked as a water expert with GTZ for the development of water policy and the updating of the National Water Master Plan for Jordan. He was nominated and selected for the Next Generation of Water Leaders Program (Stockholm, 1999) to participate in the formulation of the World Water Vision 21st. Participated in the formulation of the Strategy of Biodiversity and Water.

He published over 30 articles in international peer-reviewed journals. He was the Dean of Scientific Research at Applied Science University, Jordan. He published several articles on the domain of water policy and planning, sustainable development, and knowledge management. He is founding board member in Jordan Green Building Council, Fair Trade Jordan, and Green Fund for Environment.

Abstract:

The GCC countries are characterized by rich oil reserves but limited water resources. However, the adaptive capacity is high as manifested in harnessing technology to desalinate water. The amount of desalinated water in the GCC countries amounts to about two-thirds worldwide. The geo-politics in the Gulf after the Gulf war and the aftermath of the Arab Spring and the global risks of climate change require new thinking and discourse. Climate change may define new domains of hydro-eco-security in the Gulf since it has salient implications to overall security of water, energy, food, and economies.

The aim of this paper is to present a new perspective on water-environment linkages in the GCC region in the era of globalization. It intends to introduce the concept of regionalism to achieve an integrated water/environmental management. Linkages between water, food and trade are of crucial significance to achieve "water-energy-food" security. The paper intends to present three major shifts in thinking about water-environment. These include: i) ecosystem management of water resources at a regional level, ii) the realization of virtual water (water embedded in food) in the regional water balance, iii) and the notion of eco-region.

GCC as "region" represents a critical mass and a logical unit of analysis for water and environmental assessment and management compared to nation-state. Complementarities among nation-states in water, food, and trade represent comparative advantages and economies of scale for each nation-state.
This paper argues for the imperative for a comprehensive development regionalism and regional science graduate which focuses on R&D. The fact that regional management programs exist and persist, in spite of nationalist rivalries, shows the imperative need for environmental cooperation *(the "resource management" argument).* In sum, development regionalism contains the traditional arguments for regional cooperation such as territorial size and economies of scale.

The Gulf region is experiencing ecological degradation, species extinction and habitat loss coupled with water scarcity, variability and uncertainty due to urbanization, population growth, migration, growing consumption patterns, regional conflicts, and climate change. This has resulted in increased pressures on ecosystems resilience, habitats, species, and water basins. Also, the impacts of climate change on the water sector, in combination with increased demand and population growth, will compound problems of water scarcity. The situation is complicated by a set of factors. First, sea pollution and impact of the Gulf war on marine life. Second, the region is only water scarce but rich in energy, which enhances its ability to secure more water. A transition to sustainable development is crucial in light of the "peak oil" phase and investing in clean technology and renewable energy is imperative.

Many GCC countries are over-drafting their aquifer systems leading to a serious water deficit. In Oman, Saudi Arabia and UAE groundwater constitutes at least one third of the total volume obtained from conventional sources. On the other hand, Bahrain, Kuwait, and Qatar rely completely on groundwater. Sustainable management of groundwater sourced from coastal aquifers is a major challenge facing many countries in the Arab region due to salt water intrusion resulting from over-pumping for domestic or agricultural use. The quality of these coastal aquifers is being further threatened by the expected rise in sea levels. This risk has already been manifested along as along the coastline of the GCC countries. New metrics are needed beyond GNP to measure the progress of society.

The new wave of social transformations in the Arab region is likely to influence water governance and to shape new models of sustainable regional integration through establishing shared infrastructures in R&D, water, energy, and protected areas (*hima*).

Keynote: Hamid Bakir, CEHA/WHO, WHO Guidelines on Drinking Water Quality: Preventative Water Safety Management Framework

Hamed Bakir,
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The World Health Organization Guidelines for Drinking Water Quality (WHO/GDWQ)recommend the basic and essential requirements to ensure the safety of drinking-water are a"framework" for safe drinking-water, comprising the following three elements:

1. health-based targets established by acompetent health authority;
2. adequate and properly managed water supply systems (adequate infrastructure,proper monitoring and effective planning and management); and
3. a systemof independent surveillance.

The most effectivemeans of consistentlyensuring the safetyof a drinking-water supplyis through the useof a comprehensive riskassessment and riskmanagement approachthat encompasses allsteps in the water supply
from catchment to consumer.

In the WHO/GDWQ,such approachesare termed water safetyplans (WSPs). The WSPapproach has been developedto organize andsystematize a long history of management practices applied to drinking-water and toensure the applicability of these practices to the management of drinking-water quality.WSPs represent an evolution of the concept of sanitary surveys and vulnerabilityassessments that include and encompass the whole of the water supply system and itsoperation. The WSP approach draws on many of the principles and concepts fromother risk management approaches, in particular the multiple-barrier approach andhazard assessment and critical control points (as used in the food industry).

A WSP has three key components,which are guided by health-basedtargets andoverseen through drinking-water
supply surveillance:

1) a*system assessment* to determinewhether the drinking-water supply chain (up to the point of consumption)as a whole can deliver water of a quality that meets identified targets. This alsoincludes the assessment of design criteria of new systems;

2) identifying control measures in a drinking-water system that will collectively control identified risks and ensure that the health-based targets are met. Foreach control measure identified, an appropriate means of *operational monitoring*should be defined that will ensure that any deviation from required performanceis rapidly detected in a timely manner;

3) management and communication plans describing actions to be taken during normaloperation or incident conditions and documenting the system assessment,including upgrade and improvement planning, monitoring and communicationplans and supporting programmes.

The primary objectives of a WSP in ensuring good drinking-water supply practice are the prevention or minimization of contamination of source waters, the reduction or removal of contamination through treatment processes and the prevention of contamination during storage, distribution and handling of drinking-water.

WSPs are a powerful tool for the drinking-water supplier to manage the supplysafely. They also assist surveillance by public health authorities. Key benefits for watersuppliers implementing WSPs include: demonstration of "due diligence"; improved compliance; rationalizing and documenting existing operational procedures, leading to gains
in efficiency, improvement of performance and quicker response to incidents; better targeted and justification for long-term capital investments based on riskassessment; improved management of existing staff knowledge and identification of criticalgaps in skills for staff; and improved stakeholder relationships.

Keynote: Fouad Abousamra, UNEP ROWA, Ecosystem Approach for the Management of Water Resources

Dr.Fouad Abousamra

Fouad Abousamra is currently working for UNEP ROWA in Bahrain as regional coordinator for Land, Water and Marine and Coastal ecosystems management for West Asia region. During the period of 1999-2011he worked for UNEP-Mediterranean Action Plan and MED POL programme responsible for follow up activities related to the implementation of legal instruments related to water management , urban and industrial management, and sea dumping activities as well as preparation of policy oriented assessments. Born in Syria, Fouad Abousamra read for the BSc in Applied Chemistry, at the University of Damascus, a Doctorat in Applied Chemistry as well as a Diploma on Pollution Issues in the University of Louis Pasteur,France and Doctorate es-sciences in Natural Sciences(water) at the University of Paris VI. Before his appointment with UNEP MAP he worked as an advisor to the Ministry of Environment of Syria and served as Head of the Environmental Studies Department at the Higher Institute of Applied Sciences and Technology (HIAST) as well as Head of the Environmental Research laboratory at the Scientific Studies and Research Center of Damascus, Syria.

Abstract:

We live in a world of ecosystems – and our existence would not be possible without the life-supporting services they provide. Properly-functioning ecosystems in turn are fundamentally related to water security .Unfortunately the Millennium Assessment reported that 60% of the ecosystem services accessed are declined with the main drivers of this decline being anthropogenic in nature, it is human –environment interactions that result in the greatest disturbances or imbalances in the structure or function Experience from around the world however clearly indicates that we continue to degrade or overexploit ecosystems to meet our natural resources needs of ecosystem.

Of all the resources required for sustaining ecosystems and the services they provide to human health and well being, water is arguably the most important. Water systems are very sensitive to human activities in their surrounding drainage basins consequently the degradation or elimination of ecosystem services because of the unsustainable use of ecosystems is usually visible where water resources are concerned. The results of misusing water resources and resulting ecosystem degradation and its impacts on ecosystem services illustrate the negative impacts of non sustainable water use. Water resources were initially viewed as a commodity to be utilized in the same sense as oil, as an example with meeting human water needs being the primary concern of water resources managers. This approach is unsustainable and need to be reviewed in order to ensure ecosystem sustainability as well.

Governments faced difficulties to implement IWRM due to the complex scientific, socioeconomic and financial elements to be considered. IWRM must balance all ecosystem services to be most effective. Ecosystem Approach would ensure the "environmental and ecological sustainability" and resulting ecosystem services of water.

Removal of Hazardous gases of Ammonia and Hydrogen Sulfide from Polluted Water by Forced Jet-Air Injection: A Bench Scale Study

By

Eng. Abdullah Al-Matouk, Eng. Mishari Khajah and Dr. Abulbasher Shahalam

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Abstract:

The problem of hazardous gases of ammonia and hydrogen sulfide in polluted water generated from domestic and industrial sources is very common. Wastewater from domestic sources and many industries dealing with petrochemical products are prone to contain such gases in saturated and supersaturated levels. Particularly, the fertilizer industries produce a sizable amount of such discarded liquid streams. These gases are health hazards to workers and other personnel coming in direct and indirect contact of the gas.

A bench scale study on the stripping off ammonia and hydrogen sulfide gases from polluted wastewater stream by injecting forced jet-air into wastewater (liquid-stream) has been carried out. For testing purposes, wastewater from an operating wastewater treatment plant laden with such gases was utilized. The tests were performed at bench scale. This paper contains the results and experience of the jet-air stripping of the gases. In general, the removal of such gases by 15-40% appeared to be feasible.

Introduction

General

Biological reduction of organic and inorganic pollutants containing protein and other nitrogenous chemicals generates ammonia (NH_3) gas. Similar biological activity on sulfurous chemicals produces hydrogen sulfide (H_2S) gas. Municipal wastewater, most agricultural wastewater, and wastewater from many industries which use nitrogenous and sulfurous chemicals are laden with nitrogenous and sulfurous chemicals. Under natural or controlled environments, anaerobic biological activities in wastewater tend to produce NH_3 and H_2S gas (Metcalf & Eddy, 1991). In open environments at atmospheric pressure, these gases exit into the air to maintain atmospheric equilibrium of partial gas existence in the air. However, in confined environments, these gases build up in liquid and contact air. The municipal sewer system, sites of anaerobic processes for treatment of municipal wastewater and sites of liquid-sludge occurrence in treatment plants are very common places where above-normal concentrations of these gases exist. These gases cause odor problems and pose fire and explosion hazards. In addition, they cause human health problems for workers remaining in contact with the gas. In humans, these gases cause nausea, headaches, vomiting etc. Treatment of these gases in municipal wastewater is an integral part of wastewater treatment in all normal treatment plants (Kazuhiro, 2000).

The problems associated with odorous gases in large sewer trunk lines, pumping stations, and treatment plant head-works are common phenomena. In common wastewater treatment plants, in-plant aeration, conveyor-line aeration, wet-well aeration, gas masking and deodorant use are practiced to reduce the problems associated with these gases. For reduction of gas trapped in liquid, traditional air stripping is the most common method. However, the need for more efficient methods for gas removal from water remains (Ando, 1980).

This study was initiated with the objective of investigating the effectiveness of removing NH_3 and H_2S at different air flow rates in the liquid jet reactor using wastewater containing NH_3 and H_2S (reduced gases). Fortunately a natural source of these gases was identified in a local wastewater treatment plant at Riqqa, Kuwait. Samples of wastewater from the plant thickener unit were utilized for most of the experiments.

This paper contains the description of an innovative process for air stripping and methods used to test the process (jet-air injection into wastewater), the experiments, results, discussion and conclusion.

Test Gases

Ammonia and hydrogen sulfide gases laden in wastewater were used for testing the efficiency of forced jet air injection method in reducing gas concentration in water.

Ammonia: Aqua ammonium or ammonium hydroxide are terms that refer to a solution of NH_3 in water. NH_3 dissolved in water is present mainly as ion of ammonia NH_4+ or as a non-ionized molecule NH_4OH (ammonium hydroxide). Hydrated molecules of NH_3 also exist as $NH_3.H_2O$ or $NH_3.2H_2O$. NH_3 which exists as a non-ionized molecule of NH_3 is a gas and may be present in water only in gaseous forms. In open environment, it usually escapes in the air as it is lighter than air itself.

NH_3 is remarkably soluble in water. Under standard conditions of temperature and pressure, a saturated solution might contain about 30% NH_3. However, NH_3 (gas) concentration also may be increased in water solution if its escape from liquid is blocked by a physical barrier or an adverse change in vapor pressure, pH, temperature, foreign material (such as salts) content in water. Most of NH_3 dissolved in water is dissolved NH_3 in the form of NH_3; a small fraction combines with water to form NH_4OH from ions of NH_4+ and OH- (FAO, 2011; Metcalf & Eddy, 1991; WPCF, 1979).

The dissolution of ammonia in water follows Equation 1.

$$[NH_4+]\,[OH-] / [NH_3] = 1.8x10^{-5} \qquad [1]$$

Its equilibrium constant (K_A) value is $1.8x10^{-5}$ and the pK_A value is 4.7. Knowing the pH and NH_3 (gas) concentration, the equation 1 can be used to calculate the amount of aqua ammonium expected in water. When the gas is in equilibrium, its removal has to be done by inducing physical-chemical disturbance in the solution system (Sawyer, 1967).

It is a colorless gas under standard environmental conditions, emitting a sharp and acrid odor. It is hazardous to human health. Human skin dissolves in it. High contents of the gas can suffocate humans and animals. However, once in the air and open environment, the compound is oxidized through physical and biological means to form a stable gas of nitrogen (N_2) and other compounds of NO_2 and NO_3 (WPCF, 1979; Metcalf & Eddy, 1991).

In nature, anaerobic bacterial reduction of nitrogen bearing compounds, such as proteins, produces NH_3. (Under anaerobic condition, NH_4 will be formed from domestic wastewater due to bacterial action on organic materials). Wastewater in sewer systems produces NH_3 gas in oxygen deficient environment and accumulates in sewer gas and water under confined conditions

and higher partial pressure of the gas in contact with air. Once exposed to reduced pressure in treatment plants, the gas evolves and creates objectionable odorous conditions. Modern industries producing fertilizer from NH_3 produce large amounts of ammonia wastewater.

The removal or reduction of NH_3 gas from wastewater is usually done by air stripping which is time-consuming. As aqua ammonium is a weak base, oxygen injection or acidic solution injection into air enhances the stripping process and its effectiveness. But the method is costly due to chemical use. The search for improved application methods of air stripping and contact methods of chemicals in water for NH_3 removal is an on-going process (Sawyer, 1967).

Hydrogen Sulfide: H_2S is a colorless gas. It is a very poisonous and flammable gas with a characteristic foul odor of rotten eggs at concentrations up to 100 parts per million. The gas is naturally produced from anaerobic bacterial breakdown of organic matter containing sulfur. It is found abundantly in natural gas and wastewater generated in industries dealing with natural gas and fuel products. Wastewater in sewers and storage may contain this gas in high concentrations. When gas laden water is suddenly shaken up or released by turning of pump or when sewage is released into a drop manhole, a significant amount of this gas may evolve. The first opening in the system resulting in a lethal cloud above sewer manholes can pose grave risk to anyone exposed to it. There are numerous cases of accidents reported in sewer and sewage works in pipelines, pump-houses and wastewater treatment plants. Groundwater in wells can also contain H_2S gas produced in anaerobic environment in aquifer systems containing sulfur content in high concentrations.

Aqua H_2S is a basic chemical and has the following equilibrium condition in water:

$$[H+]\,[HS-] / [H_2S] = 9.1\text{x}10^{-8} \qquad [2]$$

Its equilibrium constant (K_1 for first hydrogen dissociation) value is $9.1\text{x}10^{-8}$, and the pK_1 value is 7.0. Knowing the pH and H_2S (gas) concentration, Equation 2 can be used to calculate the amount of aqua H_2S expected in water. The basic gas properties associated with universal gas law and Henry's Law also apply to this gas (FAO, 2011).

Materials and Methods

The aim of the project was to reduce the NH_3 concentration through the use of a plunging jet reactor. It was assembled at the Kuwait Institute for Scientific Research (KISR) wastewater research plant at Sulaibiya. The unit (Figure 1) is a rectangular tank (reactor) made of plastic material with the following dimensions: height 70 cm, depth 40 cm and width 40 cm.

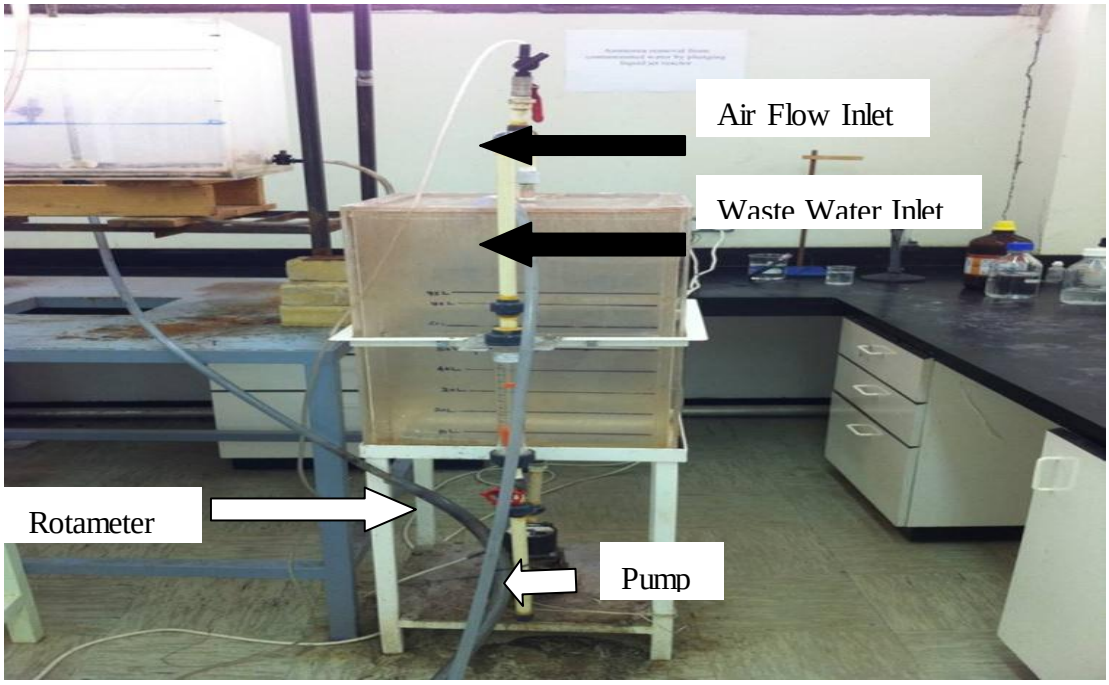

Fig. 1. Assembled jet-air reactor.

Plunging jets can be operated either as unconfined or confined devices. In an unconfined system the liquid jet plunges into an open liquid pool, creating a conical down flow dispersion of fine bubbles and a surrounding up flow of larger coalesced bubbles, as shown in Figure 2. In this case, the penetration depth of the bubbles is small, due to the submerged spread jet being out; hence, the bubble contact time with the liquid is short.

A confined plunging liquid jet system has apparently more potential use with pure gases and may be utilized to improve gas transfer rate out of liquid body. In this investigation, both confined and unconfined plunging jets were studied. As the liquid that contains NH_3 and H_2S are in confined areas debarred of oxygen to sustain anaerobic bacteria activity, it is usually very difficult to collect samples with high concentrations of the gases and preserve them in the liquid before analytical tests are performed in the laboratory. However, a local wastewater treatment

plant at Riqqa in Kuwait was found to have an operating sludge thickening and digestion process. Wastewater in this process contains high contents of reduced gases such as NH_3 and H_2S. Most of the tests were thus conducted utilizing wastewater samples collected from the thickened sludge stream. Within a period of 4 months, about 111 samples were tested. The 54 confined and 57 unconfined sample tests were performed.

All parametric laboratory tests were conducted at the Sulaibiya Wastewater Laboratory according to standard methods (APHA, AWWA and WEF, 2005).

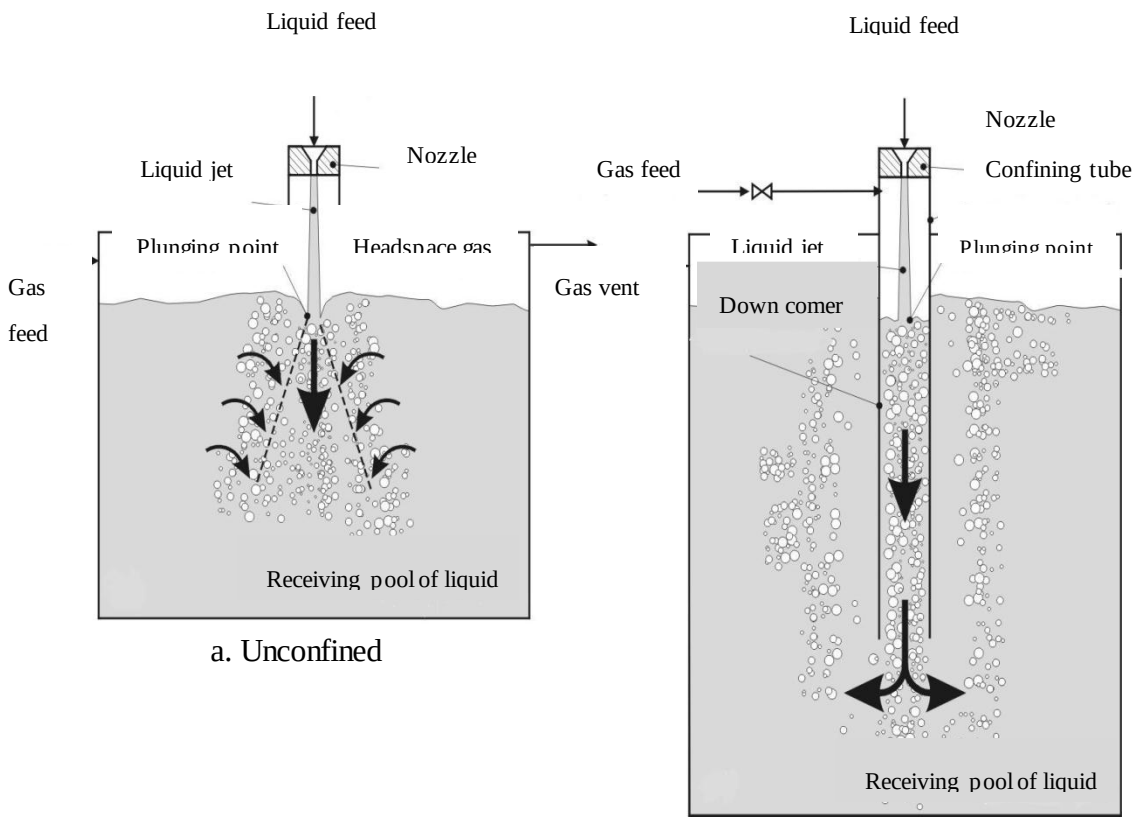

Fig. 2. Jet-air injectors (Source: Al-Anzi, 2006, page number 6).

Results and Discussion

General

Two main groups of data, corresponding to two test conditions of confined and unconfined injection of air into the wastewater mass, were acquired in the study. The outlet results show the wastewater quality after 15 min of rigorous air injection. The 15 minutes air injection was found to reach the almost exhausted state of the air stripping.
Average TSS in all tested samples was 1,658 mg/l; the conductivity ranged between 3,510 to 8,950 µS/cm; average temperatures was about 28°C; the compressor air flow was at 2 bars; nozzle diameter was about 2mm; and the air flow velocity out of the nozzle was 5.36 m/s at 1% pressure loss in pipes and the jet.

The following are the graphical representation of NH_3 and hydrogen sulfide reductions in under variable control factors: DO level, pH and air injection per unit volume of reactor. The pH was adjusted to test the pH variation effect on NH_3 removal. It varied from slightly below neutral condition to pH 12. The pH effects on H_2S were measurable up to a pH value of 10 at atmospheric pressure. The pH adjustment was performed adding 1N chemical solutions of Na (OH) or HCl in wastewater.

Effect of Air Injection Rate per Volume of Treated Water

Effect of jet-air injection rate per volume of wastewater on the reduction of stripped gases of NH_3 is shown in Fig. 3. The best removal of gases was obtained at an air injection rate of 0.033 m^3 of air per m^3 of liquid per min. Increasing the rate beyond this rate did not show any clear indication of improvement.

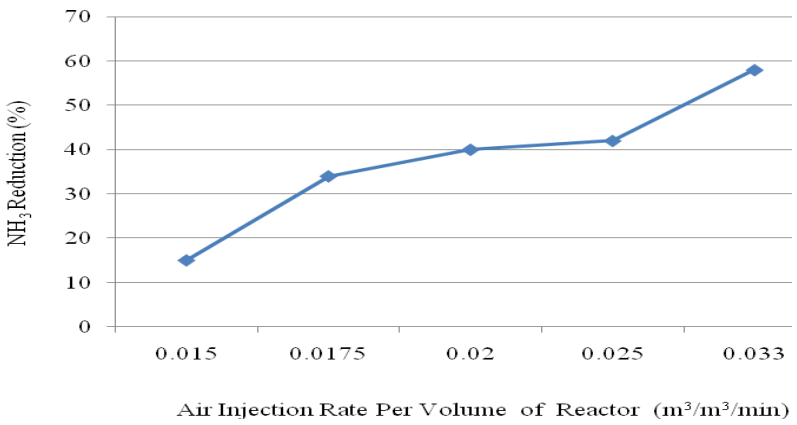

Fig. 3. Air injection rate per volume vs. NH_3 reduction

Wastewater Quality vs. Gas Release. The effect of pH, DO, and reactor volume on the percentage of NH_3 and H_2S removed by jet air injection into gas laden water under confined and unconfined environment is shown in Fig. 6 to 17.

pH vs. Gas Reduction: Graphical presentation of the reduction of NH_3 gas achieved in confined and unconfined tests at different pH levels appear in Fig.4, while the reduction of H_2S achieved in confined and unconfined tests at different pH levels appear in Fig. 5.

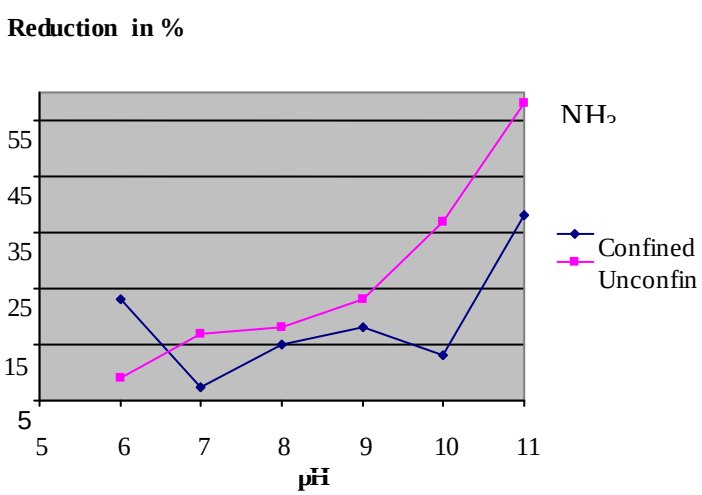

Fig. 4. Confined and Unconfined jet air injection – NH_3 reduction vs. pH

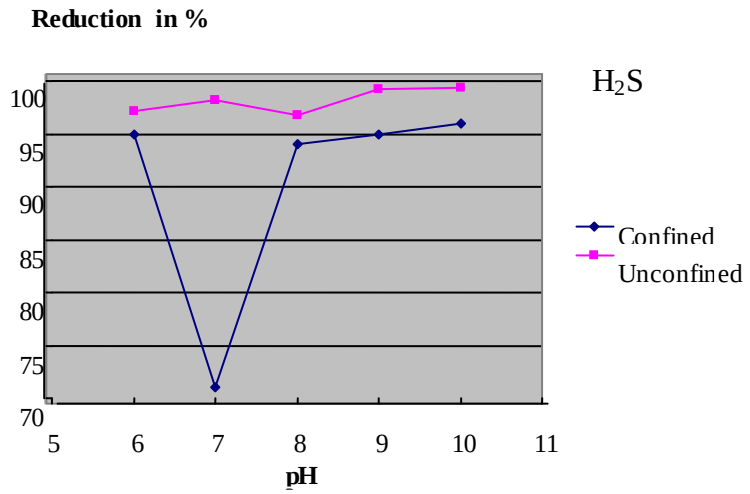

Fig. 5. Confined and Unconfined jet air injection – H_2S reduction vs. pH.

At acidic range (pH=6), NH_3 reduction was about 25% but the reduction percentage fell as pH remained neutral or slightly above neutral. However the reduction increased to about 40% as pH neared 11, which is a basic condition. By chemical attributes, NH_3 is a weak base and it dissolve easily in water at high pH. Therefore, more NH_3 was evolved as the gas was stripped. The relationship of pH with NH_3 reduction is more expressive in the unconfined case (Fig. 4). A consistent increase in NH_3 removal was noticed as pH increased. Maximum reduction of about 58% was accomplished.

H_2S reduction appeared to be less affected by pH level. The reduction achieved was high, within the range of 80 to 99% (Fig. 5). However, the highest removal of H_2S gas by 99% was achieved under unconfined jet air stripping.

Dissolved Oxygen vs. Gas Reduction: The effects of DO on NH_3 removals at various DO levels using confined and unconfined jet air injections are shown in Fig.6. The results of similar tests for H_2S removals under confined and unconfined jet actions with variable DO are shown in Fig. 7.

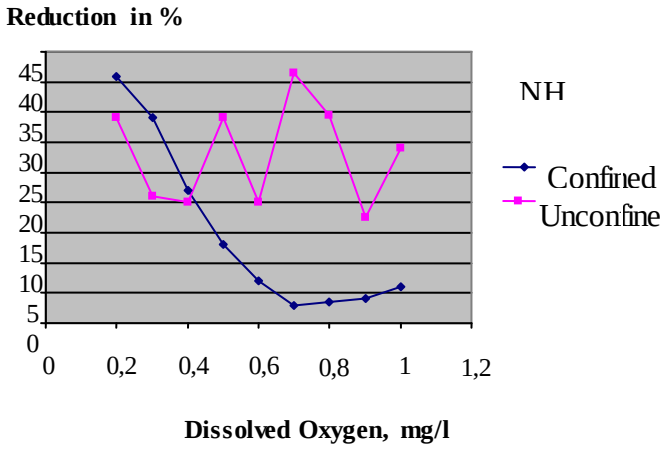

Fig. 6. Confined and Unconfined jet air injection – NH_3 reduction vs. DO

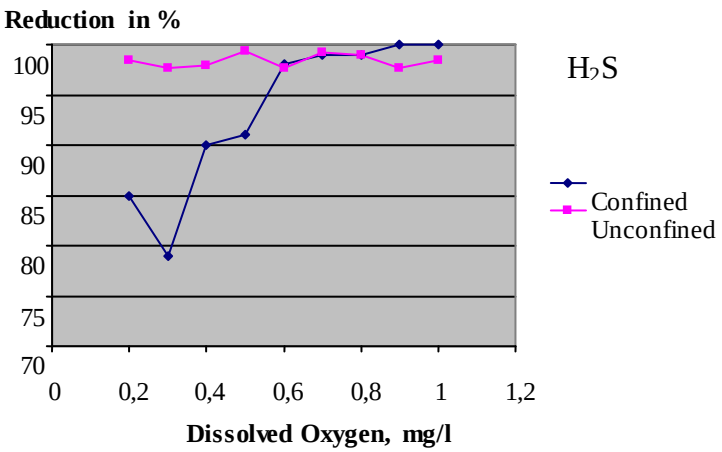

Fig. 7. Confined and Unconfined jet air injection – H_2S reduction vs. DO.

The effect of DO is vividly expressed in NH_3 reduction under confined jet air injection (Fig. 6). As DO in water increases, the extent of anaerobic condition in water decreases resulting in less NH_3 in water. Consequently the available NH_3 to be removed from water is also less. The scope for reduction drops. Under unconfined jet aeration, reduction of NH_3 does not show any clear relationship with DO. The reduction is consistent and remains within the range of 20 to 41% (Fig. 6). The reduction of H_2S appears to be independent of the DO level (Fig. 7) although, its production rate by bacterial action is high at low DO. The rate of removal of H_2S ranged from 97.5 to 99.5% for unconfined jet aeration, irrespective of changes in DO level.

Reactor Volume vs. Gas Reduction: Graphical presentation of the reduction of NH_3 gas achieved in tests with confined and unconfined injectors; at different liquid volumes are shown in Fig. 8 while the reduction of H_2S achieved in tests with confined and unconfined injectors, at different liquid volumes, appear in Fig. 9.

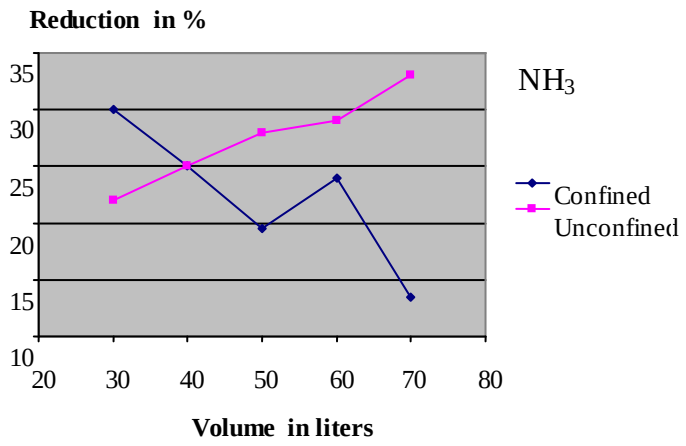

Fig. 8. Confined and Unconfined jet air injection – NH_3 reduction vs. Reactor Volume.

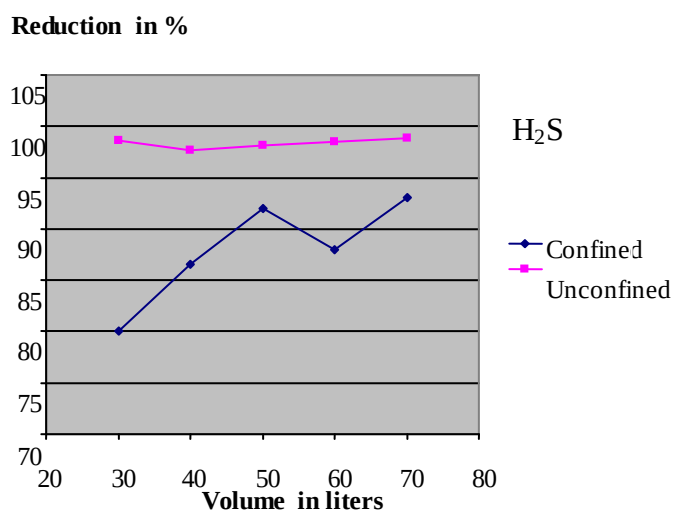

Fig. 9. Confined and Unconfined jet air injection – H_2S reduction vs. Reactor Volume.

At a fixed rate of jet air injection, NH_3 gas reduction in confined cases decreases as the volume of treated water increases (Fig. 8). The outcome is quite expected. However, the result shows that NH_3 gas reduction increases slightly as volume of water increases in unconfined jet aeration.

Under the limited scope of the study, the outcome remains unexplained. The H_2S reduction at variable volumes of water (Fig. 9) in both confined and unconfined jet aeration with variable volume is consistently high at 80 to 99%.

Sensitivity of pH, DO, and Water Volume on Stripping of Gases from Water

Table 1 contains the linear correlation coefficients of NH_3 and H_2S gas reduction achieved in the studied cases with respect to factors of pH, DO, and reactor volume (treated wastewater). The table shows the correlation coefficient of NH_3 reduction as a function of three factors. The most sensitive factor in the case of unconfined NH_3 gas stripping appeared to be the volume of treated water (R^2 = 0.984). At a given rate of air supply, the observation is highly rational and expected. The observation was further supported by the relation between NH_3 stripping and the amount of air supplied per volume of tested water (R^2 = 0.908). For NH_3 gas stripping under unconfined conditions, the second most important factor is pH (R^2 = 0.935). Significant correlation is also evident for H_2S gas but to a lesser extent. In unconfined cases, the effect of DO on gas stripping appeared to be nominal.

Table 1. Sensitivity of Some Factors on NH_3 and H2S Gas Stripping Under Confined and Unconfined Conditions

Injection Status	Test Gas	Linear Correlation Coefficient			
		pH	DO	Reactor Volume	Air Supply Rate per Volume of Gas-laden Water
Confined	NH_3	0.478	0.844	0.849	-
	H_2S	0.086	0.835	0.852	-
Unconfined	NH_3	0.935	0.076	0.984	0.908
	H_2S	0.816	0.160	0.347	-

In confined cases, among the three tested factors of pH, DO and volume of treated water affects the gas reduction significantly. Second important factor is the DO.

Conclusions

Based on the results of the study, the following conclusions were derived:

- As high as 58% of NH_3 gas can be stripped off by jet air confined or unconfined injection into wastewater laden with the gas under variable factors of pH, DO and air injection rate per volume of liquid.
- As high as 98% of H_2S gas can be stripped off by jet air injection into wastewater laden with the gas.
- Between confined and unconfined jet injection of air, the unconfined condition is preferred for better gas reduction.
- NH_3 gas removal by jet aeration is most sensitive to pH and the amount of air supply per volume of wastewater per minute. The best result was obtained at a gas injection rate of 0.033 m^3 of air/m^3 of water/ min.
- H_2S gas removal is also significantly sensitive to pH and air injection rate.

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The Impact of Thermal Springs on the Population of Hammam Ali, Dhamar Governorate, Yemen

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Abstract

Hammam Ali, is situated 73 kilometers south west of the capital Sana'a, and 35 km from the City of Dhamar, with an average elevation of 1506 meters above sea level. It is one of the most famous therapeutic bathing areas (hydrographic hot springs) located in Yemen, with latitude of 14° 50' 58 N and a longitude of 43° 46' 10 E. These thermal springs emerge from the foothill of Al-Kaher Mountain and the shallow groundwater of the alluvial and volcanic aquifers. This study was conducted to evaluate the impacts of Hammam Ali springs on the population. Nine thermal springs were analyzed for pH, EC, TDS, T Alk, CO_3, HCO_3, SO_4, NO_3, Ca, Mg, Na, and F. Benefits of springs were evaluated by conducting a social survey with 50 respondents. All thermal springs (38-62°C) are unsuitable for drinking purposes as they contain high concentrations of F (10.2 -13.5 mg/l) reflected as dental fluorosis and Na (289 - 321 mg/l). A drinking water collection tank was therefore constructed on top of the mountain (less F), however, 76% respondents were unsatisfied with the general water situation. Typhoid, malaria and bilharzias are common diseases according to 74%, 70% and 66% respondents, respectively. Waste water from thermal baths drained onto streets, drinking water and garbage might be the main causes (66%, 54% and 18% respondents). Competing for spring water is a daily challenge particularly for poor people due to some powerful spring owners (18%) who prohibit them from digging for new springs. The income from recreation activities is nearly invisible. Respondents request the intervention of the government for water projects (90%) and development in tourism (45%) and agriculture (20%). For the wellbeing of population and a healthy environment it is highly recommended to improve spring water management in Hammam Ali.

Keywords: Hot springs, Hammam Ali, impact, population, IWRM

Introduction

Millions of tourists travel yearly to geothermal destinations such as volcanic features, geysers and hot springs worldwide. Such type of tourism is nowadays called geotourism 'which incorporates the concept of sustainable tourism in that destination should remain unspoiled for future generations'. The Hawaii Volcanoes National Park, the Yellowstone National Park, the geothermal and the volcanic activity at Rotorua, New Zealand and Mount Etna in Italy are known worldwide for such attractions (Heggie, 2009). Spas have been developed since early ancient history to cure arthritis, rheumatism, skin diseases….etc. Water composed of a combination of minerals is used for hydrotherapy and may include thermal-based medical programs (George, 1994).

Thermal springs can be of great socio-economic and socio-cultural impact. They are increasingly used as spas, in industrial processing, in aquacultures and for power generation. The Eiland thermal spring located in the Limpopo province, close to the Great Letaba River, South Africa, has been developed as a resort with water temperature regulated at 38°C (Olivier et al, 2011). Thermal waters as found in the Usak province in the western part of Turkey are used for swimming bathing, and medicinal purposes. Some are natural thermal springs originating from the Menderes Massif Metamorphics (Davraz, 2008).

Heritage may often be implemented as a flexible economic tool without concern for the kind of ideological problems. In a study carried out in Kurokawa Onsen, a hot springs resort located on the island of Kyushu, Japan, it is stated that 'local actors are acquiring concrete, long-lasting social and economic benefits that can exist comfortably within the heritage tourism landscape' (McMorran, 2008).

A number of studies have found that geothermal water may contain toxic elements such as arsenic and mercury and pathogenic organisms. The thermal springs in the northern part of Limpopo are not for human consumption for their high fluoride levels (Olivier et al, 2011). According to WHO drinking water guidelines its concentration should not exceed 1.5 mg/L. Fluoride is found in natural waters as seas, lakes and rivers in concentrations up to 1 mg/L and are expected to be found in calcium poor waters. High fluoride concentrations in drinking water contribute to dental and skeletal fluorosis (WHO, 2006), arthritis, decreased thyroid function and detrimental effects on the brain (Carton, 2006).

High fluorosis prevalence was observed in Elementaita, Rift Valley, Kenya (Kahama et al, 1997). Fluoride values up to 11.6 mg were recorded in hot springs (T > 36ºC) in the Ethiopian section of the East African Rift Valey (Reimann et al, 2003) which may have direct health implication. Hydrothermal origin was suggested for the high F values. Hot springs containing F up to 7.3 mg/L have been observed in and around San Antonio de los Cobres, Argentina. As

dilute meteoric water resources are scarce and rainfall is low it was recommended to develop cost-effective technologies to reduce F concentrations (Olivier et al, 2011).

Fluoride prevalence is not uncommon in Yemen. In a study on fluoride prevalence in Hidhran and Al-Burayhi Basin, northwest to Taiz city, Yemen, 83.9% of total groundwater samples revealed values higher than the recommended 1.5 mg/L, while 16.13% of total samples prevailed values higher than 5 mg/L. Hydrogeochemical investigations indicated the possibility of water-rock interaction as the main reason for the presence of F ions (Al-Amry A. , 2009). Fluoride concentrations up to 7 mg/L were recorded in Al-Azareq Basin, in the southern part of Al-Dhala governorate (Al-Amry A. , 2011).

The concept of Integrated Water Resources Management has been rediscovered in the 1990s though attractive but not always applicable. Water problems are not any more solved by water experts as these become increasingly more complex. 'In fact, it can be successfully argued that the time has already come when water policies and major water-related issues should be assessed, analyzed, reviewed, and resolved within an overall societal and development context; otherwise the main objectives of water management, such as improved standard and quality of life of the people, poverty alleviation, regional and equitable income distribution, and environmental conservation cannot be achieved' (Biswas, 2004).

Study Area

General Information

Hammam Ali is a village in Al-Manar district, Dhamar governorate. It is located 73 kilometers south west of the capital Sana'a, and 35 km from the City of Dhamar, with an average elevation of 1506 meters above the sea. Hammam Ali has a population of 1611 inhabitants consisting of 821 males and 790 females (about 51% males and 49% females) and 233 households (CSO, 2004). It is one of the most famous therapeutic bathing areas (hydrographic hot springs) located in the central highlands of Yemen, with latitude of 14° 50' 58 N and a longitude of 43° 46' 10 E. These thermal springs (more than 16) emerge from the foothill of Al-Kaher Mountain and the shallow groundwater of the alluvial and volcanic aquifers. Main public services as water, electricity do not exist. Telecommunication and health supplies are weak.

The study area has an average annual precipitation of 300 mm during the two main rain seasons in spring (March to May) and summer (July to August) and scarce surface water. Consequently, the groundwater has come under constant exploitation for agricultural and domestic uses. The Social Fund for Development (SFD) in coordination with French Red Cross (FRC) financed and constructed a drinking water reservoir in which water originating from a natural spring located on Al-Kaher Mountain is collected.

The area depends in its economic development on agriculture (it is well known for its famous orange trees) and family tourism for recreation in thermal baths. The socio-economic importance of thermal springs has not yet been given much attention in Yemen in general and in Hammam Ali in particular. In the past, citizens of Hammam Ali faced problems due to the accumulation of garbage and municipal waste water on streets causing serious pollution of soil and surface water. Wastewater produced by thermal baths in Hammam Ali is drained on village streets, mixing up with garbage. FRC in coordination with the Yemeni Red Crescent (YRC) has therefore installed sewage drainage pipes to collect this wastewater into collection tanks. However, the garbage on streets remains scattered without collection causing an unacceptable view and unhealthy environment. Lack of awareness about hygiene and proper water and waste water management are main concerns.

Geology and tectonics (Al-Kohlani, 2008)

The young volcanic series of Yemen are of the age 10-5 Ma (late Miocene to Recent) and they include eight volcanic fields with recent volcanic activities. One of them is the Dhamar-Rada'a volcanic field (extensive Quaternary volcanics) which covers an area of about 1477 km^2. The study area is located in the western part of this field which is characterized by both central and fissure activities and has been affected by intense vertical tectonism, resulting in the formation of horst and graben structural patterns. It is also characterized by volcanic cones, domes, sheets and lava flows. The field is mainly composed of basaltic lava flows, and lithified and stratified basic tuffs and agglomeratic pyroclastics. The chronological sequence of lithological units is as follows:

- Holocene - Recent Alluvial and wadi gravel
- Pliocene to Holocene - Quaternary Recent volcanics
- Paleocene Tertiary volcanics Yemen Trap series (YTS)
- Mesozoic - Cretaceous Tawilah sandstone Group
- Precambrian Basement, undifferentiated rocks

The Precambrian rocks (low- to medium-metamorphic rocks) consist of meta-sediments (sericite-chlorite schist) and meta-volcanic rocks (gneisses), with marked foliation that outcrop to the north and east of Dhamar city. The basement is unconformably overlain either by the Tawilah sandstone formation or the Volcanic Trap series. The Tawilah group consists of cross-bedded continental sandstone. It is overlain by volcanics to the north of Dhamar city which is unconformably underlain by the Precambrian gneiss. The sandstone beds have thicknesses up to 200 m north of Dhamar and 30 m near Isbil east of Dhamar, but up to 1200 m to the west of Dhamar, dipping to the west. The sandstone varies from typical sandstone to pebbles. Tertiary volcanics lie directly above the Tawilah formation and consist of ash, tuff and ignimbrite, interbedded with extensive basaltic lava flows. In some areas of Yemen, the thickness of the YTS reaches up to 2000 m; but around the area of Dhamar to Rada'a, the thickness ranges from 900 to 1000 m. These volcanic layers formed an extension plateau at the end of the Tertiary period cut by numerous vertical faults. The Quaternary volcanics are represented by central and fissure volcanism. The fissure volcanism is characterized by widespread basaltic lava flows and spatter cones, extensive basaltic obsidians, and pumices in the Dhamar-Rada'a area.

This study aims to evaluate the use of hot springs at Hammam Ali in respect to IWRM (environmental, health, agricultural, socioeconomic and technical aspects…etc.).

Methodology

The impact of 9 hot springs in Hamam Ali was evaluated by conducting a social survey with 50 randomly chosen adult respondents in face to face interviews with 28 men and 22 women (56% men, 44% women). Structural interviews with teachers, local council members, and NGO members were conducted to identify the impact of hot springs on the population in the frame of IWRM aspects (environmental, health, socio-economic, tourism aspects … etc.).

Nine water samples were collected in 1 liter glass bottles from springs in Hammam Ali and analyzed for physico-chemical analysis (pH, EC, TH, TDS, T Alk, CO_3, HCO_3, SO_4, NO_3, Ca, Mg, Na, K, Cl and F). Water samples were analyzed according to standard methods of water examination (APHA, 2010). The total dissolved solids (TDS) were calculated by multiplying the measured EC values by 0.65. The EDTA Titrimetric Method was used to determine calcium and total hardness as $CaCO_3$ in mg/L. Magnesium was estimated as the difference between the total hardness and calcium as $CaCO_3$ mg/L. A Flame Photometer M 7DC DR LHNGE model was used to measure sodium and potassium in the water samples. A Spectrophotometer HACH DR 4000 model was used to screen sulphate directly and the nitrate was derived from the recorded nitrogen value. The Argentometric method was used to determine chloride. The total alkalinity (T. Alk.) was measured by direct titration with standard hydrochloric acid and accordingly values of carbonate and bicarbonate concentrations were calculated. An additional water sample from Al-Kaher drinking water spring was collected and analyzed for its suitability for drinking purposes.

Results and Discussion

Hamam Ali thermal springs (more than 16 springs) are located in Anis area about 30 km west of Dhamar City. The geological set up of the area consists of volcanic rocks of Tertiary age represented by basalt, Raiodiocite and riolitic rocks. In addition semi horizontal beds consist of tuff and clastic rocks are also present in the top of the area geological cross section. The general trends of the faults and fractures in the area are North-East, North-North East and East-West. The mineral dissolved content in the water is about 1 gm/litre. The water temperature ranges between 40 – 96.31°C as in Mesh Al-Kafer (Ibb). The majority of these springs are located along major faults with a North-West and South-East trend or in the junction areas of several faults with different trends which reflect the complex geological and structural set up of the Tertiary volcanic rocks. Most of these springs emerge from the banks of the Wadis which are recharged by rainfall while others have deep thermal origin. The average yield of these springs ranges between 1 liter/sec as in Wadi AL-Tawir spring to 30 liter/second in Damt.

Spring water in Hammam Ali is, in general, used for all purposes (drinking, households, irrigation and medical treatment). Drinking water often may not be available where the people live, and according to tradition women, they often have to walk for hours to get the daily water ration for a family. Water scarcity and pollution pose a threat for drinking water supplies (Reimann et al, 2003). The structural interviews in Hammam Ali revealed that an average of 2 persons/household, mostly children and women, fetch water on a daily basis from Al-Kaher cold spring (24.7°C). About 68% respondents rely on this spring for drinking purposes and on hot water from a spring at the village mosque for other domestic uses. Some 54% respondents rely on private water wells for domestic and agricultural uses and the remaining few percent on water vendors from neighboring villages and bottled water. However, it must be noted that the households have an average of 9 family members (max 18 members).The age of water fetching persons vary from children under 10 years old to adults over 40 years. Girls are the most affected since they are usually not allowed to finish basic education, which ends up to grade 9. Although a drinking water collection tank was constructed at Al-Kaher spring, about 76% of respondents are unsatisfied with the current water situation which might be referred to water scarcity and low water quality of springs and private wells.

Hammam Ali is well known for recreation (family tourism) and its beautiful landscape. Its population benefits from thermal springs as spas and can be referred to heritage tourism. Families, mainly from neighborhood villages and some Yemeni migrant families coming mainly from the Gulf countries, target this area at the end of the harvesting season. Thermal baths are owned by local families or sometimes by individuals (18% of respondents only) and represent a source of income where each spring usually diverts to more than one thermal bath. Six percent respondents rent a spring to stock up their monthly income. Spas are typically integrated in simple housings including rooms for accommodation. Visitors generally rent these housings, many of which are not in good condition. Nevertheless, the income of inhabitants from recreation activities is nearly invisible. Tourist infrastructure as high standard hotels, restaurants, wastewater systems, water delivery, transportation, electricity, and others are not adequate which leads to a negative impact on tourism activities and accordingly on a low economic income.

It is observed that the famous orange trees are becoming increasingly replaced by Qat, which is considered as a cash crop and generates a fast income. As in every part of the country, small scale agribusiness is dominant. Marketing agricultural goods of the region is almost limited to the recreation season.

Many inhabitants of Hammam Ali are under the poverty level. Competing for spring water is a daily challenge particularly for poor people due to powerful spring owners (rich and famous families) who prohibit them from digging for spring water till they pay for it. It is prohibited to construct buildings or carry out projects prior the agreement of these powerful people. Some conflicts observed among inhabitants are referred to spring ownership. The Sheikh in general is the person who solves the conflicts in the area. Thermal baths built by the government are

destroyed to force tourists to enter their baths. The influence of the government in tribal areas in general is weak as long as a tribal representative is part of it.

The wastewater collection system for thermal baths installed by the FRC (Fig 1) constitutes of three consecutive ponds, treating water through precipitation of heavier wastes. However, water in the final stage is not of efficient quality for irrigation purposes. It was observed that plants close to the surrounding areas are mostly damaged, which is most probably due to irrigation with treated waste water produced from the ponds.

Citizens of Hammam Ali are in general satisfied with the waste water collection tank system except those living in the neighborhood of the ponds where mosquitoes are believed to cause malaria (according to 70% respondents) in addition typhoid (74%), diarrhea (66%) and bilharzias (20%) are common among the population. Waste water of thermal baths (few spill their waste water onto streets + leaking drainage pipes), domestic waste and garbage are believed to be the main causes of illnesses mentioned earlier according to 66%, 54% and 18% respondents, respectively. Nevertheless, 12% of respondents are not aware about the reason for the spread out of these illnesses. Sick people have to travel to Dhamar city for better treatment alternatives since Al-Wahda Hospital in Hammam Ali does not provide sufficient health services which leads to additional costs for transportation and medical treatment.

Physico-chemical parameters of the 9 analyzed hot spring water samples are recorded in table 1. The results indicate that the temperature of springs range between 38ºC and 62ºC. Spring water in Hammam Ali is generally alkaline in nature (pH 8.15 – 8.89) which might be referred to dominant sodium (average of nearly 308 mg/L). The EC varies from 1250 to 1416 µS/cm and TDS from 800 to 900. The F concentration of all springs (10.4-14.4 mg/L) highly exceed the WHO permissible limit of 1.5 g/L which make them not suitable for drinking purposes. This explains the prevalence of dental fluorisis (brownish teeth) observed in the study area (Fig 2). Calcium and carbonate concentrations are comparatively low in concentration which might be referred to $CaCO_3$ precipitation. Chloride, sulphate, nitrate and magnesium are within the WHO standard limits for drinking water quality. Al-Kaher drinking spring water analysis reflects acceptable results; the fluoride concentration is even relatively low.

Fig 1: Waste water ponds constructed by FRC

Fig 2: Dental fluorosis among inhabitants

Respondents request the intervention of the government for water projects (90%) in kind of providing potable water. The development in the tourism sector was requested by 46% and in agriculture by 20%. Replacing Qat trees by orange trees, finding alternative benefits from thermal springs, the limitation of powerful inhabitants were among other concerns to be solved.

In the context of IWRM it is recommended to improve water and waste water management. Spa activities could be socioeconomically feasible if infrastructure and trained human resources are present at place. The concerns of locals should be seriously taken into consideration by the government. Fluoride reduction of springs might be achieved by calcium ion treatment or dilution as alternative drinking water resource. Public participation in planning and implementing projects are of great importance to avoid future conflicts.

Table 4: Physico-chemical parameters of 9 spring water samples in Hammam Ali village

Spring	EC	T	pH	TH	TDS	T.alk	Mg	Ca	Na	K	F	Cl	SO_4	NO_3	CO_3	HCO_3
	µS/cm	°C	21 °C		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Drinking water	748	24.7	7	200	510	325	50	150	-	-	0.8	-	45	8.8	-	400
Al-Amam	1250	61.4	8.59	26	813	813	1.5	7.8	304	3.0	10.2	96.0	124.4	5.4	12.0	418
Ali	1252	60.5	8.59	28	812	812	2.3	7.2	310	3.1	10.7	93.0	134.0	5.0	14.4	422
Al-Amah	1257	53.8	8.89	28	817	817	0.9	9.6	308	3.3	10.6	91.0	132.4	5.9	19.0	415
Ghailan	1267	54.5	8.72	21	823	823	0.9	7.0	289	3.1	12.3	97.0	155.0	7.9	16.0	421
Ammar	1285	54.0	8.85	28	837	837	2.0	7.8	305	3.1	13.5	98.0	151.0	5.0	26.0	400
Mausa	1344	47.0	8.51	45	874	874	3.5	12.0	315	3.9	12.2	96.0	189.0	12.0	-	443
Al-Musalah	1253	47.0	8.15	25	815	815	1.8	7.0	308	3.0	12.4	91.0	142.0	5.0	9.1	431
M Ghailan	1416	38.5	8.38	54	896	896	2.9	17.0	321	4.0	11.4	94.0	187.0	5.0	8.2	432
A. Al-Barik	1294	38.5	8.38	31	841	841	2.0	8.9	310	3.8	11.7	94.0	151.0	10.0	33.0	374
Maximum	1416	61.4	8.89	54	896	896	3.5	17.0	321	4.0	13.5	98.0	189.0	12.0	33.0	443
Minimum	1250	38.5	8.15	21	812	812	0.9	7.0	289	3.0	10.2	91.0	124.4	5.0	8.2	374
Average	1291	50.6	8.56	32	836	836	2.0	9.4	307.8	3.4	11.7	94.4	151.8	6.8	17.2	417.3

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Decision Support System for Efficient and Environmental Water Allocation in Mahmoudia Canal Watershed

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Abstarct

Many models have been developed during the last decades to facilitate the decision making process in water resource planning and management. For a variety of reasons, many of these models are no longer in use. Restoring, enhancing and updating these models are often economically attractive when the cost is compared with that of developing new models. A DSS model has been developed by DELFT HYDRAULICS in 1998. The system incorporates three sub-models, SIWARE, WLM, and DELWAQ for transport dispersion, and water quality in order to form a complete package for watershed system modeling. The DSS instrument was applied to the Nile Delta region, but after that it became obsolete because of many reasons. This paper highlights the modifications that have been carried out on this old version. The updated model has been applied in Mahmoudia watershed area in the western of Nile delta. The Mahmoudia canal command area suffers from inequity of water distribution at the branch canals, unavailability/insufficiency of irrigation water, deterioration of water quality, and supplementary irrigation by reuse saline drainage water, which is highly polluted by nutrients, pesticides, heavy metals, and organic loads. The Decision Support System DSS in the study area was applied in the study area to enable the decision makers to reallocate the irrigation and drainage water in Mahmoudia districts based on socioeconomic and environmental aspects.

Two scenarios have been carried out for 2017 strategy namely environmentally allocated drainage water reuse and irrigation improvement interventions at tertiary and quaternary levels. The reallocated drainage water reuse has resulted in improving drainage water salinity, evapotranspiration and accordingly crops yields in the southern western areas of the watershed. The optimistic scenario of irrigation improvement has resulted in 20.3% increase in drainage water salinity. To secure the additional drinking water requirements for Alexandria in 2050, three other scenarios have been designated for 2050 strategy, namely maximizing drainage water reuse from main drains, intermediate drainage reuse from branch drains, and desalination option.

The modeling results shows that maximizing drainage water reuse in Agriculture will result in decreasing the Edko and Mariut Lakes outflows to the Mediterranean sea by 30% and 10% respectively and the salinity of drainage water at the exit of Mahmoudia watershed will increase

in the intermediate reuse scenario more than the maximum reuse scenario, while the lowest salinity concentration of drainage water will be in the desalination scenario, where no maximizing of drainage water will occur.

According to the DSS modeling results and the benefit cost analysis, which considers the cost of economic and environmental damages, the paper recommends applying the intermediate drainage water reuse as a strategic option for water management in Mahmoudia watershed to supply the increasing drinking water demands for Alexandria city by the year 2050.

1. Introduction

New methods for addressing water resources problems are being developed and implemented using advanced computer facilities for data management and analysis. Among these newly evolved methods are the Decision Support Systems (DSS). Many authors described them as interactive computer-based systems that help in solving certain problems (Johnson (1986), Sol (1987), Turban (1989), Hamad (1993), and Abu-Zeid (1996). The main objective of using DSS in water management is to enable decision making by examining alternative solutions in an interactive manner.

The Water Resources System in Egypt consists of Natural Resources, Socio-Economic, and Administrative and Institutional sub-systems (Pennekamp and Wesseling, 1993), each of which is highly complex in its own. Due to this complexity, it is difficult for expert decision-maker to assess the impacts of proposed actions and consequently make decisions based only on his own experience.

The Ministry of Water Resources and Irrigation (MWRI) has realized this issue and started some time ago to develop mathematical models to help the decision-maker in his task. The objective of most of these models is to simulate how different interventions could affect the system and to quantify their impacts. These models can be categorized into:

1. Water supply models that aim at predicting the inflow to Lake Nasser by estimating the amount of rainfall over the Nile Basin and using rainfall-runoff techniques;

2. Water demand models that aim at simulating water management within the country. A large number of models do exist in this category and vary according to the level of application. Some of these models simulate water management at the national level, some at the regional level, and the others at the farm level. Most of these models consider all water uses and all water sources. Examples of these models are Simulation of Water Management in Arab Republic of Egypt Model (SIWARE) and Operational and Planning Distribution Model (OPDM);

3. Water quality models that simulate water quality management in Egypt. They take into account pollution sources and water quality processes. Example of these models are Delft Water Quality Model (DELWAQ) and Waste Load Model (WLM); and

4. Agro-economic models that aim at simulating the agriculture sector in Egypt. They take into account most of the system constraints such as available water, land, and labour. The aim of these models is to define the optimum cropping pattern based on economic criteria. Examples of these models are Agricultural Sector Model of Egypt model (ASME) and NILECON model.

Despite the large number of the available models, only a few are currently in use while the rest are either not used at all or not used effectively. This situation on one hand affects the management process of the water resources system and on the other represents a considerable economic loss given the important investment in money, time, and effort needed to develop these models. Based on the analysis and evaluation of some of the available models (15 models), the reasons of not using the models effectively are identified as being one or more of the following:

- Some of these models were developed a long time ago using old versions of programming languages that had certain limitations;
- Some of them are complex and do not have a user-friendly interface, making them difficult to be used;
- The majority of the models have been developed and calibrated using data obtained from pilot areas only, and were not validated for use at a higher level (e.g. regional or national level). To use them more widely, huge amount of data would be required, needing much time and effort;
- Some of the models are too rigid to accommodate new changes in the system;
- A group of these models was developed outside Egypt and brought to the country, thus the source codes are not available. Any modifications to these models will be difficult without consulting the developers.

1.1 Objectives of the study

The objective of the work reported in this paper is to:

- Update the Decision Support System for Nile Delta, Egypt in order to restore and put it again on the track by adapting, and upgrading it.
- Model application, calibration, and validation at Mahmoudia canal command area
- Assess the required water allocation scenarios
- Analyzing the model results

1.2 Model description

The DSS contains a number of modules:

- SIWARE (developed by the Dutch Staring Centre) computes the flows and water balance;
- WLM (Waste Load Model) calculates the loads form municipal, industrial and agriculture sources;
- DELWAQ (Delft Water Quality Model) simulates water quality processes and computes concentrations of pollutants;

1.2.1 SIWARE model

The SIWARE model consists of four main modules (Figure 1), each one with special functions (Roest, 1998):

- WDUTY module to compute the farmers' water demands, based on an unlimited supply of good quality irrigation water.
- DESIGN module to allocate the available irrigation water to the main canal intakes, based on the areas with different crops grown in the respective commands. DESIGN also computes the target levels throughout the irrigation system for all location where regulating structures are present.
- WATDIS module to compute the actual water distribution. WATDIS is a hydraulic model and confronts the target levels to be maintained by the irrigation authority for a

fair distribution of water with the water demand of farmers, which try to maximize their share. Direct losses from the irrigation system to the drains are included in the computations through accounting for the day - night discrepancy between supply in the canals and the water uptake by farmers.

- REUSE module to compute required reuse of drainage water from the drainage system and the resulting salinity of the (mixed) irrigation water. In addition to the actual consumptive use of water by crops, the soil salinity and drainage **losses.** The module computes also the unofficial reuse of drainage water by farmers. REUSE also accounts for municipal drainage water and computes the transport of the generated losses to the coastal lakes.

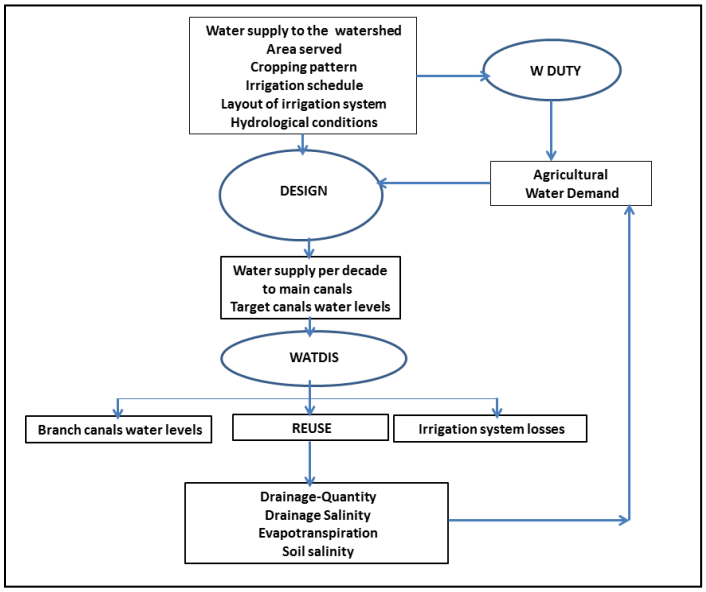

Figure**1.** The SIWARE flow chart

The western Nile Delta has been schematized into 87 calculation units in SIWARE model (Figure 2). In each calculation unit, different characteristics are identified as crop type, and soil characteristics.

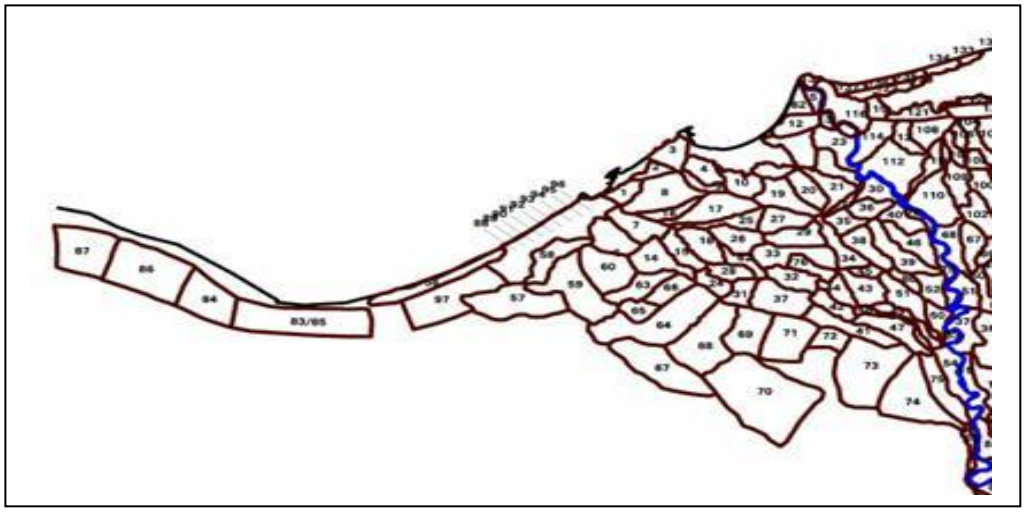

Figure 2: Schematization of the western Nile Delta into calculation units

1.2.2 Waste Load Model WLM

The WLM provides the input for the DELWAQ water quality model. The WLM consists of two major functional modules, a waste load production module (kg BOD per inhabitant or kg NO_3 per feddan and a waste load treatment module, which considers the effect of natural and artificial treatment especially for the different systems of wastewater treatment plants in the study area.

In the WLM model, the following pollution sources and treatment nodes are distinguished:

- Domestic waste load production
- Agriculture waste load production
- Industrial waste load production
- Purification in waste water treatment plants
- Natural purification in septic tanks and local surface water

1.2.3 DELWAQ Model

The DELWAQ model determines the concentration of substances in waterways. The transport of substances is governed by the advection-diffusion equation, which is solved by DELWAQ. The substances and the processes influencing concentration levels of the substances are available from a built-in library including more than 100 substances and more than 1,000 processes. The substances enter the modeled area as boundary concentrations or as dry waste loads.

1.3 Description of the study area

The Mahmoudia canal command area is located near the northern edge of the west delta in Behaira governorate. The canal runs for a distance of 77 km from the Rosetta branch of the Nile

down to the Mediterranean Sea at Alexandria as shown in figure 3. The climate in the Mahmodia area is generally cool in winter and moderately hot in summer. It serves a total gross agricultural area of about 305,000 feddan (net area 240,000 fed the difference is urbanized areas, roads, and waterways) through 70 branch (distribution) canals. The Mahmoudia canal command area suffers from inequity of water distribution at the branch canals, unavailability/insufficiency of irrigation water, deterioration of water quality, and supplementary irrigation by drainage water reuse, which is highly polluted by nutrients, pesticides, heavy metals, and organic loads.

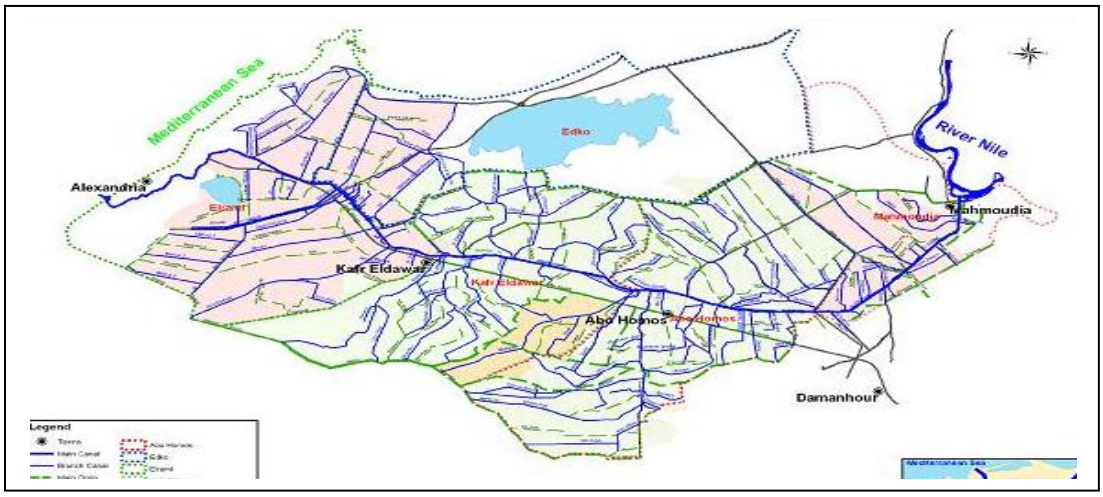

Figure 3: Location of Mahmoudia watershed in the western Nile delta.

2. Approach and Methodology

2.1 Model modifications

Special modifications were developed for some visual basic files and some other executable files. The updated files had to be added to system and system 32 of windows XP. An open data structure program was also developed to open and modify database files, DELWAQ history files and map files within the DSS model.

2.2 Model building and application

2.2.1 WLM schematization

The WLM schematization includes editing the WLM network according to the point and non-point pollution sources and identifying the natural and artificial treatment systems in the

watershed map. The domestic and industrial waste loads are also identified on the database and the schematization map. After that, the WLM loads are positioned for DELWAQ

2.2.2 DELWAQ setting

The process of water quality modeling is implemented by editing DELWAQ segments, identifying process coefficients, setting the boundary conditions, and entering water quality monitoring data in monitor.ntw and monitors his files for model calibration.

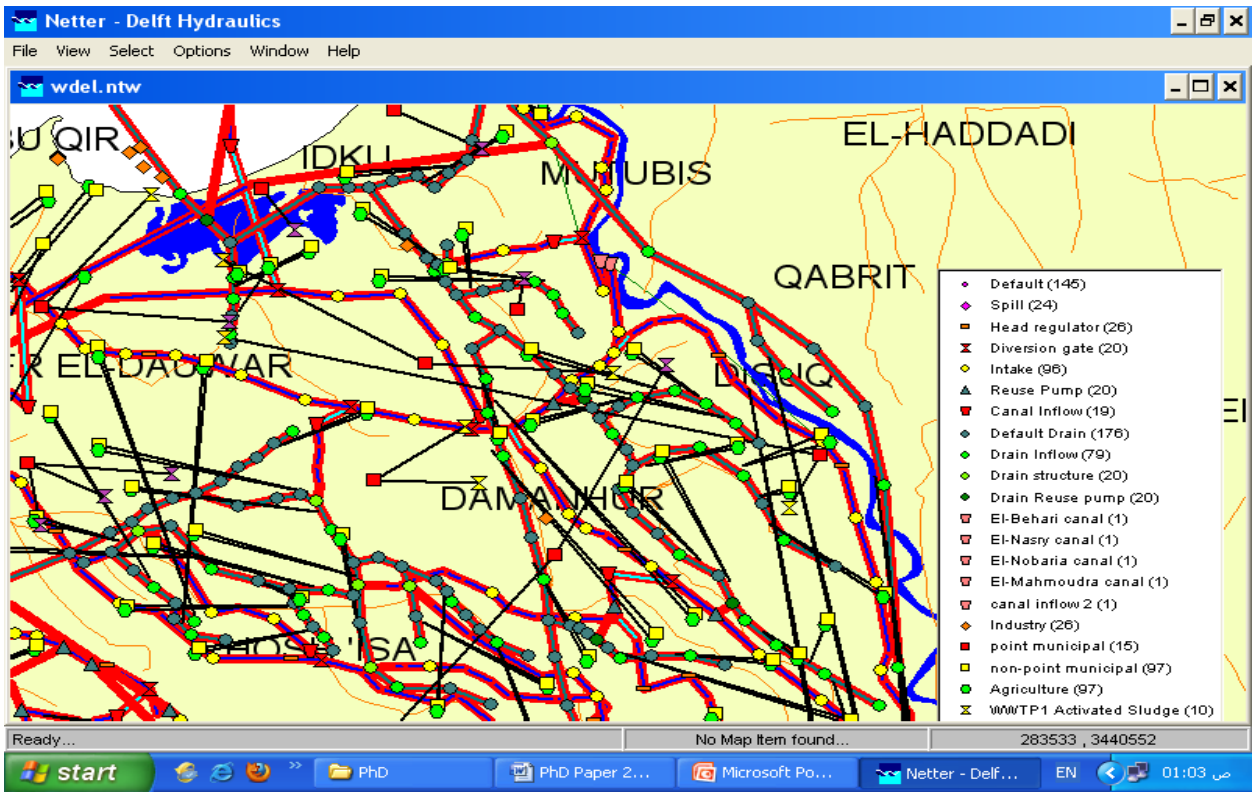

Figure 4: WLM schematization

2.3 Data used for the analysis

The data used for the analysis includes discharge and water quality data of the main, branch canals, and main drains by different sectors within Ministry of Water Resources and Irrigation in Egypt. The monitoring locations include 14 locations for discharges and 40 locations for water quality (Water Management Research Institute, 2008)

2.4 Model calibration and validation

SIWARE model input parameter estimation and checking (validation) has been performed at the three levels for which measured data are available namely:

- At canal command level for checking water allocation procedure
- At irrigation branch canal level for checking water distribution within the irrigation canal command
- At the drainage catchment level for checking the integrated results of irrigation water supply, hydraulic and operational relations in the irrigation canal network, field water distribution, evapotranspiration, drainage and salt accumulation relations, official, and unofficial drainage water reuse

The simulation results were compared with the available data of irrigation supply and drainage discharge. Simulated water discharge at Mahmoudia canal after conjunction with Khandak El-Sharki canal agrees fairly well with reported measured discharge values by the Ministry of Water Resources & Irrigation in 2007 with a standard error of 9.8% as shown in figure 5.

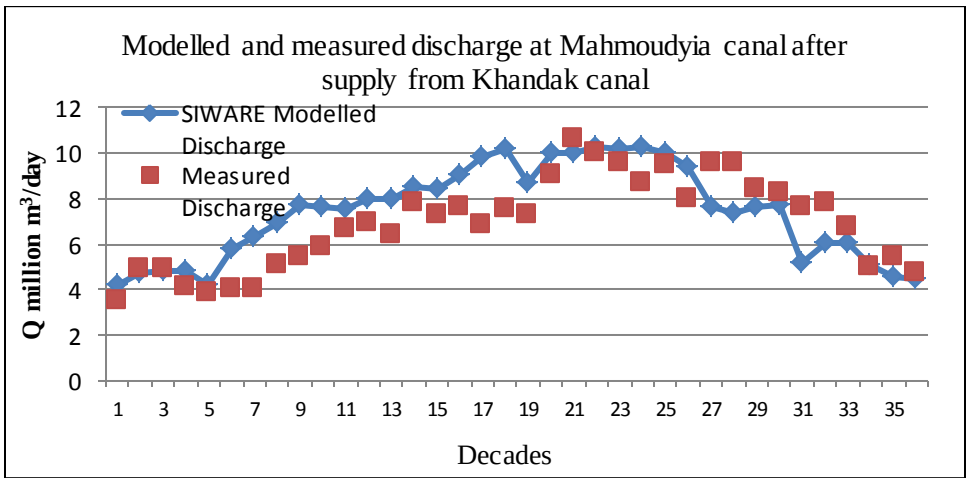

Figure 5: Measured and simulated flow rates at Mahmoudia canal

Total simulated discharge of the branch canals and the main drains agree quite well with observations for 2007. The same is true for the salinity expressed as chloride and the salt load.
The calibrated model has also been applied on the period from 2008 till 2010 to cover a substantial range of variation in water supply to the Western Nile Delta. Total simulated discharge and average salinity for this period shows a fair agreement with observations for the complete period.

DELWAQ model has also calibrated and the simulation results of BOD_5 in 2007 were compared with the field observations in this base year. The simulated BOD_5 concentrations agree fairly well with reported measured values by the Ministry of Water Resources & Irrigation in 2007 with a standard error of 9.7% as shown in figure 6

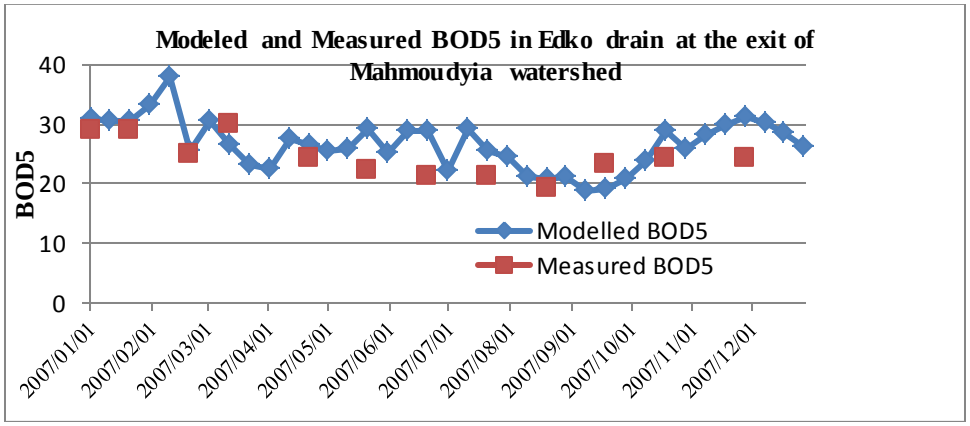

Figure 6: Modeled and Measured BOD5 in Edko drain at the exit of Mahmoudia watershed

3. Designation of Scenarios

3.1 MWRI Strategy for 2017

Three scenarios for MWRI strategy for 2017 have been designated namely

3.1.1 IIP scenarios

The effect of irrigation improvement intervention on water saving has to be estimated before design the irrigation improvement scenarios to be modeled. The irrigation losses can be categorized as follows:

- Conveyance losses include any branch, tertiary, and quaternary canal spills (operational or accidental) and reservoir seepage, and evaporation that might result from management as well as losses resulting from the physical configuration or condition of the irrigation system.
- Distribution and tail escape losses
- Field application losses including deep percolation or surface runoff

Table 1: The different irrigation efficiencies at each intervention of IIP

Irrigation system	Conveyance efficiency	Distribution efficiency (tail escape flows)	Field application efficiency (deep percolation and runoff losses)	Overall irrigation efficiency	Expected Efficiency improvement
Unimproved	85%	98%	65%	54%	0
Mesqa improved	92%	98%	65%	59%	5%
Mesqa and Marwa improved	99%	98%	65%	64%	10%
Continuous flow	100%	100%	65%	65%	11%
Level basins and irrigation management practices	100%	100%	85%	85%	31%

Unfortunately, the IIP improvement works have been restricted in Mesqa improvement and the Mesqa improvement works implemented in 131,000 feddan within Mahmoudia command area from 2000 to 2004 has not resulted in a concrete water saving. The results of the monitoring and evaluation program of IIP showed that the southern parts of Abo Hommos district still suffer from water shortage in El-Zini, Sidi Azab, and Mahlet Keil branch canals. It was estimated that the reduction of excess canal water released to the drains had to increase the salinity concentration of the drainage water after IIP (National Policy For Drainage Water Reuse, 1998) and this approach must be dealt with caution because other factors were not taken into consideration. However, this approach leads to conclude that no water saving has been achieved in Zawiet Naeim canal command area because the salinity level in Abo Hommos drain has not increased after completion of Mesqa improvement works in 2005 as shown in figure 7. While the northern parts of Abo Hommes district has likely shown water saving in Nasr Allah canal of 5% because the salinity level has increased by 10%

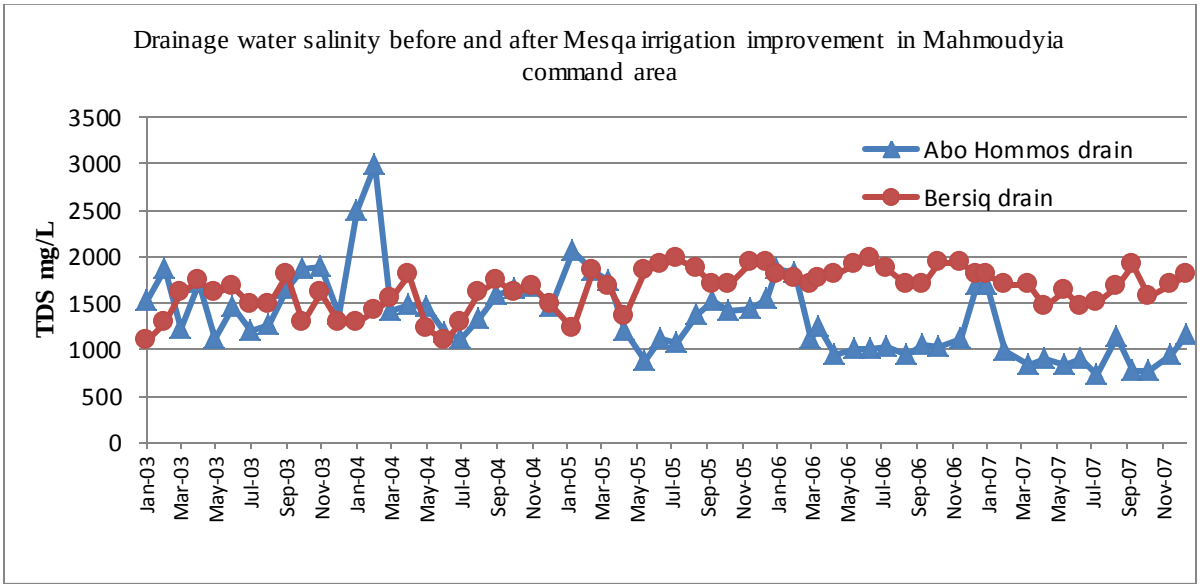

Figure 7: Drainage water salinity in Abo Hommos district before and after Mesqa irrigation improvement

According to the type, interventions have to be implemented in Mahmoudia command area during IIIMP project, two scenarios will be designated as follows:

- Finalize Mesqa improvement works in Mahmoudia command area which will result in 5% water saving in the optimistic scenario
- Finalize Mesqa and Marwa improvement works in Mahmoudia command area which will result in 10% water saving in the optimistic scenario

3.1.2 Reallocation of the current drainage reuse

The area irrigated from drainage water in Mahmoudia watershed is about 40,000 feddan. The Behira irrigation districts' reported that the quantity of reused drainage water is about 404million m^3/year, 45% of which is unofficial reuse (Integrated Irrigation Improvement and Management, 2010) . The drainage water reuse from Edko drain represents only 25% of the total used drainage water in Mahmoudia watershed, although it has less salinity and pollution loads than Omum drain. Therefore, this scenario assumes increasing the drainage water reuse from Edko to 50% of the total used drainage water.

3.2 MWRI Strategy for 2050

The domestic and industrial annual water demands from Mahmoudia canal will increase from 1.3 BCM to 2.1 BCM. To secure the additional municipal water demands three scenarios have been designated.

3.2.1 Maximizing drainage water reuse from main drains

If the improvement works fail to achieve water saving, the drainage water reuse has to be maximized to secure the agricultural water demands because of the prioritization of fresh water allocation to drinking water demands in Alexandria. The consequences of maximizing drainage water reuse will decrease of the yield of the sensitive crops especially vegetables, soil salinization, will cause less water flow to the coastal lakes, and decrease more health hazards associated with drainage water reuse.

3.2.2 Maximizing drainage water reuse by intermediate reuse

Intermediate reuse means mixing branch drain water for local reuse before the water goes to the main drain. Contrary to centralized reuse, intermediate reuse conserves drainage water at local level and helps mitigate water shortages at branch canal ends.

3.2.3 Desalination Option

The domestic and industrial annual water demands from Mahmoudia canal will increase from 1.3 BCM to 2.1 BCM. This scenario assume that no additional fresh water from Mahmoudia canal will be supplied to water treatment plants and the drinking water requirements for the population in the new urbanized area in Alexandria or for more summer tourists . The additional drinking water requirements have to be secured by desalination. This requires constructing two mega desalination plants in Alexandria each of 1.1million m^3/day and restored energy of 2400 MW and the installation cost of each plant will be 800 million US$.

4. Results and Discussions

4.1 Water quantity results

The modeled results for water management and water distribution show improvement in water allocation using DSS model and the Water use Index for agriculture has improved especially for the downstream districts namely El-Raml and Kafr El-Dawar at which WUI reach 1.4 and 1.32 in the DSS environmental reallocation scenario instead of 1.2 before reallocation as shown in figure 8. WUI is the measured volume of water supplied to a defined area divided by the crop-specific water demand arising from that area (ET or Evapotranspiration). The environmental reallocation can still be applicable till 2017. After that the drinking water for Alexandria and northern coast will sharply increase. To maintain WUI values in 2050, drainage water reuse has to be increased to reach 1.1 BCM/yr in Mahmoudia watershed and intermediate drainage reuse has to be applied for all the districts with a mixing ratio of 1:1with fresh water. The consequences of this scenario will be economical and environmental damages.

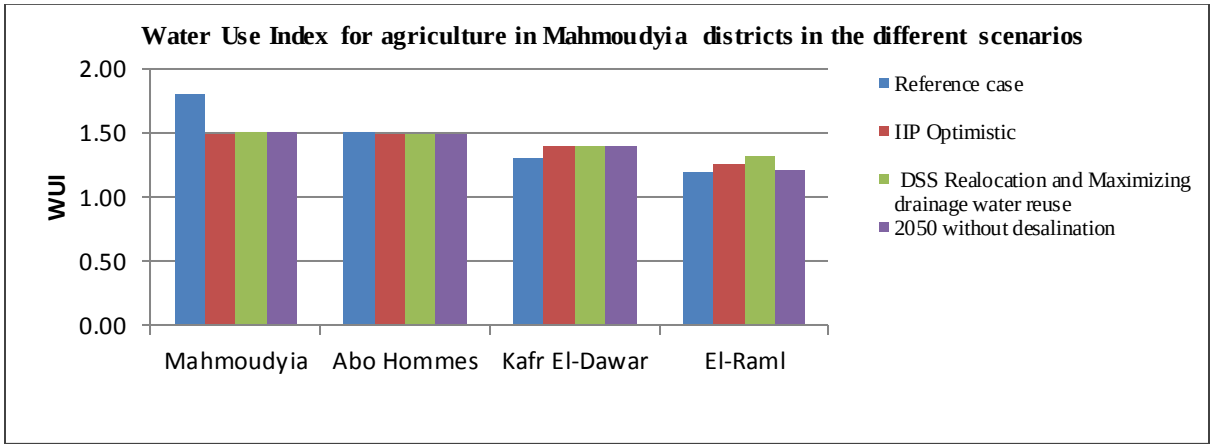

Figure 8: WUI for agriculture in Mahmoudia districts in the different scenarios

4.2 Water Quality results

The modeled scenarios show that the chloride concentrations of drainage water vary from 10 to 30 mg/L. Chloride is selected in DELWAQ to express water salinity; therefore a correlation was realized between electrical conductivity and chloride concentration for drainage water in Mahmoudia command area.

The range of modeled electrical conductivity values varies from 1.5 to 3.5 dS/m as shown in figure 9. The average drainage water salinity in Edko drain will increase by 20% from the reference case and reach 2.66 dS/m (1704mg/L) in the optimistic scenario assuming 10% water saving after implementation of Mesqa and Marwa improvement. The average drainage water salinity in Edko drain will increase by 10% from the reference case and reach 2.4 dS/m (1536 mg/L) in the optimistic scenario assuming 5% water saving after implementation of mesqa improvement works only. The average drainage water salinity in Edko drain will exceed 3 dS/m (1920 mg/L) in the pessimistic scenario assuming no water saving results from irrigation improvement works and drainage water reuse will be maximized. As the water salinity (ECw) increases within the slight to moderate range, production of the more sensitive crops may be restricted due to an inability to achieve the high leaching fraction needed, especially when grown on the heavier, more clayey soil types. If the salinity of the applied water exceeds 3.0 dS/m, as shown in figure 9, the water may still be usable but its use may need to be restricted to more permeable soils and more salt tolerant crops where the high leaching fractions are more easily achieved. The modeling results of the other biological and microbiological water quality parameters show that there is a slight difference between the designated scenarios. Maximizing drainage water reuse will result in the maximum pollution loads to the northern lakes, because the main drain discharges will be mixed of irrigation canal water to supply the agricultural water demands instead of dilution of the organic loads carried from the upstream locations at Edko and Omum drains.

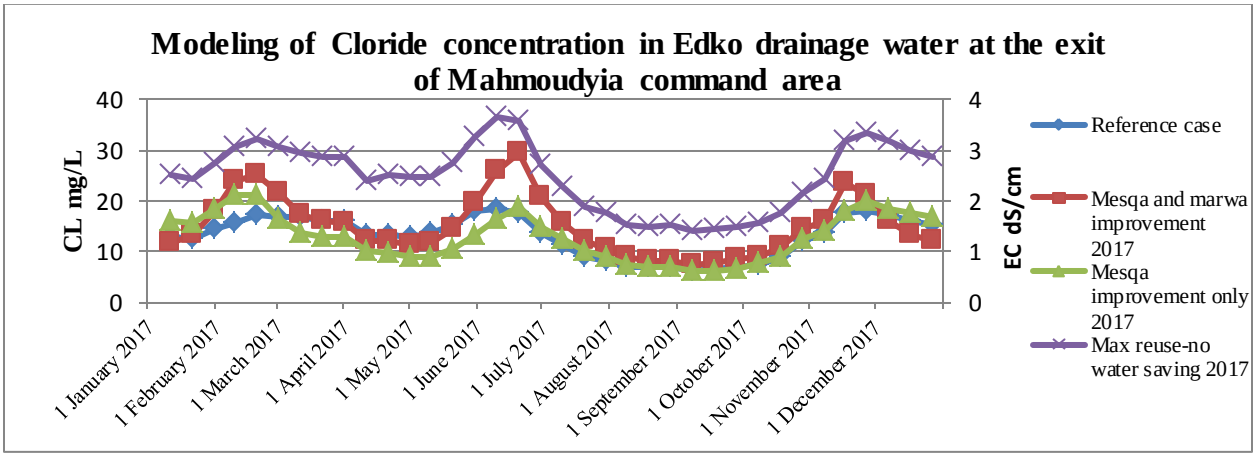

Figure 9: Modeling chloride and EC in Edko drain at the different scenarios

The modeling results of 2050 strategy scenarios show that:

- During summer season, the salinity of Edko drainage water at the exit of Mahmodia watershed increases in the intermediate reuse more than the maximum reuse scenario, while the lowest salinity concentration of drainage water will be in the desalination scenario, where no maximizing of drainage water will occur.
- During winter season, the pumping stations of the intermediate reuse will operate for small periods and accordingly more drainage water will flow from the branch drains to the main drains and the salinity concentrations in Edko drain will be the lowest, while the main mixing stations will operate for longer periods during the maximum drainage water reuse scenario and accordingly the salinity levels of this scenario will be the maximum as shown in figure 9.

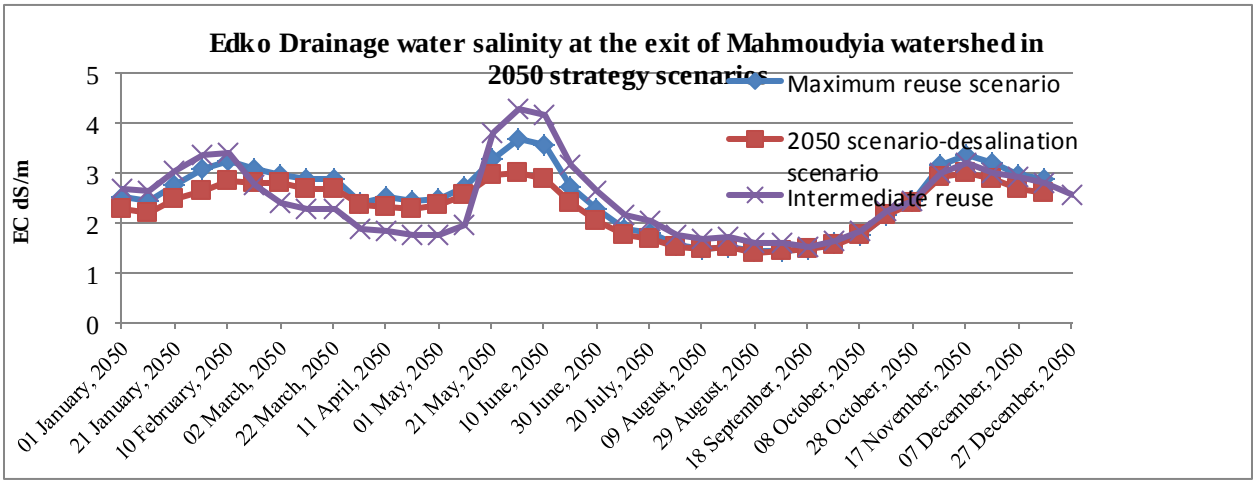

Figure 9: Edko drainage water salinity at the exit of Mahmodia watershed in 2050 strategy

4.3 Optimization of scenarios

4.3.1 Cost of environmental and economic damages

The increase of the reused drainage water salinity above 3dS/m results in economic and health impacts of maximizing drainage water reuse will be as follows:

- Decrease of some main crops yield (maize, rice, Berseem) by 25%, and Bean, onion, and pepper by 50% due to the high salinity of irrigation water (>3dS/m) in case of maximizing drainage water reuse from main drains.
- Health hazards to the farmers using drainage water in irrigation and also to the population due to proximity to irrigation schemes. Disability Adjusted Life Year DALY method developed by WHO was used to estimate health hazards damage cost for 40,000 farmers and the population in the proximity of irrigation schemes. Drinking water pollution causes diarrhoeal deaths and DALY cases amounts to be about 0.38% according to (WHO, 2009).
- Fishery loss due to the decrease of drainage water flowing to Lake Edko.

The total cost of annual health and economic damage resulting from maximizing drainage water reuse is about 34 million US$, while it decreases to 16.634 million US$ for intermediate drainage reuse from the secondary drains because the intermediate drainage water reuse will result in less health hazards, and accordingly less environmental and economic impacts.

4.3.2 Infrastructure Costs

To secure the increasing drinking water demands in Alexandria and the northern coast, is required to construct two mega desalination plants in Alexandria each of 1.1million m^3/day and 2400 MW and the installation cost of each plant will be 800 million US$. In addition to the installation costs (249 million US$) of the necessary embankment and sheet piling works to increase the carrying capacity of Mahmoudia canal to 147 m3/sec at El-Atf and 131m3/sec downstream El-Khandak El-Sharki (Ghazi, 2008).
The required infrastructure for intermediate reuse scenario are 48 pumping stations, each pumping station includes three units of 0.50m3/sec. In addition to, constructing delivery pipelines of length 148km and 48 drain water weirs downstream the pumping sites to capture drain water and store night-time drain flows. The installation costs will be about 8.2million US$.

4.3.3 Cost Benefit Analysis

The cost benefit analysis of the three scenarios for 2050 strategy shows that out of the three strategy options, two are feasible namely the intermediate reuse, and maximizing reuse because the B/C ratio are 3.51, and 1.94 respectively. Desalination is not feasible because B/C ratio is 0.25 (less than one) as shown in Table 2.

Table 2: Cost Benefit Analysis of the options for 2050 strategy

Option	Annualized capital cost Million US$	Annual O&M plus labour costs Million US$	Annual Environmental and economic damage costs Million US$	Total annual costs Million US$	Annual Increased Annual Benefits Million US$	Benefit/ Cost ratio
Maximize drainage water reuse from main drains	8.7	2.33	34	45.03	87.5	1.94
Intermediate drainage water reuse	4.8	3.5	16.6	24.9	87.5	3.51
Desalination	73	280	0	353	87.5	0.25

5. Conclusion and Recommendations

The decision support system (DSS) developed by Delft Hydraulics in 1998 became obsolete and has not been used for many reasons. Special modifications were developed for some visual basic files and some other executable files. The updated files had to be added to a system and system 32 of windows XP. Open data structure program was also developed to open and modify database files, DELWAQ history files and map files within the DSS model.

The modified model was calibrated, validated, and applied for 2017 and 2050 strategies options. Three scenarios for 2017 strategy were designated namely, allocating the current drainage reuse, assuming water saving of 5% and 10% due to irrigation improvement projects. The allocated drainage water scenario results in enhancement evapotranspiration and the yields at the tail reaches irrigated from Omum drain by 10%. While the optimistic irrigation improvement scenario results in increase the evapotranspiration and the yields at the tail reaches irrigated from drain water by 15% but the average drainage water salinity in Edko drain will increase by 20% from the reference case and reach 2.66 dS/m (1704mg/L) but there will be no effects on the flushing and fishery production in Lake Edko.

Three other scenarios were modeled and analyzed for 2050 strategy namely, maximizing drainage water reuse from main drains, intermediate drainage water reuse and desalination option. The results of the model show that maximizing drainage water reuse scenario will result in increasing the salinity in Edko drain to exceed 3dS/m, while the intermediate drainage reuse and desalination scenarios will result in less saline drainage water. Maximizing drainage water will result in reducing the drainage inflow to LAKE Edko by 50% without affecting the fishery yield because the lake will still be flushed. However, drainage inflow to Lake Mariut will be

reduced by 25% but the deteriorated Lake ecosystem cannot withstand the resulted impacts such as decreasing lake flushing times and more pollution and less fish production.

The cost benefit analysis which has been carried out in this study taking into consideration the costs of environmental and economical degradation of each scenario, shows that the intermediate drainage water reuse is the most suitable environmental and economical option to be adopted in 2050 strategy.

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Analysis Impact of Inland Seepage in North Nile Delta Region: A Case Study

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Abstract

Successful drainage depends largely on a proper diagnosis of the excess water causes in the soil. Diagnosis process should consider climate, topography, pedology, surface water hydrology, irrigation and groundwater hydrology (or hydrogeology). In land drainage studies, it is important to know the rate of water table rise, and its fall. If the groundwater is not being recharged, the fall of the watertable depends on the transmissivity of the water-transmitting layer, and the hydraulic gradient.

Motobas was selected as a study area in the North Delta Region at Kafr El-Shekh Governorate which is a new reclaimed coastal area affected by seepage. It has a gross area about 13000 feddan. It is located between the Mediterranean Sea and El-Borrols Lake. Therefore, it is expected that this area will receive high seepage amounts from the Sea, the Lake, and upward groundwater. A study was carried out for six months to estimate the total seepage amount, its movement and the loss of water by infiltration from Sedi-Yousef main canal. Several data were collected while others were measured and Darcy Law was used to calculate the amount of seepage and its rate from El-Borrols Lake, the Mediterranean Sea, and the upward groundwater seepage.

The total measured amount of seepage reaching to the main open drains from the Sea, the Lake and deep groundwater is 28991 m^3/day. The amount of water lost due to irrigation water surplus in the main irrigation canal is 9.61 m^3/sec, and represents about 93.12% of the total drainage rate of the whole study area. The amount of seepage from the Lake, the Sea, and upward groundwater seepage represents 0.126%, 0.003%, and 3.1% of the total drainage rate (891838 m^3/day), respectively. It can be concluded that the main problem is the high irrigation water coefficient applied in the feeding irrigation canal due to cultivation of rice crop during summer season which led to high seepage losses from irrigation surplus.

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Introduction

There are about 20-30 million hectares severely affected by salinity out of the 235 million hectares currently irrigated. In additional to 60-80 million hectares are affected to some extent with waterlogging and salinity. Many of these areas will continue to go out of production unless corrective measures are introduced. Waterlogging can be reduced by applying efficient irrigation and artificial drainage (horizontal drains or tube wells). Accumulated salts brought by irrigation should be leached out of the soil profile and disposed away of the area in an acceptable manner. Traditionally, irrigation and drainage systems were designed, constructed and managed separately. Most of the time, the applied irrigation water exceeds the crop water requirement (over irrigation), the subsurface drainage system is over designed, and the drains are always designed at depths suitable for deeper root crops. All these lead to more loss of irrigation water and applied fertilizers, which lead to the pollution of groundwater and drainage water (FAO, 1990).

The water table in the Nile Delta rose to a depth less than 1.0 m below the soil surface being shallower towards the north. Amer (1981) reported that reduction in crop yield may reach 70% when the water table rises from a depth of 1.5 m to 0.50 m. This reduction is attributed to the limited depth available for the root system and the accumulation of salts due to the high water table. Although, salt affected soils spread in the form of patches over the entire cultivated area they are more common in the northern region of the Delta. The soil of this region is heavy clay affected with sodicity and upward seepage of groundwater occurs (Farid et al, 1979).

In the newly reclaimed lands where the soils are of light texture a high water tables develop quickly as a result of canal seepage as well as deep percolation from the irrigated fields. Furthermore, many of these reclamation areas are located at higher elevation to prevent waterlogging and salinisation and to ensure a favourable groundwater balance. An optimum drainage strategy will include measures to reduce drainage water recharge. The proposed drainage strategy is based on following a three part approach to solving existing or possible future drainage requirements: implementation of general measures to reduce drainage flows; monitoring and evaluating hydrologic changes and taking action to minimise their impact; and adaptation and further monitoring.

Description of Study Area

Location

The total area of Motobas is about 13000 feddan and in the future another 8000 feddan will be added so that it will reach about 21000 feddan. The study area is located North Motobas town at the Northern coast of Kafer El-Sheikh Governorate, south Mediterranean Sea. At the area's northern part, the new international coastal road is located while at its southern part EL-Borrols Lake is located. In the eastern part, the new extension reclamation areas is located while in the western part is El–Borrols area, as can be seen in Figure (1). The actual cultivated area now is representing about 28% of the total area (13000 feddan). The area is extended along its length to about 15km in the direction from east to west parallel to the coast of the Mediterranean Sea and the width of the area is about 3 km in the direction from North to south.

Irrigation System

Sedi-Yousef irrigation canal is the source of irrigation water feeding the study area which takes its water from the extension of El-Nour irrigation canal by irrigation pump station. El-Nour canal is fed by mixed water with agricultural drainage water pumped to it by pump station number (11) which cause the slightly higher salinity observed in its water. Sedi Yousef irrigation canal distribute its water through five branch canals which distribute the water through a Secondary irrigation canals. The main and distribution irrigation canals were lined to eliminate seepage. The irrigation type used is surface irrigation by flooding. As it is planned, the irrigation water coefficient is 50 m^3/fed./day, taking into consideration that crops with high water requirements such as rice will not be cultivated, although it was observed that farmers cultivate rice in most of the cultivated area in summer so the actual irrigation water coefficient reached to 83 m^3/fed / day. The actual irrigated area in Motobas is about 3690 feddan and its irrigation coefficient varied between 30 and 35 m^3/fed / day.

Drainage System

The study area is provided with main and secondary open drains. The main drains end by Motobas drainage pump station which pumps its water into El–Borrols Lake. The open drainage systems were designed and constructed according to a drainage coefficient 50% of the irrigation coefficient in Motobas area. The average drainage rate is equal to 41.5 m^3/fed/day.

Figure (1): Location of study area

METHODOLOGY

Data collection

Field studies

The topographic survey was made in which the area was divided by four straight lines in which the distance between each two rows is equal 2 km and these lines started after 2 km from the coast of the Mediterranean Sea. The Total Station Device was used for surveying to get land levels and land slope using the four lines mentioned before. Also the water levels in the water ditches were obtained during the topographic survey. Before starting the field studies, about 16 locations were identified along the four longitudinal lines and each line has four grid points. In each grid point several information were collected about soil texture and salinity, shallow and deep ground water depths, and depth and type of hand pans or impervious layer. Also, installation of 16 observation wells were carried out in the four studied lines to a depth of 1.5 m in which each study line was represented by four observation wells. These observation wells were used to measure the depth and fluctuation of shallow water table. In addition, 12 deep piezometers were installed at the four studied lines in which each line was represented by three

piezometers. These piezometers were installed to measure both the depth of the deep groundwater and the piezometric pressure. These piezometers were installed at 10 m depth below soil surface or until the impervious layer, Figure (2). The main purpose of these piezometers is to know the direction of groundwater movement, and to estimate the expected amount of upward seepage and the expected seepage amount from the sea and also from the lake. The soil hydraulic conductivity measurements were carried out in 12 locations using the auger-hole method. Moreover, 48 soil samples were collected until a depth of 1.5 m below soil surface in which three samples were taken at each soil profile to determine the physical and chemical characteristics of the soil.

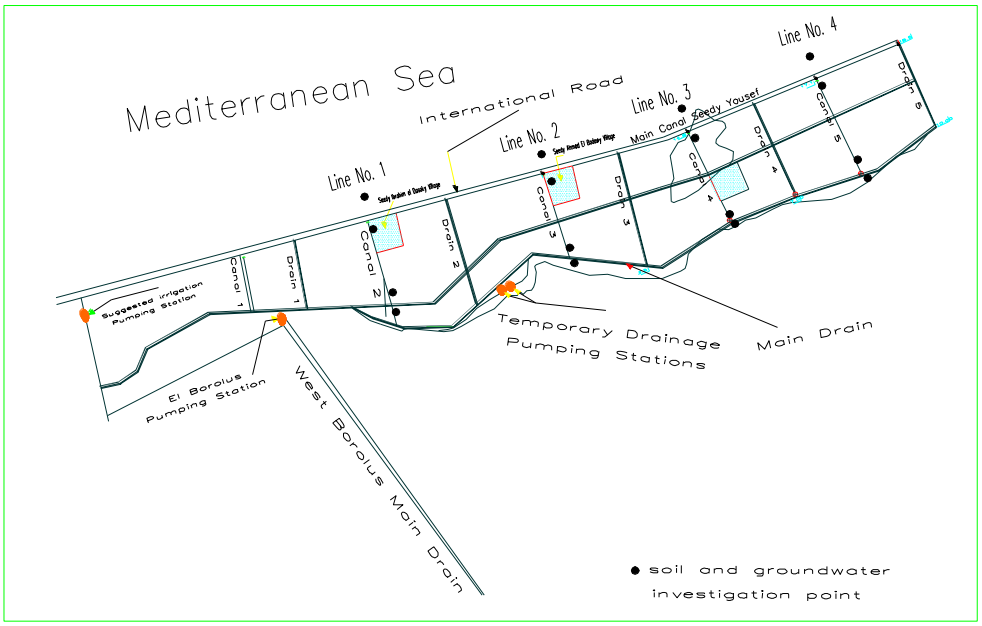


Figure (2): Locations of Field Studies at Motobas area

Determination of Upward Seepage

To calculate the upward seepage, Darcy's law (1856) was used in the form:

$$q = K (\Delta h/L) A$$

Where:

q: Amount of upward seepage (m^3/d)

K: Hydraulic conductivity in the layer where seepage water flows (m/d)

Δh/L: Slope or hydraulic gradient (represented by difference of water levels / length of seepage pass –dimensionless)

L: Length of seepage passes (m)

A: Area affected by seepage (m^2)

The amount of seepage for the whole study area was calculated using the results of soil hydraulic conductivity, average water table levels, width of the study area, and the distance between the sea or the lake and the main open drain which receives the seepage water. It is also calculated for the cultivated area only. A simple mathematical model of water balance was used to check the calculated results.

RESULTS AND DISCUSSION

Topography

Results of topographic survey show that the area has general slight slope (less than 0.01%) started from the international coastal new road in the North towards the southern direction until the main open drain and the lake, This slope is irregular in most of the area and inversed in other parts. There is also a slope from east and west towards the middle of the area and lower spots are found as shown in Figure (3).

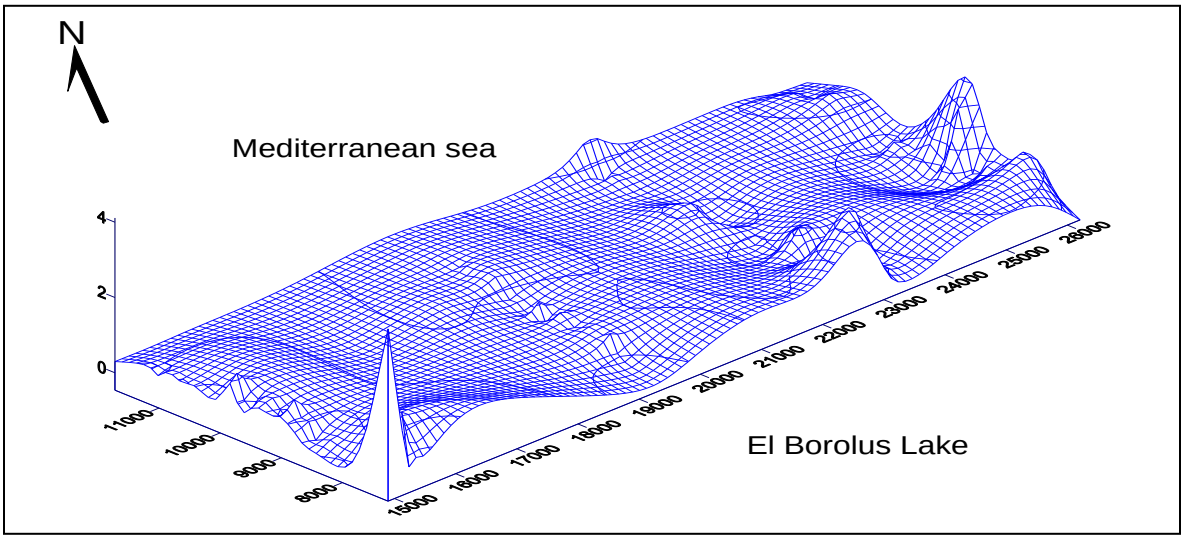


Figure (3): Results of Topographic Survey

Soil Results

Soil texture and hydraulic conductivity

The top soil layer consists of sandy surface till 1.5m, loamy sand, clay loamy till 2.5m and clay with very low permeability (impervious layer). The light soil texture dominated in the top soil layer will enhance seepage from water courses towards the study area. Higher permeability values were obtained in some locations and will enhance seepage from water courses into the study area. The average values of soil hydraulic conductivity in the locations (1) and (2) of seepage line extended from north to south are 1.49 and 2.04 m/day with an overall average of 1.76 m/day. This value is less than the average values of location (3) (3.13 m/day) which is along the seepage line near from of El-Borrols lake. Therefore, it is expected that the amount of seepage from the lake will be higher than from the sea when both distance and hydraulic gradient is the same as shown in table(1).

Chemical Composition of Soil

Table (2) shows the chemical composition of soil at Motobas area which indicates that the soil is highly saline with an overall average of 51.1 dS/m so it needs leaching even in the cultivated parts. The ESP values varied between 7.8 and 52 with an overall average of 29.5, which indicates

that sodium ion is the dominated ion in the soil. The soil of the study area can be classified as saline-alkali soil.

Table (1): Average soil hydraulic conductivity values measured in Motobas area

Location	Average values of soil hydraulic conductivity (m/day)				
	Row (1)	Row (2)	Row (3)	Row (4)	Mean
Location (1)	1.64	1.22	1.60	1.50	1.49
Location (2)	2.70	1.95	1.83	1.67	2.04
Location (3)	3.07	3.30	3.14	3.03	3.13

Table (2): Chemical composition of soil at Motobas area

	pH	EC (dS/m)	Soluble Cations (meq/l)					Soluble Anions (meq/l)			ESP
			Ca	Mg	Na	K	CO3	HCO3	SO4	Cl	
Min. Value	7.2	5.3	9.0	11.0	23.0	0.7	0.0	4.0	22.0	18.0	7.8
Max. Value	8.1	127.0	252.0	233.0	880.0	1.0	0.0	5.0	576.0	900.0	52.0
Mean	7.8	51.1	93.0	92.0	318.0	0.9	0.0	4.5	217.0	287.0	29.5

Shallow Watertable

The average watertable depth in the study locations 1, 2, 3, 4 measured at each study line varied between 0.05 to 1.68 m below soil surface with an overall average of 0.90 m, Table (3). There are considerable variations observed in the watertable depths due to the small cultivated part at irrigation branches 1, 2 and 3 in which the shallow watertable depths were recorded, while in the uncultivated part and also near from the main open drains south study area close to drainage pump station, the measured watertable depths were deeper. It is expected that the watertable will became shallower especially during leaching and cultivation period of the uncultivated part because the impervious layer is not deep enough (about 2.5 m below soil surface). Figure (4) shows the average watertable levels and the direction of its movement. From that figure it can be concluded that the lowest values of watertable levels are located near the main open drains and their movement is mainly in the direction of the main open drains where the lowest levels are observed.

Deep Groundwater

The average values of the measured depth of deep groundwater in the study area were varied between 0.55 m above land surface and 1.80 m below soil surface with an overall average of 0.49 m below soil surface as shown in Table(4) and Figure(5). The results of deep groundwater indicated that there is piezometric pressure near from El–Borrols Lake (middle of the study area) and reach to about 0.55 m above land surface. Also, the levels of the deep groundwater is higher than Mean sea level in more than half of the study area especially in the south and southern–western parts of the study area where the height of deep groundwater reach the value of 1.38 m near El–Borrols lake. Moreover, the deep groundwater moves towards the sea and its source might be the higher watertable in the North Delta Region. When the values of shallow watertable

	Line (1)				**Line (2)**				**Line (3)**				**Line (4)**			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Average Watertable depth (m)	0.73	0.82	0.86	0.20	0.85	0.86	0.91	1.24	0.68	0.74	1.09	0.89	0.92	0.87	1.41	1.16

levels were compared with the values of deep groundwater levels it was found that the levels of deep groundwater are higher than the levels of the shallow watertable in most of the area with about 0.15 to 1.79 m, Table (5) which indicates that there is upward seepage with an average value of 0.51 m in the whole study area.

Watertable levels (m+msl)	-0.05	-0.06	-0.24	-0.05	-0.10	-0.35	-0.58	-0.41	-0.61	-0.71		-1.03	-0.11	-0.29	-0.57	-0.86

Table (3): Average results of shallow waterable depthand levels measured in the study area

Table (4): Average depth and levels of deep ground water in the study area.

	Line (1)			Line (2)			Line (3)			Line (4)		
	1	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**
Average Watertable depth (m)	0.62	0.96	1.38	0.46	0.17	-0.55	0.96	0.77	1.47	0.25	-0.25	0.86
Deep Groundwater levels (m+MSL)	-0.25	-0.31	0.75	0.33	0.0	1.38	-0.46	-0.35	0.23	-0.35	0.88	0.64

Table (5): Upward seepage of deep groundwater and the direction of its movement

	Line (1)			Line (2)			Line (3)			Line (4)		
	1	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**	**1**	**2**	**4**
Average shallow watertable levels (m+MSL)	-0.05	-0.06	-0.05	-0.10	-0.35	-0.41	-0.61	-0.71	-0.11	-0.29	-0.57	-0.29
Average deep watertable levels (m+MSL)	-0.25	-0.31	0.75	0.33	0.0	1.38	-0.46	-0.35	0.23	-0.35	0.88	0.64
Difference in levels	0.20	0.24	-0.81	-0.44	-0.35	-1.79	-0.15	-0.36	-0.34	0.06	-1.45	-093
Seepage direction	↓	↓	↑	↑	↑	↑	↑	↑	↑	↓	↑	↑

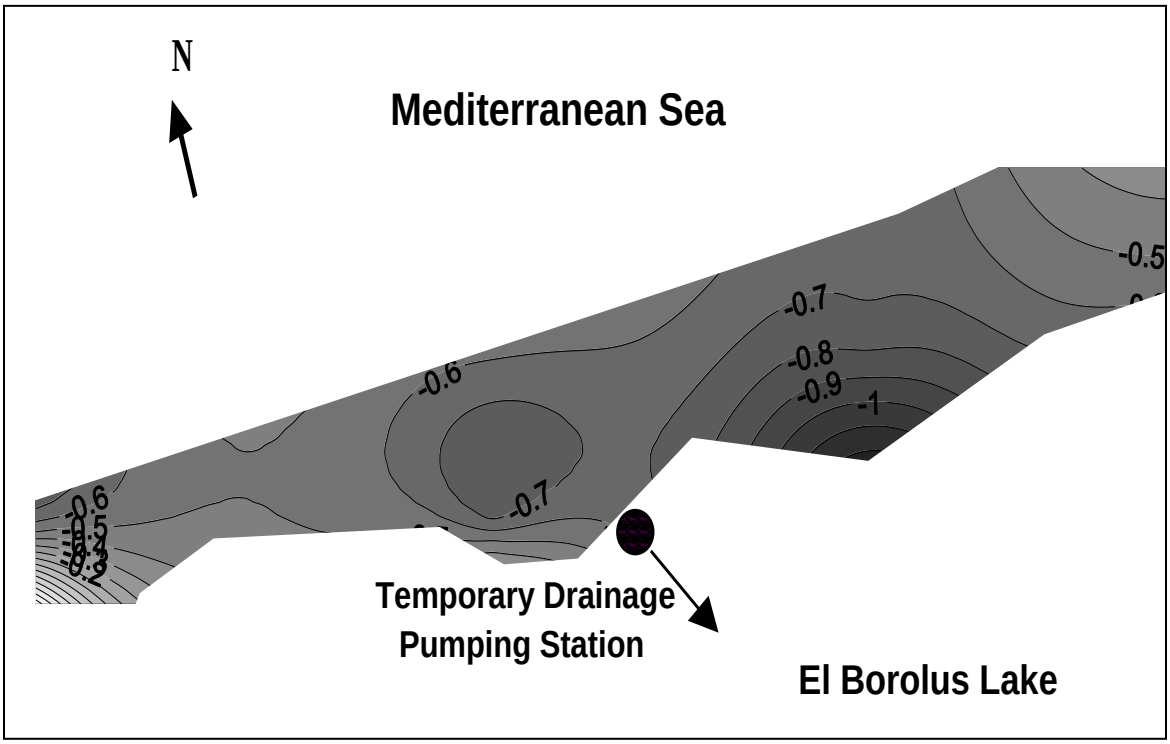


Figure (4): Average watertable levels and its movement in Motobas area

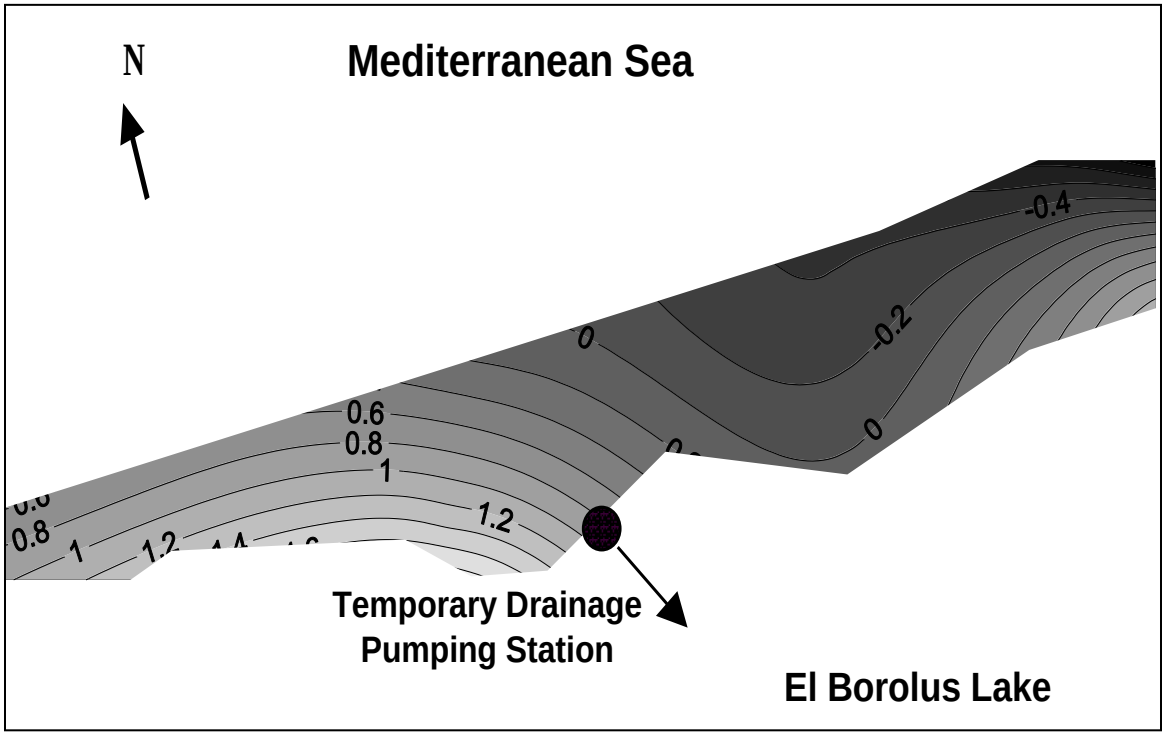


Figure (5): Average deep groundwater levels and the direction of its movement in the study area Upward Seepage

The following results are used to calculate the upward seepage using Darcy law:

- Average soil hydraulic conductivity in the sea direction is 1.76 m/day
- Average soil hydraulic conductivity in the Lake direction is 3.14 m/day
- Average hydraulic conductivity of the impervious clay layer is 0.001 m/day
- Length of seepage line between the sea and the main open drains is 5000 m
- Length of seepage line between the Lake and the main open drains is 162 m
- Level difference in the sea direction (Δh) is 1.5 m
- Level difference in the Lake direction (Δh) is 1.72 m
- Difference between shallow and deep groundwater table levels is 0.51 m

Table (6) illustrated the output results of seepage amounts using Darcy law for the whole study area. It can be concluded from these results the big distance between the sea and the main open drains and lower soil hydraulic conductivity led to smaller seepage amount transported to these drains, but this amount increases in the direction between the lake and the main open drains due to the small distance between the lake and these drains due to the small distance between these drains. Higher soil hydraulic conductivity values were observed in this direction. The upward seepage from deep groundwater is representing the highest seepage amount due to the high piezometric pressure existed in the study area. Figure (7) shows the seepage lines from the sea and the lake towards the study area.

The data shown in Table (6) revealed that the percentage of the total seepage amount to the total amount of drainage water for the whole study area is only 3.25% which represents a small amount. In addition, Table (7) shows the amount of both drainage water and seepage obtained in the case of actual cultivated area (about 28% of the total study area).

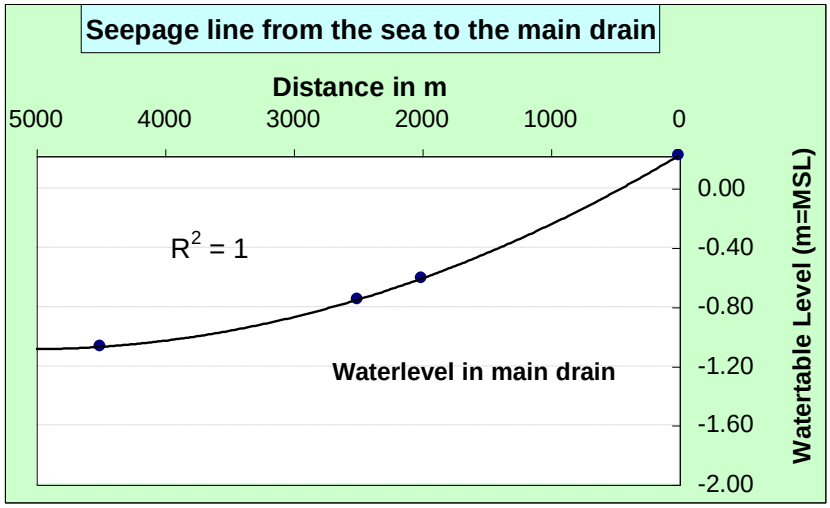
Table (6): Amount of seepage and drainage water calculated from a simple model of water balance for the whole study area

Inputs	Amount	
	m^3/day	m^3/sec
Surplus of irrigation water lost by seepage	830154	9.61
Rainfall	32434	0.38
Sewage water	260	0.003
Seepage from the lake	1119	0.013
Seepage from the sea	25	0.0003
Upward seepage	27846	0.32
Total seepage	**28990**	**3.24**
Total drainage water	**891838**	**10.32**

In addition, Table (7) shows the amount of both drainage water and seepage obtained in the case of actual cultivated area (about 28% of the total study area). The results shown in Table (7) revealed that the total amount of seepage water actually affecting the study area, which is coming from the sea, the lake, and upward seepage, is 26043 m^3/day. This value of seepage amount is very close to the one obtained when the whole area is cultivated (28990m^3/day).

Table (7): Input parameters used to estimate the amount of seepage and drainage water from the actual irrigated area.

Input parameters	Result
Average drainage discharges measured in the main open drains	0.96 m^3/sec. (83238 m^3/day)
Actual irrigated area (feddan)	3690
Water consumption (m^3/fed./day)	17
Irrigation coefficient (m^3/fed./day)	32.5
Actual amount of drainage water from irrigated land (m^3/fed/day)	57195
Amount of seepage water from the sea, the lake, and from upward seepage of deep groundwater (m^3/day)	26043



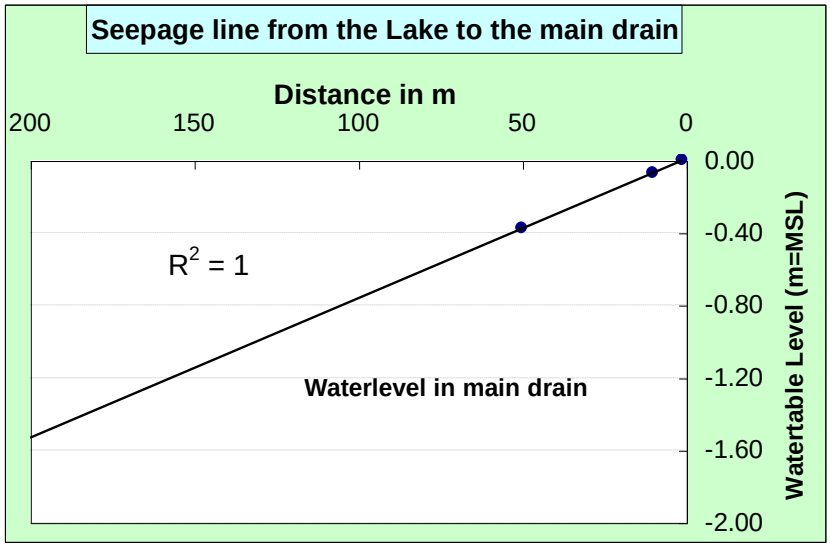


Figure (6): Seepage lines from the sea and El–Borrols Lake in the study area.

Conclusions

It can be concluded from this study that the general slope of the study area is slight or gentle slope (less than 0.01%) and it is irregular in most of the study area, flat in others and inversed in some locations. It can be also concluded that the top soil layer till a depth of 1.5 m below soil surface has sandy soil texture followed by loamy sand to clay loam till a depth of 2.5 m and followed by an impervious clay layer with very low permeability. The measured values of soil hydraulic conductivity varied between 1.22 and 3.3 m/day and the geometric mean is 2.1 m/day. Moreover, the soil salinity is rather high and varied between 5.3 and 127 dS/m with overall average of 51.1 dS/m. The higher salinity values were observed in the uncultivated parts in the area and in the deeper soil layers. The minimum soil salinity value measured was 5 dS/m and this indicates that the leaching stage for the area is not completed even in cultivated parts.The dominant salts in the three studied main open drains, irrigation water, and in El-Burruls lake are sodium chloride, potassium chloride, sodium sulphate, calcium bicarbonate, and magnesium sulphate. This will indicate that these salts have the same origin and also will indicate that most of salts are coming mainly from the lake more than the sea.

The average watertable depths measured in the area varied between 0.05 to 1.68 m with overall average of 0.90 m below soil surface. It was obvious that the watertable depths are slightly shallow in the cultivated parts while it became deeper in the uncultivated parts near the main open drains. It is expected that after cultivation of the whole area (13000 feddan), the watertable will become shallower. The shallow watertable depths were observed in the direction of the sea or the lake and moves toward the main open drains where the lowest levels recorded are there.

The average deep groundwater depths measured in the area is varied between 0.55 m above soil surface (due to piezometric pressure near the lake) to 1.80 m below soil surface with overall average of 0.49 m below soil surface. The deep groundwater levels are higher than the mean sea level (MSL) in more than 50% of the area and reach maximum values in south and south-west parts of the area. This deep groundwater moves in the direction of the sea and it is recharged from the high watertable existing in the North Delta Region. The average value of the upward seepage is about 0.51 m. The total amount of seepage reaching the main open drains from the sea, the lake and from the deep groundwater for the whole study area is about 28990 m^3/day (3.24 m^3/sec.). Also, the total seepage amount in the cultivated area only (28% of the total area) is 26043 m^3/day.

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SESSION 8:
SPECIAL SESSION ON "WATER-ENERGY NEXUS"

Keynote: Walid Saleh, UNU-INWEH, Water and Energy Security in the GCC

Dr. Saleh holds a PhD., (1994) in Water & Environmental Resources Engineering from Concordia & McGill Universities, Montreal, Canada, with research interests in the areas of: Optimization, and Control-Volume Modeling of Groundwater Recharge and Surface/ Subsurface water Flow in Arid to Semi Arid Lands.

Since 1997, Dr. Saleh joined the United Nations University/International Network on Water, Environment, and Health (UNU/INWEH). As a Regional Coordinator for the Middle East & North Africa (MENA), Dr. Saleh employs the resources available through the network to conceive, develop, implement and manage programs and projects that address water problems in MENA region. Dr. Saleh takes a multi-disciplinary, ecosystem approach to water and watershed management. This approach fosters the application of appropriate technologies to meet water needs and assist environmental industries in developing countries to ensure the ongoing availability of affordable products and services.

Pervious consulting experience was with Ecologistics International Limited, Waterloo, Ontario as a Director-Middle East Operations. Dr. Saleh prepared several proposals addressing a wide range of water & environmental issues. These proposals were well received by European Union, Canadian International Development Agency (CIDA) and other funding agencies.

A Concept Paper: Community of Water and Energy for the Human Environment Walid Saleh, PhD, PEng; Regional Coordinator, MENA Region, The United Nations University-Institute for Water, Environment, and Health (UNUINWEH)

Abstract:

Water and Energy have become key drivers of economic and social development to benefit mankind and his environment. The availability of one resource without the other has profound impact on the sustainable social-economic development of any country. The natural synergy between water and energy is simulated by nature through the hydrologic cycle, growth of plants (photosynthesis), food production, which the sources of energy to man, animals and birds. Forests and organic matter have been a source of energy either through direct combustion or through the historic formation of fossil fuel and coal. More than 50% of the world industrial water uses are used in direct (hydropower generation) or indirect way (in cooling the power plants) to produce energy. As water is life, it cannot be served without energy input either in the form of potential energy (gravity flow) or electrical energy (desalination, treatment, and distribution).

Across West Asia and North Africa countries (WANA) most maintain an imbalance in the population-water resources equation demonstrating water deficits; and some others display surplice in energy resources. With very few exceptions, there is a need across these countries to regulate their relationships concerning the shared resources of water and fossil fuel. These shared resources can be a driving force for regional cooperation based on common interest that address the concerned countries needs of water and or energy.

In the past 20 years, Turkey has examined the possibilities of exporting water through the peace pipe line; a project was proposed to supply Syria, Jordan, Palestine, Israel, and Arabia with water. The recent published Blue Peace; rethinking Middle East Water report, states that on the average Turkey can at least export 1-1.5 BCM from its national rivers (excluding Tigris and Euphrates) to the Jordan River Valley countries.

Based on the above, this paper respectfully proposes the establishment of a Community of Water and Energy among Turkey, Syria, Lebanon, Jordan, Iraq, and Palestine. In which these countries can set the stage for regional and trans-regional cooperation. Such a community is a reminder of the Community of Coal and Steal in postwar Europe that was created in 1955 and developed into the European Common Market, the European Commission and the European Union in few decades. European cooperation sets an example for other regions to follow.

The first step is to set up a Cooperation Council for Water and Energy among Turkey, Syria, Iraq, Lebanon, Jordan and Palestine as a political mechanism to establish common standards for water value, sustainable management of water and energy resources. This can also set regional strategies; promote common values, culture, social and economic integration for the better human environment in these countries.

Keynote: Thameur Chaibi, Institut National de Recherche en Génie Rural, Eaux et Forets, Tunisia, Water and Energy systems analysis

Dr Chaibi is a the Head of the Department of Rural Engineering at the National Research Institute for Agricultural Engineering, Water and Forestry in Tunisia. He obtained his Ph.D. from the Swedish University of Agriculture Sciences (SLU) in the field of Agriculture Engineering and Climate Technologies. He has been appointed in 2008 to serve the African Union in developing and coordinating processes in Science, Technology and Innovations policy in Africa. He is the representative of the African Academy of sciences in Northern Africa and follow of the Thirst Word of Academy of Sciences (TWAS). He served in various capacities as associate member of the Environmental Security panel under the NATO Science for Peace and Security and the European Commission Frameworks Programmes.

Towards an Implementation Policy for Renewable Energy Driven Desalination Systems in MENA Region

M. T. Chaibi*, O. Mahjoub
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medthameur@iresa.agrinet.tn

Abstract:

Water resources is scarce in the MENA region (Middle East and North Africa), one of the most arid areas in the world. In addition to the severe water related problems in the region, the potential in water resources presents a greater regional disparity as regards quality and quantity aspects.

Most of MENA countries are rapidly approaching full utilization of its available water resources and the scarcity of water resources is even more acute as the possibilities of developing new sources are limited and their costs are increasing. However, the region is with an abundance of natural resources, but unequally distributed as great gaps exist between countries rich in natural resources and countries in dependent on such resources.

MENA region is lagging behind in implementing future plans call for a reduction on reliance on imports and for increased emphasis on conservation and renewable energy as well as water management and new water sources development.

The growing need to find solutions to the problems of fresh water supply in arid areas of the MENA countries has driven the governments to seek for the potential of desalination systems

based on renewable energy sources concepts in alleviating water stress and for issues to incorporate renewable energy sources desalination in water policy and development program.

Renewable Energy Driven Desalination Systems strategy is considered not enough investigated and analyzed to be incorporated in the global scale of water policy as priority is going towards the water saving and catchments management and the intensification of the water demand management.

The promotion of the potential for desalination using alternate energy sources is in need of major improvements regarding the comprehensive institutional and policy reforms and the creation of knowledge basis areas.

Keynote: Carol Chouchani Cherfane, UN-ESCWA, Prospects and challenges of promoting links between water and energy in the region

Carol Chouchani Cherfane
Chief, Water Resources Section
Sustainable Development and Productivity Division
UN Economic and Social Commission for Western Asia (ESCWA)

Carol Chouchani Cherfane is Chief of the Water Resources Section in the Sustainable Development and Productivity Division at the United Nations Economic and Social Commission for Western Asia (ESCWA) in Beirut, Lebanon. Her current work focuses on supporting Arab regional initiatives on shared water resources management, climate change and water supply and sanitation. She previously served as Team Leader of the Technology and Enterprise Development Team in the same division. Prior to joining ESCWA, she worked for the the Harvard Institute for International Development. She
holds degrees from the Fletcher School of Law and Diplomacy (Boston) and Georgetown University (Washington, DC). Her doctoral research was on trade and environment issues facing the Arab region.

Abstract:

Water and energy are vital resources whose integrated management is necessary to achieve sustainable development. While traditionally addressed at the sector level, the intersecting challenges presented by water security, energy security, food security and climate change offer an important opportunity for integrated policy dialogue and priority setting within a sustainable development framework. In promoting this nexus, a regional approach to integrated natural resources management is necessary so as to maximize mutual benefits and mitigate the potential for conflict.

Energy is required for the pumping and distribution of water through supply networks and for desalination. Conversely, water is need for the generation of hydropower and solar energy. There are numerous other mutual dependencies that also exist between the water and energy sectors. Policy priorities must thus be identified during development planning and implementation that consider consumption and production patterns and trade-offs in the water scarce region of Western Asia. However, the nexus becomes more complex when priorities related to food security are incorporated, as these require consideration of agricultural water use efficiency, rural development needs, food imports and the virtual water trade.

The dependency of Arab countries on water resources that originate outside the Arab region complicates this matter further. For instance, the generation of hydropower along the Nile River must now be balanced against the need for drinking water and water for agricultural production

in order to meet food security needs and income generation objectives in rural areas. Trade-offs related to the use of shared groundwater resources present a similar dilemma in the Middle East. As part of efforts to catalogue shared water resources in Western Asia, ESCWA is collaborating with the German Federal Institute for Geosciences and Natural Resources (BGR) to prepare an *Inventory of Shared Water Resources in Western Asia* that catalogues and maps shared surface waters and groundwater resources in the region.

The impact of climate change on water resources presents another important dimension to consider, as the availability of water resources in face of harsher climates will have important implications for precipitation, evapotranspiration and salinity, and associated effects on freshwater availability, agricultural productivity, desalination, water supply and sanitation, and health. To this end, ESCWA is coordinating a *Regional Initiative on the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region* that brings together United Nations, League of Arab States and specialized organizations (LAS, ESCWA, UNEP, UNESCO, UNU, WMO, ACSAD, SMHI, GIZ) to examine the effects that climate change will have on the Arab region based on regional climate modeling and hydrological modeling tools that will serve as a basis for identifying vulnerability hotspots in the Arab region.

Advancing regional integration by examining the water-energy-food security nexus is adopted as an ESCWA strategic objective endorsed by member states for the coming years. In support of this objective adn to further research in this area, ESCWA is hosting an inter-governmental consultation of senior representatives from water and energy ministries in June 2012 to identify regional water and energy priority issues for further examination.

Qatar Water Challenges

M. A. Darwish* and Rabi Mohtar
Qatar Environment and Energy Research Institute, QF

Abstract

Qatar experienced rapid economic growth due to oil and natural gas (NG) discovery and exportation. Qatar natural renewable water resources (rainfalls and ground water) are scarce; per capita available fresh water resources is estimated at 71 m^3/ per year in 2005. This is far below the water poverty line of 1,000 m^3/y/cap. Compared to their replenishment rates, ground water (GW) withdrawal rates are excessive, (), and is used mainly for irrigation. Very small amount of GW is treated to become potable water and is distributed to consumers. The municipal potable water is mainly (99%) of desalinated seawater (DW), and 1% GW. The consumptions of DW and electric power (EP) are continuously rising due to the increases of both population and standard of living. The population has more than doubled from 2000 to 2010. The DW is produced in power plants generating both EP and DW, and is called Cogenerating Power-Desalting Plants (CPDP). These CPDP's are using either: simple gas turbines (GT) cycle or GT combined with steam turbine to form GT Combined Cycle (GTCC). Thermally driven multi stage flash (MSF) desalting system is mainly used to desalt seawater. Large MSF units are operated in CPDP to get their thermal energy (as steam) needs either from: (i) heat recovery steam generators (HRSG) coupled with GT, or (ii) steam discharged or extracted or discharged from the ST of the GTCC. The CPDPs consume huge amounts fossil fuel (FF), mainly NG. Burning FF pollutes the environment by emitting carbon dioxide (CO_2), carbon monoxides, and nitrogen oxides (NOx), which are greenhouse gases (GHG) causing global warming. Raising the efficiencies of EP and DW production can decrease their negative impact on the environment. The sustainability of water in Qatar is questionable. The extracted GW is several times its replenishments rate. Municipal water supply depends almost on desalting seawater by MSF, which is energy intensive and costly process. Deploying more energy efficient desalting system such as Seawater Reverse Osmosis (SWRO) system can save large volumes of NG, the nation's main source of income. The use of treated wastewater (TWW) is limited to some agriculture and landscaping. The ratio of TWW to municipal water supply is low, about 25%. It is also essential to promote conservation measures for both water and power. The objective of this paper is to review the water profile in Qatar, and recommends solutions to solve the growing water scarcity in the country.

Keywords: *Corresponding Author: email: madarwish@qf.org.qa

Nomenclature

BCF billion cubic feet
BPST back pressure steam turbine
cap capita
d day
DW desalted seawater
ECST extraction condensing steam turbine
EP electric power
FAO food agriculture organization of the united nations
G giga (10^9)
GHG green house gases
GJ giga Joules (10^9 Joule)
GT gas turbines
GW giga Watt
GWh giga Watt hours (1 GWh = 3600 GJ)
GTCC combined gas/steam turbines cycle
GW ground water
HRSG heat recovery steam generator
kWh kilo Watt hour (1 kWh = 3600 kJ
M million, (10^6)
mg/l, milligram per liter
MIGD million imperial gallons per day (4546 m3/d, or 62.62 kg/s)
MSF multi stage flash desalting
MW megawatt (10^6 Watt)
MCF million cubic feet
NG natural gas
QEERI Qatar Energy and Environment Research Institute
QF Qatar Foundation
RO reverse osmosis
ST steam turbine
SWRO seawater reverse osmosis desalting system
TWW treated waste water
WW waste water

1- Introduction

Qatar is currently experiencing great expansion in economic activities and significant increase in population. The population increased from about 0.744 Millions (M) to 1.7 M from 2000 in 2010, or 2.28 times increase, see Figure 1. The Qatar Environment and Energy Research Institute (QEERI), established in 2011, is interested in finding the energy, water, and carbon foot prints of different sectors in Qatar. This paper is a first step to review the water profile.

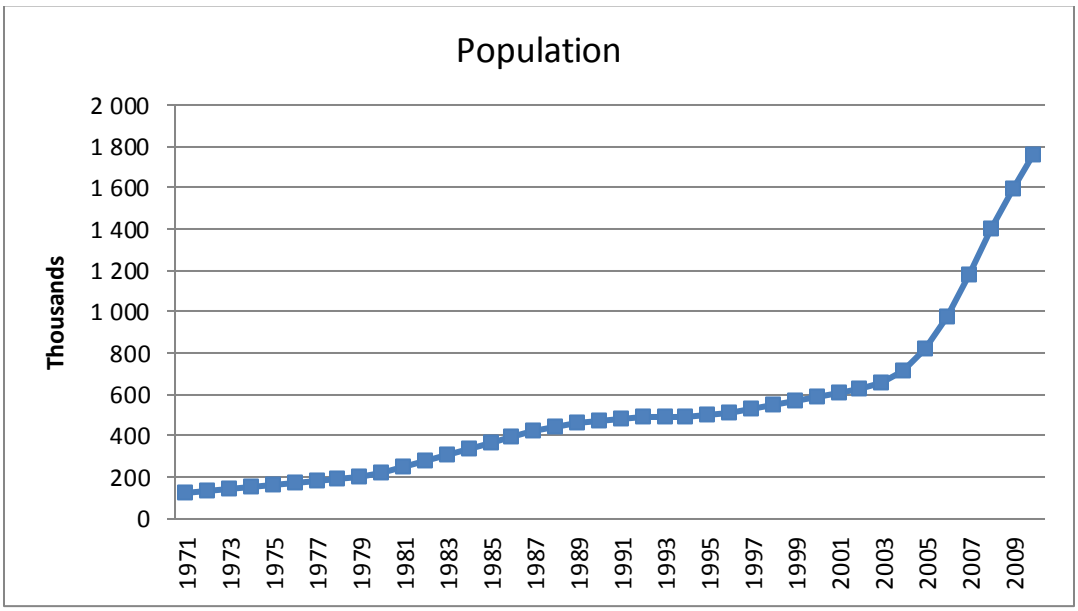


Figure 1: Qatar population growth rate against years [1]

2- Qatar Main Water Sources

Qatar is an arid country of harsh and fragile environment, high summer temperature (>40°C), low rainfall (annual average 82mm) with high evaporation rate (annual average of 2,200 mm), and low nutrient availability in the soil. Natural renewable water resources of rainfalls and ground water (GW) are scarce. Continued population and economic growth raise concerns about water security. Water security means reliable access to safe water at affordable price for every person in order to have healthy, dignified and productive life. The annual per capita (y.ca) natural water resource of the country was estimated at 71-m^3/y.ca in 2005 [3]; far below the water poverty line of 1,000-m^3/y.ca.

In 2005, the annual water withdrawal was 440 Mm^3, with a share of 59% for agriculture, 2% for industrial, and 39% for municipality. This annual withdrawal includes renewable fresh water

resources as well as potential over-abstraction of renewable GW or fossil GW and eventual use of Desalted Seawater (DW) or Treated Wastewater (TWW). In the same year (2005), the agriculture water consumed 220 Mm^3 of GW and 25 Mm^3 TWW, while the municipal water consumed 149.2 Mm^3 DW, and 1.2 Mm^3 GW. The renewable share (58 Mm^3) of total freshwater withdrawal (221 Mm^3) is about 26%. This means that water use is unsustainable, as withdrawal exceeds recharge rates and the GW is over-exploited. In 2009, the DW provided almost 99% of Qatar's municipal water demand and some commercial uses [4].

2.1- Rainfall

The rainfall rates are low, variable, unpredictable and highly erratic in time and space. Its average in the last 20 years was about 82 mm/year, Fig. 2, while evaporation rate is high. Rainfall is not considered reliable for supplementing irrigation and maintaining agriculture because of its low intensity and variability. Yet it represents the main source of irrigation water in the form of recharge to GW [3].

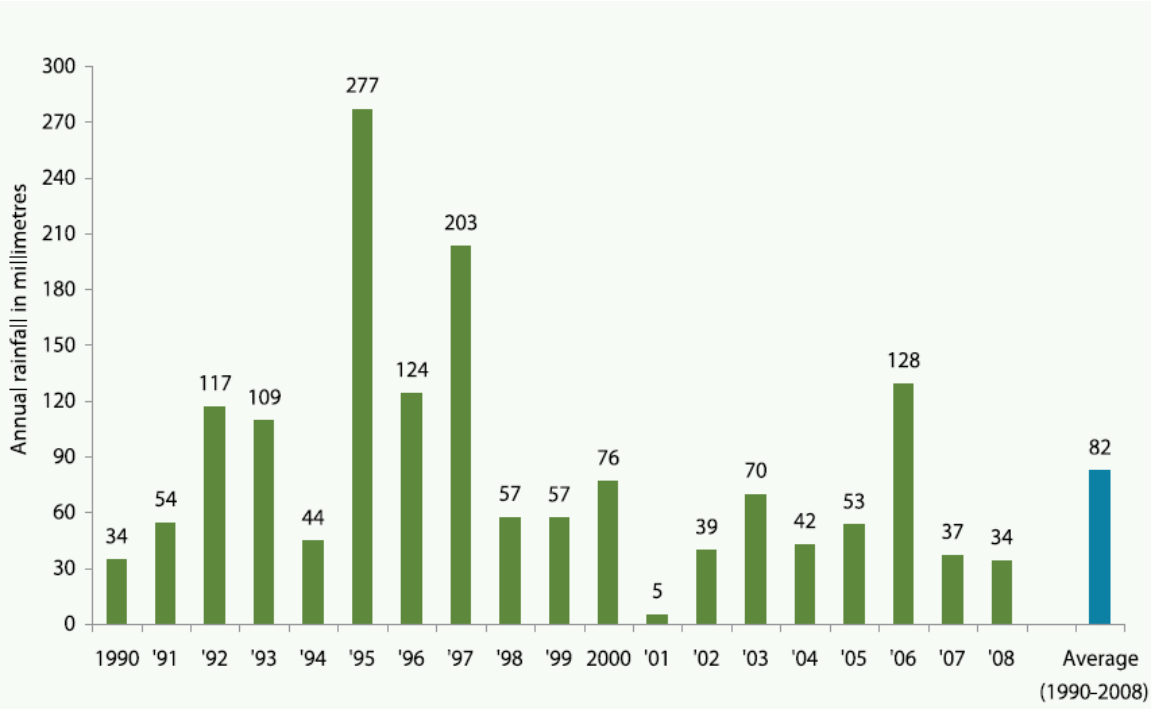


Figure 2: Annual rainfall in Qatar along the years showing average of annual 82 mm [2]

2.2- Ground Water (GW)

There are two main basins of GW: the Northern GW (NGW) and Southern GW (SGW) Basins; and three secondary basins called Abu Samra, Doha and the Aruma deep GW basins in southwest of the country Fig. 3. The NGW Basin is the most important GW source. It has acceptable quality for agriculture. Its salinity varies from 500 to 3000 mg/L and increases towards the sea reaching 10 000 mg/L near the coasts due to seawater intrusion. It covers about 19% of total land area and at 10 - 40m water depth below ground.

The SGW Basin extends to about half of the land area. Its replenishment rate is much less than NGW Basin. Within the basin, water levels are mostly at least 30-m below the surface. It is a poor aquifer lacking continuity with adjacent aquifers. Water salinity is relatively high and not suitable for agriculture (3,000-6,000 mg/L) [2]. The SGW basin draws on the Alat artesian aquifer in Abu Samra. The Abu Samra aquifer recharge source is in Saudi Arabia. The aquifer extent is limited with an average thickness of 15 m. The total depth of wells ranges from 22 to 80 m below the ground surface. Its salinity ranges, in general, from 4,000 to 6,000 mg/L. The Aruma aquifer in southwest Qatar comprises approximately 130 meters of granular limestone belonging to the Aruma Formation. The drilling data of exploratory and production wells indicate that relatively good quality water (with a salinity level of about 4 000 mg/l) at deep depths of 450-650 m exist in southwest Qatar.

The average annual GW recharge from rainfall is estimated internally at 55.9 million cubic meters per year (Mm^3/y). In addition there is an inflow of GW from Saudi Arabia estimated at 2.2 Mm^3/y, making the average total renewable groundwater resources 58.1 Mm^3/year for the period 1972-2005. Extraction of GW from both the NGW and SGW was about 220.2 Mm^3 in 2004-2005 as shown in Figure 4. This resulted in water abstraction rates many times the natural GW recharge rate. Continued over-exploitation of fossil GW reserves threatens the remaining reserves from saltwater intrusion, while overuse of ground water for agriculture is resulting in soil salinization and desertification.

Source: Redrawn from Amer and Abdel-Wahab, 2009, derived from FAO Studies Project, 1981

Figure 3: Groundwater Basins in Qatar [2]

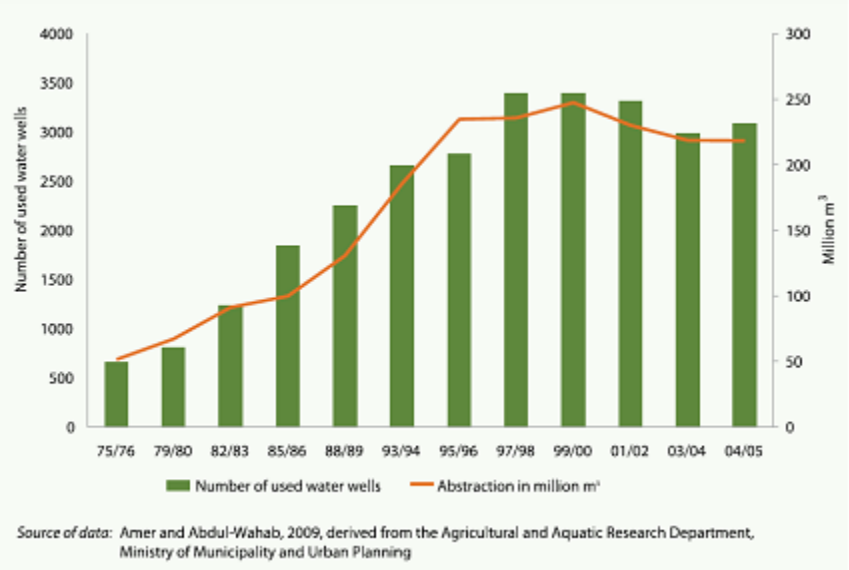


Figure 4: Number of Wells and Water Abstraction in Qatar [2]

2.3- Treated Waste Water (TWW)

Qatar's population has 100% access to clean drinking water; while the sewage network covers about 68% of all over Qatar's buildings and 95% of Doha's buildings. About one-third of

municipal wastewater (WW) is treated and recycled. The balance is lost as leakage or from buildings not connected to the sewer system in the suburb. In 2004, the number of Qatar residents connected to sewer were 54,766, while 19,794 residents were not connected, (i.e. 26.5% not connected). Most of the supplied municipal water is of potable quality. This water is misused in services that do not need this high quality water such as garden irrigation, car washing, toilet flushing, and others.

The flow of treated effluent from the two main treated waste water (TWW) plants in Doha had reached between 140,000 and 150,000 m^3/day in 2005. The two main sewage treatment plants use tertiary treatment and account for 96% of the TWW influent, while a number of smaller plants serving smaller communities account for the balance. The known TWW plants and their capacities in (m^3/d) are: Doha West known as Sailiyyah (135,000), Doha South known as Nuaija (112,000), Doha North known as Lusil (60,000), Doha Industrial area (12,000), Al-Khor (4,860), and Al Thakhira known as Dakheri (30,000). So, the capacity of all the WWT plants is 354,000 m^3/d. Another WWT plant of 28,700 m^3/d capacity started to be built in 2009 at the site of the new airport for its landscape irrigation. So the capacity of total WWT plants is expected to increase to 129.4 Mm^3/y.

The recycled TWW is used for irrigation of some crops and landscaping as shown in Fig. 5. Reclaimed TWW for re-use has become common practice worldwide. It is a water source that should be fully utilized specially in arid areas like Qatar. Its treatment cost for re-use with potable quality is lower than the cost of desalting high salinity brackish or seawater. It is an available water source that exists right at the doorstep of urban communities. It increases with the increase of inhabitant numbers, per capita consumption, and standard of living. Extending the WW treatment of tertiary level of limited usage for irrigation to quaternary level (of potable water quality) by using hyper-filtration (reverse osmosis) opens the door of using the TWW as part of municipal water. This will improve the water security by not becoming completely dependent on DW. DW production is vulnerable to oil spills, operation interruption, etc.

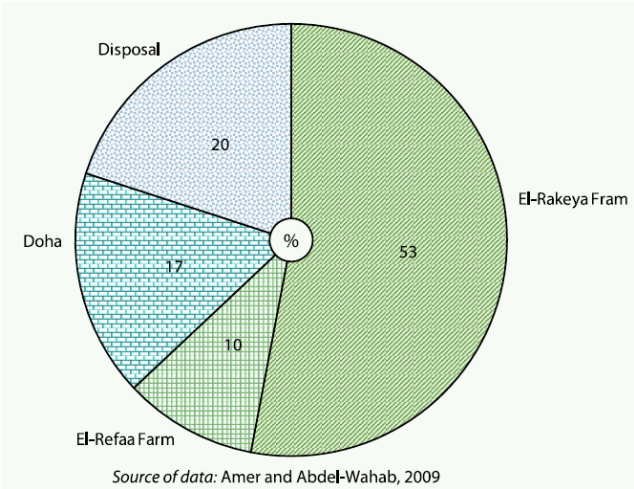


Figure 5: Use of treated wastewater in 2005 [2]

2.4 Desalted seawater (DW) and municipal water

Qatar's first desalination plant was commissioned in 1953, and had 680 m^3/d capacity. More plants were added later, and some were demolished. The largest desalination facility is located in Ras Abu Fontas (RAF), in the southern part of Doha, and meets most of the civil sector demand. Other desalination plants are mainly used to supply water to the industrial sector in Dukhan, Ras Laffan, Messaied, Umm Bab, the remote outskirts of Abu Samra and the Al Shamal military camp. Large capacity desalting plants are combined with Power Plants (PP), forming what is called Cogeneration Power Desalting plants (CPDP). Table 1 shows the main CPDP in Qatar with their Electric Power (EP) capacities in MW, and DW capacities in cubic meters per day (m^3/d) as well as in Million Imperial Gallons per day (MIGD).

The DW plants capacity reached 1.49 Mm^3/d in 2011 by the operation of Ras Abu Girtas and Ras Abu Fontas new desalting plants. There is heavy reliance on DW, and its production is on the rise. DW production by the predominantly used MSF units is energy-intensive and costly process. It negatively affects the environment. Recently (2012), Qatar contracted a firm to build 5,760 m^3/d multiple-effect distillation (MED) thermo-compression desalination plant for $8.3M, or $1.54M/1000 m3/d, [5]. Efforts are needed to use more efficient desalting systems to minimize its carbon emission due to the combustion of fossil fuel (natural gas) used for desalting, and its threat to sensitive marine environments.

The annual DW productions in Mm^3 was increased from 178 in 2004 to 226 in 2006, 251 in 2007, 312 in 2008, 340 in 2009, and 373 in 2010, which is a significant annual increase of 14%. The annual fuel energy consumed by desalting units in Qatar is estimated in the next section along with its effect on the environment.

Table 1: Main power and desalting plants and their capacities [2]

Desalination Plant	Power plant capacity, MW	Total Capacity m^3/d	Total capacity, (MIGD	Starting date
Ras Abu Aboud				
Ras Abu Fontas A	497	318,226	70	1980
Ras Abu Fontas B	609	150,000	33	1995
Ras Abu Fontas B1	377	240,000	53	2002
Ras Abu Fontas B2	567	136,000	30	
Ras Laffan A	756	181,843	40	2003
Ras Laffan B	1025	272760	60	2006

Meisieed	2007			2009
Ras Girtas	2730	286,400	63	2010
Satelites	184			1983
Total	8752	1,450,229	349	

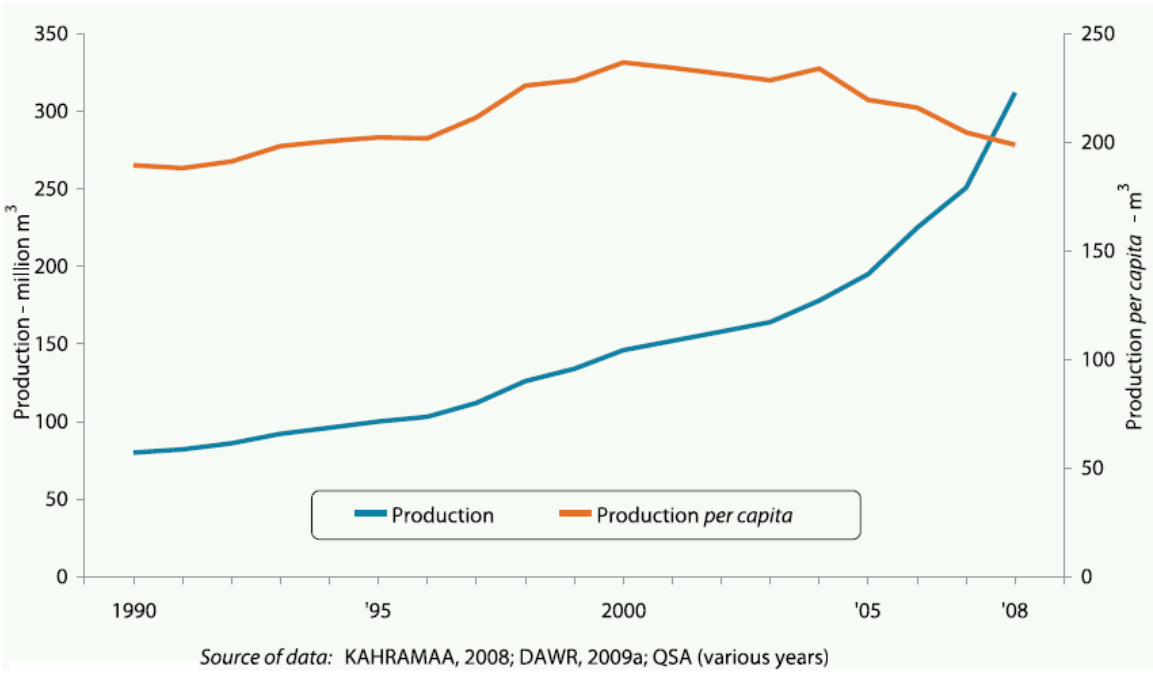


Figure 6: Qatar DW increase from 1990 to 2008 [2]

2.4.1 MSF Desalination Energy consumption

Most desalted seawater in Qatar is produced by the predominantly used MSF desalting system combined with power plants. The MSF units are supplied with steam from heat recovery steam generators (HRSG) using the hot gases exhausted from gas turbines (GT) to produce this steam. Also steam can be extracted (or discharged) from steam turbines of GTCC to the MSF units. The HRSG in GTCC uses the exhaust gases from GT to produce steam, which is supplied to steam turbines producing additional EP without fuel supply. The GTCC is the most used type power cycle nowadays due to its high efficiency (≅50%). In GTCC, shown in Figure 8, each GT is combined with one HRSG. The steam generated from three HRSG (also three GT) is supplied to one steam turbine. The GTCC cycle is used in several power plants in Qatar such as Ras Abu Fontas A, Ras Abu Fontas B, Ras Abu Fontas B2, Ras Laffan-A, Ras Laffan B, Ras Laffan C, **Ras Girtas Power, and M**esaieed Power plant.

When MSF units are combined with the GTCC, two types of steam turbines can be used. The first is Extracted-Condensing Steam Turbine (ECST) where part of the expanding steam is extracted to the MSF units, while the balance continues its expansion to a condenser. The other type is the Back Pressure Steam Turbine (BPST) where all the expanding steam is exhausted to the MSF units at the pressure required by these units as shown in Figure 7. Typical energy consumed by the MSF system are: pumping energy of 4 kWh/m^3 (14.4 kJ/kg work or electrical energy), and 270 kJ/kg of thermal energy obtained by condensing the supplied steam to the MSF brine heaters. This steam is usually supplied at 2-3 bar pressure, and saturation temperature of 120°C.

The real value of the 270 kJ/kg thermal energy supplied as steam to the MSF units lies in its ability to produce work (or EP). If this steam was expanded in low pressure LP turbine to the condenser, it would produce more power. So, supplying steam to the MSF is considered as work (or EP) loss, which can be calculated; and would be equivalent to the thermal energy supplied to the MSF unit.

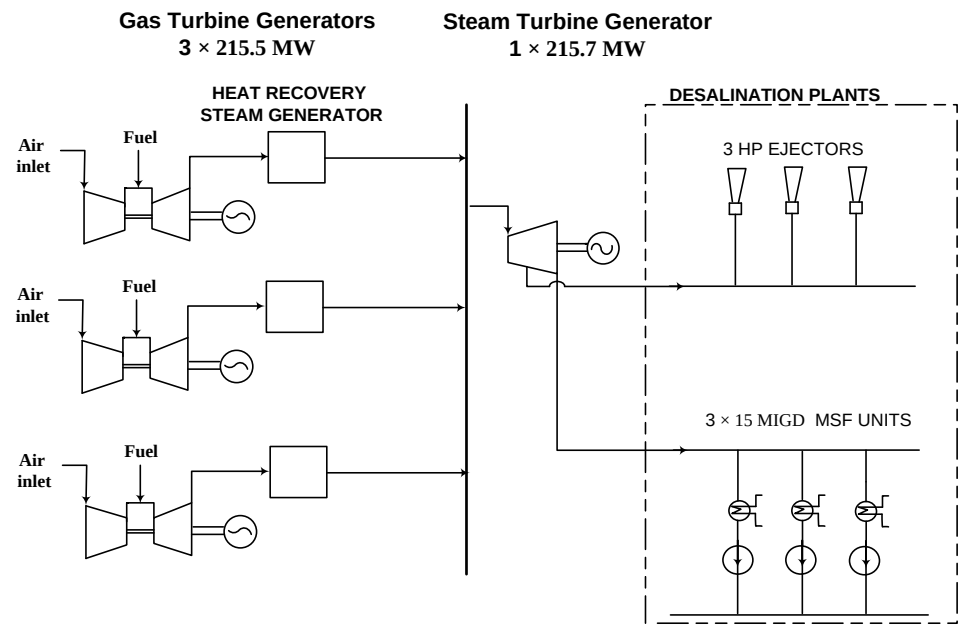
The case considered here for a real plant, see Fig. 8, having 3 MSF desalting units of 15 MIGD capacity each (or 2638 kg/s total capacity). The steam leaving the turbine is at the rate of 1050.6 ton per hour (291.83 kg/s), 2.8 bar pressure, 159.4°C temperature, and 2782.8 kJ/kg enthalpy. If this steam was expanded in LP turbine to condenser pressure at 8 kPa, its enthalpy would be 2330 kJ/kg, and the work output would be

Lost work due to steam supply to 3 MSF units = 291.83(2782.8 – 2330) = 132,142 kW

Another small amount of steam is extracted from the steam turbine, but at higher pressure to operate the steam ejectors of the 3 MSF plant at 19.9 t/h (5.53 kg/s) flow rate, 30.1 bar pressure, 448.1°C temperature, and 3342.5 kJ/kg enthalpy. If this steam was expanded in a turbine to the condensing pressure of 8 kPa, its enthalpy would be 2330 kJ/kg, its work output is

Lost work due to steam supply to 3 MSF ejectors = 5.53(3342.5-2330) = 5599 kW

So the total work loss by the steam supplied to the 45 MIGD (2368 kg/s) is 137,741 kW, or 58.2 kJ/kg (16.16 kWh/m^3). Since the pumping energy of the MSF is in the range of 4-kWh/m^3, the total equivalent mechanical energy (counting for pumping and thermal energy) to produce one m^3 of desalted water is about 20-kWh/m^3.



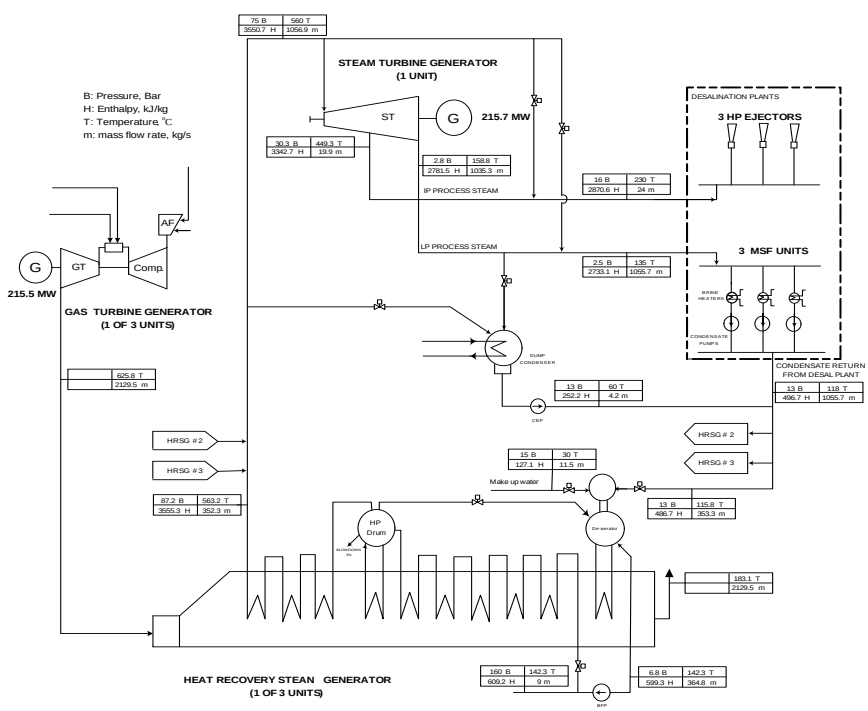


Figure 7a: CPDP using GTCC of 3GT, 3HRSG, 1 steam turbine, and 3MSF units [6]

The fuel energy consumed by the CPDP to produce the 20 kWh/m^3 equivalent energy required for produce DW production can be calculated by assuming power plant efficiency of 45% as 20×3600/(0.45) = 160,000 kJ/m^3 or 160 MJ/m^3. This shows the clear benefit of combining the

MSF units with power plants. If the steam required to the MSF units was taken directly from fuel operated steam boiler, the fuel energy required for the brine heater would at least be equal to 270/0.9 = 300 MJ/m^3, where 270 is the thermal energy required in MJ/m^3 and 0.9 is the best small boiler efficiency. Thus the use of CPDP saves at least 50% of the fuel energy when the MSF is directly driven by fuel operated boiler.

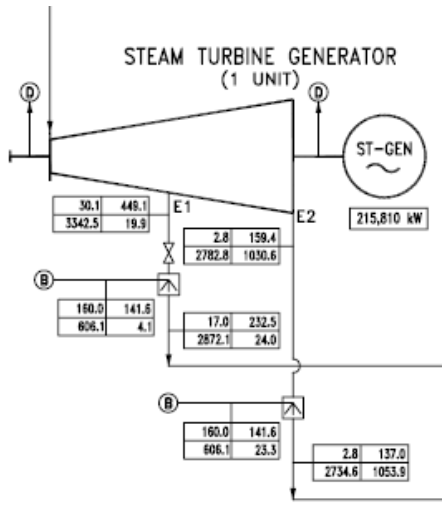


Figure 7b: Steam cycle conditions in the CPDP [6]

Consumed fuel due to desalting seawater and its CO2 emission

2.4.1b Desalination Energy Consumption and CO_2 Emission

In 2010, the Qatar productions of EP was 28144 GWh and of DW was 373 Mm^3 (1.022 Mm^3/d). The consumed fuel energy and its resulted CO_2 emission to generate the EP and DW are calculated here. The equivalent consumed EP per m^3 of DW by the MSF desalting system was given before, about 20-kWh/m^3. So, the consumed equivalent EP to desalt 1.022 Mm^3/d is:

Consumed EP for DW per day = 1.022 Mm^3/d $\times$ 20 kWh/m^3 = 20.44 GWh/d.

Consumed EP for DW per year = 7460.6 GWh in 2010.

This gives total equivalent EP output of both electricity and DW as 35605 GWh, (28144 for EP + 7461 for DW), with DW share of 21%. By assuming 35% average efficiency due to part time operation most of the time with low efficiency, the consumed fuel energy by the CPDP is 366.3 MGJ. This 366.2 MGJ is equivalent to 61.03 million barrel of oil (bbl), or 348.9 billion cubic feet (BCF) of NG. The heat content of one bbl is assumed equal 6 GJ, and of 1000 cubic feet (CF) of NG is 1050 kJ. Qatar produced 3154 BCF of NG in 2009, while consumed 745 BCF.

Therefore, the CPDP consumed NG is more than 11% of Qatar NG total production in 2009, and about 40% of total NG consumption.

The mass of fuel burned in CPDP (366.2 BCF) is equal to 366.2×0.0208 = 7.602 M ton of NG, with the contribution of 1.6 M ton by DW. The produced CO_2 due to burning 7.602 M ton of NG is 7.602×0.75×44/12 = 20.922 M tons. The contribution of DW in this amount is 1.6 M ton. This means that the production of each one m^3 of DW causes the emission of 11.23 kg/m^3 CO_2. In brief, desalting 373 Mm^3 in 2010 (1.02 Mm^3/d) causes burning of 1.6 tons of NG and the emission of 4.4 million tons of CO_2.

It worth to mentioning here that the choice of seawater reverse osmosis (SWRO) to desalt seawater in place of the MSF system can save 75% of the fuel used and reduce the CO_2 emission with the same ratio. The average SWRO energy consumption with brine energy recovery devices is 5 kWh/m^3.

2.41c Desalination impact on marine environmental

Besides polluting the air and emission of CO_2 by burning NG fuel to produce DW, the MSF desalting process has negative effects on marine environment by: (i) seawater intake and impingement of marine species on intake screens, (ii) Brine discharge of high salinity brine with chemicals used in pre-treating the feed water, and (ii) Thermal discharge to sea by high temperature brine and cooling seawater. For an MSF unit of capacity D, the intake to the heat rejection section of the MSF as cooling water, M_c, is about 6 times D, or 6 D. Part of M_c (after being heated) is treated to become the makeup F (F≅ 3 D). The balance (Mc - F), ≅ 3 D is discharged back to sea through the outfall; say at ≅ 11°C higher than seawater temperature and at the same seawater salinity. Part of F becomes the distillate D, and the balance is the brine B (≅ 2 D). B is rejected back to sea through the outfall. The rejected brine B has, say at 11°C higher than seawater temperature and at salinity about 50% higher than that of sea salinity. So, the MSF outfall flow rate is 5 D and at 11°C higher than that of seawater. The high flow rates of seawater intake in MSF intensifies the negative effect on marine species by impingement; increase the chlorine discharge due to the chlorine added to seawater at the intake, and its overall negative effect on marine life. As an example, the Ras Abu Fontas A desalting plant of 70 MIGD (318,220 m^3/d) has intake flow rate 92,814 m^3/h, and the outfall flow rate is 79,555 m^3/h.

In year 2010, the produced DW in Qatar was 1.02 Mm^3/d; the heat rejected to the sea is at the rate of 3.1 GW. It may be noted that the heat discharged to the sea is almost equal to the thermal energy? added to the desalting units. This can be checked by knowing that the thermal energy used by the MSF is in the range of 270 MJ/m^3, then the heat added to produce 1.02 Mm3/d (11.8 m^3/s) is 3.18 GW.

3- Water Storage

In 2010, the storage water capacity was 2.673 Mm^3, mainly in reservoirs located in CPDP (1.31 Mm^3), and 1.36 Mm^3 in other locations, and the balance is in high towers and ground tanks, see Table 2. The daily DW production (and consumption) was more than 1 Mm^3/d in 2010. The water storage increase from 2006 to 2010 is shown in Figure 8. This means that the storage capacity is less than three times of daily consumption, which can create critical situation if the vulnerable desalting plants become non-operational for any reason. Strategic water storage is required to cover the demands for several weeks.

Table 2: Water Storage Capacity in Qatar in 2007 [2]

Storage Facility	Storage Capacity (m^3)	Percentage
Reservoir	1,927,542*	97.2
Ground Tank	25,167	1.3
Elevated Tank	2,987	0.1
Water Tower	27,640	1.4
TOTAL	**1,983,336**	**100**

* Exludes non-operating reservoir under refurbishment or maintenance
Source: KAHRAMAA, 2008

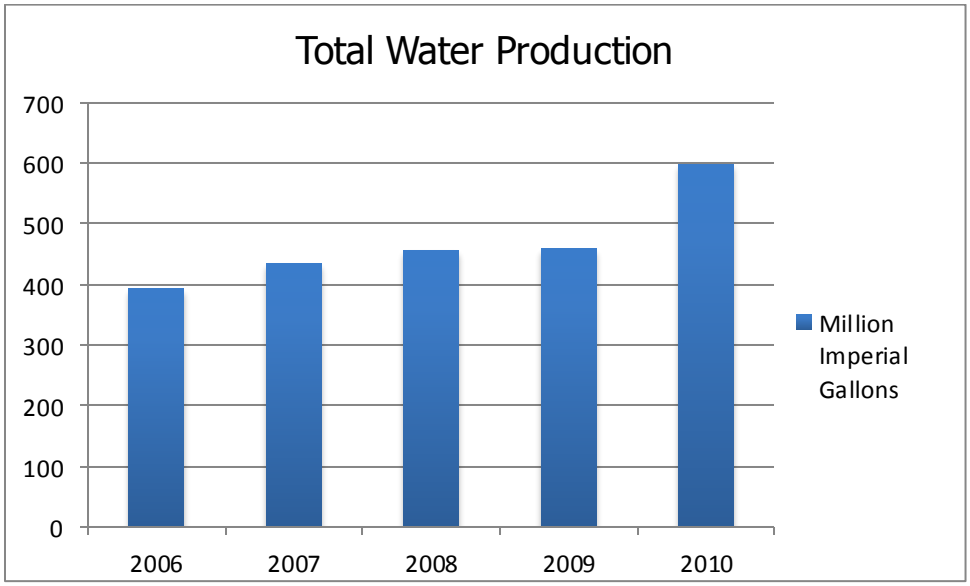


Figure 9: Water Storage Capacity Development from 2006 to 2010 [4]

4. Water Consumption:

Qatar water strategy is to use GW for agriculture, DW to provide potable municipal water, and reclaimed TWW for irrigation of forage crops and landscaping. Agriculture areas are scattered where the GW of reasonable salinity are available for farming. Extractions of GW from the NGW and SGW basins were 220.2 Mm^3 in 2004/2005.

Municipal water of potable quality is mainly DW from seawater, and little contribution from desalting GW. In 2010, municipal water consumption was 1.02 Mm^3/day (373 Mm^3/y), while the population was 1.7 M. This gives 600 liters per day per capita (l/d.ca) potable water consumption, considered as one of the highest worldwide. The main reason for high consumption is the politically motivated low or no prices paid by consumers. The Qatari nationals get water for free, while expatriates (about 80% of population) pay highly subsidized price of about \$1.2/m^3, about 35% of the real cost. Example of government water subsidization in 2003 is illustrated in Table 3.

As mentioned before, the average annual GW extraction between 2004 and 2005 was 220.2 Mm^3. If this extraction is kept the same in 2010, then the daily per capita consumed GW is 355 l/d.ca. The effluents of the TWW plants in Doha were 129.4 Mm^3/y (354,520 m^3/d or 208 l/d.ca). Therefore, the total daily consumption of water is 1163 l/d.ca, which is extremely high. In 2003, the ratio of residential water consumptions (for Qatari's and non-Qatari) was 74%, Table 3. Thus, water demand management programs should be imposed to reduce household consumption. Distribution of household water in Qatar is given in Figure 9.

The contribution of agriculture to the economy is negligible, as it represents less than 1% of the GDP (gross domestic product). However, it consumed about 60% of the country's water in 2005. The development of the agricultural sector is limited by several factors, such as scarce water resources, low water quality, unfertile soils, and harsh climatic conditions. All these factors have contributed to low crop yields and resulted in importing of most agricultural products, dates being the only exception.

Table 3: Qatar 2003 water consumption and government subsidy [2]

Sector	Subsidy per unit (QR/m^3)	Total consumption (Mm^3)	Total subsidy MQR	% distribution of subsidy
Residential (Qatari)	10	52.3	524	63
Residential (non Qatari)	5.6	24.6	138	17
Commercial	5.6	10	56	7
Government	10	3.6	36	4
Industrial	5.6	13.4	75	9
Total	8.0	103.9	829	100

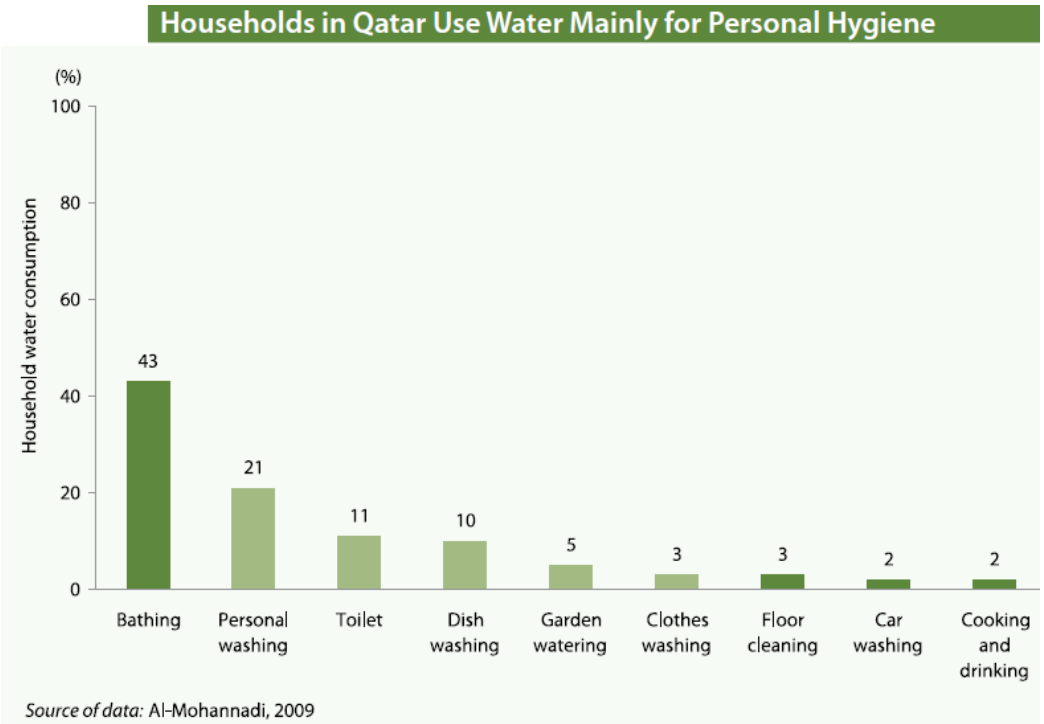


Figure 9: Distribution of household water in Qatar [2]

In 2005, total water withdrawal was estimated to 444 million m^3, of which 262 million m^3 or 59% for agricultural purposes, 39% for municipal purposes and 2% for industrial use. Of the total reused treated wastewater of 43 million m^3 (an increase of more than 70% since 1994), 26% was supplied to Doha to be used for landscape irrigation, the remaining part being conveyed via pipelines for irrigation of forage crops in two farms, see Table 4. All water used for irrigation is pumped from wells and from the sewage treatment plants to the farms and Doha. There is no pricing system and water is given free to farmers, all what they pay is the cost of pumping. Measuring and limiting the abstraction should be implemented.

Table 4. Water Withdrawal by different sectors in Qatar in the year 2005 [2]

	Agriculture		Domestic		Industry		Total	
	Million m3/year	%	Million m3/year	%	Million m3/year	%	Million m3/year	%
Groundwater	218	83.5	2.4	1.4	-	-	22.7	49.7
Treated Sewage Water	43.2	16.5	-	-	-	-	43.2	9.7
Desalinated Water	-	-	171.8	98.6	8.4	100	180.2	40.6
Total	261.5	100	174.2	100	8.4	100	444.1	100
% by sector	58.9		39.2		1.9		100	

The water budget has been changed drastically in 2010, as DW became 373 Mm^3/y (compared to 180 Mm^3/y in 2005 or 207% increase in 5 years). Similarly TWW was increased from 43.3 Mm^3/y in 2005 to 129.4 Mm^3/y in 2009, almost 300% in 4 years. The GW withdrawal is limited by government. If the GW is limited to 200 Mm^3/y, then the total water withdrawal would be 702.4 Mm^3/y. The percentage water withdrawals in 2010 can be about 53.1% for DW, 18% for TWW, and 27.9% for GW.

5- Water Sustainability

The sustainability of water in Qatar is at risk. The extracted GW rates are several times its replenishments rate. The first sustainability condition is the rate of consumed renewable resource should be less than or equal its replenishment rate. The municipal water supply depends almost completely on DW. The used desalting process is energy-intensive, and costly. The fuel consumed, NG, is finite and non-renewable. The second sustainability condition is that the rate of consumed non-renewable resource (NG here) should be less than the rate of developing another alternative; however, there is no alternative here. Burning fuel to produce DW emits gases, which pollutes the air and contributes to the greenhouse gases (GHG) causing climate change. The desalting process also negatively affects the marine environment. The third sustainability condition that polluting gases should be treated to render them unharmed to the environment; which is not the case here. The use of TWW is limited to some agriculture and landscaping, and at low rate compared to potable water consumption (about 25%). The TWW is a water resource; and most of it is unused.

6- Measures to be considered

There are clear advantages of seriously considering some intervention measures, such as:

1- Conservation is the best resource. Raising public awareness and education, using water conserving measures, and restructuring water prices are to be used for water conservation.
2- Most WW in Qatar is treated to the tertiary level and is used for irrigation. The dissolved organics and other contaminants present in tertiary treated effluent are known or suspected to be detrimental to various reuse applications and still limit full utilization of this valuable resource. The Quaternary treatment is defined and used as the treatment producing potable water quality to meet unrestricted residential uses and industrial applications requiring ultra-pure water. Membranes of different pore sizes are usually used in this process such as micro-filtration (MF), ultrafiltration (UF), nano-filtration (NF), and hyper-filtration reverse osmosis (RO) in descending pore diameter order. As a general rule, MF is suitable for the removal of suspended solids, including larger micro-organisms like protozoa and bacteria. UF is required for removal of viruses and organic macromolecules down to a size of around 20 nm. Smaller organics and multivalent ions may be removed by NF while RO is even suitable for the removal of all dissolved species. However direct human consumption of this treated effluent may be objectionable for psychological and probably religious reasons, although it can satisfy the potable water requirements and used for human consumption in many parts of the world. The quaternary treated are used as direct potable water or recharged to aquifers for storage and then extracted for potable purposes in many parts of the world. Examples are given in reference [7]. An example is the Sulaibiya treatment plant in Kuwait [8], which uses UF and RO to produce potable water quality from tertiary municipal waste-water effluent. The RO removes dissolved salts and harmful contaminants, including bacteria, viruses and chemicals. This plant is the largest facility of its kind worldwide using RO and UF membrane-based water purification. The plant had initial daily capacity is 0.375 Mm^3/d and is designed for extension to 0.6 Mm^3/d in the future. Its output can be used with no limitation for agriculture, industry, and some building's application. The output can be also used for aquifer storage charge to save the GW from depletion and deterioration, especially in the NGW basin.
3- Increasing natural recharge of aquifer by drilling of wells (with a special design including a perforated casing and graded gravels) in depressions to recharge water from occasional storm through the wells to depths that reach the water bearing formations to accelerate the natural recharge of floodwater.
4- Decrease the losses between municipal water supply and the treated waste water (TWW), which represents only 25% of the municipal water supply, and should be at least 60%.

Conclusion and Recommendations

In addressing water security concerns, Qatar needs to take serious step to conserve water and to develop integrated water management (IWM) program. The following steps should be considered:

- Formulating Integrated water resources management
- Capacity building and institutional strengthening;
- Looking for innovative desalination technologies that minimize both cost of water production and the environmental impact should be further investigated;
- Promote the technology of Wastewater treatment (WWT);

- Promote the use of treated waste water for agricultural and industrial use
- Promote storage of treated Wastewater in aquifers as strategic water storage;
- Expanding the use of Dual distribution system, one for potable quality water for drinking and cooking, and one for less quality for landscaping, toilet flushing, etc.;
- Managing Water Demand, a more effective way against water scarcity, risk and vulnerability;
- New water pricing: Water pricing needs to reflect the scarcity value of water so that governments do not end up subsidizing the depletion of an essential natural resource and polluting the environment;
- Formulating education and training programs which could result in considerable water saving primarily through behavioral change and good practices;
- Relying on renewable energy for desalting water and wastewater treatment;
- Developing programs to optimize and monitor the collection and distribution of water resources from rainfall, groundwater, desalination, aquifers and recycling, and direct each of these to its most appropriate and efficient use;
- Expanding the capacity of water storage facilities to ensure the reliable supply of water, especially potable water, for months instead of merely days; and
- Demand-side considerations include: Developing a strategy to manage demand and ensure efficiency of use in all sectors, coordinating and integrating the work of water agencies, eliminating wasteful practices, adopting advanced and appropriate technology, and constraining extravagant or unnecessary consumption.

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SESSION 9:
AGRICULTURAL WATER MANGEMENT

Real time soil water measurement technology for improved irrigation management in arid environments.

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Abstract

Technology to measure soil water content and soil salinity based on the dielectric properties of soil (as influenced by water) has advanced in recent years. At the same time, improved capabilities in logging data and transmitting it from the field has enabled near real time and near continuous remote monitoring of soil water content and its dynamics. As water is a scarce and valuable resource in the Gulf, much of which is used in irrigation, the ability to cost effectively observe irrigation infiltration, uptake and movement below the root zone is an important tool to improve irrigation management. Our objective was to conduct a preliminary assessment of two recently available dielectric sensors to remotely monitor and manage the irrigation component of a field research program at the International Center for Biosaline Agriculture, in Dubai, UAE. The two sensors were the 10HS and the 5TE from Decagon (Pullman, WA, USA). The 10HS measures soil water content while the 5TE also measures electrical conductivity and temperature, from which salinity can be inferred. The sensors were used with Decagon EM50G loggers which transmit data using GSM cellular technology to a website for downloading as required. Three 10HS sensors were located at depths of 10, 30 and 50cm in a research plot in a sandy soil irrigated with relatively low salinity water. A 5TE sensor was located at 30 cm depth in a plot irrigated with saline water. All sensors were read every 10 minutes. Preliminary results show that the sensors responded immediately to changes in soil water content, enabling irrigation infiltration, redistribution, crop water uptake and deep percolation to be readily observed in near real time. While calibration would likely improve the absolute accuracy of measurement, observation of the relative changes in soil water content without calibration yields valuable information that would be of great value in irrigation management.

Introduction

Agriculture is often a major user of water resources in arid regions such as the Middle East and North Africa, including the Arabian Peninsula (Jagannathan et al., 2009; Arab Environment. Water. Sustainable Management of a Scarce Resource. 2010; Abu Dhabi Water Resources Master Plan. 2009). The combination of scarce water resources, high evaporative demand which causes high crop water requirements, and the high infiltration rate of sandy soils require that irrigation be managed very carefully in order to use irrigation water as effectively as possible. There can be a tendency to err on the side of excess irrigation at the farm level due to a lack of good information on irrigation scheduling and management, insufficient experience and skills on the part of the operators of the irrigation systems, and insufficient economic incentive to manage water better. While the irrigation system and its design are important factors in making the best possible use of water, it is the management of the system that ultimately determines its effectiveness. For example, drip irrigation may be capable of high efficiency, but without good management its full potential cannot be achieved. Without sufficient information, there is a tendency to apply excess water in order to eliminate the risk of crop stress and reduced yields caused by insufficient irrigation. There is potential for significant water savings in reducing excess irrigation and thereby minimizing the application of water that does not contribute to crop production. An example would be reducing percolation of water below the root zone that exceeds leaching requirements.

One method of better irrigation management is to regularly measure soil water content. Various methods of doing this have been available for many years, ranging from simple gravimetric techniques using soil samples to the use of complex and expensive instruments such as the neutron probe. Evett (2007) reviews different methods and technologies for measuring soil water content. Each method has its advantages, disadvantages and suitability. Soil water sensors that produce an electric signal have an advantage in terms of ease of measurement and the ability to interface to automatic data loggers. A simple example is sensors that measure electrical resistance such as gypsum blocks and Watermark sensors. Both of these require water from the surrounding soil to move in and out of the sensor in response to water potential gradients, and so may suffer from a response lag, particularly in sandy soils where water content changes can be rapid.

In recent years sensors based on measurement of soil dielectric properties have become commercially available. Such sensors use the large difference in dielectric properties of air and water to estimate soil water content and its changes over time. Depending on the technology, most such sensors are classified as either Frequency Domain or Time Domain. Frequency Domain sensors typically measure the capacitance of the soil between fixed electrodes operating

at a particular frequency. However capacitance is dependent on the dielectric permittivity of bulk soil, which is a complex property that depends not only on water content but also on the electrical conductivity of the soil water and on temperature. Most capacitance sensors do not measure the electrical conductivity of the soil but minimize its effect on measurements of soil water content by operating at an appropriate frequency. McCann et al (2007) reported on one type of capacitance sensor (EnviroSCAN®, Sentek Pty. Ltd., Stepney, South Australia)[5] configured as multiple sensors mounted on a probe contained in an access tube that is inserted in the soil. This Multi-Sensor Capacitance Probe (MCP) makes simultaneous measurements of soil water content at multiple depths. The technology has been extended to make measurements of the dielectric permittivity at two frequencies (Starr et al 2009). One frequency is used to measure soil water content while minimizing the effect of electrical conductivity, while measurements made at the other frequency are sensitive to electrical conductivity. The effect of soil water content can then be separated from the effect of electrical conductivity to estimate both.

Another range of capacitance sensors is available from Decagon (Pullman, WA, USA). These are single sensors which must be inserted in the soil at the desired depth. An example is the 10HS that was introduced in 2008 and which samples a larger volume of soil than other sensors in the range.
(http://www.decagon.com/products/sensors/soil-moisture-sensors/10hs-soil-moisture-large-area-of-influence/). The 10HS sensor responds to the dielectric permittivity of approximately 1100 cm3 of soil in an ellipsoidal cylinder surrounding the sensor, as shown in figure 1. However, the electric field distribution is strongly weighted toward the sensor surfaces, so that soil water near the sensor will have a greater effect than soil water at the edge of the measurement volume (http://www.decagon.com/assets/Uploads/10HS-Volume-of-Sensitivity.pdf).

[5] Trade names are used in this publication to provide specific information. Mention of a trade name does not constitute a guarantee or warranty of the product or equipment by International Center for Biosaline Agriculture or an endorsement over other similar products.

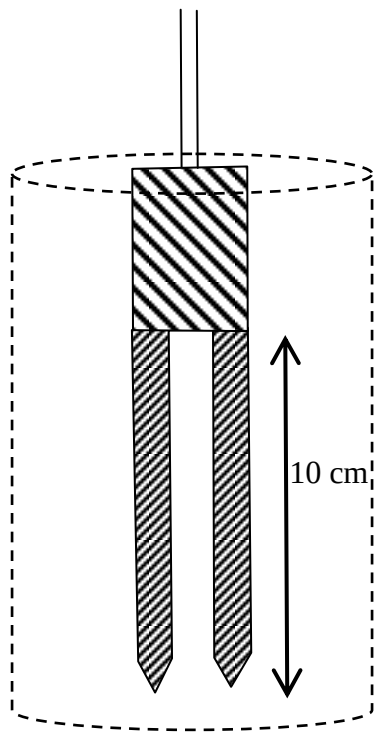

Figure 1. Decagon 10HS sensor and sampling volume

The 10HS sensor, in common with those described in McCann et al, operates at a frequency of 70 MHz to minimize the effect of electrical conductivity. A factory calibration equation is claimed to be suitable for most soils with a saturation extract electrical conductivity up to 10 dS m^{-1}. This calibration uses an equation to estimate dielectric permittivity from sensor readings, from which volumetric water content is estimated using another equation, such as that of Topp (1980). Details can be found in the sensor manual

(http://www.decagon.com/assets/Manuals/10HS-Manual.pdf) .

Another Decagon sensor, the 5TE, was also introduced recently. It measures soil water content, soil temperature and the bulk electrical conductivity of the soil. The 5TE sensor is smaller than the 10HS, resulting in a smaller measurement volume. Decagon also manufactures data loggers, including loggers that can transmit data by radio or cellular telephone technology.

The objective of this study was to conduct initial evaluations of the 10HS and 5TE sensors to determine their potential use in on-farm irrigation scheduling and management under arid conditions.

Methods.

10HS sensors

Three Decagon 10HS sensors were installed vertically at depths centered at 10, 30 and 50 cm in one of a number of research plots at the International Centre for Biosaline Agriculture (ICBA) 25 km south of Dubai, UAE (25° 06' 31'' N, 55° 22' 59'' E). The soil at the site is Carbonatic, Hyperthermic Typic Torripsament having a negligible level of inherent soil salinity (0.2 dS m^{-1}) amended with organic compost from cow manure (41% organic matter, 1.64% moisture, pH=7.7, C/N=16.5, 1.5% N, 1.65% K and 1.22% Na, Al Bayadir®, Jabel Ali, Dubai, UAE) at the rate of 10 tons ha^{-1}, incorporated into the arable layers. A crop of pearl millet [*Pennisetum glaucum* (L) R. Br. Accession IP13015] was sown on 3 May 2011 in the 8 m^2 plot with a density of 20 plants m^{-2}.

A guideline to the amount of irrigation required was determined from daily potential evapotranspiration (ET_0) estimated using the FAO Penman-Monteith method based on daily data from a Campbell Scientific weather station located at ICBA. Irrigation with water of 2 dS m^{-1} electrical conductivity was applied every two days, with the irrigation amount varying between 0.75 and 1.5 ET_0 in order to record the sensor readings over a range of soil water contents. The irrigation amount was adjusted based on the trends of the soil water measurements over a number of days. If soil water content increased over time, the irrigation amount was reduced, and vice versa.

A drip irrigation system designed to provide a relatively high instantaneous application rate was used. The lateral lines were spaced 30 cm apart and equipped with on-line emitters spaced at 50 cm and having a nominal flow rate of 16 l hr^{-1}. This resulted in an average application rate of approximately 1.8 mm min^{-1} which was sufficiently high to cause ponding and redistribution of water over the surface. The purpose was to reduce the near-surface variability in soil water content caused by the "point source" effect inherent in drip systems, particularly in sandy soils. At deeper depths the soil water content becomes more spatially uniform due to lateral movement.

The sensors were read at 10 minute intervals using a Decagon EM50G logger equipped with GSM cellular communication. The data were transmitted four times a day to a Decagon website from which they could be downloaded as desired. The sensors were used with the standard factory calibration relating measured dielectric permittivity to volumetric soil water content. Custom calibrations would probably improve absolute accuracy, but the standard calibration is likely sufficiently accurate to observe relative changes in soil water content.

5TE sensors

In addition to the three 10HS sensors, a 5TE sensor was installed at 30 cm depth in a second plot irrigated with saline water having a nominal electrical conductivity of 8 dS m^{-1}. Irrigation management was the same as the plot with the 10HS sensors. Soil water content, temperature and bulk conductivity were measured at 10 minute intervals, and the data were used to estimate the electrical conductivity of the soil water according to the method of Hilhorst (2000), as referenced in the sensor manual.

Univariate analyses were carried out for the soil water content of each soil layer and the total of the three layers and (P=0.95) correlations between the cited variables were estimated using Bivariate normal ellipse analyses at 0.95. All analyses were performed with SAS Software System Version 6.1 and JMP5 module (SAS Institute, Cary, NC, USA) using the univariate and bivariate procedures.

Results and discussion

Table 1 summarizes crop development in terms of dates, growth degree days and leaf area index. The maximum root depth was 60 cm.

Table 1. Crop development timetable.

Growth stage	Date	Growth degree days (reference to 10°C)	Leaf Area Index
Emergence	8 May	19	NA
3 leaves	10 May	65	NA
6 leaves	15 May	110	NA
End of tillering (12 leaves)	8 June	435	1
Flowering (17 leaves)	20 July	935	6.5

The data from the sensors provided valuable information for irrigation management during the period from the beginning of stem elongation to flowering.

Figure 2 shows volumetric soil water content at the three depths over the course of the experiment, together with daily ET_0 and its 7-day moving average, and illustrates various features useful in irrigation management. Examples include:

1. Soil water content from 8 to 21 June generally declined at all three depths. The decline at 50 cm and the diurnal fluctuations at that depth indicate that the crop was probably extracting water from that depth. Irrigation water infiltrated fairly rapidly down to 30 cm as seen by the increase in soil water content following irrigation, but not down to 50 cm. The conclusion was that irrigation was not keeping up with evapotranspiration.
2. A large irrigation on 21 June attempted to reverse the downward trend, but subsequently the downward trend resumed. Irrigation water was still not infiltrating rapidly down to 50 cm, but soil water content stabilized.
3. A week later, beginning on 29 June, irrigation was increased to try and increase soil water content. This had the desired effect as soil water content at 50 cm steadily increased over the next week but did not show any rapid rises following irrigation that would indicate infiltration.

4. At the end of July, a large irrigation did infiltrate rapidly to 50 cm. If such a pattern was

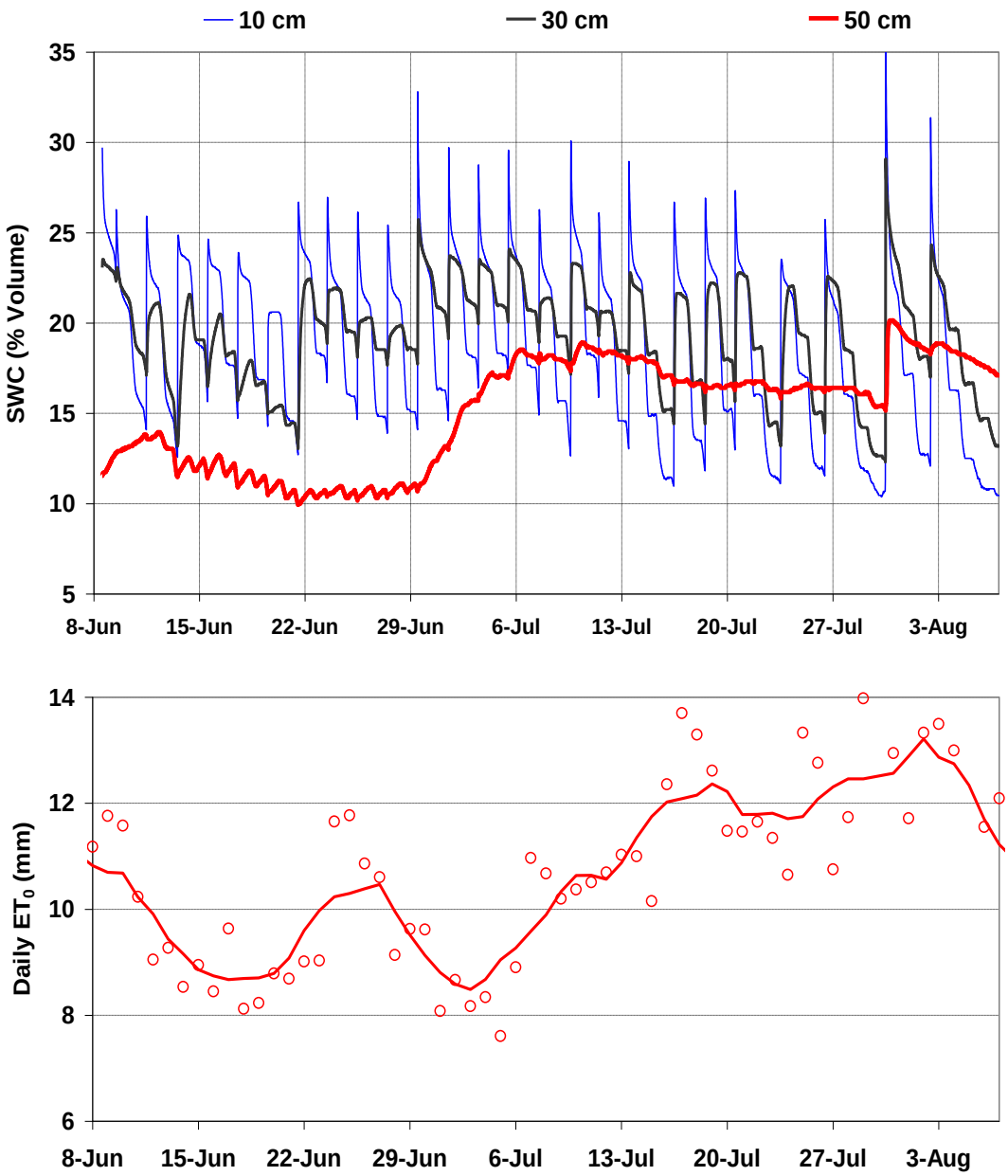

Figure 2. Volumetric soil water content measured at 10 minute intervals at depths of 10, 30 and 50 cm throughout the season (top) and (bottom) daily potential evapotranspiration (ET_0) with the 7 day moving average.

routinely observed, it would indicate excess irrigation and deep percolation. This was observed instead of the fact that the root density was maximum at 60 cm and the plant reached its maximum water consumption (maximum LAI).

The total water content in the measured profile can be obtained by summing up the water contents of the layers represented by each sensor (figure 3). In this case, the sensors were at depths of 10, 30 and 50 cm, and the layers represented could be approximated as 0-20, 20-40, and 40-60 cm. Each sensor would then be in the middle of a 20 cm layer. For example, if the sensor at 30 cm measured a volumetric soil water content of 15%, it would imply a water content of 30 mm in the 200 mm thick 20-40 cm layer. Figure 3 shows the total water content in the top 60 cm over the season, and the same trends of decreasing and increasing water content as shown in figure 2 during various periods can also be seen, with more clarity but less detail.

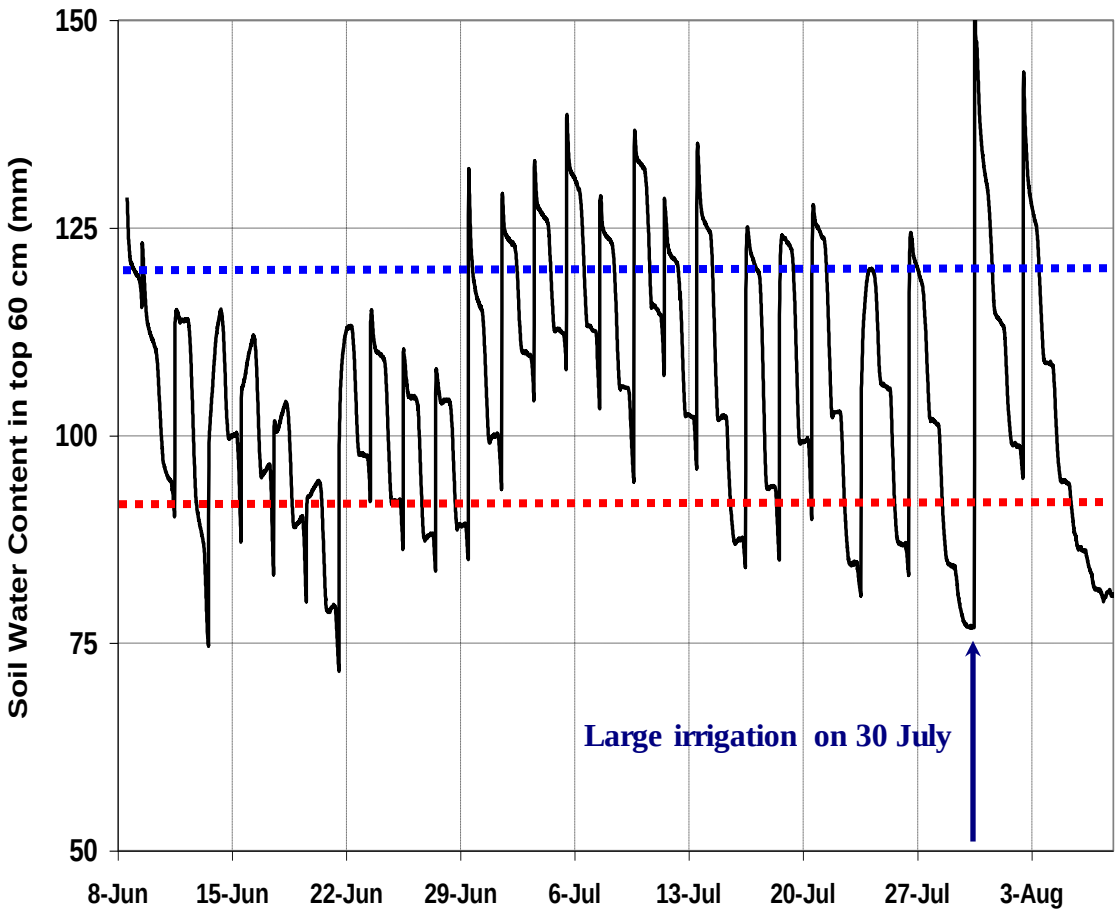

Figure 3. Total soil water content in top 60 cm throughout the experiment, obtained by summing the measurements at three depths. The dashed lines represent example upper and lower limits of desirable soil water content.

Establishing upper and lower limits to the desired range of soil water content would help in managing irrigation so as to maintain water content within this range. For example, if the upper

limit (represented by field capacity) was 20% by volume, then the upper limit of soil water content in the top 60 cm of soil would be 120 mm. Likewise, if the lower limit, (represented by the allowable depletion before stress occurs) was 15%, the water content in the top 60 cm would be 90 mm. There would therefore be 30mm of water between these limits. These example limits are shown in figure 3, and it can be seen that there were periods when water content fell below this example lower limit, and periods when the example upper limit was exceeded.

During the period from the beginning of stem elongation to flowering, soil water content in the top 60 cm ranged between 72 and 163 mm. Three irrigation regimes can be distinguished according to the SWC fluctuation: 8-29 June; 30 June-29 July and 30 July-17 august. Bivariate normal ellipse analysis (P=0.95) for relationships between total SWC in the top 60 cm layer and the three individual layers showed correlation higher than 87% for the upper layer contrary to that to the lower layer (r = 0.22). However the influence of the three irrigation regimes on SWC of the 40-60 cm layer was observed on the 3 stair steps showing deep water percolation.

It can be seen in figure 3 that there was a large irrigation on 30 July following a two day period with no irrigation. Soil water content before this irrigation was likely too low, but was likely too high after the irrigation. If so, the data from the three soil depths before and after the irrigation should show the dynamics of soil water content, particularly infiltration rates and whether the irrigation water infiltrated to 50 cm.

Figure 4 shows the data for 30 July. The irrigation began at 11:20 am, and is quickly reflected in the rapid rise in soil water content at 10 cm, and shortly afterwards by the rise at 30 cm. Field

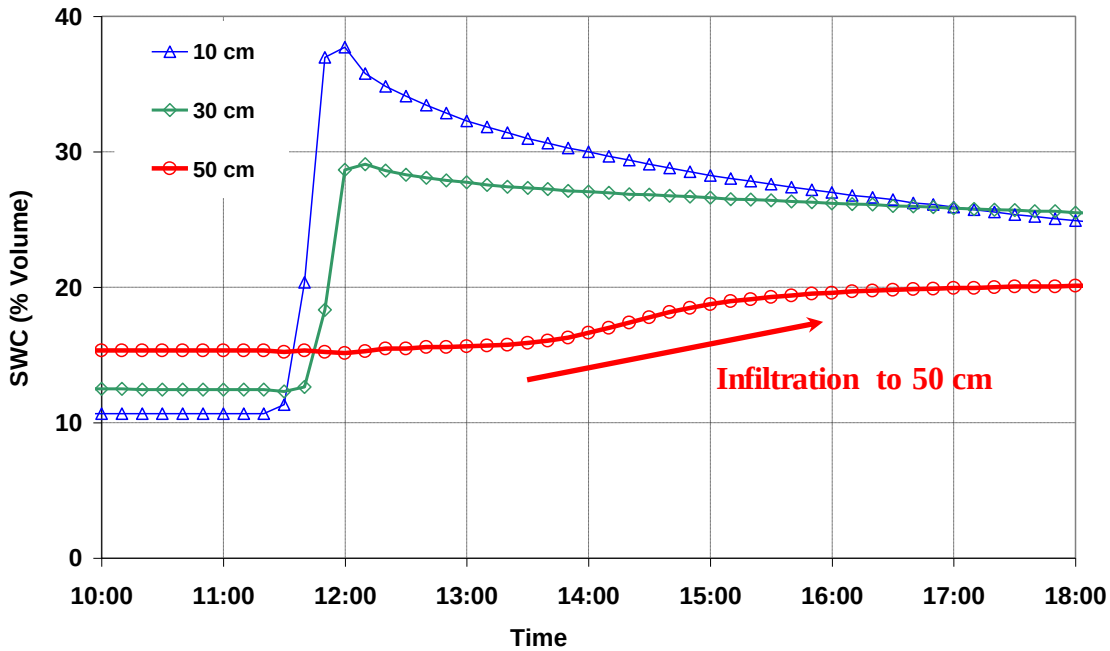

Figure 4. Soil water content measured every 10 minutes at 10, 30 and 50 cm before and following a large irrigation on 30 July.

capacity at 10 cm was exceeded and the resulting downward drainage from that depth rapidly reached 30 cm. Soil water content at 30 cm did not decline as rapidly as at 10 cm, probably because the downward drainage from 30 cm was not much more than the infiltration from above. Water did infiltrate to 50 cm, as can be seen by the more gradual rise in soil water content about two to three hours after irrigation. Over the next two days water content declined at 50 cm (not shown in figure 4), indicating that there was deep percolation and that the irrigation on 30 July applied more water than the soil could hold within the root zone.

The relative net rates of infiltration or drainage from a particular depth can be determined. For example, soil water content at 50 cm. increased from a relatively constant 16% by volume (approximately) to 20% by volume. If the measurements at 50 cm represent the soil layer from 40 cm to 60 cm, then water content in this layer increased from 32 mm to 40 mm. This 8 mm increase occurred over approximately 2 hours. At 30 cm, the increase in soil water content was much more rapid. Soil water content increased from approximately 13% before irrigation to a peak of 29% in 30 minutes. In terms of infiltrated water, the layer from 20 cm to 40 cm that is represented by the sensor at 30 cm increased from 26 mm to 58 mm, an increase of 32 mm in half an hour. While there may be error in this absolute infiltrated depth (due to factors such as

using a standard rather than a specific calibration), the relative changes do show the rapid infiltration that can be expected in sandy soils such as those in this study.

Another aspect of frequent soil water measurements is the ability to estimate crop water uptake. This can be done when the other factors that cause soil water to change are relatively small. An example is shown in figure 5, which shows total soil water down to 60 cm (top) and soil water in the three individual layers from 0-20, 20-40, and 40-60 cm (bottom) as measured during the two day period of 24 and 25 June. On 24 June there was no irrigation, but on the following day there was an irrigation around mid morning.

The shaded areas in figure 5 approximate the nighttime periods from 6pm to 6am. It can be seen that soil water content was relatively constant during the overnight period on the morning of 24 June. However, beginning early in the daytime period, at about 8am, soil water started to decrease and continued to do so before leveling off again at about 7pm, the beginning of the nighttime period. Soil water was then relatively constant during the nighttime period, but at about 7am, at the beginning of the daytime period on 25 June, it started to decrease again. The irrigation that occurred between 11 am and 12 noon caused a sharp rise in soil water content that obscured any further daytime decrease.

At the beginning of the daytime period on 24 June, total soil water content was about 110 mm, and at the end of the daytime period it was about 92 mm. The measured decrease in total soil water was therefore about 18 mm. Reference evapotranspiration (ET_0) on that day was 11.2 mm. The crop coefficient was likely greater than 1.0 (middle of the stem elongation stage, 14 leaves, and LAI>2), and there was also likely to have been advection from the bare soil surroundings. The crop therefore likely used more water than ET_0 but probably not as much as 18mm. Site specific calibration would increase the absolute accuracy of the soil water measurements and therefore the estimates of water used. However, the relative changes are still informative, and

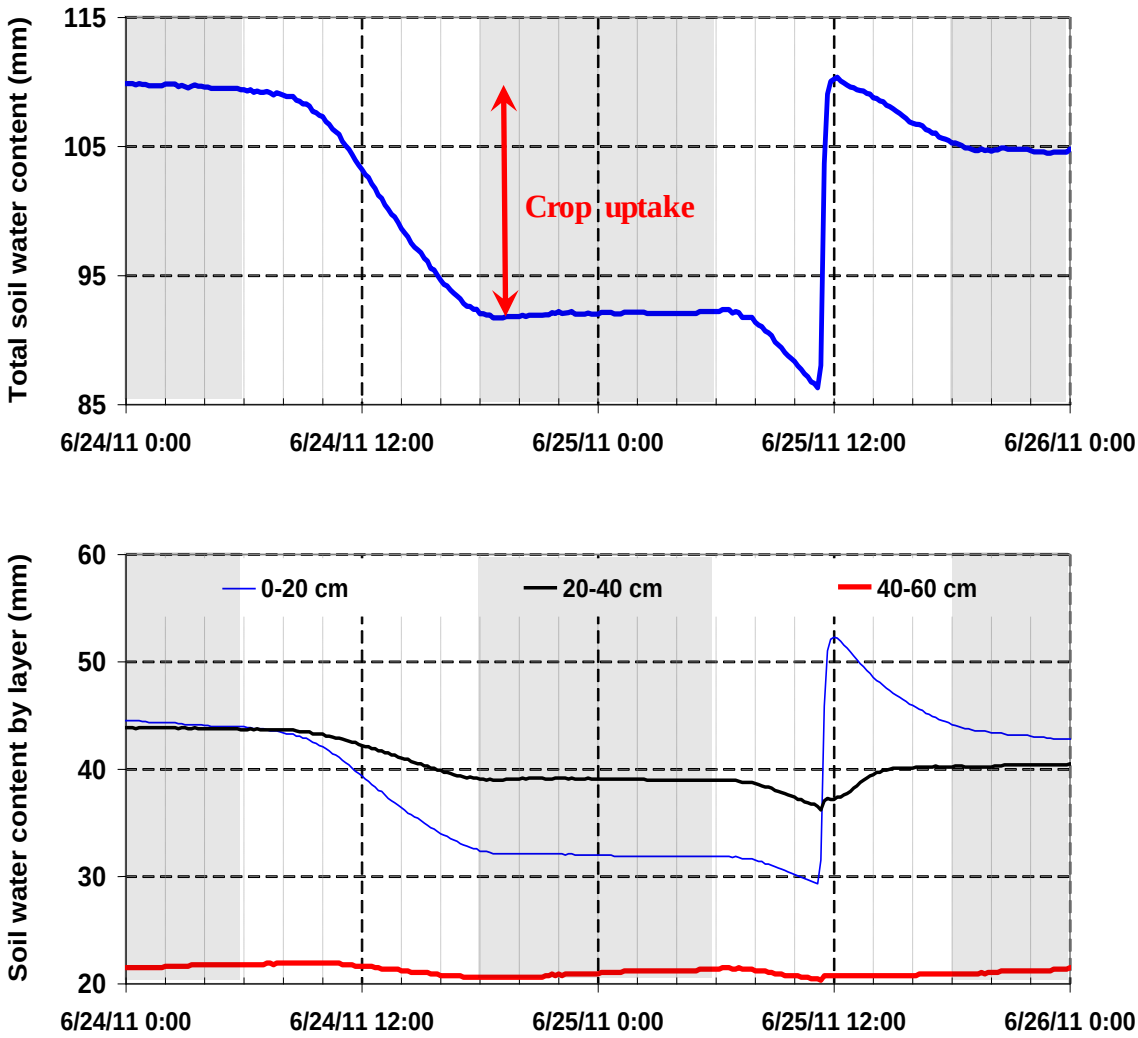

Figure 5. Example of total soil water content in top 60 cm (top) andsoil water content in each of the three layers (0-20, 20-40, and 40-60 cm) (bottom), for a two day period that includes one day without irrigation. Shaded areas indicate approximate nighttime period (6pm to 6am).

clearly show root water uptake. Furthermore, the soil water reductions in the three individual layers (figure 5 bottom) indicate the relative water uptake from each depth. The greatest reduction in soil water was from the top layer, 0-20 cm, followed by the intermediate layer (20-40 cm). Root water extraction was low but still discernible in the bottom layer (40-60 cm). It is therefore likely that most of the roots were in the top layer.

Figure 6 shows example data from the 5TE sensor from 1-13 July at 30 cm depth. Figure 6a shows soil water content and the expected pattern of rapid increase soon after irrigation and subsequently a slower decrease from drainage and crop water uptake.

A soil will have higher electrical conductivity when it is wet than the same soil when it is dry. This will be particularly so when the soil water itself has higher conductivity due to its salinity. The salinity of the soil water is the primary factor of interest, but it is not possible to measure the salinity of soil water from only a measurement of the bulk electrical conductivity of the soil. The soil water content must also be known, especially in a sandy soil where soil water content can change rapidly due to drainage and limited water holding capacity.

The measurements of soil bulk electrical conductivity (figure 6b) follow a pattern similar to that of soil water content (r = 0.74), as would be expected. The values of bulk conductivity in this example are mostly between 0.15 and 0.3 dS m^{-1}, significantly lower than the conductivity of the irrigation water, as would be expected in a porous medium consisting of relatively non conducting solid particles and air filled pore spaces.

Measurements of electrical conductivity, particularly when the primary conducting medium is a liquid such as saline water, are influenced by temperature. Figure 6c shows measured soil temperature (at 30 cm), and clearly shows the diurnal pattern and the longer term trends. Soil temperature was primarily within the relatively narrow range of 31 to 35°C, and so the influence of temperature changes on measured bulk electrical conductivity was probably not important relative to the influence of changes in soil water content.

Figure 6d shows the estimated electrical conductivity of the soil solution (the pore water), using the method of Hilhorst (2000), which is based on measurements of dielectric permittivity, temperature and bulk conductivity. The pattern is generally opposite to that of soil water content and electrical conductivity. This is expected because, as the soil is re-wetted by irrigation (soil water content increases), some of the pore water is replaced. The pore water before replacement is likely more saline than the irrigation water that replaces it because of water (but not salt) uptake by the crop. Thus, when soil water increases the electrical conductivity of the pore water decreases. Conversely, as soil water decreases due to crop uptake, the electrical conductivity of the remaining pore water will increase. This can be seen in the period from 3-8 July. The

irrigation on 3 July reduced estimated pore water conductivity to about 5 dS m^{-1}, after which it steadily increased to near 40 dS m^{-1}. While these estimated pore water conductivity values may not be accurate in an absolute sense (the irrigation water was nominally 10 dS m^{-1}) but the sensor measurements indicate 5-7 dS m^{-1}, they may be sufficiently accurate to show trends and to be used to help manage salinity.

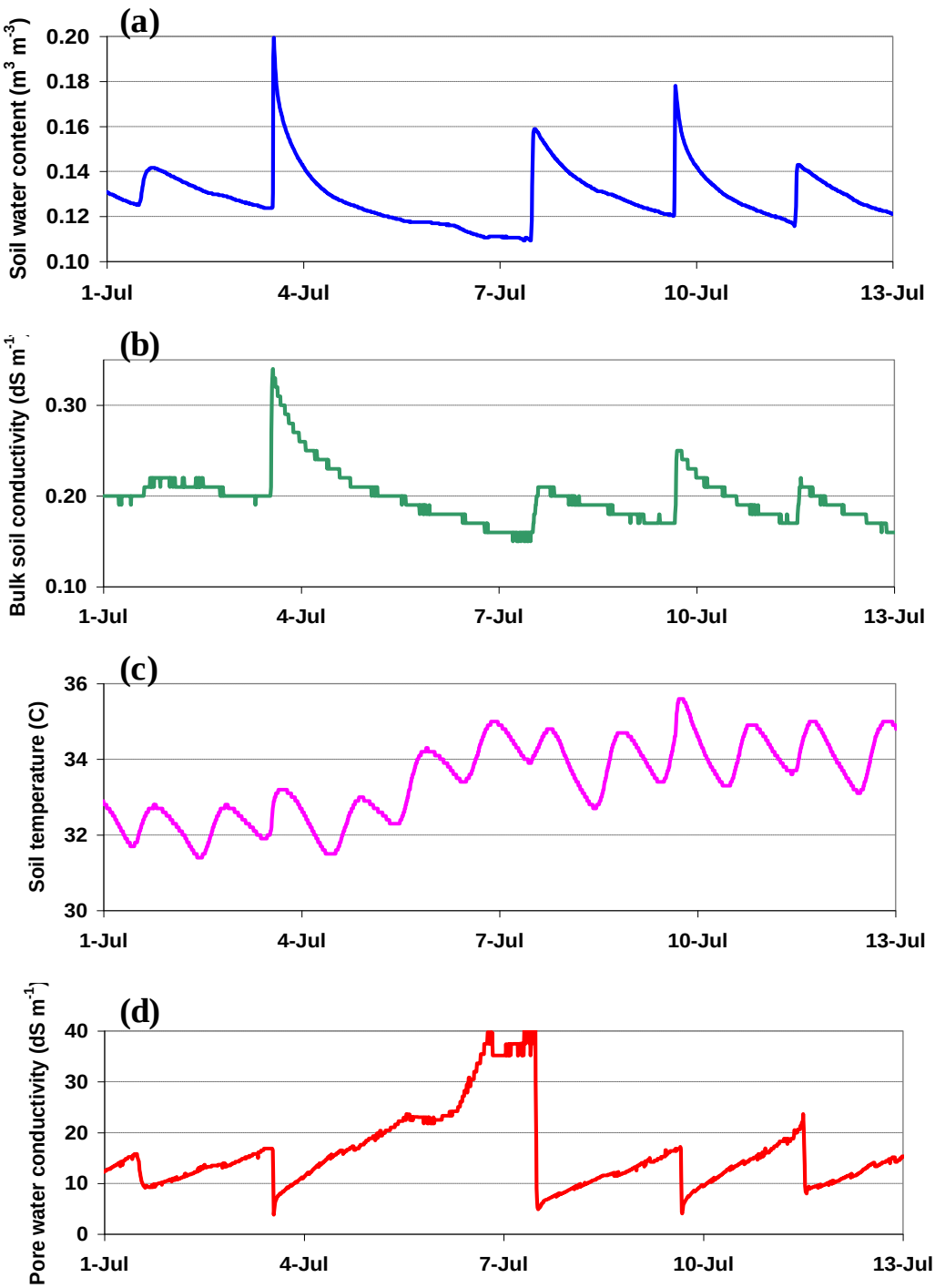

Fig 6. Example of measurements made using 5TE sensor at 30 cm depth. Soil water content (a), bulk soil electrical conductivity (b), and temperature (c), all used to estimate pore water electrical conductivity

Conclusion.

This preliminary field evaluation of the 10HS and 5TE sensors is encouraging in terms of their use in irrigation and salinity management. More detailed laboratory calibration would likely help absolute accuracy, but accuracy using the sensors with the factory default calibrations may be sufficient for many purposes. Compared with alternative sensors that are commercially available, these appear to offer a good balance between accuracy, cost and ease of use. Further evaluation under the arid and saline conditions prevalent in the Gulf would be warranted.

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حساب وتقييم حركة المياه الإفتراضية بين دول الخليج العربية

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الخلاصة

إن علاقة المياه بالغذاء علاقة أساسية، فنقص الموارد المائية يؤدي حتما إلى نقص الغذاء، وهو ما يتوقف عليه وجود العالم ذاته، والغذاء أصبح اليوم من أخطر الأسلحة التي تستخدمها الدول في علاقتها بالدول الأخرى، وبالتحديد الدول المصدرة للغذاء وعلاقتها بالدول المستوردة له. ولا شك في إنه من خلال هذه العلاقة تتحكم الدول المصدرة في الدول المستوردة، وفي سياستها الخارجية والداخلية في كثير من الأحيان. وهذا الوضع يخلق بدوره العديد من الآثار السلبية، منها صعوبة تخطيط الإنتاج الزراعي وصعوبة تخطيط الصادرات والواردات الزراعية، مما يشكلان معا مخاطر الإضطراب في السياسات والقرارات. تقدم المياه الإفتراضية خيارا لمتخذي القرار في تحقيق وإنجاز هذه الأهداف, بحيث تسد النقص في الموارد المائية من خلال إستيراد المحاصيل ذات الإستهلاك العالي للمياه, وتؤمن الغذاء في بعض المحاصيل التي تفتقر لها الدولة وتعتمد على مواسم معينة. كما قد تساهم هذه الأهداف في رفع الوعي بالمياه الإفتراضية كمفهوم جديد في توفير الموارد المائية على المستوى المحلي, بحيث يتم إستخدامها في مجالات أخرى وتشجيع الحركة الاقتصادية للدولة من خلال تفعيل الإنتاج المحلي في المحاصيل التي تستهلك مياه قليلة, وبذلك يتم تقديم الدعم لها كون المياه الإفتراضية تؤمن بعض الحماية للموارد المائية إلى جانب بعض السياسات التي يجب أن تتبناها الدولة لحماية مواردها. وقد هدفت هذه الدراسة إلى حساب حركة المياه الافتراضية بين دول الخليج العربي، واعتمدت خطة الدراسة على المقارنة بين كمية المياه المستهلكة في المحاصيل الزراعية والمنتجات الحيوانية في ست فئات، هي: الخضروات، والفواكه، والحبوب، واللحوم، والدواجن، ومنتجات الحليب والألبان والبيض، من خلال حساب كميات الصادرات والواردات منها، وبالتالي حساب المياه الافتراضية في كل محصول زراعي ومنتج حيواني. أوضحت النتائج أن تجارة المياه الافتراضية أمر واقع في دول مجلس التعاون الخليجي، ولكن لم يتم أخذها في الإعتبار في سياسات إدارة وتخطيط الموارد المائية بعد. كما طرحت الدراسة بعض الأسباب المتعلقة بالتخوف من إتخاذ تجارة المياه الافتراضية كأحد سياسات إدارة المياه، وتضمنت أسباب سياسية واقتصادية تركزت في الخوف من الهيمنة الإقتصادية والسياسية التي يمكن أن تنتج عن التحكم في الغذاء وأن رفع مستوي التعاون والتكامل الإقليمي بين دول مجلس التعاون وبين هذه الدول العربية والإسلامية الأخري, قد يسهم لحد كبير في الحد من هذه المخاوف.

كلمات مدخلية: *الموارد المائية, المياه الإفتراضية, السياسات الزراعية, الأمن الغذائي*

1. المقدمة

تعتبر المياه من أبرز الموارد الأساسية لأي مجتمع إلا أنها كثيرًا ما تكون مستنزفة، بسبب النمو السكاني السريع وزيادة معدل استهلاك الفرد للمياه، مما أدى إلى تفاقم المشكلة محليًا وعالميًا. وتُصنف دول مجلس التعاون الخليجي ضمن الدول الجافة وشبه الجافة بسبب وقوعها في إقليم شبه الجزيرة العربية الصحراوي الذي يعاني من ندرة الموارد المائية، وشح الموارد السطحية وتعتمد معظم هذه الدول بشكل رئيس على موارد المياه الجوفية التي تعاني من الاستنزاف. ويتميز الأقليم بنمط استهلاك عالٍ للمياه وتسارع الطلب عليها. ونظرًا لذلك، تعتبر مسألة الإدارة المثلى للموارد المائية ذات أهمية كبيرة لتجنب الآثار المترتبة على مستقبل التنمية الاقتصادية والاجتماعية.

بشكل عام، ركزت سياسات إدارة المياه في دول مجلس التعاون الخليجي على جانب العرض بشكل رئيس، وذلك لتحقيق السياسات الزراعية الداعية لتحقيق الإكتفاء الذاتي من الغذاء، مما دعا حكومات دول المجلس إلى توجيه اهتماماتها لمشروعات التنمية الزراعية، وتوسيع نطاق القطاع الزراعي لتحقيق ذلك. وقدمت هذه الدول العديد من الحوافز الاقتصادية في شكل إعانات ودعم لزيادة الإنتاج الزراعي، وبالتالي شكل ذلك مزيدًا من الضغط على الموارد المائية المتاحة. وعلى الرغم من ضعف المساهمة الاقتصادية للقطاع الزراعي، فإن غالبية دول مجلس التعاون الخليجي تقدم إعانات سخية ودعمًا للخدمات في هذا القطاع في محاولة لزيادة مستويات الاكتفاء الذاتي في بعض السلع الأساسية وكذلك كوسيلة لإعادة توزيع عائدات النفط. وتواجه دول مجلس التعاون الخليجي حالياً أزمة مياه حادة، مما يستوجب أن تسارع إلى اعتماد سياسات واقعية وتنظيمات مؤسسية، تمكنها من السيطرة على الطلب العالي على المياه، لضمان أن تستخدم المياه بصورة أكثر كفاءة في مختلف القطاعات (البنك الدولي, 2005).

إضافة إلى ذلك، تعاني منطقة الخليج من نمو سكاني متزايد بشكل ملحوظ يصاحبه زيادة في المتطلبات المائية، أدى إلى استنزاف خزانات المياه الجوفية التي يقابلها ضعف عطاء الطبيعة للموارد المائية. ونتيجة لذلك كان لا بد من التطرق إلى مفهوم المياه الافتراضية Virtual Water كأحد الأدوات التي بدأ استخدامها عالمياً، لتعظيم الاستفادة من الموارد المائية والذي قد يساهم في ترشيد استهلاك المياه، وتحديداً على مستوى القطاع الزراعي، الذي يشكل أهمية كبرى لدول مجلس التعاون الخليجي كأحد المقومات لتحقيق الاكتفاء الذاتي.

كان أول من اقترح مصطلح المياه الافتراضية هو Tony Allan في أواخر عام 1994، وتعرف بأنها المياه المستخدمة لإنتاج المحاصيل الغذائية، وذكر في دراسته أن عددًا قليلاً من البلدان التي توصف بأنها تعاني من ندرة المياه، تقوم بإنتاج المنتجات الغذائية بدلاً من استيرادها، مع عدم كفاية الموارد المائية لديها، على الرغم من أن هناك دولاً عالية الاستهلاك للمياه في سبيل الحصول على المنتجات الغذائية. وحيث إن الموارد المائية محدودة في دول المنطقة، فينبغي أن تستخدم بكفاءة من خلال عدم تخصيص الجزء الأكبر من هذه الموارد لإنتاج منتجات عالية الاستخدام للمياه (مثل المحاصيل والورق، وما إلى ذلك)، وإيجاد طرق بديلة لترشيد استخدام المياه مع عدم الإخلال بالهدف الذي تسعى إليه الدول للحصول على نسبة من الاكتفاء الذاتي بحيث تكون المياه متاحة لأغراض اقتصادية أخرى يمكن أن تسهم في المزيد من القيمة المضافة لها على الصعيد الإقليمي وتستهلك كميات أقل من المياه (Allan، 1998).

وتساهم المياه الافتراضية في قيام بعض الدول بدعم الدول الأخرى، في تلبية احتياجاتها المائية وتحديداً تلك التي تعاني من ندرة الموارد المائية، وبذلك يكون بمقدورها تحقيق الأمن المائي عن طريق استيراد المنتجات عالية الاستهلاك للمياه بدلاً من استخدام المياه لإنتاج جميع المنتجات محلياً، كما يمكن ذلك البلدان الغنية بالموارد المائية من الربح الاقتصادي بسبب وفرة الموارد المائية من خلال زراعة المحاصيل عالية الاستهلاك للمياه وإعادة تصديرها وخلق نوع من التجارة الحقيقية ما بين الدول غنية الموارد المائية والدول فقيرة الموارد المائية.

لا يتوافر لدول الخليج العربي أي مصادر سطحية للمياه، وتعتبر المياه الجوفية المصدر الطبيعي الوحيد الذي يمكن استثماره فيها. وتنقسم هذه المياه إلى: عذبة (تستخدم لأغراض الشرب، والاستعمالات المنزلية)، ومياه قليلة الملوحة (تستخدم لأغراض الزراعة، وسقاية الماشية)، والمياه عالية الملوحة، وتستخدم لأغراض خاصة بعد تحليتها. يتمثل الهدف الرئيس لهذا البحث في دراسة وتطبيق وتحليل مفهوم المياه الافتراضية على حركة الصادرات والواردات بين دول مجلس التعاون الخليجي من السلع الغذائية الرئيسية (الحبوب، الخضروات والفواكه، اللحوم ومنتجات الدواجن، والحليب ومنتجات الألبان)، وحساب كمية المياه الافتراضية لدول الخليج العربي من خلال عرض المياه الافتراضية كخيار إستراتيجي لترشيد استهلاك المياه في القطاعات المختلفة.

2. الموارد المائية والقطاع الزراعي بدول الخليج العربية

تعتبر الظروف المناخية في بلدان مجلس التعاون الخليجي من بين أقسى الظروف المناخية في العالم التي تؤثر على توفر الموارد المائية، وخصوصاً الموارد السطحية. وتشمل الموارد المائية في هذه الدول المياه السطحية من خلال مياه السيول في مناطق ساحل البحر الاحمر وخليج عدن، والمياه الجوفية المتوفرة في ترسبات الأودية، والمياه غير المتجددة في الطبقات العميقة. ويتراوح متوسط نصيب الفرد سنوياً من الموارد المائية العذبة المتاحة بين حوالي 60 مترًا مكعباً و 370 مترًا مكعباً، مما يجعل هذه البلدان أقل بلدان العالم تمتعاً بهذه الموارد. ويمكن أن يهبط متوسط نصيب الفرد من المياه العذبة المتاحة في بلدان مجلس التعاون الخليجي بحوالي النصف إلى ما يقرب من 94 مترًا مكعبًا بحلول عام 2030 على أساس توقع زيادة عدد السكان الذي يمكن أن يصل إلى 56 مليون نسمة. والمملكة العربية السعودية هي الوحيدة التي تمتلك كميات كبيرة (حوالي 340 بليون متر مكعب) من المياه الجوفية غير المتجددة في خزانات مياه جوفية عميقة، ولكنها آخذة في النضوب بسرعة. ومن الواضح أن بلدان مجلس التعاون الخليجي تواجه مسؤولية ضخمة تتمثل في ضرورة إدارة مواردها المائية بأقصى درجة ممكنة من الكفاءة (البنك الدولي، 2005).

وحازت قضية الأمن الغذائي والتنمية الزراعية في دول الخليج العربي اهتمامًا كبيرًا منذ بدء الثمانينيات، وتم خلال هذه الفترة تشجيع التوسع في الإنتاج الزراعي وتوفير الأراضي والمياه والدعومات الزراعية لمدخلات عملية الإنتاج الزراعي بهدف تعظيم الإنتاج الزراعي وتحقيق الاكتفاء الذاتي من الغذاء دون النظر بشكل جدي إلى قضية إدارة المياه واستدامتها، وهي التي لها دور فاعل في أية تنمية زراعية. وتمثل قضية شح مصادر المياه في تلبية الاحتياجات الزراعية، ونفاد المخزون الجوفي المائي وتدني نوعية المياه الجوفية من أبرز المشاكل التي تواجه دول المنطقة.

هذا وقد ارتفع الطلب على المياه في القطاع الزراعي والذى قد يرجع إلى سياسات دعم حكومات دول مجلس التعاون الكبير للإنتاج الزراعي، وكذلك للمنتجات الزراعية من خلال ضمان شرائها من المنتجين لتعظيم العوائد المالية. ولقد أدت هذه السياسة إلى تشجيع المزارعين على الإنتاج الزراعي واستهلاك كميات كبيرة من الموارد المائية الطبيعية على الرغم من محدوديتها في دول المجلس. وتدل هذه الزيادة على استمرار السياسات الزراعية الهادفة إلى تحقيق أقصى قدر ممكن من الإنتاج الزراعي في دول المجلس واستمرار الإعانات الزراعية لتحقيق ذلك دون النظر إلي محدودية الموارد المائية. وبحلول عام 2000 بلغ استهلاك القطاع الزراعي أكثر من 90 % من مجموع المياه الجوفية المستخرجة، في حين كانت مساهمته في إجمالي الناتج المحلي لدول المجلس تتراوح ما بين أقل من 1% لمملكة البحرين ودولة قطر ودولة الكويت، و 6% للمملكة العربية السعودية (زباري, 2008).

3. السياسات الزراعية لدول الخليج العربية

وضعت دول مجلس التعاون سياسة زراعية مشتركة في عام 1996، وتهدف هذه السياسة إلى تحقيق التكامل الزراعي بين دول المجلس وفق إستراتيجية موحدة تعتمد على الاستخدام الأمثل للموارد المائية المتاحة وتوفير الأمن الغذائي من مصادر وطنية. وقد حاولت دول مجلس الخليج العربية تحقيق أكبر درجة من الاكتفاء الذاتي، وبالتالي اعتمدت سياسة التوسع في المساحات المروية من خلال حوافز اقتصادية. ويبين جدول رقم (1) المساحات المحصولية في دول الخليج العربية في الفترة من 2001- 2003. ويلاحظ من الجدول تزايد نسبة الأراضي المستغلة من الأراضي القابلة للزراعة في دولة الكويت، ففي حين كانت 47% في عام 2001 وصلت إلى 55.6 % في عام 2003، بينما في المملكة العربية السعودية زادت هذه النسبة بمقدار 0.3 % خلال الفترة من 2001 – 2003. و في مملكة البحرين تناقصت هذه المساحة, حيث كانت 36.46% عام 2001 ثم قلت إلي 34% عام 2003.

ويبين جدول رقم (2) الإنتاج الزراعي والحيواني لدول الخليج العربي ما بين 2001- 2003 ، حيث تزايدت نسبة إنتاج الحبوب في الإمارات العربية المتحدة حتى وصلت إلى 300 طن في العام 2003، بينما تناقص إنتاج الخضار وتزايد انتاج اللحوم الحمراء، وفي سلطنة عمان تناقص إنتاج الحبوب حتى وصل 21.9 ألف طن بعدما كان 25.94 ألف طن في العام 2001، وكذلك تزايد إنتاج اللحوم والخضروات على السواء في مملكة البحرين منذ العام 2001 وحتى العام 2003 ووصل 9.5 الف طن للخضروات و9.6 ألف طن للحوم.

جدول (1): المساحة الكلية (ألف كم2) ومساحة الأراضي المزروعة (ألف دونم) في دول الخليج العربية في الفترة من 2001- 2003

الدولة	البيان	2001	2002	2003
الإمارات العربية المتحدة	المساحة الكلية	83.60	83.60	83.60
	مساحة الأراضي القابلة للزراعة	2690.60	2709.40	2607.30
	مساحة الأراضي المستغلة	2622.30	2655.30	2549.00
	نسبة الأراضي المستغلة من الأراضي القابلة للزراعة	97.50%	98.00%	97.80%
البحرين	المساحة الكلية	0.72	0.72	0.72
	مساحة الأراضي القابلة للزراعة	110.00	110.00	64.00
	مساحة الأراضي المستغلة	40.00	38.00	38.00

	نسبة الأراضي المستغلة من الأراضي القابلة للزراعة	36.40%	34.50%	34.00%
المملكة العربية السعودية	المساحة الكلية	2250.00	2250.00	2250.00
	مساحة الأراضي القابلة للزراعة	488990	488990	488990
	مساحة الأراضي المستغلة	41900	42040	43570
	نسبة الأراضي المستغلة من الأراضي القابلة للزراعة	8.60%	8.60%	8.90%
سلطنة عمان	المساحة الكلية	309.5	309.5	309.5
	مساحة الأراضي القابلة للزراعة	غير متوفر	غير متوفر	غير متوفر
	مساحة الأراضي المستغلة	176	175	174
	نسبة الأراضي المستغلة من الأراضي القابلة للزراعة	غير متوفر	غير متوفر	غير متوفر
دولة الكويت	المساحة الكلية	17.8	17.8	17.8
	مساحة الأراضي القابلة للزراعة	198.5	198.5	198.5
	مساحة الأراضي المستغلة	93.3	106.3	110.3
	نسبة الأراضي المستغلة من الأراضي القابلة للزراعة	47.00%	53.60%	55.60%

المصدر: الأمانة العامة لمجلس التعاون لدول الخليج العربية - العدد الرابع عشر، 2005

جدول (2): الإنتاج الزراعي والحيواني (ألف طن) لدول الخليج العربية مابين 2001- 2003

	السنة	الحبوب	الخضروات	الفواكة والتمور	اللحوم		الألبان
					اللحوم الحمراء	الدواجن	
الإمارات العربية المتحدة	2001	0.2	579	794.7	26.3	28.1	179
	2002	0.1	467	795.2	27.6	28.5	201.8
	2003	0.3	289.8	783.6	29.1	41	215
مملكة البحرين	2001	---	9.7	11	1	42.9	6.2
	2002	---	7.92	11	0	5	6.2
	2003	---	9.5	14	9.6	5.5	1.8
المملكة العربية السعودية	2001	2594	2106	1210	160	459140702*	737555785^
	2002	2856	2137	1240	162	411731440*	825878026^
	2003	2952	2214	1331	---	412355234*	857735356^
سلطنة عمان	2001	25.8	172.2	313.4	9.2	14.7	42

	2002	24.8	162	329.2	9.4	11.9	43
	2003	21.9	163.1	---	9.7	14.5	44
دولة الكويت	2001	13.71	160.78	15.1	3.6	33	33.2
	2002	21.5	173.42	12.9	3.8	37.4	36.7
	2003	27.8	200.34	17.5	4.1	37.4	42.9

المصدر: الأمانة العامة لمجلس التعاون لدول الخليج العربية - العدد الرابع عشر، 2005
*بالعدد
^ باللتر

4. حساب المياه الافتراضية للمحاصيل الزراعية

استخدمت المعادلة التالية (Hamouda and El-Sadek, 2007) في حساب المياه الافتراضية للمحاصيل الزراعية من خلال معرفة الواردات بالطن لسنة معينة مضروبًا بقيمة المياه المستخدمة في موقع الاستهلاك. وتم تطبيق المعادلة باستخدام برنامج Excel والتعويض في البيانات الواردة من دول المجلس وهي الصادرات والواردات بين دول الخليج العربي.

$$\text{Water savings } (m^3) = \text{Import (ton)} * VWV_{consmp.\,site}$$

حيث:

$$VWV_{consmp.\,site} = \text{Virtual water value per crop } (m^3/\text{ton})$$

حيث يعبر $VWV_{consmp.\,site}$ عن قيمة المياه الافتراضية للمحصول إذا أُنتج في موقع الاستهلاك، وتم حسابها لكل محصول على حدة في بلد المنشأ بالمليون متر مكعب لكل طن. ثم تم تصميم أشكال توضح حجم حركة المياه الافتراضية الواردة والصادرة لكل دولة خليجية.

تم الحصول على المعطيات من موقع منظمة الأغذية والزراعة (الفاو) على شبكة الانترنت (www.fao.org)، وكانت كما يوضحها الجدول أرقام (3), (4), (5) ليتم استخدامها في حساب المياه الافتراضية بالنسبة للمحاصيل الزراعية.

جدول (3): محتوى المياه الافتراضية للحبوب بالمتر المكعب/ طن

الدولة	القمح	الشعير	الذرة	حبوب
مملكة البحرين	1989	1625	708	3158
دولة الكويت	2991	1625	708	3158
المملكة العربية السعودية	1989	1625	936	3158
الإمارات العربية المتحدة	1906	1625	936	3158
سلطنة عمان	2105	1625	936	3158

جدول (4): محتوى المياه الافتراضية للفواكه بالمتر المكعب/ طن

الدولة	اليوسفي	عنب	بطيخ أحمر	مانجو	بطيخ أصفر
مملكة البحرين	1063	1078	459	2769	458
دولة الكويت	1063	1078	398	2769	458
المملكة العربية السعودية	1063	1078	464	2769	494
الإمارت العربية المتحدة	888	1235	302	2769	427
سلطنة عمان	888	1235	301	2769	427

الدولة	موز	برتقال	ليمون وليمون جاف	تمر	فواكه طازجة
مملكة البحرين	3041	2373	1666	3996	2777
دولة الكويت	3041	2373	1846	3996	2086
المملكة العربية السعودية	3041	2373	1846	4173	1807
الإمارت العربية المتحدة	2742	2373	1638	3991	1550
سلطنة عمان	1752	2373	1031	2375	2248

جدول (5): محتوى المياه الافتراضية للخضروات بالمتر المكعب/ طن

الدولة	بصل أخضر	كرنب	خس	بطاطس	بصل جاف	ثوم	فاصوليا خضراء	باذنجان
مملكة البحرين	158	251	162	376	327	688	234	921
دولة الكويت	158	249	158	351	302	688	234	923
المملكة العربية السعودية	158	251	162	377	360	688	234	912
الإمارات العربية المتحدة	158	193	142	242	308	688	165	765
سلطنة عمان	158	193	142	205	308	688	165	765
الدولة	**باميا**	**ذرة**	**خضروات طازجة**	**سبانخ**	**طماطم**	**زهرة**	**القرع**	**خيار**
مملكة البحرين	522	1134	367	64	305	287	355	285
دولة الكويت	522	1134	376	64	307	272	310	206
المملكة العربية السعودية	522	1134	259	64	384	287	353	201
الإمارات العربية المتحدة	522	1134	333	27	177	192	183	143
سلطنة عمان	522	1134	339	27	166	192	183	143

5. النتائج والمناقشة

1.5 حركة المياه الافتراضية بين دول مجلس التعاون الخليجي

تم استخلاص البيانات بعد تعديلها وتصنيفها ووضعها في جداول لكل دولة، لكل فئة من الفئات الست في الدراسة لكل السنوات المتوافرة واستخدام برنامج الأكسل لحساب كميات المياه الافتراضية ولاستنتاج النتائج والتعويض بالمعطيات، ومن ثم عمل مقارنة بين حركة المياه الافتراضية المصدرة والمستوردة بين دول الخليج العربي. وكذلك مناقشة وتحليل الصادرات والواردات من المحاصيل الزراعية والمنتجات الحيوانية من حيث كمية المياه الافتراضية التي تحتويها.

2.5 المملكة العربية السعودية

تُعتبر المملكة العربية السعودية من البلدان الرائدة في تصدير السلع واستيرادها، التي تُعتبرُ عنصراً أساسياً في هيكلها الاقتصادي الوطني، كما أنَّ للمملكة مصالح تجارية واقتصادية واسعة النطاق وسِجِلا حافلا في ميدان التعاون الاقتصادي مع دول المنطقة.

يوضح الجدول رقم (6) واردات المملكة العربية السعودية في الفئات الست محل الدراسة، حيث تعتبر المملكة العربية السعودية المورد الأكبر لدول المنطقة عموما، وتحديدا في فئتي اللحوم والخضروات، حيث بلغت واردات المملكة العربية السعودية من اللحوم في عام 2006 ما يقارب 6.487 مليون طن، أي ما يعادل 87.6 م م^3 مياها إفتراضية واردة. وكانت الأقل عام 2000 حيث بلغت 8.9 م م^3 مياها إفتراضية واردة، أي ما يعادل 659 ألف طن. بينما كانت الخضروات الأقل إستيرادا في عام 2004 حيث بلغت 8.3 م م^3 ، والأعلى إستيرادا عام 2002 حيث وصلت 13.8م م^3 مياه إفتراضية، بينما الفواكة كانت هي الأقل إستيرادا، حيث بلغت 1.79 م م^3 مياه إفتراضية في عام 2002. أما أعلاها فقد بلغت 2.78 م م^3 عام 2007. أما فئة منتجات الحليب والألبان والبيض فهي الأقل إستيرادا، فقد بلغ أعلى إستيرادا لها في عام 2007، حيث بلغت 8.3 م م^3 والأقل في نفس الفئة عام 2004 حيث وصلت إلى ما يقارب 0.22 م م^3.

جدول (6): المياه الإفتراضية الواردة للمملكة العربية السعودية في الفئات الست محل الدراسة بالمليون متر مكعب للأعوام 2000-2007

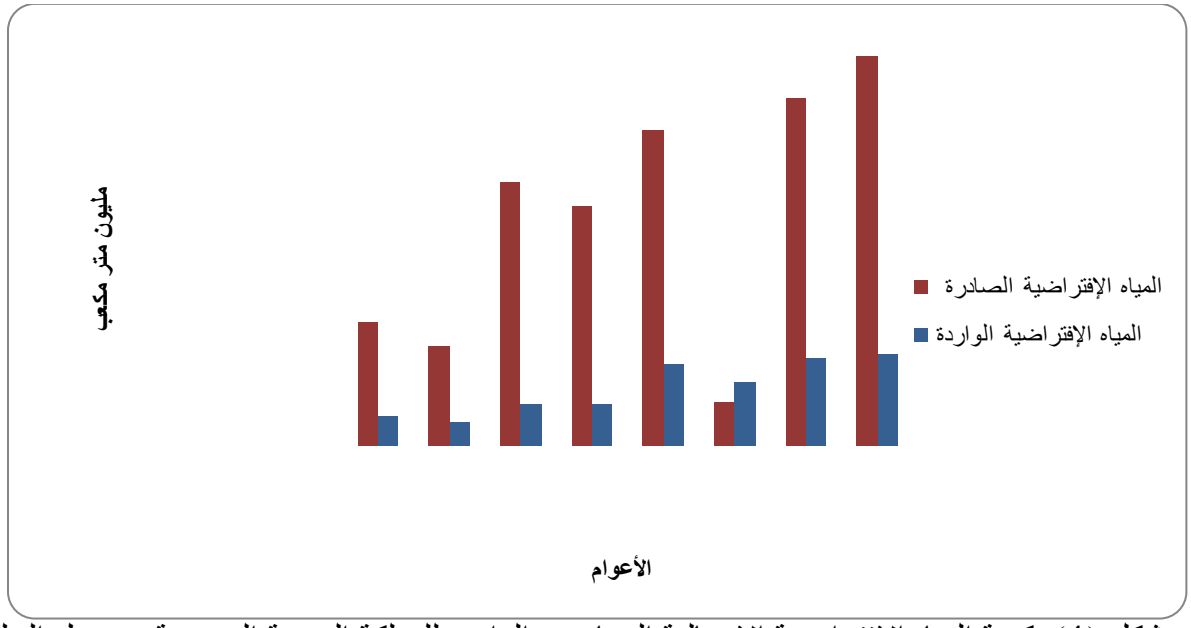
الفئة	المياه الافتراضية الواردة م م^3							
	2000	2001	2002	2003	2004	2005	2006	2007
الخضروات	9.8	9.7	13.8	11.2	8.3	9.1	9	10.1
الفواكة	2.2	2.1	1.79	2.24	2.19	2.29	0	2.78
الحبوب	1.1	1.7	1.2	3.6	3.3	2.2	3.8	3.5
اللحوم	8.9	11.6	27.9	29.1	81.3	55.2	87.6	85.2
الدواجن	12.6	3.2	5.3	3.49	3.73	4.57	2.2	2.4
الحليب والألبان والبيض	1.1	0.73	0.39	0.87	0.22	3.2	3.1	8.3
المجموع	**35.7**	**29.03**	**50.38**	**50.5**	**99.04**	**76.56**	**105.7**	**112.28**

وبشكل عام فهناك زيادة عامة في حجم واردات المملكة العربية السعودية خلال الفترة من 2000 إلى 2007, حيث إرتفعت المياه الافتراضية الواردة من 35.7 م م^3 إلى 112.28 م م^3 بنسبة زيادة 214.5%, وخصوصا في فئات اللحوم (857%), الحليب والبيض والألبان (654%), الحبوب (218%), بينما قلت في فئة الدواجن بنسبة 81%.

يوضح الجدول رقم (7) صادرات المملكة العربية السعودية في الفئات الست محل الدراسة، حيث كانت الخضروات الأعلى تصديرا فقد بلغت عام 2007 مايقارب 420.4 م م^3. والأقل عام 2001 حيث بلغت 93.4 م م^3، بينما الأقل في فئة المحاصيل الزراعية كانت الحبوب حيث بلغت أقل كمية عام 2002 حيث وصلت إلى 0.12 م م^3، والأعلى تصديرا لها عام 2007 حيث بلغت المياه الإفتراضية الصادرة ما يعادل 24.4 م م^3 . بينما في فئة المنتجات الحيوانية, فقد كانت الأعلى تصديرا الدواجن حيث بلغت أعلى قيمة لها عام 2005 وبلغت المياه الإفتراضية الصادرة 21.6 م م^3. بينما الأقل كانت عام 2002 فقد بلغت 4.1 م م^3 ، بينما كانت منتجات الألبان والحليب والبيض الأقل تصديرا، والتي قاربت أعلى قيمة لها عام 2005, حيث وصلت إلي 0.71 م م^3. ويمثل الشكل رقم (1) كمية المياه الإفتراضية الإجمالية الصادرة والواردة للمملكة العربية السعودية من دول الخليج العربية في الفئات الست للأعوام 2000-2007. ويلاحظ هنا الزيادة في حجم صادرات المملكة من المياه الافتراضية بنسبة 216%, وخصوصا في فئات الحبوب والخضروات والحليب والبيض والألبان, بينما قلت المياه الافتراضية الصادرة من المملكة في فئات الفواكه والدواجن.

جدول رقم (7): المياه الإفتراضية الصادرة للمملكة العربية السعودية في الفئات الست محل الدراسة بالمليون متر مكعب 2000-2007

الفئة	المياه الافتراضية الصادرة م م^3							
	2000	2001	2002	2003	2004	2005	2006	2007
الخضروات	105.8	93.4	295.8	274.1	352.5	0	379.1	420.4
الفواكة	28.7	6.7	22.1	10.3	16.1	16.9	12.3	16.7
الحبوب	0.13	0	0.12	3.8	1.7	12.9	16	24.4
اللحوم	0.22	0.21	0.21	0.2	0.38	0.45	0.25	0.26
الدواجن	15.7	19.8	4.1	4.2	13.9	21.6	17.2	13.3
الحليب والبيض والألبان	0.11	0.19	0.32	0.65	0.11	0.71	0.65	0.64
المجموع	**150.66**	**120.3**	**322.65**	**293.25**	**384.69**	**52.56**	**425.5**	**475.7**



شكل (1): كمية المياه الإفتراضية الإجمالية الصادرة والواردة للمملكة العربية السعودية من دول الخليج العربية في الفئات الست للأعوام 2000-2007

3.5 سلطنة عمان

يُشكِّل قطاع الزراعة في سلطنة عمان ركيزةً من ركائز التنمية الاقتصادية لما يتمتّعُ به من مواردَ مائية متجددةٍ ومساهمة عالية نسبيا في الناتج المحلي، وتوفير فرص العمل ولقمة العيش للكثير من العمانيين الذين تُمثل لهم الزراعة الحياة الاجتماعية والاقتصادية على أرض السلطنة. ونظراً لعدم تأثُّر الزراعة أو اختفائها باكتشاف النفط، أو التطوّر الاقتصادي والاجتماعي, ولكنها تطورت مع بعضها لتساهم بِنصيبٍ متزايد في توفير الغِذاء للجميع، فقد تبنّت وزارة الزراعة العديد من الخطط والسياسات والبرامج الزراعية التي تهدف إلى التنمية المستدامة والحفاظ على الموارد الطبيعية، حيث حدّدت وزارة الزراعة الأهداف الرئيسة والسياسات لكلِّ قِطاع بهدف تحقيق مزيدٍ من التنمية المستدامة في قطاعي الزراعة بشقَّيهِ النباتي والحيواني، وسعياً إلى تطويرِ وتحديث أنظمة الإنتاج لتحقيق أعلى جودة للمنتجات الزراعية وزيادة العائد الاقتصادي والبيئي والاجتماعي.

يوضح الجدول رقم (8) أن الأعلى في واردات المحاصيل الزراعية كانت فئة الفواكة، حيث بلغت عام 2007 ما يقارب 14.9 م م^3. والأقل في نفس الفئة كانت في عام 2004 حيث بلغت 4.1 م م^3 ، بينما الأقل في واردات سلطنة عمان في المحاصيل الزراعية كانت الخضروات، حيث بلغت أعلى قيمة لها عام 2002 وبلغت ما يعادل 8.33 م م^3. والأقل كانت عام 2007 حيث بلغت المياه الإفتراضية الواردة 0.91 م م^3. بينما في المنتجات الحيوانية كانت الأعلى إستيرادا فئة اللحوم، حيث بلغت أعلى مياه إفتراضية واردة عام 2002 ما يقارب 17.4. بينما الأقل كانت في عام 2007 حيث بلغت المياه الإفتراضية الواردة 6.7 م م^3، أما الأقل في المنتجات الحيوانية إستيرادا كانت منتجات الحليب والألبان والبيض، حيث بلغت أعلى قيمة لها عام 2007 حيث وصلت إلى 0.20 م م^3 مياه إفتراضية واردة. أما الأقل استيرادا فقد كانت خلال عامي 2003 و2004 وبلغت 80 ألف م^3 . ويلاحظ خلال فترة الدراسة ارتفاع المياه الافتراضية الواردة إلى قيم

قصوى في عام 2002 و2006 ثم انخفاضها, ويرجع ذلك إلى ارتفاع استيراد الفواكه واللحوم بشكل أساسى في هذين العامين.

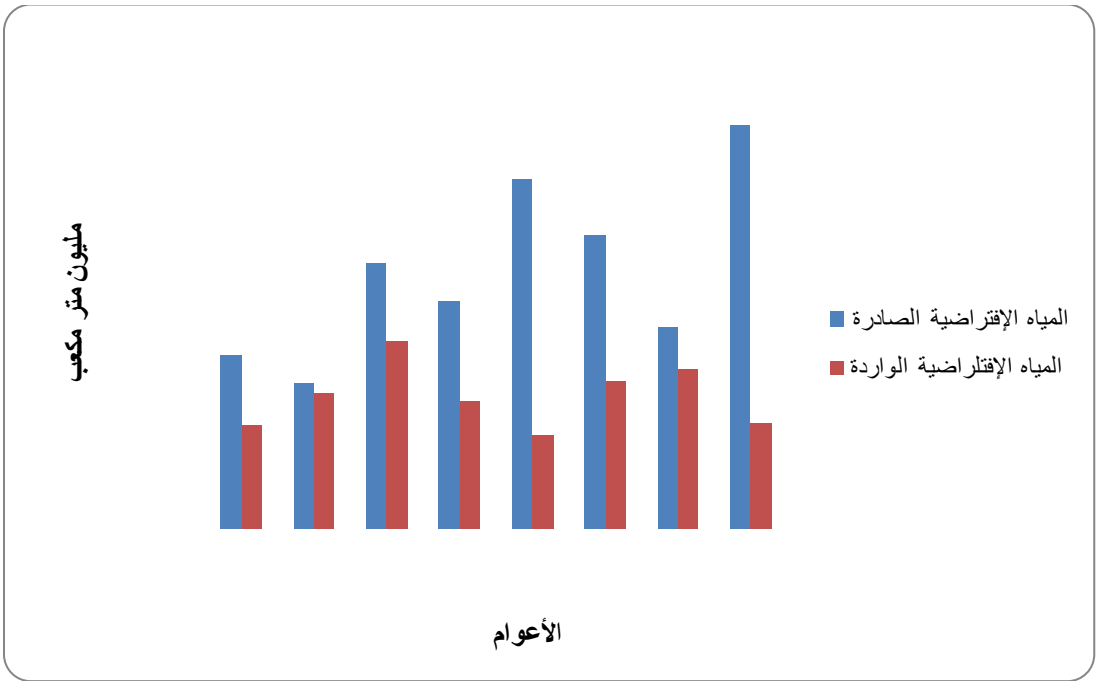
جدول (8): المياه الإفتراضية الواردة لسلطنة عمان في الفئات الست محل الدراسة بالمليون متر مكعب للأعوام 2000-2007

الفئة	المياه الافتراضية الواردة م م^3							
	2000	2001	2002	2003	2004	2005	2006	2007
الخضروات	1.01	1.49	8.33	1.63	1.39	1.72	1.54	0.91
الفواكة	4.9	5.3	9.4	13.3	4.1	14.7	14.7	14.9
الحبوب	11.8	13.5	9.9	0.74	6.3	10.6	11.3	1.6
اللحوم	7.03	11.41	17.4	14.4	10.2	8.2	10.4	6.7
الدواجن	0.13	0.85	0.57	0.58	0.39	0.33	0.73	1.5
الحليب والألبان والبيض	0.15	0.18	0.11	0.08	0.08	0.12	0.14	0.2
المجموع	**25.02**	**32.73**	**45.71**	**30.73**	**22.46**	**35.67**	**38.81**	**25.81**

يوضح الجدول رقم (9) صادرات سلطنة عمان في الفئات الست محل الدراسة, بينما يبين الشكل رقم (2) كمية المياه الإفتراضية الإجمالية الصادرة والواردة من سلطنة عمان للفئات الست للأعوام 2000-2007، حيث كانت فئة الخضروات هي الأعلى تصديرا في المحاصيل الزراعية، حيث بلغت أعلى قيمة لها عام 2004 وبلغت المياه الإفتراضية الصادرة ما يعادل 78.2 م م^3. والأقل تصديرا كانت في عام 2001، حيث بلغت 8.14 م م^3. وكانت الحبوب الأقل تصديرا في المنتجات الزراعية، حيث بلغت أقل قيمة لها عام 2007 حيث بلغت 0.09 م م^3. بينما الأعلى قيمة لها كانت 0.15 م م^3 عام 2002، بينما في المنتجات الحيوانية فقد كانت الأعلى هي فئة اللحوم، وبلغت أعلى مياه افتراضية صادرة لهذه الفئة عام 2007، والتي بلغت 29.6 م م^3 ، والأقل كانت عام 2003 وبلغت 5.4 م م^3. بينما الأقل كانت فئة الدواجن، حيث بلغت أقل قيمة لها عام 2005 ووصلت إلي 77 ألف م^3، بينما الأعلى كانت عام 2000 حيث وصلت 270 ألف م^3 . ويلاحظ من الشكل رقم (2) زيادة كمية المياه الإفتراضية الإجمالية الصادرة عن الكمية الواردة مما يعكس وفرة نسبية في الموارد المائية في سلطنة عمان.

جدول (9): المياه الإفتراضية الصادرة لسلطنة عمان في الفئات الست محل الدراسة بالمليون متر مكعب للأعوام 2000-2007

الفئة	المياه الافتراضية الصادرة م م^3							
	2000	2001	2002	2003	2004	2005	2006	2007
الخضروات	17.1	8.14	34.5	46.7	78.2	53.7	25.7	64.5
الفواكة	3.44	6	6	3.9	4.76	3.8	4.75	3.5
الحبوب	0.1	0.14	0.15	0.1	0.1	0.1	0.1	0.09
اللحوم	21.1	18.6	22.7	5.4	5.9	15.6	22.4	29.6
الدواجن	0.27	0	0	0.18	0	0.077	0.15	0
الحليب والألبان والبيض	3.3	2.6	0.98	0.088	0.036	0.16	0	0.36
المجموع	45.31	35.48	64.33	56.368	88.996	73.437	53.1	98.05



شكل (2): كمية المياه الإفتراضية الإجمالية الصادرة والواردة في سلطنة عمان للفئات الست للأعوام 2000-2007

4.5 الإمارات العربية المتحدة

إنَّ ما حقّقه القطاع الزراعي في دولة الإمارات العربية يُعدُّ طفرة كبيرة في الإنتاج الزراعي في سعيها إلى تحقيق نوع من الاكتفاء الذاتي في الخضروات والفواكه والأعلاف الحيوانية وغير ذلك, متبعةً وسائل التقنية الحديثة والطرق المتقدمة للإنتاج باستخدام البذور المنتقاة، وتحسين وسائل الريِّ، ومقاومة الأمراض

والحشرات، والمحافظة على الموارد الطبيعية من مياه وتربة، وإقامة محطات البحوث الزراعية والإرشاد الزراعي.

يوضح الجدول رقم (10) واردات الإمارات العربية المتحدة في الفئات الست محل الدراسة للعامين 2006 و2007 فقط ، وقد كانت فئة الفواكة هي الأعلى حيث بلغت عام 2007 ما يعادل 16.9 م م^3، أما الأقل فقد كانت عام 2006، حيث وصلت المياه الإفتراضية الواردة 11.7 م م^3. وكانت فئة الحبوب هي الأقل في المحاصيل الزراعية, حيث بلغت أعلى قيمة لها عام 2006 وكانت 0.44 م م^3 مياها إفتراضية واردة، والأقل كانت 0.27 م م^3 عام 2006. أما فيما يتعلق بالمنتجات الحيوانية، كانت منتجات الحليب والألبان والبيض الأعلى في فئتها حيث بلغت عام 2006 أعلى قيمة لها وهي 41 م م^3 مياها إفتراضية واردة, أما الأقل فقد كانت عام 2007 وبلغت 39 م م^3 . بينما في فئة اللحوم فوصلت المياه الافتراضية الواردة أقل قيمة لها عام 2007 وكانت 2.7 م م^3, بينما الأعلى كانت 6.6 م م^3 عام 2006.

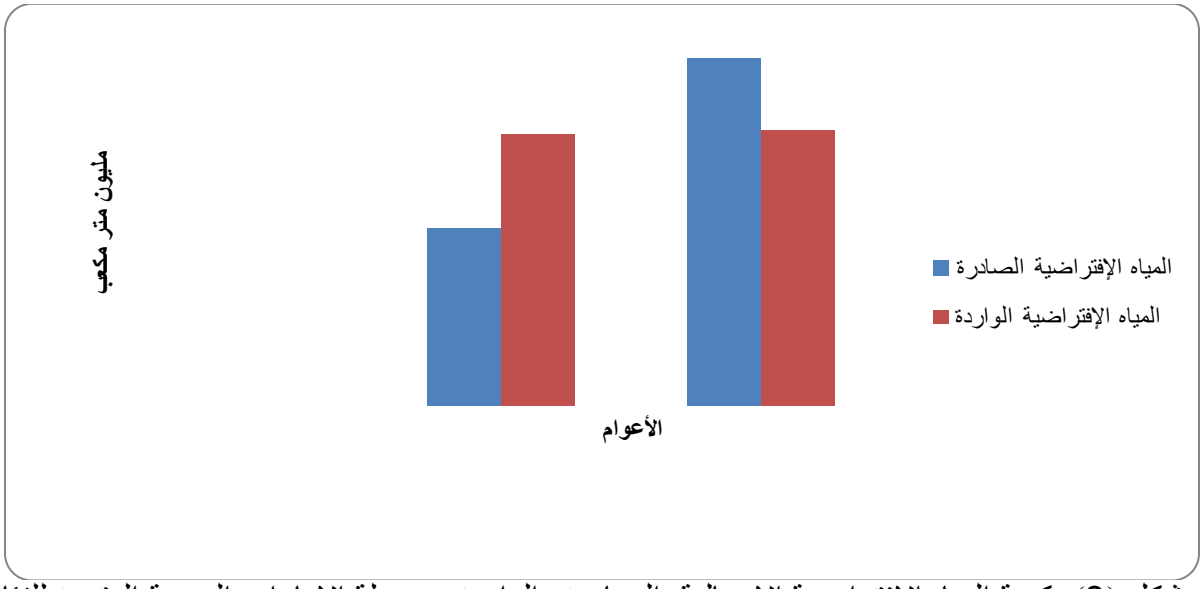
جدول (10): المياه الإفتراضية الواردة لدولة الامارات العربية المتحدة في الفئات الست بالمليون متر مكعب للعامين 2006-2007

الفئة	المياه الافتراضية الواردة م م^3	
	2006	2007
الخضروات	6.1	7.7
الفواكة	11.7	16.9
الحبوب	0.27	0.44
اللحوم	6.6	2.7
الدواجن	0	0
الحليب والألبان والبيض	41	39
المجموع	**65.67**	**66.74**

يوضح الجدول رقم (11) المياه الإفتراضية الصادرة في الفئات الست محل الدراسة لدولة الإمارات العربية المتحدة، حيث كانت فئة الحبوب أعلى في المحاصيل الزراعية وبلغت عام 2007 أعلى قيمة لها، وهي 6.1 م م^3 ، والأقل عام 2006 حيث وصلت ما يقارب 1.4 م م^3 . وكانت فئة الخضروات الأقل في المحاصيل الزراعية وبلغت أعلى قيمة للمياه الإفتراضية الصادرة لهذه الفئة عام 2007 ووصلت إلي 3.3 م م^3 ، بينما الأقل كانت عام 2006، وهي تعادل 1.7 م م^3 مياها إفتراضية صادرة، أي ما يقارب 164 طن. بينما في المنتجات الحيوانية فقد كانت الأقل في الصادرات هي فئة اللحوم، حيث بلغت أقل قيمة لها عام 2007 ووصلت إلي 0.19 م م^3 مياها إفتراضية صادرة ، بينما الأعلى كانت عام 2006 ، حيث وصلت إلي 0.2 م م^3 . بينما بلغت منتجات الحليب والألبان والبيض أعلى قيمة لها عام 2007 وكانت 73.5 م م^3، والأقل عام 2006 ووصلت إلي 37.2 م م^3 مياها إفتراضية صادرة. ويبين الشكل رقم (3) كمية المياه الإفتراضية الإجمالية الصادرة والواردة من دولة الإمارات العربية المتحدة للفئات الست للعامين 2006 – 2007.

جدول (11): المياه الإفتراضية الصادرة لدولة الامارات العربية المتحدة في الفئات الست بالمليون متر مكعب للعامين 2006-2007

الفئة	المياه الافتراضية الصادرة م م^3	
	2006	2007
الخضروات	1.7	3.3
الفواكة	2.7	0.87
الحبوب	1.4	6.1
اللحوم	0.2	0.19
الدواجن	0	0
الحليب والألبان والبيض	37.2	73.5
المجموع	**43.2**	**83.96**



شكل (3): كمية المياه الإفتراضية الإجمالية الصادرة والواردة من دولة الإمارات العربية المتحدة للفئات الست للعامين 2006 – 2007

5.5 مملكة البحرين

تسعي مملكة البحرين إلي توفير الظروف والمناخ المناسب فيما يتعلق بمستقبل الزراعة في البحرين من خلال منح المزارعين قروضاً بشروط ميسرة؛ لتطوير مجالات العمل الزراعي بشقيه النباتي والحيواني، والعمل على توفير أماكن مخصصة لعرض منتجات المزارعين المحليين في الأسواق المركزية؛ للمساعدة على حل المعضلة الكبرى للإنتاج الزراعي، وهي مشكلة التسويق وفي الوقت ذاته، تجري باستمرار التجارب الزراعية الهادفة لتحديد أفضل سبل ووسائل ومواعيد الزراعة، وإرشاد المزارعين إلى فضل الأصناف التي تعطي أعلى إنتاجية.

يوضح الجدول رقم (12) واردات مملكة البحرين في الفئات الست محل الدراسة، فيما يتعلق بالمحاصيل الزراعية فالأكثر إستيرادا كانت فئة الحبوب، فقد بلغت أعلى قيمة لها عام 2006 حيث وصلت إلي 22.1 م م^3 مياها إفتراضية واردة، بينما الأقل كانت عام 2007 حيث وصلت إلي 1.7 م م^3. وبلغت المياه الواردة في فئة اللحوم أقصي قيمة لها ووصلت إلي 7.6 م م^3 عام 2006، بينما الأقل كانت عام 2004 حيث بلغت المياه الإفتراضية الواردة 0.97 م م^3. وكانت فئة الدواجن الأقل في محتوي المياه الإفتراضية, حيث وصلت عام 2000 ما يقارب 19 ألف م^3، والأعلى قيمة لها كانت عام 2007 وبلغت 13.1 م م^3 مياها إفتراضية واردة.

جدول (12): المياه الإفتراضية الواردة لمملكة البحرين في الفئات الست محل الدراسة بالمليون متر مكعب للأعوام 2000-2007

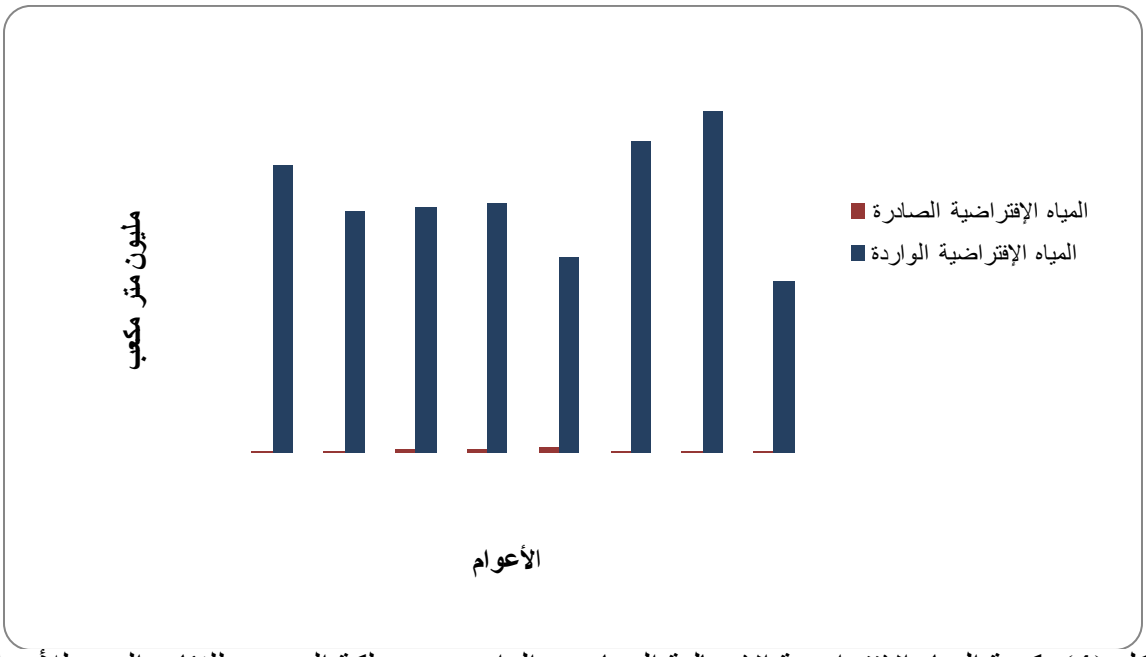
الفئة	المياه الافتراضية الواردة بالمليون متر مكعب							
	2000	2001	2002	2003	2004	2005	2006	2007
الخضروات	15.7	14.4	18.2	10.9	11.2	15.7	13.9	13.6
الفواكة	39.9	30.2	29.5	29.2	15.6	34.1	19.8	0
الحبوب	4.7	2.8	3.5	3.1	2.8	2.5	22.1	1.7
اللحوم	2.8	1.9	1.9	4.8	0.97	2.73	7.6	5.5
الدواجن	0.019	1.3	0	3.3	4.5	8.1	9.4	13.1
منتجات الحليب والألبان والبيض	20.6	19.9	18.8	21.5	21.86	27.5	26.8	16.3
المجموع	**83.719**	**70.5**	**71.9**	**72.8**	**56.93**	**90.63**	**99.6**	**50.2**

يوضح الجدول رقم (13) صادرات مملكة البحرين في الفئات الست محل الدراسة، حيث كانت الأعلى في المحاصيل الزراعية تصديرا هي فئة الحبوب، حيث بلغت أعلى قيمة لها عام 2004 وهي 0.69 م م^3، أما الأقل فقد كانت عام 2005 ، وبلغت حوالي 0.19 م م^3 مياها إفتراضية صادرة. أما الأقل فكانت فئة الخضروات, حيث بلغت أقل قيمة لها 60 ألف م^3 مياها إفتراضية صادرة عام 2007. وكانت فئة منتجات الحليب والألبان والبيض هي الأعلى في محتوي المياه الإفتراضية, وبلغت 790 ألف م^3 عام 2006, بينما الأقل كانت عام 2001 حيث وصلت 55 ألف م^3. ويبين الشكل رقم (4) كمية المياه الإفتراضية الإجمالية الصادرة والواردة من مملكة البحرين للفئات الست للأعوام 2000-2007.

جدول (13): المياه الإفتراضية الصادرة لمملكة البحرين في الفئات الست محل الدراسة بالمليون متر مكعب للأعوام 2000-2007

الفئة	المياه الافتراضية الصادرة م م^3							
	2000	2001	2002	2003	2004	2005	2006	2007
الخضروات	0	0	0	0	0	0	0	0.6
الفواكة	0	0	0.23	0	0.4	0	0	0

الحبوب	0	0.45	0.52	0.62	0.69	0.19	0	0
اللحوم	0	0	0	0	0	0	0	0
الدواجن	0	0.24	0.04	0	0	0	0	0.1
الحليب والألبان والبيض	0.085	0.055	0.22	0.44	0.61	0.41	0.79	0.14
المجموع	**0.085**	**0.745**	**1.01**	**1.06**	**1.7**	**0.6**	**0.79**	**0.84**



شكل (4): كمية المياه الإفتراضية الإجمالية الصادرة والواردة من مملكة البحرين للفئات الست للأعوام 2007-2000

6.5 مساهمة المياه الافتراضية في الميزانية المائية لدول الخليج العربية

يبين الجدول رقم (14) نسبة المياه الافتراضية الصادرة والواردة الإجمالية من الموارد المائية التقليدية وغير التقليدية في دول الخليج العربي لعامي 2000 و 2006, بينما يوضح الجدول رقم (15) نصيب الفرد من المياه الافتراضية الصادرة والواردة في دول مجلس التعاون الخليجي لعامي 2000 و2006. من الجدول رقم (14) يتبين نسبة المياه الافتراضية الإجمالية الصادرة والواردة من الموارد المائية التقليدية وغير التقليدية لعامي 2000 و 2006، حيث يتضح من هذا الجدول أن نسبة المياه الافتراضية الإجمالية الصادرة لعام 2000 للمملكة العربية السعودية إلى الموارد المائية التقليدية تبلغ 1.8 %, بينما المياه الافتراضية الإجمالية الواردة تبلغ 0.44 % من مجموع الموارد المائية التقليدية. في حين أن نسبة المياه الافتراضية الإجمالية الصادرة إلى الموارد المائية الكلية (التقليدية وغير التقليدية) تبلغ 1.6 %, أما المياه الافتراضية الإجمالية الواردة تبلغ 0.38 %. بينما في عام 2006 فقد ارتفعت نسبة المياه الافتراضية الإجمالية الصادرة إلى الموارد المائية الكلية إلى 4.5 % . في حين أن نسبة المياه الافتراضية الإجمالية الواردة قد بلغت 1.12 % مرتفعة عن العام 2000، حيث تعتبر المملكة العربية السعودية هي المصدر الأكبر لدول المنطقة.

أما بالنسبة لمملكة البحرين، فقد أوضحت النتائج أن نسبة المياه الافتراضية الإجمالية الصادرة إلى الموارد المائية الكلية لعام 2000 كانت صفر، بينما المياه الافتراضية الإجمالية الواردة بلغت 39%. مما يدل على إمكانية استفادة مملكة البحرين من حركة المياه الافتراضية في خلق موردا مائيا لها. بينما في العام 2006 فقد ارتفعت نسبة المياه الافتراضية الإجمالية الصادرة إلى الموارد المائية الكلية بما يعادل 0.36%, وكذلك نسبة المياه الافتراضية الإجمالية الواردة إلى 46%.

في حين بلغت نسبة المياه الافتراضية الإجمالية الصادرة من سلطنة عمان عام 2000 ما يعادل 2.9 % من الموارد المائية الكلية، بينما المياه الافتراضية الإجمالية الواردة بلغت نسبتها 1.7%, أما في عام 2006 فمثلت نسبة المياه الافتراضية الإجمالية الصادرة 3.4 % من الموارد المائية الكلية، مرتفعة عن عام 2000.

بالنسبة لدولة الإمارات العربية المتحدة, ففي عام 2006 بلغت نسبة المياه الافتراضية الإجمالية الصادرة إلى الموارد المائية الكلية 3.5%, بينما المياه الافتراضية الإجمالية الواردة بلغت 5.3%.
أما بالنسبة لدولة الكويت، فقد بلغت نسبة المياه الافتراضية الإجمالية لعام 2000 إلى الموارد المائية الكلية ما يقارب 2.4%، بينما المياه الافتراضية الإجمالية الواردة فقد بلغت 21.6 % من مجموع الموارد المائية الكلية لدولة الكويت، في حين قلت عام 2006 نسبة المياه الافتراضية الإجمالية الصادرة إلى الموارد المائية الكلية لتصل إلى 1%، بينما زادت نسبة المياه الافتراضية الإجمالية الواردة لتصل إلى 38.7% من الموارد المائية الكلية.

جدول (14): نسبة المياه الافتراضية الصادرة والواردة الإجمالية من الموارد المائية التقليدية وغير التقليدية في دول الخليج العربية لعامي 2000 و2006

	سنـــة 2000						سنـــة 2006					
الدولة	**المياه الافتراضية الاجمالية م م^3**		**الموارد المائية التقليدية م م^3 (%)**		**الموارد المائية الكلية (التقليدية وغير التقليدية) م م^3 (%)**		**المياه الافتراضية الاجمالية م م^3**		**الموارد المائية التقليدية م م^3 (%)**		**الموارد المائية الكلية (التقليدية وغير التقليدية) م م^3 (%)**	
	الصادرة	الواردة	الصادرة	الواردة	الصادرة	الصادرة	الصادرة	الواردة	الصادرة	الواردة	الصادرة	الواردة
المملكة العربية السعودية	150.6	35.7	1.8	0.44	1.6	0.38	425.5	105.7	5.3	1.3	4.5	1.12
مملكة البحرين	0.085	83.72	0.085	83.7	0	39	0.79	99.6	0.79	99.6	0.36	46
دولة الكويت	25.97	228.5	16	142	2.4	21.6	6.29	233	3.9	145	1	38.7
سلطنة عمان	42.31	25.02	3.2	1.9	2.9	1.7	49.1	38.81	3.7	2.9	3.4	2.7
الامارات العربية المتحدة	غير متاح	غير متاح	غير متاح	غير متاح	غير متاح	غير متاح	43.2	65.67	13	20	3.5	5.3

جدول رقم (15): نصيب الفرد من المياه الافتراضية الصادرة والواردة في دول مجلس التعاون الخليجي لعامي 2000 و2006

الدولة	عدد السكان		المياه الإفتراضية الإجمالية 2000		المياه الإفتراضية الإجمالية 2006		نصيب الفرد من المياه الإفتراضية			
							2000		2006	
	2000	2006	الصادرة م م^3	الواردة م م^3	الصادرة م م^3	الواردة م م^3	الصادرة م^3	الواردة م^3	الصادرة م^3	الواردة م^3
المملكة العربية السعودية	20,846,884	23,118,994	155.66	35.7	425.5	105.7	7.2	1.7	18.4	4.6
مملكة البحرين	637,582	724,645	0.085	83.72	0.79	99.6	0.1	131.3	1.1	137.4
سلطنة عمان	2,401,256	2,508,837	42.31	25.02	49.1	38.81	17.6	10.4	19.6	15.5
دولة الكويت	2,228,363	2,134,030	25.97	228.5	6.29	233	11.7	102.5	29.5	1091.8
الإمارات العربية المتحدة	غير متاح	4,106,427	غير متاح	غير متاح	43.2	65.67	غير متاح	غير متاح	10.5	16.0

يتضح من الجدول رقم (15) أن نصيب الفرد من المياه الإفتراضية الإجمالية الصادرة في المملكة العربية السعودية لعام 2000 قد بلغ 7.2 , إرتفع إلى 18.4 م عام 2006، بينما نصيب الفرد من المياه الإفتراضية الإجمالية الواردة بلغ 1.7 م عام 2000، إرتفع إلى 4.6 م عام 2006. أما بالنسبة لمملكة البحرين, فإن نصيب الفرد من المياه الافتراضية الإجمالية الصادرة لعام 2000 فقد بلغ 0.1 م، ارتفع عام 2006 إلى 1.1 م. في حين أن نصيب الفرد من المياه الإفتراضية الإجمالية الواردة عام 2000 بلغ 131.3 م, إرتفع إلى 137.4 م عام 2006. فيما لوحظ في سلطنة عمان أن نصيب الفرد من المياه الإفتراضية الإجمالية الصادرة عام 2000 كان 17.6 م، إرتفع قليلا إلى 19.6 م عام 2006، فيما كان نصيب الفرد من المياه الإفتراضية الإجمالية الواردة 10.4 م عام 2000، إرتفع إلى 15.5 م عام 2006. أما نصيب الفرد من المياه الإفتراضية الإجمالية الصادرة عام 2000 في دولة الكويت فكان 11.7 م إرتفع إلى 29.5 م عام 2006. كذلك إرتفع نصيب الفرد من المياه الإفتراضية الإجمالية الواردة عام 2006 ليصل إلى 1091.8 م بعد أن كان 102.6 م عام 2000.

تقدم المياه الإفتراضية خيارا لمتخذي القرار في تحقيق وإنجاز أهداف كل من الأمن المائي والأمن الغذائي, بحيث تسد النقص في الموارد المائية من خلال إستيراد المحاصيل ذات الإستهلاك العالي للمياه, وتؤمن الغذاء في بعض المحاصيل التي تفتقر لها الدولة وتعتمد على مواسم معينة. كما قد تساهم هذه الأهداف في رفع الوعي بالمياه الإفتراضية كمفهوم جديد في توفير الموارد المائية على المستوى المحلي, بحيث يتم إستخدامها في مجالات أخرى وتشجيع الحركة الاقتصادية للدولة من خلال تفعيل الإنتاج المحلي في المحاصيل التي تستهلك مياه قليلة, بحيث يتم تقديم الدعم لها كون المياه الإفتراضية تؤمن بعض الحماية للموارد المائية إلى جانب بعض السياسات التي يجب أن تتبناها الدولة لحماية مواردها.

6. الخاتمة

تناولت هذه الدراسة التحديات التي تواجهها دول مجلس التعاون الخليجي المتعلقة بندرة المياه وتأثيرها على إقتصاديات ووفرة الغذاء. وركز التحليل على تقدير حجم المياه الافتراضية الموجود في المنتجات الواردة والصادرة بين دول مجلس التعاون، لتوضيح العلاقة الوثيقة بين الإعتماد على الواردات الغذائية وندرة المياه. أوضحت الدراسة أن تجارة المياه الافتراضية أمر واقع في دول مجلس التعاون الخليجي، ولكن لم يتم أخذها في الإعتبار في سياسات إدارة وتخطيط الموارد المائية بعد. كما أن هناك بعض الأسباب المتعلقة بالتخوف من إتخاذ تجارة المياه الافتراضية كأحد سياسات إدارة المياه، وتضمنت أسباب سياسية واقتصادية تركزت في الخوف من الهيمنة الإقتصادية والسياسية التي يمكن أن تنتج عن التحكم في الغذاء وأن التعاون والتكامل الإقليمي بين دول مجلس التعاون قد يسهم لحد كبير في الحد من هذه المخاوف. هذا وقد خلصت الدراسة إلى ثلاث نتائج هامة هي:

1. أن تجارة المياه الافتراضية ضرورة لسد الفجوة بين الإنتاج المحلي والطلب على الغذاء.
2. تتطلب تجارة المياه الافتراضية بعض التغيير في ثقافة إدارة الموارد المائية في دول مجلس التعاون الخليجي.
3. يجب التركيز على تقليل المخاوف والمخاطر التي يمكن أن تنتج من تجارة المياه الافتراضية من خلال التكامل الإقليمي بين دول المجلس حتى يتسنى الاستفادة منها في إدارة المياه.

وعلى الرغم من أنّ واردات المياه الافتراضية قد تخفّف الضغط على الموارد المائية المحلية، إلا أنّه يجب الأخذ بعين الاعتبار سياسات الاكتفاء الذاتي والسياسات الزراعية التي تنتهجها الدولة والحاجة إلى رؤية واضحة لمفهوم التجارة بالمياه الافتراضية لأولوية تحقيق الأمن المائي. لذا يجب أن يكون هناك المزيد من البحوث لفهم الآثار والتفاعلات التي قد تنتج على المستويات المحلية والبيئية والاقتصادية والاجتماعية والطبيعية والوضع السياسي والإقليمي ككل. مما سبق وبالنظر إلى الاستهلاك العالي في بعض الدول للمياه في زراعة محاصيل أو استهلاكها في القطاع الحيواني, يجب أن يكون الأمن المائي على رأس قائمة الأولويات بسبب قلةِ الموارد المائية التقليدية مما يستدعي العمل الجاد للمحافظة على هذه الموارد ومحاولة تنميتها على الرغم من أن الموارد المائية الجوفية محدودة وغير متجددة، بالإضافة إلى ندرة سقوط الأمطار وارتفاع نسبة التبخّر في المنطقة بسبب الظروف الجغرافية والمناخية التي تقع تحتها، لذا يجب أن تنتبه هذه الدول إلى قضية مهمة جدًا وهي الأمن المائي.

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Mobility of Heavy Metals at the Interface: Plant-Soil Irrigated with Treated Wastewater

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Abstract

As many arid countries where evaporation is high and resources of water are depleted, Oman started to develop other resources such as desalinization and recycling of wastewater which is especially used for irrigation. The main objective of this study is to determine the mobility of metals (V, Cr, Co, Ni, Cu, Zn, Rb, Sr, Ag, Cd and Pb) at the interface of plants and soils which are irrigated with treated wastewater.

Samples of the plants: 1) Plumeria *obtura*, 2) Phoenix *dactylifer*a, 3) Bougainvillea *spectabilis*, 4) Pithecolobium *dulce* and 5) Prosopis *juliflora* have been collected with associated soil samples. Biological absorption coefficient (BAC) calculated for each species as the ratio between the concentration of elements in plant and that of the same elements in the soil, showed similar patterns for all species. However the leaves of Pithecolobium *dulce* and Bougainvillea *spectabilis* are more enriched in elements especially Pb, Rb, Cu, Cd, Zn and Ag compared to the other species. On the contrary, leaves of *Phoenix dactylifera* are characterized by low uptake of elements from the studied soil. The BAC of the elements such as Cr, Ni and V exhibits less difference between the studied species than the other elements such as Pb and Cd. Compared to plants collected from soil irrigated with tap water, mobility of elements from roots to leaves revealed that treated water reduces the mobility of V, Cr, Fe, Co; Ni, Cu, Sr and Ag contrary to that of Cu, Zn and Pb.

Introduction

Arid and hot areas are characterized by high evapotranspiration rates accompanied with low precipitation which explains the minimum recharge of aquifers and puts the water resources under depleting conditions. The situation calls for developing additional new sources of water that help in sustaining groundwater and reduce the dependence on the expensive desalination. Treated wastewater (TWW) can then provide an additional source, especially used for irrigation that consumes about 90% of the Omani water resources. Several studies have been carried out to determine the impact of the reused wastewater on chemical composition of plants (Yim and TAM, 1999; Kiziloglu et al., 2007, Kiziloglu et al., 2007, Jahantigh, 2008, Shahalam et al., 1998, Heidari et al. 2009). Most of previous studies have focused on the chemical variations induced by TWW in the soils and a particular single plant. There has been no investigation on these variations occurring on several plant species at the same time. The current study will focus on the impact of TWW on the biological adsorption coefficient (BAC) of heavy metals (V, Cr, Co, Ni, Cu, Zn, Rb, Sr, Ag, Cd and Pb) by different species of plants. The current geochemical approach is to compare the BAC of plants irrigated with TWW with the chemical composition of the same species of plants irrigated with tap water (TW) in the same area under similar prevailing conditions. This comparison is combined with a chemical characterization of TWW relative to raw wastewater before treatment.

Material And Methods

The materials used in this study were composed of water, soil and plant samples collected from the same area. These samples were collected from Sultan Qaboos University campus (Oman). Water samples include TW and TWW. Samples also include leaching waters from shallow soils (0-15 cm depth) and leaching waters from deep soils (about 20-30cm).

Several species of plants grown in natural conditions were collected and compared with the same species collected from soils irrigated with recycled water (TWW). The species include 1) Plumeria *obtura (*P. *obtura)*, 2) Phoenix *dactylifer*a (P. *Dactylifer*a), 3) Bougainvillea *spectabilis (*B. *spectabilis)*, 4) *Pithecolobium dulce* (*P. dulce)* and 5) Prosopis *juliflora (*P. *juliflora)*.

The mineralogical composition of the soil samples was determined by X-Ray diffraction. Elemental contents of all samples were determined using ICP-AES and ICP-MS, the latter for most of the trace elements, including V, Cr, Co, Ni, Cu, Zn, Rb, Sr, Ag, Cd and Pb. Repeated analyses carried out in the laboratory on a regular basis yielded analytical precisions that ranged between 5 and 10%, whereas methods detection limit is about 1ppt.

Results And Discussion

The soils in the study area consist of loamy sand and sandy loam types. X-Ray diffraction identification of minerals revealed the presence of calcite, dolomite, quartz, muscovite, anorthite, clinochlore and clay minerals. In lack of quantitative analysis of mineral content in soils, clay minerals have been detected in trace amount compared to the other minerals.

1) Soil and water

The chemical data of soluble phases in soils (Table. 1) is the average data of the upper and lower horizons separately. The pH value is nearly constant (7.5 to 7.6) indicating a neutral medium. Relative to the soil irrigated with TW, mobile fractions of the soil irrigated with TWW are enriched in Ni (about 48%), Cu (22%), Sr (17%), Ag (44%) and Cd (43%) and a depletion in V, Cr, Co, Zn, Pb and As (Fig 1).

The comparison between chemical composition of raw wastewater and recycled water (TWW) shows an enrichment in Rb (about 47%) and Pb (about 43%) and Sr (32%) and Zn (about 31%) in TWW and a depletion of Cr, Ni, Cu, Ag and Cd and no change for V and Co (Table, 1, Fig. 2).

However, the concentrations of the different elements in TWW are within the permissible limits of the standards for irrigation in Oman and with the permissible limits of heavy metals in agricultural soils, considered by the European Economic Commission (Linzon, 1994). Moreover the concentrations of trace elements in the water samples do not also exceed the permissible limits reported by FAO (Pescod, 1992).

2) Plants

Plant uptake of elements is affected by the properties of soils such as pH, Eh, organic matter, hydrous oxide of Al, Fe and Mn oxides, phyllosilicate minerals (Tamim, 1987; McLaughlin, 2002; Antonious et al, 2011).

The chemical composition of plants is included in Table 2. Tabulation of plants is indicated for two pairs: one group represents the plants irrigated with TWW (treated wastewater) and the other group includes the plants irrigated with TW. In order to determine the impact of the irrigation with treated wastewater on the chemical composition of plants, the BAC of every species irrigated with TWW was compared with that of the same species irrigated with TW. The comparison involves leaves of each species and roots for one species. Investigation of changes in concentrations of trace elements in plants irrigated with TWW relative to the same species irrigated with TW revealed that the leaves of B. *spectabilis* from TWW irrigated soils have lower concentrations of Ni, Cr, Co and Sr than the same species from TW irrigated soil contrary to Rb, Ag, Cd and Pb (Table 3, Fig 3). Leaves of P. *juliflora* collected from TWW irrigated soils showed an enrichment in most of investigated trace elements relative to leaves of P. *juliflora* collected from TW irrigated soil except for Sr (Table 3, Fig 3). Leaves of P. *obtura* from TWW irrigated soils are depleted in all trace elements relative to leaves collected from TW irrigated soil while the leaves of P. *dactylifer*a are depleted in most of trace elements. Leaves of *P. dulce* from TWW irrigated soils are enriched in Cr, Rb, Sr and Ag and unchanged in the other elements relative to the same species from TW irrigated soil (Table 3, Fig 3).

In term of uptake ability of heavy metals, by the different species irrigated with TW, P. *dactylifera* has the highest BAC relatively to the other species. The irrigation with TWW increased BAC of P. *dulce* compared to the other species. In term of elemental variations and compared to plants irrigated with TW, irrigation with TWW increased BAC for all elements in P. *juliflora* species except Sr and increased only BAC of Co in P. *Dactylifera* species. P. *dulce* species collected from the soil irrigated with TWW exhibit an increase of BAC of V, Cr, Co, Zn, Pb and Sr compared to the same species from the soil irrigated with TW. B. spectabilis collected from the soil irrigated with TWW exhibit an increase of BAC of Co, Zn and Rb and P. *obtura*

species showed an increase of BAC of Zn, V and Co compared to the same species collected from soils irrigated with TW. Irrigation with TW shows that Cd and Ag showed more uptake by plants than the other elements relative to elements in the mobile fractions of soil. Highest BAC characterizes P. *dulce* species. Irrigation of different species with TWW increase BAC of Pb. Irrigation with TWW increase BAC of B. spectabilis and P. juliflora species compared to the other species. Only Zn, V, Co seemed affected by TWW. Their BAC increased in all species collected from the soil irrigated with TWW unlike the other elements which showed irregular behavior (Table 3).

During this study, among the different species only the roots of B. spectabilis have been investigated for both types of irrigation: TW and TWW. For this species, comparison between BAC values in both cases is established (Table 3). The results showed that V, Cr, Co, Zn, Rb, Sr, Ag and Cd have been actively absorbed from the soil irrigated with TWW compared to TW and in the opposite to Ni and Cu. A previous study carried by Lay Pheng Tan et al (1999) compared the uptake of heavy metals by B. spectabilis with other plants grown on artificial topsoil revealed that *B. spectabilis* is the most tolerant plant to heavy metals among the tested plants.

Significant modifications of chemical, physical and biological properties of the soil were observed under wastewater irrigation (Kiziloglu et al. 2007; Guidi, et al. 1983; Kinkle et al. 1987; Guiller et al. 1998; Koupai et al. 2006; Alderfasi 2009). Irrigation with TWW may increase organic matter in soils (Kiziloglu et al. 2007, Maldonado et al. 2008; Mañas P, Castro E, de Las Heras J, 2009) and may explain the increase of mobility of Zn, V, Co for the different species of this study. The impact of TWW on the other heavy metals may reflect artifacts due to differences of physiology of different species of plants.

Conclusion

The present study assesses the effect of the irrigation using TWW on the soil-plant system. Several plant species were included in the study. It has been found that treated wastewater contains relatively higher concentration of Zn, Sr and Pb compared to raw wastewater and markedly increases the amounts of trace elements extracted from the soil. The chemical composition of TW and TWW indicates that the concentrations of most of trace elements are largely higher in TWW than in TW except for Pb. Only Zn, V and Co whose mobility increases in all species of plants irrigated with TWW, seem to be associated with TWW unlike the other heavy metals.

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Table and figure captions

Table.1- Average chemical composition of TWW and TW.
Table.2- BAC of the leaves of different species.
Table.3- BAC of the roots of B. spectabilis.

Fig1: A. soluble phases from TWW irrigated soil compared to soluble phases extracted from TW irrigated soil, B-.Chemical composition of TWW compared to chemical composition of raw wastewater.
Fig.2. BAC of plants irrigated with TWW compared to BAC of plants irrigated with TW

Table 1

	Waters			Soils	
(in ppb)	Raw wastewater	Recycled wastewater	Tap water	TWW irrigated soil	TW irrigated soil
V	4.79	4.82	0.13	0.051	0.0885
Cr	4.76	3.97	0.15	0.0615	0.0775
Co	3.87	3.92	0.08	0.0015	0.0045
Ni	5.83	5.26	0.61	0.058	0.03
Cu	6.65	5.64	0.19	0.0045	0.0035
Zn	11.72	17.01	0.14	0.0165	0.098
Rb	1.78	3.4	0.05	0.002	0.002
Sr	65.85	96.92	0	0.1255	0.1045
Ag	0.42	0.32	0.19	0.0045	0.0025
Cd	0.45	0.37	0.08	0.0035	0.002
Pb	20	35	38	0.001	0.0045

Table 2

	Leaves									
	P. *obtura*		P. *dactylifera*		B. spectabilis		P. *dulce*		P. *juliflora*	
(in ppm)	TWW	TW	TWW	TW	TWW	TW	TWW	TW	TWW	TW
V	66.16	44.63	74.16	64.88	207.82	119.41	232.33	119.76	154.65	46.00
Cr	38.00	97.63	30.03	94.99	123.30	173.19	132.39	63.83	132.65	19.32
Co	836.00	440.44	640.00	442.89	3727.33	1417.33	3904.00	1230.22	3805.33	270.22
Ni	94.14	404.30	61.47	271.23	505.19	1174.77	480.52	1003.43	462.17	239.07
Cu	1117.33	2819.14	460.89	1172.29	3334.00	3952.86	4041.56	4404.86	3486.89	981.14
Zn	1342.55	365.93	304.12	285.06	2855.21	498.93	2942.85	622.43	3286.73	74.39
Rb	1313.50	2308.00	743.00	1998.50	4882.50	2696.50	5613.00	4890.00	4390.00	879.00
Sr	1199.43	2003.03	1987.96	5624.49	1015.99	4255.85	2343.50	1226.06	2045.71	3649.11
Ag	173.33	782.40	130.67	1340.80	2020.22	2339.60	2695.78	3590.80	1428.00	312.80
Cd	400.57	1992.50	324.86	3329.50	5325.71	5112.50	5950.00	10128.00	3616.86	513.50
Pb	770.00	465.78	387.00	490.00	6988.00	669.33	6440.00	1554.00	4272.00	174.67

Table 3

	Roots	
	B. spectabilis	
	TWW	TW
V	112.59	38.12
Cr	83.06	37.14
Co	1422.00	242.67
Ni	140.12	179.00
Cu	957.78	1389.43
Zn	1375.27	277.60
Rb	2014.00	1292.00
Sr	4659.66	1447.50
Ag	738.00	252.80
Cd	1947.71	215.00
Pb	2170.00	180.89

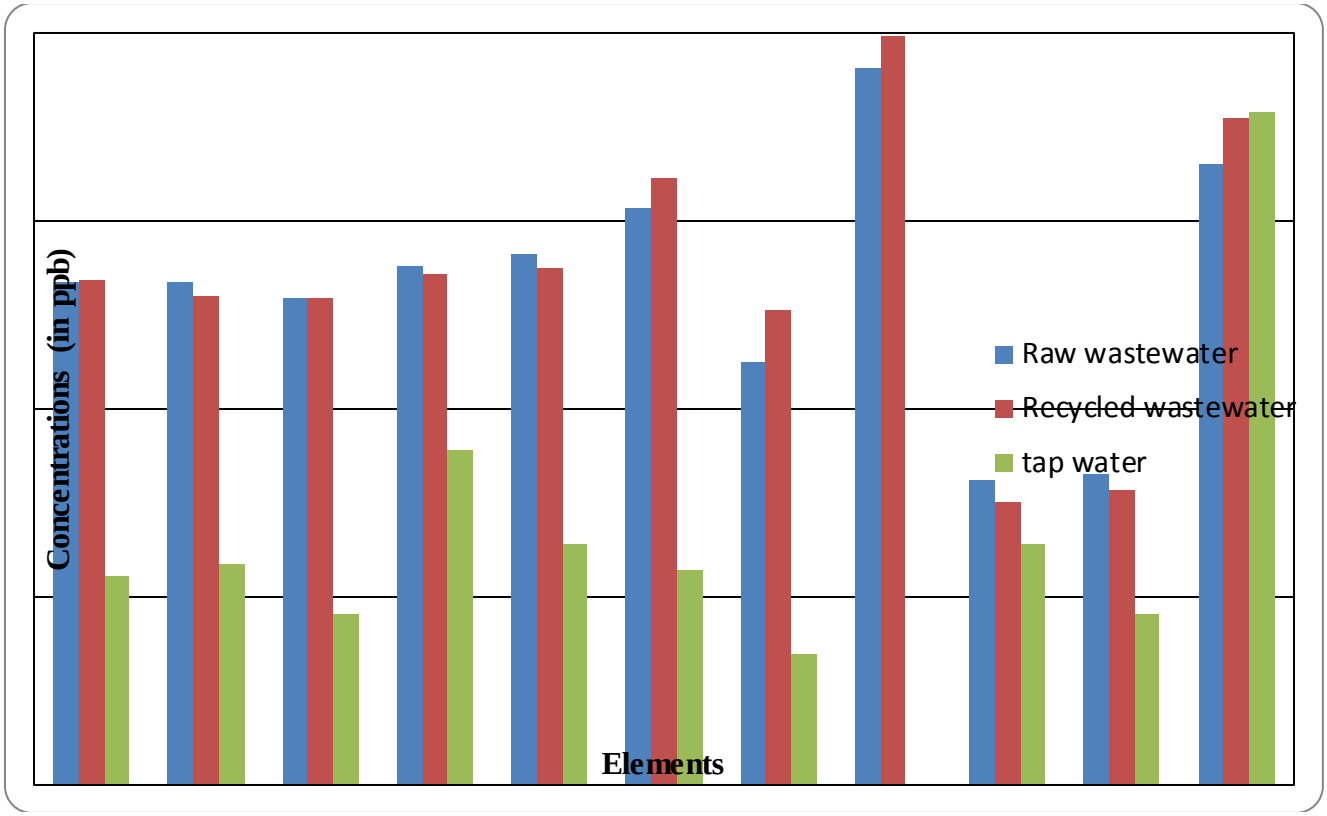
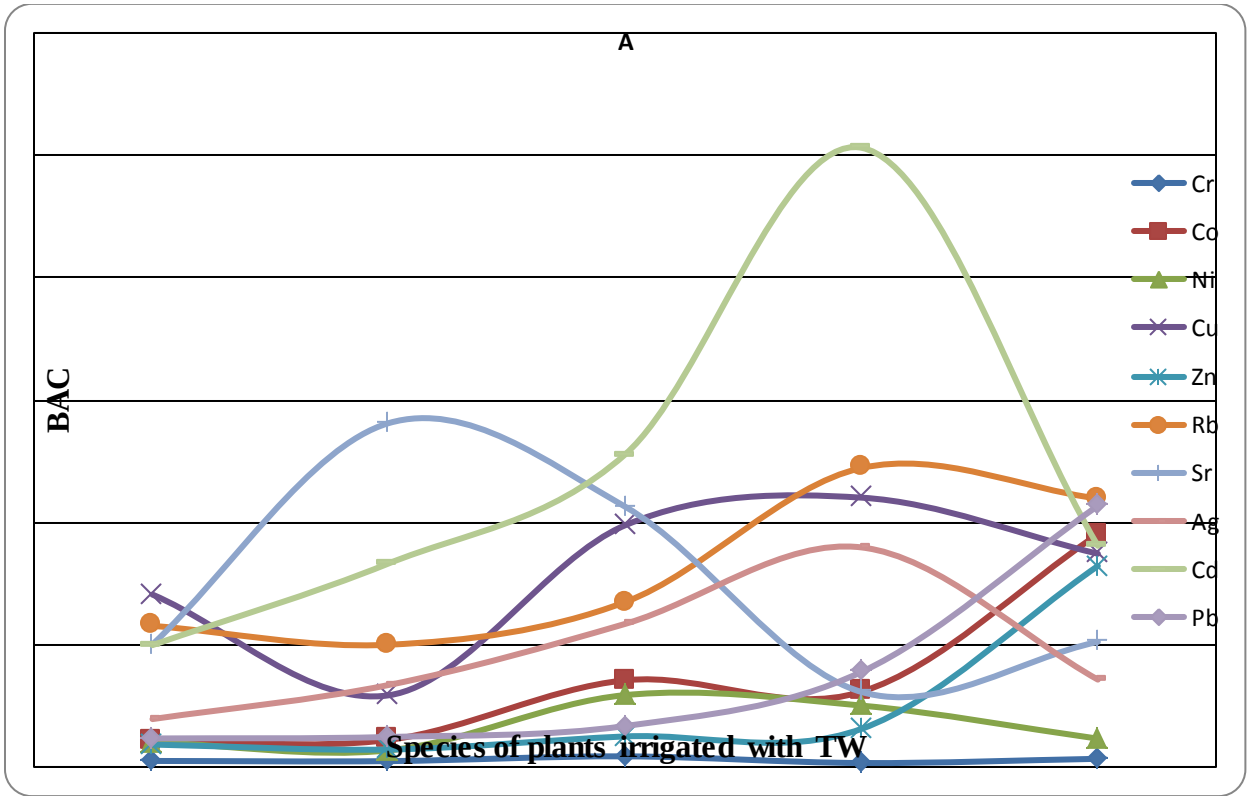

Concentrations (in ppb)
Elements
Raw wastewater
Recycled wastewater
tap water

Figure 1


A
BAC
Species of plants irrigated with TW
Cr
Co
Ni
Cu
Zn
Rb
Sr
Ag
Co
Pb

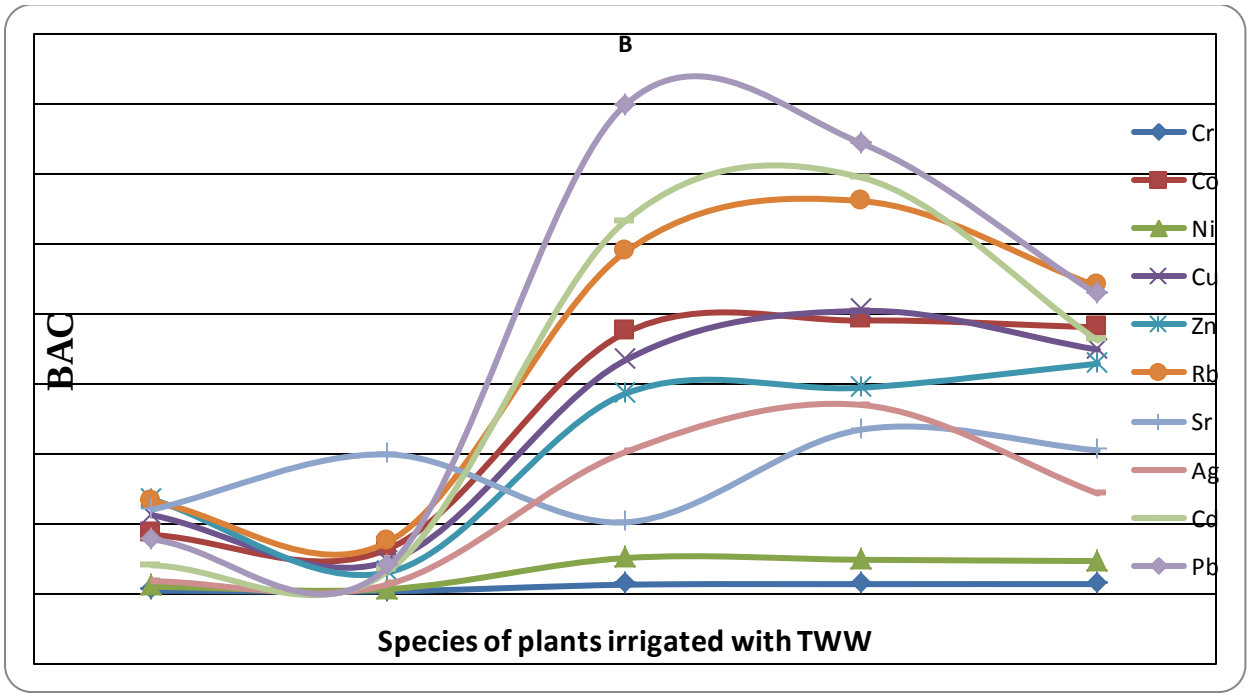

B
BAC
Species of plants irrigated with TWW
Cr
Co
Ni
Cu
Zn
Rb
Sr
Ag
Co
Pb

Figure 2

Ensuring Food Security via Improvement in Crop Water Productivity in Arid and Semi-arid Environments

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Abstract

Total food crop production still needs to increase to feed a growing world population, and this increase needs to be accomplished under increasing scarcity of water. This challenge has led to the notion that crop water productivity (WP) needs to be increased. A systematic framework built on generic principles for the analysis of WP can help to identify interventions that can contribute to the dual goal of increasing food production and saving water. This paper focuses on how to increase crop yield per unit of scarce water through better cultivar selection and better water management application to assist in maximizing irrigation efficiency and increasing yields significantly by minimizing tail water runoff and deep percolation. Irrigation scheduling - the application of desired depth of water at the right time - is a good method to achieve these goals. The use of fixed intervals and /or fixed depths of irrigation causes either over - or under - irrigation during the different parts of the growing period. This in turn leads to inefficient use of water or causes reduction in crop yields. So the use of water for agricultural production in water scarce regions requires innovative and sustainable research. Therefore, the present study involves some of these aspects, mainly relative to on-farm irrigation management including the use of irrigation schedule combination regimes (SICR) as a simple, cheap and easy way to produce more food from less water, by increasing crop water productivity (CWP) which holds the greatest potential to improve food security and reduce poverty in arid and semi-arid regions. An experiment was conducted during 2007 and 2008 growing seasons at the Agricultural faculty Research Station, Sana'a University, Sana'a, Yemen. The effects of ISCR on plant height (PH), biomass yield (BIY), grain yield (GRY), harvest index (HI), spikes m-^{2}. Kernels spike^{-1}, 100-kernal weight and wheat water productivity (WWP) of two bread wheat **(*Triticum aestivum* L.)** genotypes were studied. A split plot layout arranged in randomized complete block design with three replications was used. ISCR affected significantly in PH, BIY, GRY, HI, spikes m-^{2}. Kernels spike^{-1}, and WWP in both growing seasons. But 100-kernal weight was not varied significantly under ISCR in both seasons. Delaying irrigation application period from 10 to 20 days with the depth of 30, 40,50 and 60 mm caused statistically reduction in plant height, BMY, GRY, spikes m^{-2}and kernels spike^{-1} in both season, but HI was affected only under the sever water stress (low depths 30 and 40 mm with long period of irrigation). As well as shortening irrigation application period from 20 to 10 days with the depths of 60 and 50 mm failed to achieve significant increment in WWP in comparison with that obtained by the depth 40 and 30 mm every 10 days in both seasons. The genotypes performance varied significantly only in

BMY, GRY, spikes m-2 in the 1st season and in plant height, BMY, GRY, 100-kernal weight and WWP in the 2nd season. The highest WWP ranging from 1.02 to 1.19 and from 1.14 to1.25 kg $ha^{-1}m^{-3}$ with insignificant differences in 1st and 2nd seasons respectively which achieved by the ISCR treatments that provided a volume of water ranging from 2500 to 4200 m^3ha^{-1}. Also the highest GRY, ranging from 4861 to 5161 and from 4542 to 4792 kg ha^{-1} in 1st and 2nd seasons respectively with insignificant differences within each range, obtained by the ISCR treatments which provided a volume of water ranging from 4200 to 5000 m^3ha^{-1}.. In general, comparing the grain yield produced by the combination $D_{60}P_{15}$ (4200 m^3 ha^{-1}) which was 5161 and 4792 kg ha^{-1} in the 1st and 2nd seasons respectively with that produced by $D_{60}P_{10}$ (6000 m^3 ha^{-1}) which was 5002 and 4500 kg ha^{-1} in the 1st and 2nd seasons respectively. These results are very helpful to discover an excellent indicator that there is high potential to save large amounts of irrigation water (1800 m^3ha^{-1}) and gain an increment in grain yield, about 159 and 292 kg ha^{-1} in the 1st and 2nd seasons respectively. So it could be concluded that Irrigation Scheduling Combination Regime (ISCR) is an excellent procedure which provides proof of the existence of high potential to attain food security by producing more food while using less water. This can be achieved through enhancing CWP by using ISCR as a highly relevant tool which can be applied in many practical applications in the field at a low cost and which is easy to implement by any farmer for promoting the potential of increasing grain yield with less water. This will help attain food security in water scarce country environments, but it is needed to expand to include more combinations of depths, periods and genotypes and replicate enough under the conditions of each agro ecological level. This will provide a good guideline to change the concept of ‹‹more crop per drop›› from fiction to become fact.

Keywords: Wheat, Irrigation schedule, yield and yield components, water productivity, Dry Areas, Food security

Introduction

The great challenge for the coming decades will be the task of increasing food production with less water, particularly in countries with limited water and land resources. While on a global scale water resources are still ample, serious water shortages are developing in the arid and semi-arid regions, as existing water resources reach full exploitation. The situation is exacerbated by the declining quality of water and soil resources. The dependency on water has become a critical constraint for further progress and threatens to slow down development, endangering food supplies and aggravating rural poverty.

When water becomes scarce, demand management becomes the key to the overall strategy for managing water (Molden *et al*., 2001). Since agriculture is the major competitive use of available water, demand management in agriculture would be central to reducing the aggregate demand for water to match with the available future supplies, thereby reducing the extent of water stress. Improving productivity of water use in agriculture is an important part of the overall framework for managing agricultural demand for water, thereby increasing the ability of interested parties to transfer the water thus "saved" to economically more efficient or other high priority use sectors (Barker *et al*., 2003; Frederick, 1993; Kijne *et al*., 2003). Three dimensions of water productivity: physical productivity, expressed in kg per unit of water consumed; combined physical and economic productivity expressed in terms of net return per unit of water consumed, and economic productivity expressed in terms of net income returns from a given amount of water consumed against the opportunity cost of using the same amount of water (Kijne *et al*., 2003). The first parameter, i.e., physical productivity will be applied in the present paper. There are two major ways of improving the physical productivity of water use in irrigated agriculture. First: reducing the water consumption or depletion for producing a certain quantum of biomass for the same amount of land. Second: enhancing the yield generated for a particular crop without changing the amount of water consumed or depleted per unit of land. Often these two improvements can happen together with an intervention either on the agronomic side (by selection genotype witch capture more of the water supply for use in transpiration; exchange transpired water for CO_2 more effectively in producing biomass; and convert more of the biomass into grain or other harvestable product (Passioura, 2006) or on the water control side. Water stress affects crop growth and productivity in many ways. Most of the responses have a negative effect on production but crops have different and often complex mechanisms to react to shortages of water. Several crops and genotypes have developed different degrees of drought tolerance, drought resistance or compensatory growth to deal with periods of stress. Yemen, as an example of a country located in an arid and semi-arid environment is facing a well-known water scarcity which is an alarming problem threatening the economic development and the stability of many parts in the country. This problem has caused chronic difficulties in agriculture and has seriously undermined domestic food production in the country. As a sequence, economic problems have constrained the agricultural infrastructure development. So, the situation in Yemen, and other similar countries, needs emergency, innovative, sustainable, low cost, simple and easy interventions. The use of water for agricultural production in water scarcity regions requires innovative and sustainable research, and an appropriate transfer of technologies. Irrigation scheduling, in general, means application of desired depth of water at right time. This method could be based on monitoring soil- water – crop - climate approach and critical growth stage approach. However, determination of the evapotranspiration rate is not always an easy

action and is not an accurate method with which to plan irrigations. Therefore, it's important to ensure wide participation of poor farmer resources and to gain the great advantages of the irrigation scheduling as a good option to response positively for an urgent need to produce more food by using dwindling water resources efficiently. The use of fixed intervals and /or fixed depths of irrigation causes either over- or under-irrigation during the different parts of the growing period. This in turn leads to inefficient use of water or causes reduction in crop yields. The implementation of irrigation schedule should be adapted or applied in new pattern to become easy for practicing at farm level, with low cost, and should reflect water-crop-soil-climate relationships. The scope of this research is to involve some of these aspects, mainly relative to on-farm irrigation management by using ‹‹irrigation schedule combination regimes (SICR)›› as a simple, cheap and easy way to produce more food from less water, by increasing the crop water productivity (CWP) which holds the greatest potential to improve food security and reduce poverty in these regions. So the objectives of this study are: **I)** To examine the ability of producing more food from less water through application of irrigation scheduling combination regimes as a tool to enhance Crop Water Productivity (CWP) in dry land environments with no need for complicated measuring and monitoring soil-plant-climate factor changes. **II)** To evaluate the performance of some wheat genotypes under irrigation scheduling combination regime treatments to select that yielded highly as a positive response of better agronomic irrigation water management.

Material and Methods

This experiment was conducted during two successive seasons (2006-2007, 2007-2008) at the Agricultural faculty Research Station, Sana'a University, Sana'a, Yemen. Two wheat genotypes (Bhooth14 and Bhooth15 were chosen based on popularity in the area (where the study was conducted) at a seeding rate of 100 kg ha^{-1}. Urea was surface applied at the level of 100 kg N ha^{-1}. Date of seeding has been chosen to be critical for winter cereals to survive the harsh winter prevailing on the study area (Yemen central highlands conditions) Thus, wheat genotypes were seeded in early January for the two seasons ,which usually fell within the range of the recommended seeding dates for wheat crop in central highlands of Yemen (Mukred et al 1998). An appropriate soil preparation (ploughing, levelling and plots bordering) and weed management program was used to manage plots to nearly weed-free condition. Other agronomic management practices used in this study were those recommended for production of this crop. The treatments were organized on the field site following a randomized complete block split-plot design with three replicates. The treatments were comprised of factorial combinations of three factors. Regulated deficit irrigation depths (D_{30}, D_{40}, D_{50}, and D_{60} mm), irrigation periods (P_{10}, P_{15}, and P_{20} days) and two wheat genotypes (Bhooth14 and Bhooth15). Irrigation schedule combination regime (ISCR) treatment was the main plot factor and the wheat genotype was the sub-plot factor. Each subplot measured 2 x 2 meters (six- 0.3m row spacing) with an additional one meter of buffer zone on each side of the plot ridge. The irrigation scheduling combination treatments and their equivalent water volume per hectare(WV m^3 /ha) are shown in (Table 1).

Table (1): Irrigation scheduling combination regime (ISCR) treatments (irrigation water depth x irrigation period) and their equivalent water volumes m^3ha^{-1} $season^{-1}$(EWV)

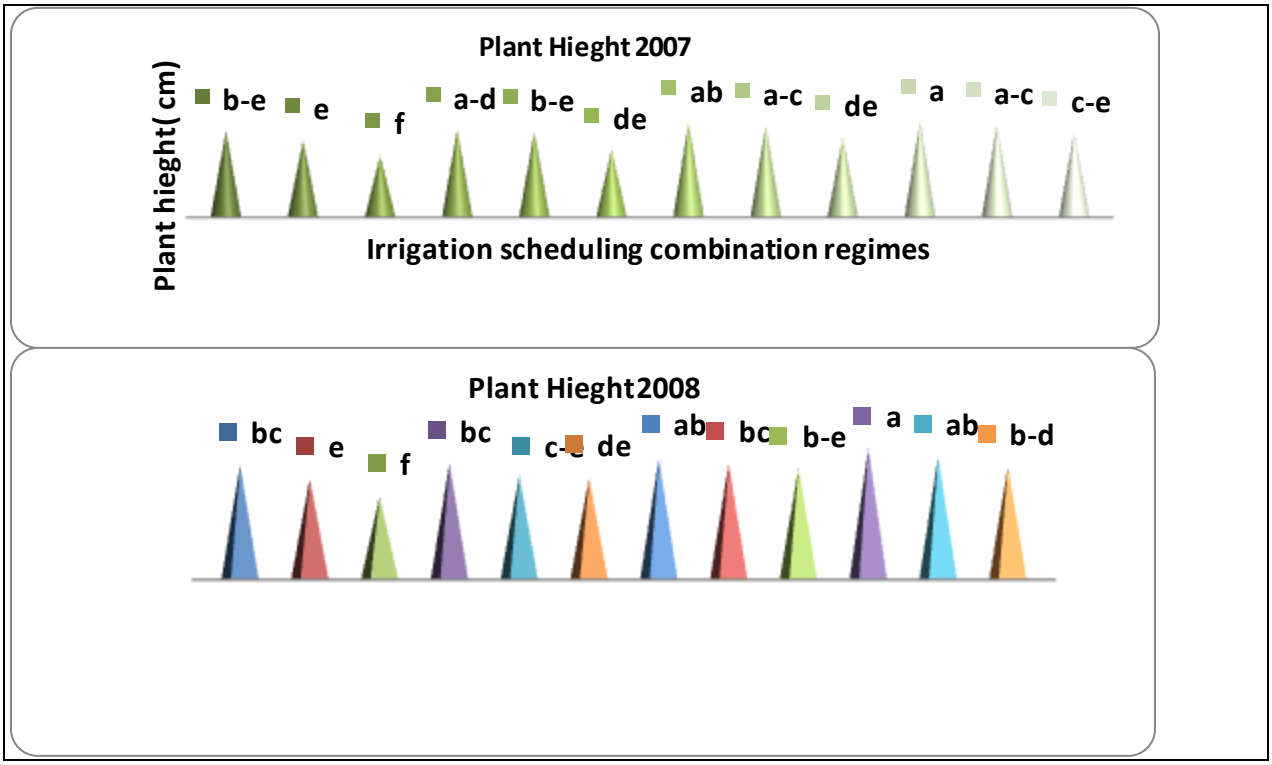
ISCR	$D_{30}P_{10}$	$D_{30}P_{15}$	$D_{30}P_{20}$	$D_{40}P_{10}$	$D_{40}P_{15}$	$D_{40}P_{20}$	$D_{50}P_{10}$	$D_{50}P_{15}$	$D_{50}P_{20}$	$D_{60}P_{10}$	$D_{60}P_{15}$	$D_{60}P_{20}$
EWV (m^3ha^{-1} $season^{-1}$)	3000	2100	1500	4000	2800	2000	5000	3500	2500	6000	4200	3000

Irrigation water depth was regulated by using water meter instrument. Four rows in the centre of each subplot were used for sampling. the number of spikes per unit area was determined by counting actual spikes in an area of two rows 1 m. Biological yield (BMY) and grain yield GRY) were determined by combining the central four rows of the plot. Harvest index was calculated by using the formula: HI= GRY / BMY *100 . From 10 spikes randomly picked within the four sampling rows of each subplot the number of kernels per spike and 100- kernel weight traits were determined. Wheat water productivity (WWP) was calculated as the ratio of grain yield and water applied in terms of kg $ha^{-1}m^{-3}$. Statistical analyses were performed by analysis of variance (ANOVA) using the SAS software (SAS Institute, USA 1999). In general, differences among treatments were considered significant only when they occurred at the 0.05 level or highly significant at the 0.01 level. Means separations were performed using least significant difference at 0.05 level.

Results and Discussion

Plant Height:

Analysis of variance showed highly significant (*P*0.01) effects of irrigation scheduling combination regimes on plant height trait in the two growing seasons. The means of plant height are shown in (Fig 1) for the two growing seasons. The means reflected various plant responses for the different irrigation scheduling combination regimes (ISCR). The highest plant (88- 81 and 93- 86 cm in 1st and 2nd season respectively) achieved by the combinations $D_{60}P_{10}$, $D_{50}P_{10}$, $D_{60}P_{15}$, $D_{50}P_{15}$ with insignificant differences in both seasons (except $D_{50}P_{15}$ in the 2nd season. The combination $D_{30}P_{20}$ produced the shortest plants (57 and 59 cm) in both seasons. The effects of the other combinations on plant height were within this range but with significant differences. Deficit irrigation caused reduction in plant height by about 35 % compared to $D_{60}P_{10}$ treatment (= 6000 m^3ha^{-1}) with $D_{30}P_{20}$ treatment (= 1500 m^3ha^{-1}) in the 1st season and by about 36.5 % in the 2nd season. The range of plant height means was from 57 cm under extreme deficit irrigation regime ($D_{30}P_{20}$ = 1500 m^3ha^{-1}) to 88 cm under over irrigation regime ($D_{60}P_{10}$ = 6000 m^3ha^{-1}) in the 1st season and from 59 cm to 93 cm in 2nd season. Similar results reported by Jalal and Al-Tabbal (2011) , Kilicand Yagbsanlar, (2010)



Means with the same letter are not significantly different

Fig.(1):The effects of irrigation schedule combination regimes in plant height of wheat in 2007and 2008 growing seasons

The analysis of variance revealed a significant (*p0.05*) differences between the two wheat genotypes only in the 2nd season, where Bhooth14 plants were taller than Bhooth15 under ISCR treatments (Fig.2)

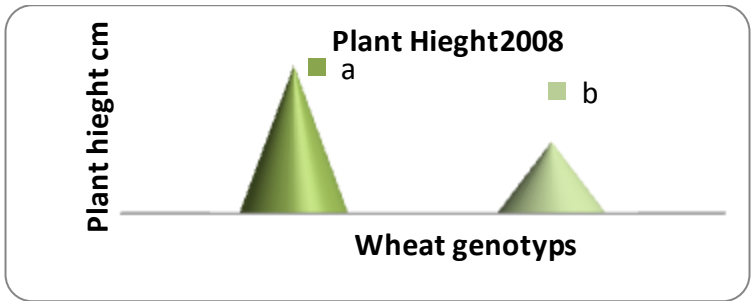


Fig.(2): plant height of two wheat genotypes under the effects of irrigation schedule combination regimes in 2008 growing season

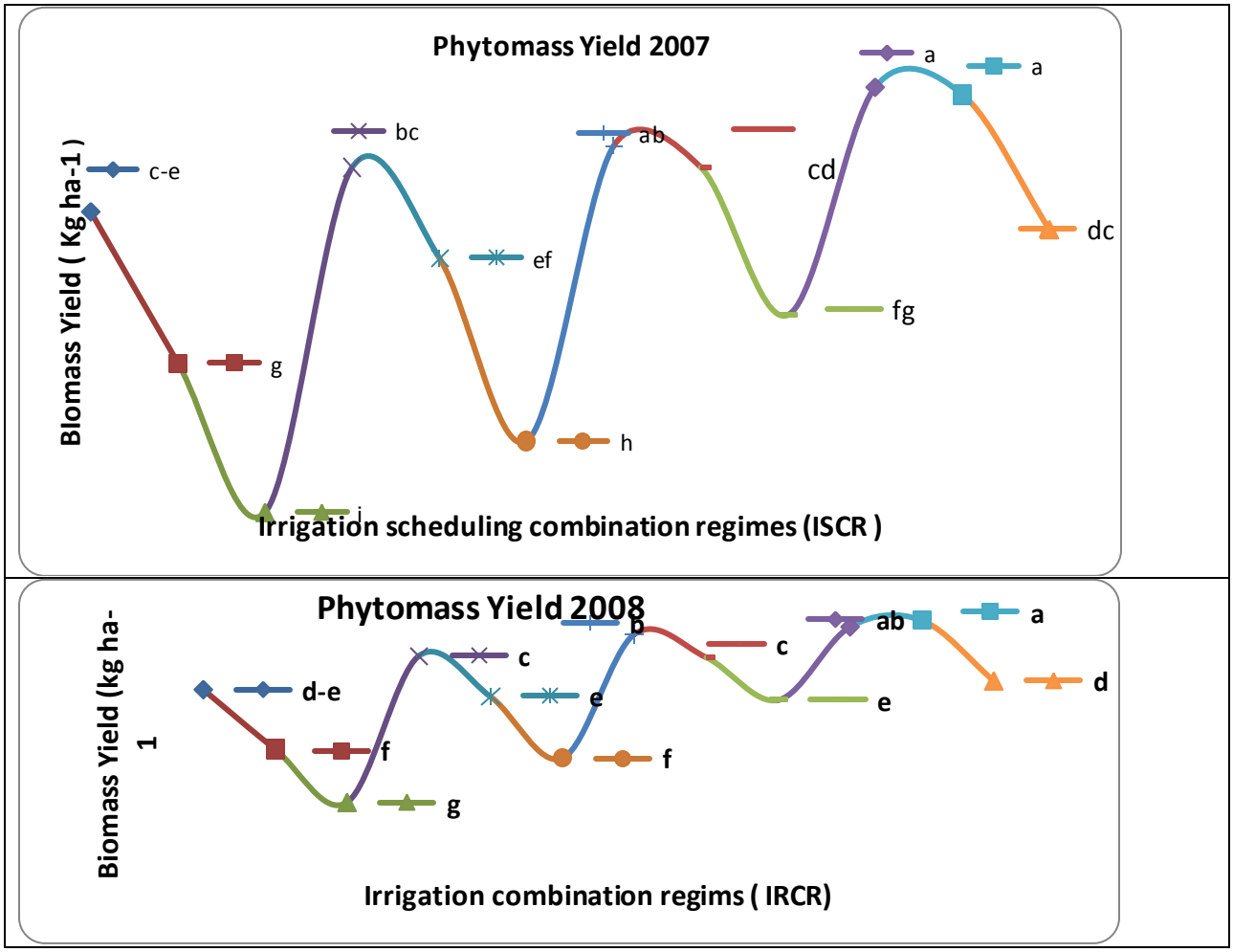
Analysis of variance also showed a significant (p 0.05) genotype x ISCR treatments that reflect a different response of each genotype under each ISCR treatment, although these differences not so large.

Table(2) The interaction between ISCR and genotypes in plant height in 2008 growing season

ISCR	EWV (m^3ha^{-1} $season^{-1}$	Bhooth14	Bhooth15
D30P10	3000	90.66	72.33
D30P15	2100	74.33	68.66
D30P20	1500	57.66	60.33
D40P10	4000	85.33	79.66
D40P15	2800	74	74
D40P20	2000	73.33	71.66
D50P10	5000	89.66	82
D50P15	3500	84.67	79.66
D50P20	2500	80.33	71.66
D60P10	6000	98.33	87.66
D60P15	4200	94	80.33
D60P20	3000	83.33	77
$LSD_{0.05}$		8.01	

Biomass Yield :

Analysis of variance showed significant differences between ISCR in their effects on biomass yield (BMY) in the two growing seasons. Means of BMY lustrated in (Fig 3). The combinations $D_{60}P_{10}$, $D_{60}P_{15}$, $D_{50}P_{10}$ (= 6000, 4200 and 5000 m^3ha^{-1} respectively) produced the highest biomass yield in the 1st season and the combinations $D_{60}P_{10}$, $D_{60}P_{15}$ in the 2nd season . The lowest biomass yield was produced by the combination $D_{30}P_{20}$ (= 1500 m^3 ha^{-1}) in both seasons . The Range of means was expanded from 1111 kg ha^{-1} under extreme deficit irrigation regime ($D_{30}P_{20}$ = 1500 m^3 ha^{-1}) to 14389 kg ha^{-1} under the combination $D_{60}P_{15}$ = 4200 m^3 ha^{-1}) in the 1st season and from 3585 to 13000 kg ha^{-1} under $D_{30}P_{20}$ and $D_{60}P_{10}$ respectively in the 2nd season. Deficit irrigation caused large reduction by about 92.2 % of BMY, in the 1st season and by about 72.5 % in the 2nd season. The most interesting observation was that the highest biomass yield ,14389 kg ha-1, was produced by the combination $D_{60}P_{15}$ (= 4200 m^3 ha^{-1}) was insignificantly higher than 14167 and 12156 kg ha^{-1} which produced by the combinations $D_{60}P_{10}$ and $D_{50}P_{10}$ (= 6000 and 5000 m^3 ha^{-1} respectively). Approximately, the same trend was obtained in the 2nd season, where, the BMY (12667 kg ha-1) produced by the combination $D_{60}P_{15}$ was insignificantly differed with that (13000 kg ha-1) produced by the combination $D_{60}P_{10}$ and was significantly higher than 12292 kg ha-1 which produced by the combination $D_{50}P_{10}$ (= 5000 m^3 ha^{-1}). The results obviously emphasized that deficit irrigation (lower depth and longer period of irrigation water application) has declining effect on biomass yield. In general, the sensitivity increases with increasing the intensity of water stress, but with more water depth and shorter period of irrigation application this sensitivity is became bitty). Jalal and Al-Tabbal (2011) found similar results



Means with the same letter are not significantly different

Fig.(3): The effects of irrigation scheduling combination regimes on biomass yield (kg ha^{-1}) of wheat genotypes in 2007 and 2008 growing seasons

Wheat genotypes were affected significantly (p 0.01) by ISCR treatments (Fig.4) This fig. illustrated that Bhooth14 achieved the highest BMY in the 1st season, while Bhooth15 exceeded significantly Bhooth14 in the 2nd season, thus , might be due to out-control conditions which lead to high infection of leaf rust in Bhooth14

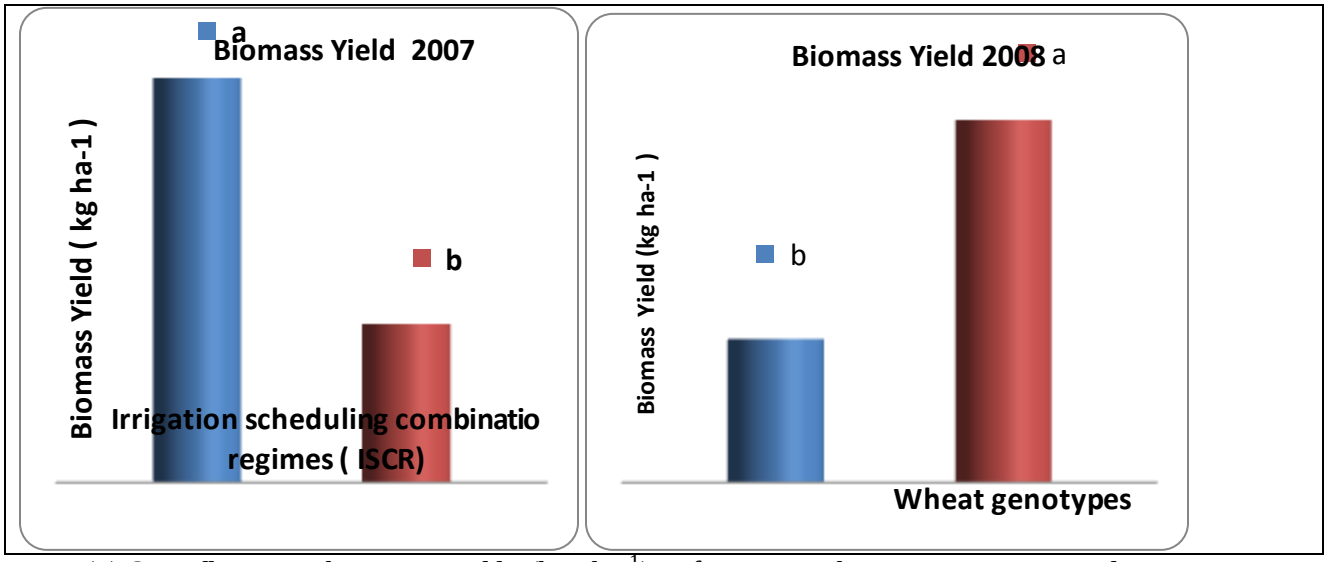


Fig.(4):Overall mean biomass yield (kg ha^{-1}) of two wheat genotypes under irrigation scheduling combination regimes in 2007 and 2008 growing seasons

Analysis of variance showed a significant (*P*0.01) genotype X ISCR interaction in biomass yield .Therefore, BMY means appeared some differences as a response of each genotype for different water regimes although these mean differences had stable trend in increasing BMY reduction of each genotype with increasing water stress severity as shown in (Table 3).

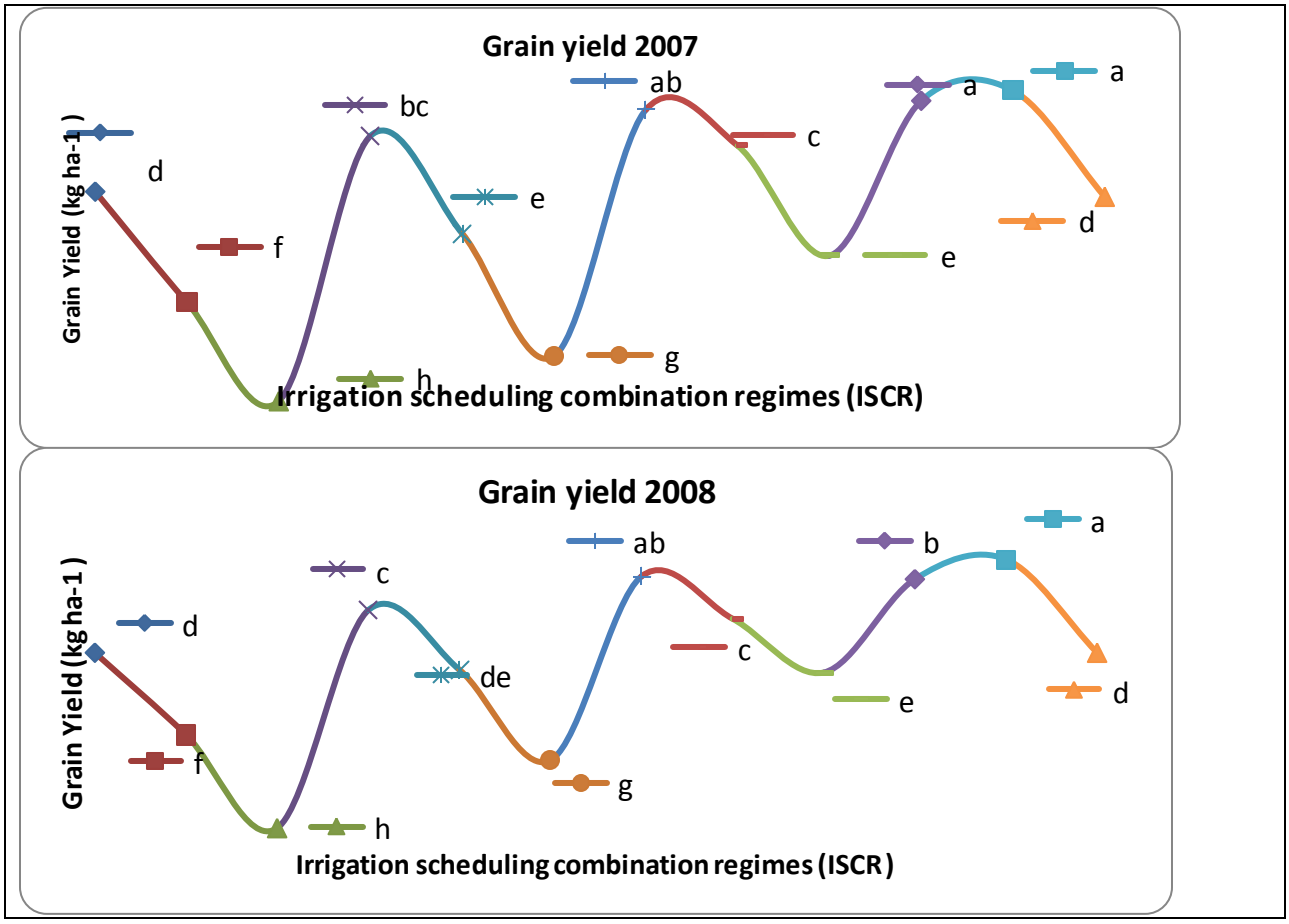
Table (3) The interaction between genotype and ISCR on BMY in 2007 growing season.

Grain Yield

ISCR	EWV (m^3ha^{-1} $season^{-1}$	Bhooth14	Bhooth15
$D_{30}P_{10}$	3000	10555.6	10444. 4
$D_{30}P_{15}$	2100	7555.6	4000.0
$D_{30}P_{20}$	1500	1111.1	1111.1
$D_{40}P_{10}$	4000	11555.6	13555.6
$D_{40}P_{15}$	2800	9777.8	8333.3
$D_{40}P_{20}$	2000	3111.1	3555.6
$D_{50}P_{10}$	5000	14444.4	9555.6
$D_{50}P_{15}$	3500	12000	11777.8
$D_{50}P_{20}$	2500	8333.3	6222.2
$D_{60}P_{10}$	6000	13777.8	15000.0
$D_{60}P_{15}$	4200	14555.6	13777.8
$D_{60}P_{20}$	3000	10555.7	9111.1
LSD0.05		2289.2	

Analysis of variance showed highly significant (*p0.01*) differences between irrigation schedule combination regimes (ISCR) in grain yield (GRY) of wheat genotypes in both seasons. Means of grain yield for each ISCR treatment in the two seasons are shown in (Fig. 5). In the 1st season

the highest GRY obtained by the treatments, $D_{60}P_{10}$, $D_{50}P_{10}$ and $D_{60}P_{15,}$ in the 1st season and $D_{60}P_{10}$, $D_{50}P_{10}$ in the second season with no substantial differences between them, whoever, the treatment $D_{30}P_{20}$ produced statistically least grain yields in both seasons. The reduction in grain yield caused by the deficit irrigation counted for 94. 6 % in comparing between highest GRY =5161 kg ha^{-1} under irrigation regime $D_{60}P_{10}$ = 6000 m^3 ha^{-1} and the lowest GRY =275 kg ha^{-1} under irrigation regime $D_{30}P_{20}$ =1500 m^3 ha^{-1} in the first season and by about 81.4 % in 2nd season in comparing the yield (833 kg ha-1) under $D_{30}P_{20}$ treatment and the yield (4500 kg ha-1) produced by the treatment $D_{60}P_{10}$ in the second season . Although the limitation of irrigation water steadily caused a significant reduction in GRY until a certain level, after that the effect irrigation depth is eliminated, thus appearing clearly in the performance of the genotypes (Fig. 5) under the combinations $D_{50}P_{10,}$ $D_{60}P_{10}$ and $D_{60}P_{15}$. Despite the large difference between these treatment in irrigation regime which counted for 1000 and 1800 m3 ha-1 respectively, but they yielded the same (insignificant differences). The meaning of this result is that irrigation water effect beyond certain regime become negligible. The analysis of the combined effect of irrigation schedule in the 1st season revealed that the limitation of irrigation water depth by 10 mm (from $D_{60}P_{10}$ to , $D_{50}P_{10}$) to save 1000 m^3 ha^{-1} caused only 5.8 % reduction in GRY. As well as the loses of GRY was only 3.1% (insignificant loses) due to delay irrigation application 5 days (expand irrigation period from 10 days to 15 days with the same depth of irrigation D_{60}), thus resulted in saving 1800 m^3 ha^{-1}in the 1st season. The same trend of irrigation schedule effects were happened in the 2nd season with the exception of the treatment $D_{60}P_{10}$ which significantly yielded lower than $D_{50}P_{10}$ and $D_{60}P_{15}$, this means that regime of combination $D_{60}P_{10}$ (as an over irrigation regime) yielded 4500 kg ha^{-1}, therefore it caused significant yield reduction(6.09 % in comparing with highest grain yield of the treatment $D_{60}P_{15}$ = 4792 kg ha^{-1}) as a result of leaching nutrients from the root zone and enhancing leaf rust infection. The results of this study revealed that the grain yields initially increased significantly with the increase of irrigation water, but the increment of yields beyond a certain level of water used negligible . Other studies have reported that the relationship between yield and water consumption is not linear (Yuan *et al*., 1992).as well as Zhang and. Pei(2000) and Peck and Kirkham (1979**)** found that crop yields initially improved with increased water consumption, but that beyond a certain water use level yields decreased . Also, Johari-Pireivatlou (2011) reported that grain yield decreased under water stress by approximately 39% as compared to the control. Jalal and Al-Tabbal (2011) found that water stress caused significant reduction in grain yield. The results of reduction irrigation regimes from 6000 m^3 ha^{-1} to 4200 m^3 ha^{-1} with insignificant reduction in GRY from 5161 to 5002 kg ha^{-1} in the 1st season and enhancing significant increment in GRY from less ($D_{60}P_{15}$ = 4200 m^3 ha^{-1}) water and avoidance substantial loses in GRY due to over irrigation under the treatment $D_{60}P_{10}$ (6000 m^3 ha^{-1}) in the 2nd season) are very important to prove that "Irrigation Scheduling Combination Regimes(ISCR) is excellent procedure for promoting the potential of increasing grain yield with less water, then achieving food security in water scarcity country environments and highly relevant tool to be used in many practical applications at field, level, with low cost.



Means with the same letter are not significantly different

Fig.(5): Mean grain yield (kg ha^{-1}) of wheat under irrigation scheduling combination regimes in 2007and 2008 growing seasons

Genotypes varied statistically in their performance in grain yield under ISCR treatments (Fig. 6) Bhooth14 produced the highest yield in the 1st season (3394 kg ha^{-1}), but it yielded lower than Bhooth15 in the 2nd season, thus might be due to unmeasured leaf rust which was more spread in the 2nd season. Jalal and Al-Tabbal (2011) stated that Cultivars were found to respond differently to water stress treatments

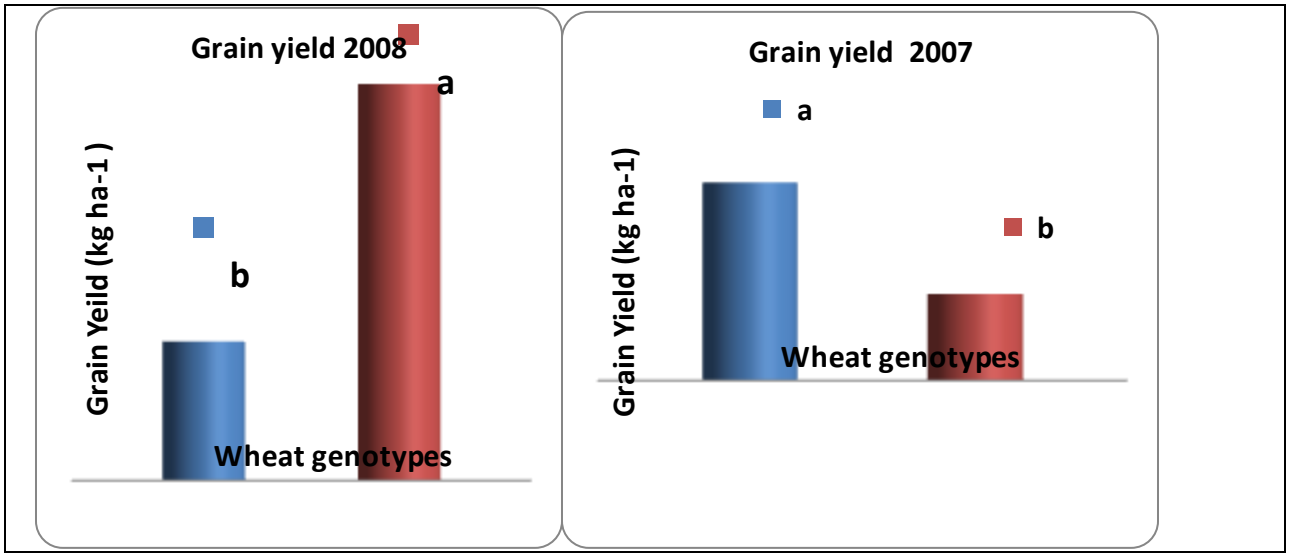


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Fig.(6):Grain yield (kg ha^{-1}) of two wheat genotypes under irrigation scheduling combination regimes in 2007and 2008 growing seasons

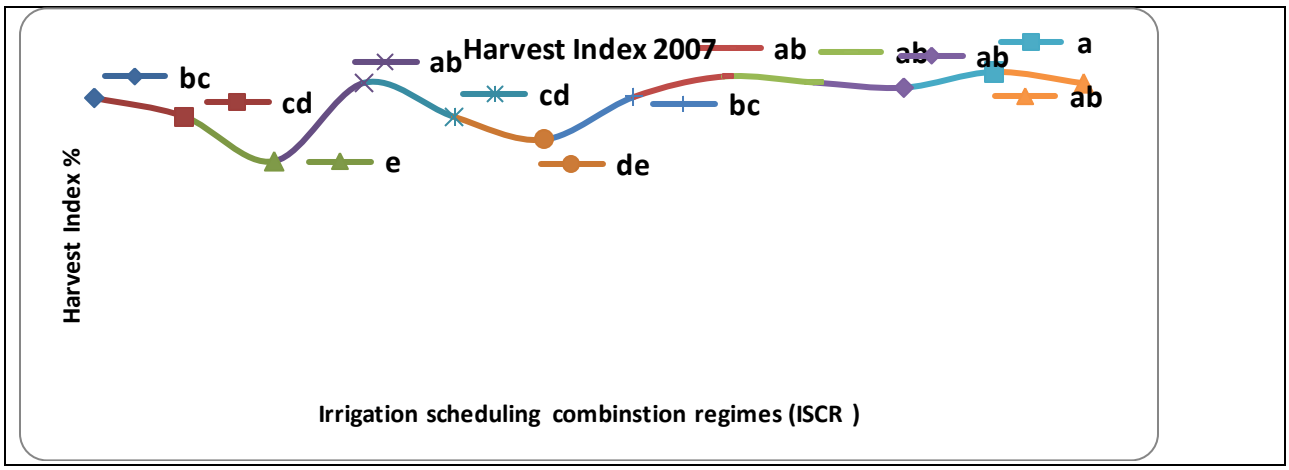
The significant interaction between genotypes and ISCR treatments under 1st season conditions is illustrated the specific response of each genotype for each ISCR treatment in producing GRY. So Mean grain yield of the two genotypes were plotted against ISCR treatment (Table 4) that obviously revealed not large differences among genotypes in their response for ISCR, where they had the same trend in losing large amount of GRY with increasing water stress (over 94% of variability in GRY was attributed to water used), but Bhooth15 was more sensitive for lower irrigation regime and more responsive for increasing irrigation regime than Bhooth14

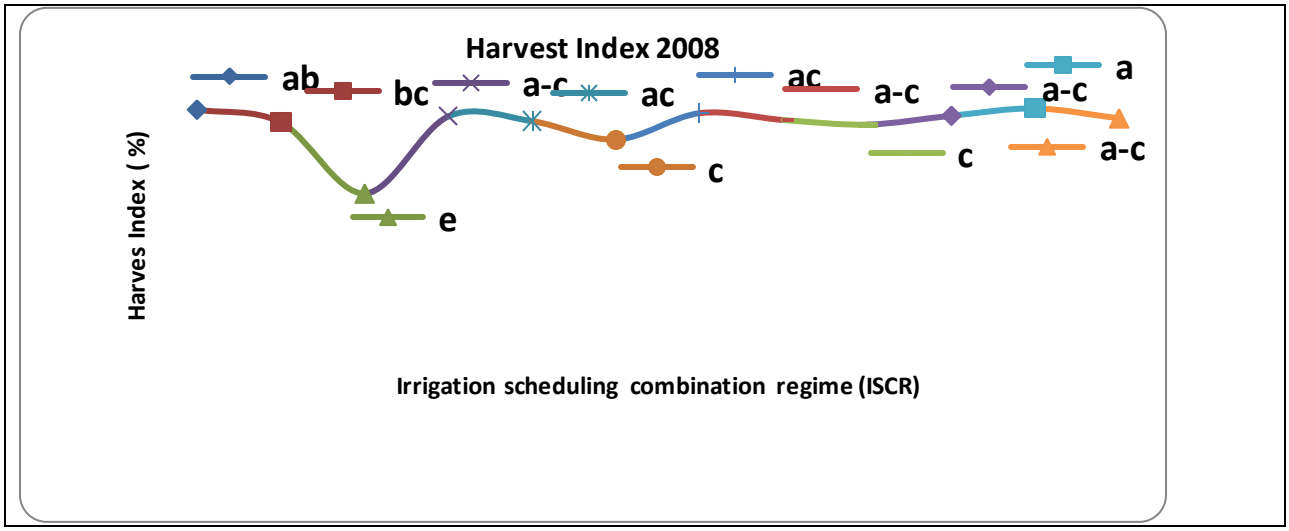
Table (4) The interaction of genotypes x ISCR in grain yield in season 2007

ISCR	EWV (m^3ha^{-1} $season^{-1}$	Bhooth14	Bhooth15
D30P10	3000	3666.7	3477.8
$D_{30}P_{15}$	2100	2300	1361.1
$D_{30}P_{20}$	1500	300	250
$D_{40}P_{10}$	4000	4055.6	4844.4
$D_{40}P_{15}$	2800	3255.5	2566.7
$D_{40}P_{20}$	2000	988. 9	977.8
$D_{50}P_{10}$	5000	4944.4	4777.7
$D_{50}P_{15}$	3500	4377. 8	4211.1
$D_{50}P_{20}$	2500	2866.6	2261.1
$D_{60}P_{10}$	6000	4983.3	5020
$D_{60}P_{15}$	4200	5155.6	5166.7
$D_{60}P_{20}$	3000	3833.3	3150
LSD0.05		607.84	

Harvest index:

Analysis of variance showed highly significant (*p0.01*) differences between irrigation scheduling combination regimes (ISCR) in harvest index (HI) of wheat genotypes in both seasons. Harvest index means for each ISCR treatment in the two seasons are shown in (Fig. 7). In the 1st season the highest harvest indices with no significant differences (≥35 %) were obtained by the irrigation regimes ≥ 3500 m^3 ha^{-1} (by the combinations $D_{60}P_{10}$, $D_{60}P_{15}$, $D_{60}P_{20}$, $D_{50}P_{15}$, and $D_{40}P_{10}$) and in the 2nd season the highest harvest indices (≥35%) with no substantial differences were achieved by the irrigation regimes ≥ 3000 m^3 ha^{-1} (by the combinations $D_{60}P_{10}$, $D_{60}P_{15}$, $D_{60}P_{20}$, $D_{50}P_{10}$, $D_{50}P_{15}$, $D_{40}P_{10}$ and $D_{30}P_{10}$). Whoever, there were statistically differences in HI means between irrigation regimes which are lower than 3500 m^3 ha^{-1} in the 1st season (under the combinations $D_{30}P_{20}$, $D_{30}P_{15}$, $D_{30}P_{10}$ and $D_{40}P_{20}$) and ≤ 3000 m^3 ha^{-1} in the 2nd season (under the combinations $D_{30}P_{20}$, $D_{30}P_{15}$, $D_{30}P_{10}$ and $D_{40}P_{20}$). The least HI obtained by the combination $D_{30}P_{20}$ (1500 m^3ha^{-1}) which was 27.5 % in 1st season and 24.5 in the 2nd season. These results revealed that the efficiency of wheat genotypes in dry matter redistribution was affected significantly only under threshold of irrigation regime (4000 m3 ha-1), above this threshold irrigation regimes had insignificant effect in H. (Arous etal. (2002) reported that in water limited environments, grain yield could be modelled by Passioura equation: GY = Water used * $WUE_{biomass}$ * HI. According with this model, grain yield could be increased by (a) the capture more water (b) the efficiency for producing dry matter per unit of used water,WUE, and (c) the ability to devote more assimilates to the grains, HI.





Means with the same letter are not significantly different

Fig.(7):The effects of irrigation schedule combination regimes in harvest index of wheat in 2007 and 2008 growing seasons

Yield components :

ANOVA analysis revealed that irrigation scheduling combination regimes affected significantly (p0.01) on a number of spikes m^{-2} and number of kernels $spike^{-1}$ but insignificantly on 100-kernal weight in both seasons. Mean yield component traits are shown in Table 5. These means reflect significant reduction as water stress increased for spikes m-2 and for kernels spike-1 , but 100-kernel weight was not affected in both seasons. These results denoted that spikes m^{-2} and kernels $spike^{-1}$ responded positively together for improving soil moisture, with insignificant response in 100 –kernel weight trait, that might be related to the high compensatory ability of wheat yield component. These results are in agreement with results founded by Duggan; et. Al. (2000) who said that without yield component compensation, a cultivar can be unresponsive to improved crop water conditions (stable) or it can have a high mean yield, but it cannot possess both characteristics. The observation of no significant differences under short irrigation period with increasing irrigation water depth from 30 to 60 mm (combination $D_{30}P_{10}$, $D_{40}P_{10}$, $D_{50}P_{10}$ and $D_{60}P_{10}$) that meant an existing of narrow sink capacity of studied wheat genotypes which is controlled by genetic limit, and there is no need to add more water than 3000 m^{-3} $ha^{-1}season^{-1}$ by the combination $D_{30}P_{10}$, because this amount was enough to forbid tiller die – back, and was enough to build enough source size to fill available sink size (kernels spike-1 and kernel size). Analysis of variance also showed significant variation (p 0.01) among wheat genotypes (Bhooth14 and Bhooth15) only in spikes m^{-2} in the 1st season and (p0.05) on 100- kernel weight in the 2nd season. Kernels per spike of both genotypes were not varied in both seasons that might be reflection to the prevailing conditions in each season. Many other studies found similar results ,Johari-Pireivatlou (2011) , Kilic and Yagbsanlar (2010 , Khayatnezhad et al (2010) reported that spike number, grain number per spike and 1000 kernel weight were affected significantly by water stress.

Table (5)The means of spikes m-2, kernels spike-1and a hundred kernel weight of studded wheat genotypes under ISCR treatments in 2007 and 2008 growing season.

Treatments	No. Of Spikes/m2		No. Of Kernels spike-1		100-kernal weight	
	2007	2008	2007	2008	2007	2008
ISC						
$D_{30}P_{10}$	388 ^{ab}	321 $^{c-e}$	31.8 $^{a-d}$	49.2 ^{cd}	4.4	4.1
$D_{30}P_{15}$	293 ^{de}	300 $^{d-f}$	30.0 $^{b-e}$	42.8 ^{fg}	3.6	3.9
$D_{30}P_{20}$	230 ^{f}	244 ^{g}	20.2 ^{e}	32.8 ^{h}	4.1	4.0
$D_{40}P_{10}$	402 ^{a}	339 $^{b-d}$	40.3 ^{a}	55.2 ^{ab}	3.7	4.0
$D_{40}P_{15}$	330 ^{c}	314 $^{c-f}$	37.7 $^{a-c}$	48.2 $^{c-e}$	3.9	3.7
$D_{40}P_{20}$	277 ^{e}	271 ^{fg}	27.7 ^{de}	41.4 ^{g}	4.0	4.0
$D_{50}P_{10}$	407 ^{a}	398 ^{a}	37.4 $^{a-d}$	57.0 ^{a}	3.9	4.2
$D_{50}P_{15}$	356 ^{bc}	284 $^{a-c}$	41.5 ^{a}	51.0 $^{c-d}$	4.2	4.0
$D_{50}P_{20}$	284 ^{e}	286 $^{e-g}$	28.8 $^{c-e}$	46.5 $^{d-f}$	4.5	4.1
$D_{60}P_{10}$	379 ^{ab}	319^{c-f}	39.4 ^{ab}	54.7 ^{ab}	4.4	4.1
$D_{60}P_{15}$	342 ^{c}	373 ^{ab}	40.0^{a}	52.5^{a-c}	4.6	4.2
$D_{60}P_{20}$	326 ^{cd}	234 $^{e-g}$	32.6 $^{a-d}$	44.1 $^{e-g}$	4.1	*3.8*
$LSD_{0.05}$	36.4	48.94	9.91	5.09	0.74	0.38
Genotypes						
Bhooth14	347^{a}	309^{a}	33.8^{a}	48.2^{a}	4.1^{a}	4.1^{a}
Bhooth15	321^{b}	325^{a}	34.0^{a}	47.7^{a}	4.1^{a}	3.9^{b}
$LSD_{0.05}$	18.16	23.40	3.19	2.46	0.27	0.16

.Means followed by different letters within a column for each year have significant differences at the level of $P<0.05$ for LSD test

Table (6):The interaction of ISCR x genotype in a 100-kernel weight in 2008 growing season

ISCR	EWV (m^3ha^{-1} $season^{-1}$	Bhooth14	Bhooth15
$D_{30}P_{10}$	3000	4.34	3.80
$D_{30}P_{15}$	2100	3.48	4.26
$D_{30}P_{20}$	1500	4.16	3.78
$D_{40}P_{10}$	4000	4.12	3.86
$D_{40}P_{15}$	2800	3.78	3.54
$D_{40}P_{20}$	2000	4.32	3.72
$D_{50}P_{10}$	5000	4.24	4.20
$D_{50}P_{15}$	3500	4.00	4.02
$D_{50}P_{20}$	2500	4.24	3.88
$D_{60}P_{10}$	6000	4.32	3.76
$D_{60}P_{15}$	4200	4	3.94
$D_{60}P_{20}$	3000	3.60	3.92
LSD0.05		0.92	

Crop water productivity:

Analysis of variance showed significant (p0.01) differences between irrigation scheduling combination regime effects on wheat water productivity (WWP) in both seasons. Means of WWP (Fig. 8 and Table 8) revealed that the range of CWP was expanded from 0.33 to 1.19 kg $ha^{-1}m^{-3}$ in the 1st season and from 0.55 to 1.25 kg $ha^{-1}m^{-3}$ in the 2nd season. The highest WWP was obtained by the combinations $D_{60}P_{20}$, $D_{60}P_{15}$, $D_{50}P_{15}$, $D_{30}P_{10}$, $D_{40}P_{10}$ $D_{50}P_{20}$, $D_{40}P_{15}$ and $D_{50}P_{10}$ in the 1st season and the combinations $D_{50}P_{20}$, $D_{60}P_{15}$, $D_{50}P_{15}$, $D_{60}P_{20}$, $D_{40}P_{15}$, $D_{30}P_{10}$ in the 2nd season.. The equivalent irrigation regimes of these irrigation scheduling combinations are located within certain range was from 3000 to 5000 m^3 ha^{-1} in the 1st season and ranging from 2500 to 4000 m^3 ha^{-1} in the 2nd season. The corresponding WWP of these regimes were in a decreased array, within the range from 1.19 to 0.97 and from 1.25 to 1.12 kg $ha^{-1}m^{-3}$ with insignificant differences in the 1st and 2nd seasons respectively. The lower WWP were achieved by lower or larger regimes outside certain best threshold as shown in Table 8 and Fig.8. These results proved that using irrigation water outside certain limit is considered mismanagement of irrigation water application in field level because neither saving water nor increasing grain yield. So, if the amount of water counted for >3000 m3 with no substantial gain, that denotes economically bad decision due to degradation of natural resources specifically water land and human efforts with no benefit that will lead to increase food poverty instead of food security.

Table (8): Mean values and order of the ISCR effects on CWP (kg $ha^{-1}m^{-3}$) of wheat genotypes in 2007 and 2008 growing seasons

ISCR	EWV (m^3ha^{-1} $season^{-1}$	CWP (kg ha-1m-3)			
		2007		2008	
		Value	order	Value	order
$D_{60}P_{20}$	3000	1.19 ^{a}	1	1.13^{b}	3
$D_{60}P_{15}$	4200	1.17 ^{ab}	2	1.14 ^{ab}	2
$D_{50}P_{15}$	3500	1.16 ^{ab}	3	1.14 ^{ab}	2
$D_{30}P_{10}$	3000	1.14 ^{ab}	4	1.12 ^{ab}	4
$D_{40}P_{10}$	4000	1.09^{abc}	5	1.01 ^{dc}	6
$D_{50}P_{20}$	2500	1.06^{abc}	6	1.25 ^{a}	1
$D_{40}P_{15}$	2800	1.02^{abc}	7	1.13 ^{b}	3
$D_{50}P_{10}$	5000	0.97^{abc}	8	0.91 ^{d}	8
$D_{30}P_{15}$	2100	0.91 ^{bc}	9	1.05bc	5
$D_{60}P_{10}$	6000	0.86 ^{c}	10	0.76 ^{e}	9
$D_{40}P_{20}$	2000	0.56 ^{d}	11	0.94^{cd}	7
$D_{30}P_{20}$	1500	0.33 ^{d}	12	0.55^{f}	10
$Lsd_{0.05}$		0.266		0.112	

Means followed by different letters within a column for each year have significant differences at the level of P<0.05 for LSD test

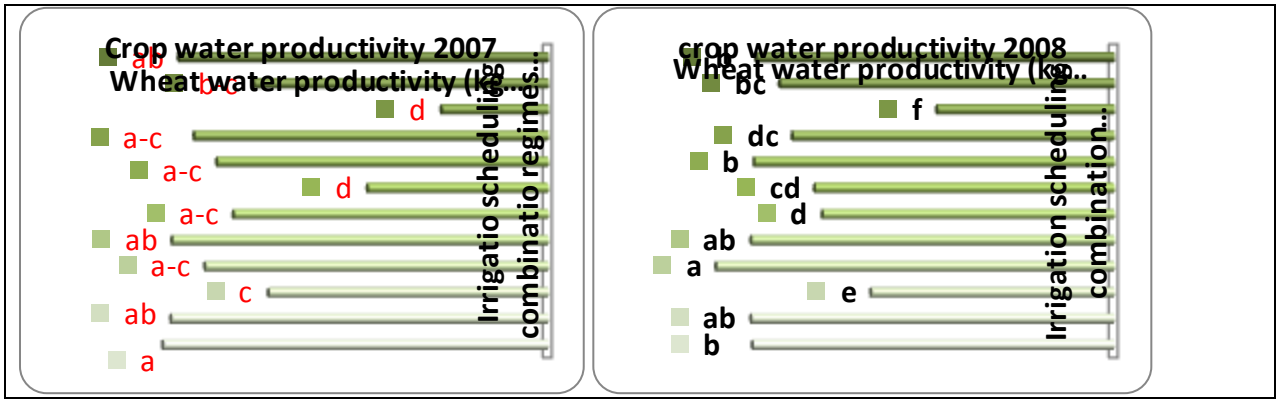


Fig.(8):The effects of irrigation scheduling combination regimes on crop water productivity of tow wheat genotypes in 2007 and 2008 growing seasons

Considering that is the main limiting resource in dry areas, the loss of grain yield due to deficit irrigation may be negligible compared with the saving in water (Owies et al. 2000). These author reported that WUE_{yield} of bread wheat under Mediterranean conditions was higher at 2/3 0f irrigation requirements compared with at full irrigation, where WUE_{yield} was lower. Peck and Kirkham (1979) stated that water use efficiency was maximum when irrigation water was applied under the modified regime, which received 7.6 cm less water. Also Oweis et al (1998a) mentioned that under scarcity conditions, maximum WP of wheat occurs at sub-optimal crop yield per unit area, but water saved by maximizing WP can be used to irrigate more land in dry areas and hence increase the total production of food .Analysis of variance showed a significant (p 0.01) differences among studied genotypes (Fig 9). Bhooth15 statistically exceeded Bhooth14 under 2nd season conditions (Bhooth14 was markedly infected by leaf rust disease in this season). Johari-Pireivatlou (2011) reported that significant genotypic variations were observed among studied durum wheat cultivars in water use efficiency.

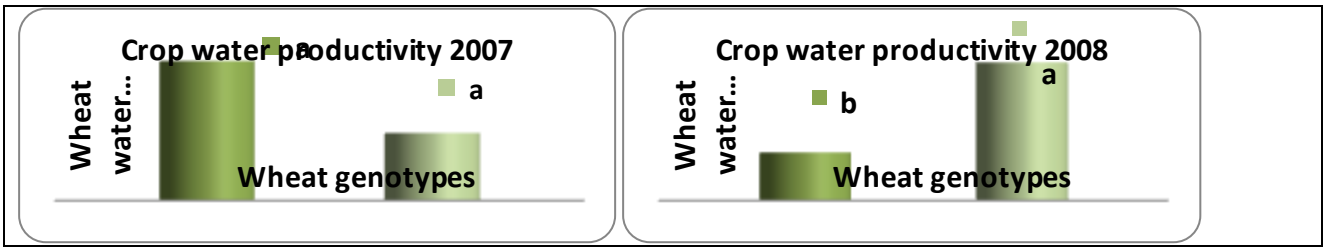


Fig.(9):The differences between two wheat genotypes in crop water productivity under irrigation scheduling combination regimes in 2007 and 2008 growing seasons

Conclusion

Irrigation schedule combination regimes affected significantly in plant height, BIY, GRY, HI, spikes m-^{2}. Kernels spike^{-1}, and WWP in both growing seasons. But 100-kernal weight was not varied significantly under ISCR in both seasons. Delaying irrigation application period from 10 to 20 days with the depth of 30, 40, 50 and 60 mm caused statistically reduction in plant height, BMY, GRY, spikes m^{-2}and kernels spike^{-1} in both season, but HI and 100-kernal weight were affected only under the sever water stress (low depths 30 and 40 mm with long period of

irrigation). Also, shortening irrigation application period from 20 to 10 days with the depths of 60 and 50 mm failed to achieve significant increment in WWP in comparing with that obtained by the depth 40 and 30 mm every 10 days in both season. The genotype performed differently only in BMY, GRY, spikes m^{-2} in the 1st season and in plant height, BMY, GRY, 100-kernal weight and WWP in the 2nd season. In general, comparing the grain yield produced by the combination $D_{60}P_{15}$ =4200 m^3 ha^{-1} which was 5161 and 4792 kg ha^{-1} in the 1st and 2nd seasons respectively, with that produced by $D_{60}P_{10}$ = 6000 m^3 ha^{-1} which was 5002 and 4500 kg ha^{-1} in the 1st and 2nd seasons respectively. This denotes that there is high potential to save large amount of irrigation water (1800 m^3ha^{-1}) and gain an increment in grain yield, about 159 (= 3.18 %) and 292 kg ha^{-1}(6.48%) in the 1st and 2nd seasons respectively. It could be concluded that Irrigation Scheduling Combination Regimes (ISCR) is an excellent procedure which has proven the existence of high potential to attain food security by producing more food with using less water through enhancing CWP. This procedure is a highly relevant tool to be used in many practical applications in the field, farm, scheme, regional and national level under each country conditions, with low cost and easy to implement by any farmer for promoting the potential of increasing grain yield with less water. Attaining food security in water scarce country environments is needed to expand to include more combinations of depths, periods and genotypes and replicate enough under the conditions of each agro ecological level. Then it will provide good guidelines to make ‹‹more crop per drop›› as fact.

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الإستراتيجية المتكاملة لإدارة مياه الصرف الصحي في سلطنة عمان

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المقدمة:

أدى التطور الذي شهدته معظم دول العالم وزيادة عدد السكان وارتفاع مستوى المعيشة إلى ارتفاع ملحوظ في الطلب على المياه ورغم أن بعض الدول لا تعاني من هذه المشكلة بسبب تنوع مصادر المياه التقليدية فيها ووجود هذه المياه بكميات تفي بالطلب إلا أن توزيع المياه الصالحة للاستعمال على سطح الكرة الأرضية ليس متساوياً . وقد أدى ذلك إلى اختلال التوازن بين الكميات المتوفرة من المياه والطلب الفعلي عليها ، الأمر الذي أدى إلى التفكير في تنويع مصادر المياه واستغلال أكبر كمية ممكنة منها بشتى الطرق. وتعد إعادة استعمال مياه الصرف الصحي المعالجة من طرق استغلال المياه التي تلاقي قبولاً ملحوظاً في الآونة الأخيرة . تستعمل مياه الصرف الصحي المعالجة في الأغراض الزراعية بطرق مباشرة أو غير مباشرة عن طريق ضخها في الأنهار. وبصفة عامة فإن نسبة إعادة استعمال المياه المعالجة للأغراض الزراعية تبلغ حوالي 60 %. تستخدم مياه الصرف الصحي المعالجة في الزراعة التجميلية والزينة مثل الشوارع والحدائق والمتنزهات وفي الزراعة المنتجة مثل الأعلاف والأشجار المثمرة والخضار والنخيل. وعلى ذلك فإن الاستفادة من مياه الصرف الصحي المعالجة يؤدي إلى المساهمة في الحفاظ على احتياطي المياه حيث أن استعمالها في الزراعة أو أي استعمالات أخرى بدلا عن المياه الصالحة للشرب سيؤدي إلى توفير هذه المياه والتوسع في المساحات الزراعية لإنتاج محاصيل متنوعة وبسعر أقل كذلك يقلل من التكاليف المتعلقة بإنتاج واستيراد واستعمال الأسمدة بسبب وجود العناصر الضرورية للنبات في تلك المياه ويقلل من تكاليف الحصول على المياه في الزراعة خاصة إذا كانت مصادر تلك المياه جوفية. تشير بعض المصادر العلمية بأن المياه المعالجة لها فوائد كثيرة منها المحافظة على البيئة من خلال معالجة هذه المياه وإعادتها إلى الطبيعة مرة ثانية كما تعمل على استدامة الزراعة حيث تستخدم المياه المعالجة في ري المزروعات والمسطحات الخضراء وتعتبر مصدر آخر من مصادر مياه الري لمعظم المحاصيل الزراعية ومن بينها الخضراوات. من المعروف أن مصادر المياه تنقسم إلى قسمين: مياه تقليدية(مياه الآبار والأفلاج والعيون والأنهار... الخ) ومياه غير تقليدية(مياه التحلية ومياه الصرف الصحي المعالجة ... الخ)، وتعتبر هذه الأخيرة (المياه غير التقليدية) مصدرا مهما من مصادر المياه المستخدمة في السلطنة، حيث تشكل مياه التحلية حوالي 80% من المياه المستهلكة للشرب وللأغراض المنزلية الأخرى، بينما تعد مياه الصرف الصحي المعالجة المصدر المستخدم في ري الزراعة التجميلية والتشجير والبستنة في المرافق العامة (الحدائق والمنتزهات...الخ) والمسطحات الخضراء على الشوارع العامة، وبالإمكان إعادة استخدمها أيضا في الأغراض الصناعية (مغاسل السيارات والورش والمصانع... الخ) وفي تهيئة الطرق وأغراض البناء المختلفة. لذا تعتبر مياه الصرف الصحي من العوامل المهمة المؤدية إلى حماية المياه الجوفية من الاستنزاف الجائر غير المقيد الاستخدام وذلك بتوفير مصدرا آخر للمياه يتم استعماله لأغراض عدة، وبناءا على ذلك، تبذل الحكومة الرشيدة بسلطنة عمان ممثلة في الجهات المختصة جهودا ملموسة لتحسين سبل إدارة مياه الصرف الصحي

وذلك لما يشكله هذا القطاع من أهمية كبيرة لارتباطه المباشر بصحة الإنسان وسلامة البيئة المحيطة، حيث تعد مياه الصرف الصحي أحد أهم مصادر تلوث مياه الشرب الجوفية ومصدرا لانتشار الأوبئة والأمراض المعدية وغير المعدية، وإدراكا بخطورة الآثار المترتبة على تسرب هذه المياه إلى باطن الأرض سعت الجهات المعنية بالسلطنة وما تزال في بذل جهودا حثيثة لإنشاء العديد من محطات المعالجة وربط الكثير منها بشبكات للصرف الصحي ونظرا لندرة وشح المياه في الدول ذات المناخ الحار والجاف مثل ما هو عليه مناخ السلطنة وسائر دول الخليج العربي جاءت أهمية الاستفادة من المياه المعالجة الناتجة من هذه المحطات بإعادة استخدامها في عمليات الزراعة التجميلية والبستنة والأغراض الصناعية.

وقد بلغت كميات مياه الصرف الصحي الناتجة من محطات الصرف الصحي الواقعة تحت إشراف الشركة العمانية لخدمات الصرف الصحي بمحافظة مسقط حوالي 2,17 مليون متر مكعب شهريا يتم استغلال ما يقدر ب 1,64 مليون متر مكعب شهريا كما هو موضح في الجدول رقم (1)، في حين بلغت كميات المياه المعالجة الناتجة من محطات الصرف الصحي الواقعة تحت إشراف وزارة البلديات الإقليمية وموارد المياه حوالي مليون متر مكعب شهريا يتم استغلال ما قدره 185 ألف متر مكعب شهريا كما هو موضح في الجدول رقم (2).

أهمية اللجوء إلى استخدام مياه الصرف الصحي المعالجة:-

- ازدياد الطلب للمياه في القطاع الزراعي والصناعي والاستهلاك البشري.
- ازدياد نسبة الملوحة في مياه الري بسبب تداخل مياه البحر مع المياه الجوفية نتيجة للضخ العشوائي للمياه من الآبار كما هو الحال بساحل الباطنة.
- ازدياد شح المياه وخصوصا مع ازدياد عدد السكان والتقدم المدني والعمراني.
- ازدياد كمية مياه الصرف الصحي المعالجة الناتجة والغير مستهلكة.

جودة مياه الصرف الصحي المعالجة:

من مساوئ إعادة استخدام مياه الصرف الصحي المعالجة بالطرق التقليدية (البيولوجية) أنها تسبب مشاكل صحية وبيئة إذا لم تتم معالجتها بشكل صحيح بسبب عدم قدرتها على التخلص من كافة أنواع الكائنات الحية الممرضة مثل الفيروسات وبعض أنواع البكتيريا وبيض الديدان المعوية وغيرها، إضافة إلى أنها قد تحتوي على تركيزات عالية من المعادن الثقيلة والمواد الكيميائية كالهرمونات مثلا التي لا تتم إزالتها في مراحل المعالجة التقليدية والتي قد تشكل خطرا على البيئة المحيطة والنباتات والكائنات الحية ، وفي حال استعمالها في تغذية المياه الجوفية فيوجد هناك الكثير من المحاذير المتعلقة بالتقنيات المستخدمة في عملية التغذية سواءا كانت تغذية سطحية أو حقن مباشر وتأثيرها على الصحة العامة للإنسان.

واستكمالا للنهج الذي تتبعه الحكومة للحفاظ على صحة الإنسان والبيئة أولت قطاع الصرف الصحي اهتماما بالغا وبذلت كل الجهود المتاحة لمعالجتها المعالجة السليمة بأحدث التقنيات المستخدمة في عمليات المعالجة كاستخدام نظام الأغشية (MBR) والمطبق حاليا في عدد من محطات المعالجة بالسلطنة والذي يساهم في الحصول على مياه معالجة عالية الجودة لأنه يعمل على التخلص من العوالق ذات الأحجام الصغيرة جدا والتي تصل إلى 0.1 ميكرون بالإضافة إلى التخلص الفعال من كافة الكائنات الحية الممرضة والديدان المعوية،بحيث يوسع مجالات إعادة استخدام مياه الصرف الصحي المعالجة بشكل آمن لا يضر بالصحة العامة للإنسان وسلامة البيئة المحيطة.

أما فيما يتعلق بالفحوصات والتحاليل التي تطبق على عينات مياه الصرف الصحي المعالجة فأهمها فحص الاحتياج الكيمائي الحيوي للأوكسجين (BOD) والاحتياج الكيميائي للأوكسجين (COD) وفحص المواد الصلبة العالقة والذائبة الكلية والأس الهيدروجيني، فحص الأمونيا والنترات الخ. كما أن هناك بعض الفحوصات المتعلقة بالجانب البكترولوجي مثل العد الكلي للبكتريا الكوليفورم (Coliform) والبكتيريا العصوية الغائطية (E-coli) كما هو موضح في الجدول رقم (3) مع توضيح المعايير كما صدرت في (اللائحة93/145).

مجالات استخدام مياه الصرف الصحي المعالجة

أ-مجال الزراعة

1. على مستوى العالم:

لقد أجريت دراسات وأبحاث مختلفة حول استعمال مياه الصرف الصحي المعالجة في زراعة المحاصيل الزراعية المختلفة وفي مناطق مختلفة من العالم. فعلى سبيل المثال استخدمت هذه المياه في ري محصول الطماطم وأدى إلى زيادة في حجم الثمار ، وفي دراسة أجريت في الأردن تبين بأن زراعة الباذنجان تحت ظروف المياه المعالجة أعطى ضعف حاصل الباذنجان المنزرع بالمياه الاعتيادية وباستخدام طرق التسميد التقليدية.

وفي دراسة أخرى أجريت في الهند في عام 1988م وجد بأن استخدام المياه المعالجة ولمدة 15سنة قد زاد محتوى التربة من الكربون العضوي وبدون أي زيادة في المعادن الثقيلة ، وفي دراسات أجريت في كازاخستان في عام 2001م وبالتعاون مع إيكاردا أظهرت النتائج بنجاح استخدام المياه المعالجة في ري المحاصيل.

هناك أربعة عناصر من المعادن الثقيلة التي يجب أن تؤخذ بعين الاعتبار بالنظر إلى صحة الإنسان والتي ربما توجد بتراكيز سامة في المياه المعالجة وهي النحاس (Cu) والنيكل (Ni) والزنك (Zn) والكاديميوم (Cd) والسؤال الذي يطرح نفسه دائماً هو هل المياه المعالجة تزيد من تركيز هذه المعادن في النبات وتؤثر في نمو المحاصيل؟ وكانت الإجابة من قبل وكالة حماية البيئة الأمريكية (USEPA) في عام 1981 أن المعادن الثقيلة ليس لها تأثير عكسي على نمو المحاصيل في مواقع مختلفة في الولايات المتحدة الأمريكية والتي استخدمت فيها المياه المعالجة ولفترة تزيد على 38 سنة .

أشارت بعض الدراسات في عام 1979م وفي إحدى المزارع التي تستخدم مياه الصرف الصحي في استراليا بأن استخدام هذه المياه ومنذ عام 1893م قد أدى إلى زيادة طفيفة في تركيز المعادن الثقيلة عند استخدامها في ري المحاصيل مقارنة بالمياه العادية ، وأكدت بعض الدراسات على أنه عند ري الخضروات بالمياه المعالجة فأن معظم المعادن الثقيلة تبقى في منطقة الجذور وهناك جزء طفيف ينقل إلى الأفرع وجزء آخر بسيط جداً لا يكاد يذكر يتحول إلى الثمار .

يعد مشروع مدينة موسكيغون بولاية ميتشجان الأمريكية لإعادة استعمال مياه الصرف الصحي من أحدث المشاريع التي أنشئت للاستفادة من تلك المياه في الزراعة وقد صمم هذا المشروع بحيث تمر تلك المياه أولا على الأراضي الزراعية ثم تصب بعد ذلك في البحيرة وتعد عملية مرور المياه في الأراضي الزراعية إحدى الطرق لإزالة الملوثات إضافة إلى فائدتها في ري بعض المحاصيل ويقوم هذا المشروع بري أكثر من 2000 هكتار من الأراضي المزروعة بمحصول الذرة .

أشارت إحدى الدراسات بأن الإنتاج العالي من الحبوب في محصول القمح وكفاءة استخدام النيتروجين يمكن الحصول عليهما من خلال استخدام معدلات قليله من النيتروجين إذا تم ري محصول القمح بمياه الصرف الصحي المعالجة. وفي إيران وجد بأن استخدام المياه المعالجة المضافة كتعويض للري قد أدى إلى زيادة تركيز في العناصر الكبرى (N و P و K) في الأوراق والجذور.

2. في سلطنة عمان:

في السلطنة أجريت عدة دراسات في محطة البحوث الزراعية ، الرميس ، للفترة من 2004 إلى 2010 بهدف استخدام مياه الصرف الصحي المعالجة ثلاثيا في زراعة الأعلاف والمحاصيل الحقلية الأخرى. شملت هذه الدراسات ما يلي:

1) استخدام المياه المعالجة في ري الأعلاف الحولية (الذرة الصفراء والذرة الرفيعة والشعير).
2) الإنتاجية وكفاءة استخدام المياه لمحصول الذرة تحت المياه المعالجة.
3) تأثير نظام الزراعة بدون حراثة على المحاصيل الحقلية تحت ظروف المياه المعالجة.
4) استخدام المياه المعالجة في ري محصول قمح الخبز.

وبصورة عامة أظهرت النتائج أن طول النبات ، والعلف الأخضر والمادة الجافة (طن/ هكتار) قد ازداد تحت تأثير المياه المعالجة وكذلك الحال بالنسبة لحاصل حبوب القمح حيث بلغ ضعف متوسط إنتاج القمح تحت الري بالمياه العذبة. وفيما يتعلق بالمعادن الثقيلة والنوعية الميكروبية للمياه المعالجة فقد وجد أن تركيز المعادن الثقيلة والميكروبات كانت منخفضة جدا أو في ضمن حدود المواصفات القياسية العمانية.

ومن خلال هذه الدراسات يمكن الاستنتاج بأن مياه الصرف الصحي المعالجة ثلاثيا تشكل مصدرا هاما لزراعة المحاصيل العلفية (الذرة الشامية والذرة الرفيعة والشعير) بالإضافة إلى محصول القمح في سلطنة عمان. خاصة بعد أن تم إجراء معظم التحليلات الكيميائية والفحوصات الميكروبية والحيوية للمياه والنبات وتبين خلوها من النشاط الميكروبي مقارنة بالمواصفات القياسية العمانية. هذا بالإضافة إلى أن هذه المياه لم تؤثر في تركيز المعادن الثقيلة في المحاصيل تحت الدراسة مقارنة بالمياه العذبة وربما يعود السبب في ذلك إلى أن نوعية هذه المياه جيدة وعولجت بطريقة متطورة.

كما قامت وزارة الزراعة والثروة السمكية ممثلة بالمديرية العامة للبحوث الزراعية والحيوانية بتنفيذ مشروع تنموي رائد لمدة عامين (2008-2010م) بجانب محطة معالجة مياه الصرف الصحي بولاية صحم التابعة لوزارة البلديات الإقليمية وموارد المياه وبتمويل من الشركة العمانية للغاز الطبيعي المسال (LNG) وباستخدام ثلاث محاصيل علفية (شعير وذرة رفيعة وذرة شامية). أشارت نتائج المشروع إلى زيادة إنتاج العلف الأخضر لمحصولي الذرة الرفيعة والشامية بنسبة 30% تحت ظروف المياه المعالجة عند مقارنتها بالنتائج السابقة والمتوفرة لدينا عن هذين المحصولين عند الزراعة بالمياه العذبة في حين كانت نسبة الزيادة 43% لمحصول الشعير. ظهرت نسبة المعادن الثقيلة في أنسجة النبات للمحاصيل الثلاثة بمستوى أدنى من الحدود القياسية الآمنة والموصى بها عند زراعة هذه المحاصيل تحت المياه المعالجة. وأظهر التحليل الاقتصادي نتائج إيجابية تشير للجدوى الاقتصادية لهذا المشروع مع متوسط معدل عائد الدخل 26 ٪.

الجدير بالذكر بأن وزارة الزراعة والثروة السمكية قامت بإنشاء مزرعة بحثية متكاملة تعنى بالدراسات المتعلقة باستخدامات مياه الصرف الصحي المعالجة ثلاثيا في الزراعة على المدى البعيد لمختلف المحاصيل الزراعية.

قضت الأوامر السامية لمولانا حضرة صاحب الجلالة السلطان قابوس بن سعيد المعظم حفظه الله ورعاه قضت بزراعة عدد مليون نخلة في محافظات الظاهرة والداخلية والشرقية ضمن توصيات ندوة التنمية المستدامة للقطاع الزراعي التي عقدت في ولاية عبري في شهر نوفمبر2009م ، حيث يقدر معدل الاستهلاك السنوي من المياه لزراعتها بحوالي 60 متر مكعب لكل نخلة في السنة بعد وصولها العام .
واعتمدت إستراتيجية توفير مياه الري للمشروع على عدة خيارات رئيسية من بينها إعادة استخدام مياه الصرف الصحي المعالجة ثلاثيا ، وتأكيدا على أهمية الاستفادة من مياه الصرف الصحي المعالجة ثلاثيا لجميع محطات الصرف الصحي في السلطنة فقد قام مشروع زراعة المليون نخلة بتنظيم لقاء علمي حول صلاحية استخدام مياه الصرف الصحي المعالجة ثلاثيا لري أشجار النخيل في مايو 2010م بحضور العديد من الجهات الحكومية ذات العلاقة إضافة الى القطاع الخاص وعدد من الخبراء المدعوين من المنظمات الدولية المتخصصة بهدف الاطلاع على البحوث والدراسات والتجارب الدولية في مجال استخدام مياه الصرف الصحي المعالجة وقدمت العديد من أوراق العمل ، وقد توصل المشاركون في اللقاء العلمي إلى إصدار العديد من التوصـــيات من أهمها إجراء دراسة على ثمار النخيل التي تروى بمياه الصرف الصحي المعالجة في بعض المواقع في الوقت الحاضر بالتنسيق مع جامعة السلطان قابوس ووزارة البلديات الاقليمية وموارد المياه ووزارة الزراعة والثروة السمكية والجهات المعنية الأخرى . وقد توصلت الدراسة إلى أن مكونات ثمار النخيل والسعف قد كانت ضمن المواصفات والمقاييس الدولية والعمانية مما يؤكد صلاحية استخدام المياه المعالجة ثلاثيا في ري النخيل وخلوها من أية آثار سلبية على البيئة وصحة الإنسان.

ب-تغذية المياه الجوفية

يؤدي ازدياد الطلب على المياه الجوفية في المناطق الساحلية إلى انخفاض مستواها مما ينتج عنه دخول المياه المالحة إلى طبقات المياه الجوفية ولحل هذه المشكلة يتم حقن مياه الصرف الصحي المعالجة في تلك المناطق لإيقاف تداخل المياه المالحة مع المياه العذبة إضافة إلى الاستفادة منها في تغذية الخزانات الجوفية كما هو الحال بمدينة صلالة حيث كانت آخر إحصائية سجلت حول استغلال المياه المعالجة في هذا المجال خلال شهر سبتمبر 2011م تقدر بحوالي 462ألف متر مكعب.

ج-مجال الصناعة

يتم استخدام مياه الصرف الصحي المعالجة في أغراض التبريد والتصنيع.كما هو الحال في مدينة صلالة حيث اتضح أن ما يقدر بحوالي 122 ألف متر مكعب تم استخدمه في المجال الصناعي خلال شهر سبتمبر 2011م كما هو موضح في الجدول رقم(4)..

د-استخدامات أخرى:

يتم استخدام مياه الصرف الصحي المعالجة في بعض دول العالم كالولايات المتحدة الأمريكية لضخ المياه المعالجة في الوديان وتترك لتنساب مسافة قدرها 1كم خلال الرمل والحصى قبل استرجاعها ثم توجه المياه المسترجعة بعد ذلك إلى ثلاث بحيرات متصلة ببعضها ومحاطة بحديقة عامة, تستخدم بحيرتان منها لصيد الأسماك ورياضة القوارب بينما يتم تعقيم البحيرة الثالثة بمادة الكلور لتستخدم للسباحة والمرافق الترفيهية الأخرى.
كما استخدمت مياه الصرف الصحي المعالجة رباعيا (المعالجة المتقدمة) في العديد من دول العالم لأغراض الشرب بعدما تعرضت بعض المناطق للجفاف.

التوصيات:

1. تبنى إستراتيجية وطنية لاستغلال كافة مياه الصرف الصحي المعالجة ثلاثيا واعتمادها جزءا مكملا للخطة الوطنية لاستغلال المياه باعتبارها مصدرا متجددا وقابلا للزيادة على أن يتم التركيز على استخدامها في المحاصيل التي تم إجراء الدراسة عليها.
2. استمرارية إجراء الدراسات والبحوث على المحاصيل الزراعية التي تروى بمياه الصرف الصحي المعالجة وضرورة تقييم ومراقبة مشاريع إعادة استخدام مياه الصرف الصحي المعالجة ثلاثيا في الزراعة.
3. مراجعة وتحديث اللائحة الخاصة بإعادة استخدام مياه الصرف الصحي المعالجة ثلاثيا لكي تتضمن الشروط الصحية التي تكفل إدارة المخاطر بالنسبة للكائنات الحية الدقيقة والمعادن الثقيلة.
4. ضرورة التوسع في مشاريع الصرف الصحي وذلك من خلال ربط وتوصيل المنازل والمنشآت الأخرى بالشبكات.
5. ضرورة إجراء مراقبة وتقييم لأداء محطات الصرف الصحي للتأكد من كفاءتها وجودة المياه المنتجة وفق المعايير المعتمدة.
6. تشجيع إنشاء مشاريع تعتمد على مياه الصرف الصحي المعالجة.
7. توعية المجتمع بأهمية مياه الصرف الصحي المعالجة ثلاثيا وصلاحية استخدامها في المجالات الزراعية والصناعية.
8. أهمية تشكيل لجنة فنية منبثقة من لجنة دائمة تعنى بمتابعة مياه الصرف الصحي المعالجة.

جدول رقم (1) محطات الصرف الصحي التابعة لمحافظة مسقط:

اسم المحطة	سعة المحطة (م3/اليوم)	كمية المياه المعالجة الناتجة (م3) شهريا	كمية المياه المعالجة المستخدمة (م3) شهريا
الأنصب(القديمة+الجديدة)	65.800	1.281.111	1.009.972
دارسيت	21.000	594.770	407.035
شاطئ القرم	7.500	91.283	35.731
المعبيلة	1.950	80.475	80.475
الخوض	600	38.259	33.406
مدينة السلطان قابوس	2.500	37.245	37.245
العامرات	850	18.609	18.497
قريات	1.300	13.683	5.461
بوشر	420	5.794	4.291
المنومة	80	3.520	3.510
جبرو (حي المينا)	150	2.332	2.332
عينت	150	1.612	-
المجموع		2.168.694	1.637.955

جدول رقم(2) كميات المياه المعالجة الناتجة من محطات الصرف الصحي

م	الولاية	السعة (م3/اليوم)	كمية المياه الداخلة (م3/اليوم)	كمية المياه الخارجة (م3/اليوم)	كمية المياه المستخدمة (م3/اليوم)	كمية المياه الغير مستخدمه (م3/اليوم)	الملاحظات
1	هيماء	120	37	35	35	-	
2	دباء	120	125	121	9	112	
3	نزوى - السوق	250	148	128	128	-	تستخدم للغرض الزراعي
4	خصب	600	399	279	159	120	تستخدم للغرض الزراعي
5	سمائل الجديدة	2700	1403	1166	-	-	
6	نزوى – وادي كلبوه	450	217	203	194	9	تستخدم للغرض الزراعي
7	الجبل الأخضر –سيح قطنه	120	113	94	17	77	
8	السويق	120	94	67	57	10	تستخدم للغرض الزراعي
9	عبري	1800	1699	1676	896	780	تستخدم للغرض الزراعي
10	محضة	2500	3222	3221	-	-	
11	صور القديمة	2000	1072	1070	161	909	تستخدم للغرض الزراعي
12	إبراء	4500	918	883	815	68	تستخدم للغرض الزراعي

13	بخاء	180	68	63	27	36	تستخدم للغرض الزراعي
14	سناو	120	73	68	22	46	تستخدم للغرض الزراعي

جدول رقم(2) كميات المياه المعالجة الناتجة من محطات الصرف الصحي

م	الولاية	السعة (م3/اليوم)	كمية المياه الداخلة (م3/اليوم)	كمية المياه الخارجة (م3/اليوم)	كمية المياه المستخدمة (م3/اليوم)	كمية المياه الغير مستخدمه (م3/اليوم)	الملاحظات
15	بدبد	250	69	64	57	7	تستخدم للغرض الزراعي
16	إزكي	180	153	141	140	1	
17	القابل	250	93	80	71	9	
18	جعلان بني بو حسن	600	291	276	100	176	
19	المضيبي	600	159	145	104	50	
20	ينقل	250	219	215	118	97	تستخدم للغرض الزراعي
21	ضنك	250	190	185	10	175	
22	بهلاء	600	52	30	17	13	تستخدم للغرض الزراعي
23	بركاء	2000	2243	1682	461	1221	
24	الكامل و الوافي	250	129	117	59	58	
25	جعلان بني بو علي	600	251	219	98	121	
26	شناص	600	495	446	329	117	
27	بدية	300	181	149	112	37	
28	الرستاق	7200	2611	2559	802	1757	
29	صحم	5000	1995	1793	436	-	
30	مصيرة	1800	965	917	5	912	

جدول رقم(2) كميات المياه المعالجة الناتجة من محطات الصرف الصحي

م	الولاية	السعة (م3/اليوم)	كمية المياه الداخلة (م3/اليوم)	كمية المياه الخارجة (م3/اليوم)	كمية المياه المستخدمة (م3/اليوم)	كمية المياه الغير مستخدمه (م3/اليوم)	الملاحظات
31	صور - الجديدة	1400	1140	1057	454	603	تستخدم للغرض الزراعي
32	البريمي - الجديدة	3000	3377	3272	1955	1317	
33	نزوى - الجديدة	5600	3947	3540	320	2220	المتبقي سيتم استخدامه في مشروع النخيل
34	محوت -النجدة	120	79	78	-	-	
35	منح	180	97	58	50	8	
36	الجزع	180	62	61	-	-	
37	حمراء الدروع	180	34	30	19	1	
38	الحمراء	120	48	43	43	-	
39	لوى الجديدة	3000	2052	1949	278	1671	تستخدم للغرض الزراعي
40	نزوى - الرحبة	100	7	7	-	-	
41	الجبل الأخضر- سيق	150	45	40	-	-	
42	الخابورة	500	438	409	-	-	
43	المصنعة	950	778	720	198	522	
	الإجـــــمالـــــــــــــــي		31.788	29.353	8.756	13.260	

جدول رقم (3) بعض معايير مياه الصرف الصحي المعالجة (اللائحة 93/145):

المـــــــــــــــادة	المعيار {مليجرام/ لتر}	
	أ	ب
الاحتياج الكيميائي الحيوي للأوكسجين{5 ايام عند 20 درجة مئوية} BOD	15	20
الاحتياج الكيميائي للأوكسجين COD	150	200
المواد الصلبة العالقة SS	15	30
المواد الصلبة الذائبة الكلية TDS	1500	2000
عدد عصيات القولون البرازية (في كل 100مللتر) Faecal Coliform (per 100ml)	200	1000
عدد بويضات الدودة الشريطية الحية (في كل لتر)	<1	<1
الاس الهايدروجيني PH	6 - 9	6 - 9
النشادرأو أمونيا { على شكل نيتروجين}(Ammonia (as N	5	10
نيتروجين النترات { على شكل نترات } Nitrate (as NO3)	50	50
النيتروجين العضوي { على شكل نيتروجين} Organic Nitrogen (as N)	5	10
البورون {على شكل بورون} Boron(as B)	0.5	1
الكادميوم { على شكل كادميوم} Cadmium (as Cd)	0.01	0.01
السيانيد { على شكل سيانيد} Cyanide (total as CN)	0.05	0.1

جدول رقم(4) مجالات إعادة استخدام المياه المعالجة (اللائحة 93/145):

	(أ)	(ب)
المحاصيل	الخضروات والفواكه المحتمل أكلها طازجة خلال أسبوعين من الري	الخضروات المطبوخة أو التي تم تصنيعها . الفواكه إذا لم يتم ريها خلال أسبوعين من حصادها . الأعلاف والغلال والحبوب
الحشائش و مناطق الزينة	الحدائق العامة أعشاب حدائق الفنادق المناطق الترفيهية المناطق والبحيرات التي يرتادها الجمهور	المراعي و المناطق التي لا يرتادها الجمهور .
تغذية الخزانات الجوفية	جميع أنواع الخزانات الجوفية المراقبة والمقيدة من قبل الوزارة	
أساليب الري	الري بالرشاشات أو أساليب الري الهوائية الأخرى التي لا يسمح بها في المناطق التي يرتادها الجمهور إلا في أوقات محدودة .	
أي تطبيقات أخرى لإعادة الإستخدام	تخضع لموافقة الوزارة	

Treated Wastewater Management and Reuse in Arid Regions: Abu Dhabi Case Study

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Abstract

In arid regions, treated wastewater is an environmental, social, and economic resource that needs to be managed in an appropriate way. Reusing of treated effluent that is normally discharged into the environment from municipal wastewater treatment plants is receiving increasing attention as a reliable water resource. The volume of this resource is being considered in the planning and implementation of water resources projects. Irrigating agricultural crops with recycled wastewater has been practiced in arid and semi-arid regions and is rapidly getting popular in the countries of the Arab Regions. In the last three decades, rapid economic development coupled with population growth and large agricultural sector expansion have forced the government to rely on non-conventional water resources such as desalination and treated wastewater as secondary sources for irrigation water supply. Treated wastewater has the most potential as marginal water suitable for growing forages, landscaping, fruit orchards and non-vegetative crops. In Abu Dhabi Emirate, the annual production of treated wastewater is about 450 million cubic meters which is about 7.2% of the total Emirate water production. Only about 60% of the treated wastewater is reused in wetlands, landscaping, and recreation areas due to the capacity of distribution system after treatment. Recently, a new strategy for assessing the alternative options for reusing the treated wastewater was developed including irrigation of agriculture crops and aquifer recharge. Irrigating agricultural crops with recycled wastewater has been practiced in arid and semi-arid regions and is rapidly getting popular in the countries of the Arab Region. Reuse of treated wastewater involves several types of risks: Health, Environmental, Economic and Strategic. It is difficult to measure these risks. This paper presents assessment of different options for reuse of the treated wastewater and maps out the risks, creating a basis for understanding the continuation of the work plan that will create financial functions representing various risks. However, when making such an analysis, one must consider the cost of avoiding the development of a treated wastewater supply project. The main soils commonly existing in the project area, Al Nahda agriculture farms, are classified according to the USDA Soil Taxonomy as Typic Torripsamments, mixed, hyperthermic. They are typically excessively drained or somewhat excessively drained and have rapid to very rapid permeability. The

texture is fine sand with low electrical conductivity (ECe less than 2 dS/m) and negligible quantities of gypsum and carbonates.

Keywords: Environment, Treated Wastewater, Abu Dhabi, UAE, Soil, Agriculture, Aquifer Recharge.

1. General Background

Wastewater reuse has drawn increasing attention worldwide as an integral part of water resources management. Such a move is driven by two major forces: scarcity of freshwater resources and heightened environmental concerns. Meanwhile, economical considerations are also becoming increasingly important amid the introduction of market-based mechanisms in environmental and water resources management. Reclaimed wastewater from municipalities and industries has been used as an additional source of water supply in many parts of the world, especially in areas where water resources are scarce and population and economic growth is rapid. The situation in Abu Dhabi is a typical case in point. Reclaimed wastewater can be used for many purposes, including agricultural irrigation, groundwater recharge, car washing, toilet flushing, urban lawn watering and recreational amenities, road cleaning, etc. Of all the users of reclaimed wastewater, public gardens irrigation has been by far the major user in many areas in Abu Dhabi Emirate where wastewater is reused. This is mainly because of the large water use in irrigation, relatively low quality requirement, and relatively low cost of infrastructure for the irrigation water supply. Reclaiming and reusing the wastewater is not a new concept. The practice can be traced back to several centuries ago. In the scientific literature, there are a large number of studies on wastewater treatment from technological and engineering aspects. Concerns on health impacts of using reclaimed wastewater, especially for irrigation and groundwater recharge have also drawn increasing attention in the last decade. However, studies of the economic viability and institutions of wastewater reuse have been few.

Treated domestic effluent is a valuable extra water source that can be reused for diverse purposes, primarily for agriculture production, aquatic life preservation, and aquifer recharge. Groundwater enrichment with effluent is maintained primarily via Soil Aquifer Treatment (SAT) (Quanrud et al. 2003). Advanced wastewater treatment is required in order to maintain adequate levels of sustainable agriculture production, decelerated Stalinization processes of the ground waters and to prevent long range adverse effects of gradual environmental pollution (Rebhun 2004). Complying with these challenging goals can be attained mostly by implementing the membrane technology (Lopez et al. 2003).

Abu Dhabi Emirate is an arid region where the average annual rainfall is less than 100mm. The water resources components found within the Emirate are traditional or conventional resources (rainfall, springs, wadis, sabkhas, lakes, ponds and groundwater) and non-traditional or unconventional resources (desalinated water and treated wastewater). Groundwater occurs in the Emirate as either consolidated or unconsolidated surficial deposit aquifers or as bedrock/structural aquifers and contributes 63.6% to the total water demand, followed by desalinated water (29.2%) and treated wastewater (7.2%) as shown in Figure (1).

Groundwater supply is decreasing and the imbalance between supply and demand is being filled by ever increasing amounts of desalinated water (EAD, 2009a).

Although wastewater reclamation and reuse has been recognized as a promising strategy to alleviating water scarcity and reducing the impacts on the environment, the actual reuse of treated wastewater is rather limited. In Abu Dhabi Emirate only 60% of the total treated quantities are reused and the rest are discharged into the environment (RSB, 2009). Increasing the reused volumes will relieve the pressure in using costly desalinated water and the over-abstracted brackish groundwater as show in Figure (2).

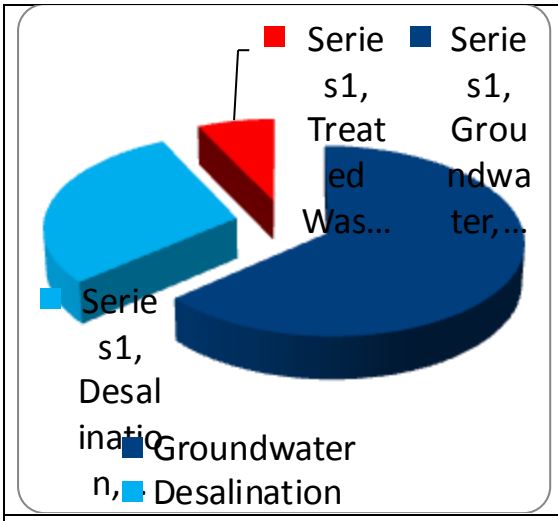

Figure 1: Abu Dhabi Water Resources.

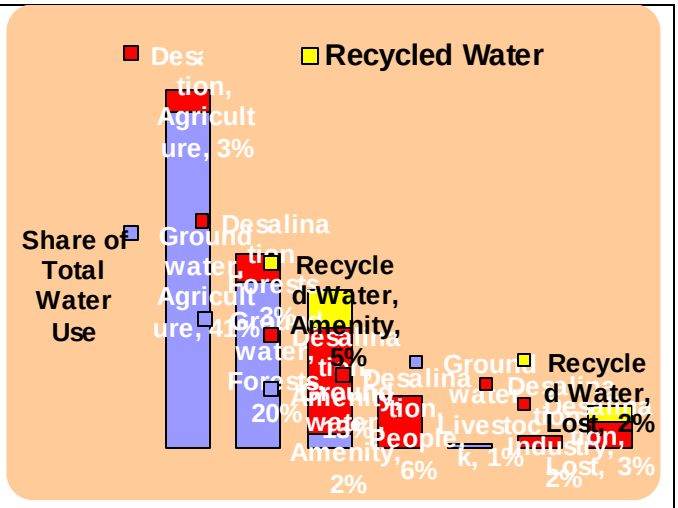

Figure 2: Water use in Abu Dhabi Emirate

2. Treated Wastewater Production

2.1 Present Status

Abu Dhabi has treated domestic and municipal wastewater in centralized treatment facilities since 1973. The Emirate has continued with its development of excellent wastewater treatment facilities. There are now 32 wastewater treatment plants, split equally between the Western and Eastern regions. Combined, they produce about 244.7 million m³/yr. Zakher (Al Ain) and Al Mafraq (Abu Dhabi) plants produce 94% of all treated effluent, which is mostly used for irrigation of parks, gardens and other recreation amenity areas. The main wastewater treatment plant serving the Abu Dhabi city is Al Mafraq plant with a maximum design capacity of 260,000 m^3/day. The main sewage treatment plant serving Al Ain City is Zakhir

plant with a maximum capacity of 54,000 m^3/day. The plant is currently operating at peaks of 120,000 m^3/d, which increases a risk of deterioration in the quality of effluent and sludge produced, as well as the risk of by-pass influent to the percolation area at the rear of the treatment plant. The other STPs are quite small, but because of remote urban expansion, some are now over-loaded and are presently being prepared for upgrading (Figure 3).

Due to the increasing number and size of developmental and industrial projects planned in the emirate of Abu Dhabi, an increase in the demand for sewage treatment plants is expected. The main sewage treatment plants currently operating in the emirate of Abu Dhabi are heavily overloaded, leading to the generation of low quality treated effluent. Furthermore, the overload could result in disposal of raw sewage in the marine environment and/or desert. During emergency situations in the sewage treatment plant, more than 25% of the raw sewage inflow is diverted to the marine environment creating environmental crisis to marine quality and ecology. The discharge point of excess treated effluent and over flow line is located at the Musaffah Industrial Area south channel. In 2005, the management of all STPs became the responsibility of the newly formed Abu Dhabi Sewage Services Company (ADSSC), under the regulatory control of the Abu Dhabi Regulation and Supervision Bureau, which is also responsible for regulating the potable water and electricity sectors.

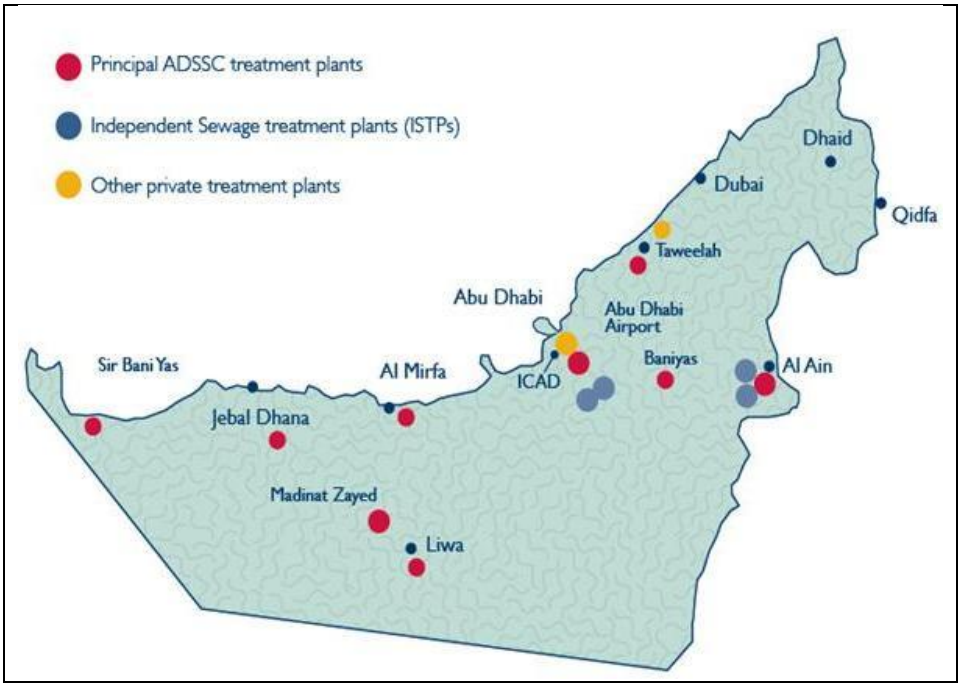

Figure 3: Location of Abu Dhabi Main Wastewater Treatment Facilities.

3.2 Future Wastewater Treatment Plants

A phased expansion of the sewerage system and reclamation and reuse infrastructure has been planned to accommodate the development of Abu Dhabi. The Strategic Tunnel Enhancement Program (STEP) will construct a sewage tunnel twenty meters below the surface of Abu Dhabi. The building works are expected to be completed by 2013. In addition, a private company – Al Etihad Biwater Wastewater Company – has been licensed to construct four large wastewater treatment facilities. The first two of these at Al Wathba will serve Abu Dhabi, and each will have a design capacity of 345,000 m^3/day. Veolia Besix holds an operating license for Wathba 2 and the Allahamah treatment plants. As a result of this expansion, the sewerage system will be able to collect sewage from the entire Abu Dhabi drainage area. A new pumping station will feed this to the Mafraq and Al Wathba facilities. Two new facilities will be built for Al Ain. The design capacity of Al Saad plant will be 92,000 m^3/day and that of the Al Hamah plant 149,500 m^3/day as shown in Table (2).

3. Treated Wastewater Reuse

3.1 Present Status

Wastewater initially provided the bulk of the water for amenity and landscaping purposes. However, as the volume increased from the 1990s supply outstripped the irrigation systems capacity to fully utilize it. Where this occurred irrigation shortages were made up from desalinated water. The fact that desalinated water is seven times more expensive to produce had no impact on this allocation because it was free for municipal uses. Thus there were few incentives to better manage the recycled water supply or remove the constraints in the distribution network. Independent calculations of irrigations application in the Abu Dhabi area put current use at 4,800 mm/year – at least double the amount needed for urban greening (Dornier/GTZ, 2009). Until recently the main drawback of the 200 km distribution network on Abu Dhabi Island was the relatively small size of the pipes. In addition, the flows are still controlled manually and water is not properly budgeted and storage reservoir operation (and there are 119 storage reservoirs) is haphazard – some reservoirs receive excessive flow while others get no flow at all or very limited flows. Many of the control instruments do not function properly and some may have been removed. ADSSC's consultants have recommended an irrigation network detection and leakage study which would help identifying unknown off takes, cross connections and valve status. However, the budget for this at AED 60,000 looks woefully inadequate.

Table 1: Present Major Treatment Facilities in Abu Dhabi Emirate (2011).

Eastern Region		Abu Dhabi and Western Region	
Treatment Plant	Production (million m^3/yr)	Treatment Plant	Production (million m^3/yr)
Al Ain - Zakher	43.80	Al Mafraaq	186.40
Al Araad	0.02	Al Khatem	0.27
Al Dhahira	0.16	Ghantout	0.24
Al Faqah	0.20	Al Maraa	2.38
Al Haiar	0.68	Mirfa Cans Factory	0.07
Al Khazna	0.39	Bainounah	0.35
Al Qoaa	0.72	Madient Zaied	3.49
Al waqan	0.46	Liwa	0.28
Al Yahr	0.08	Abu Al Abyad Island	0.12
Bu Keriayah	0.10	Sir Bani Yas Island	0.13
Remah	0.36	Ghuwaifat	0.19
Seih Ghraba 1	0.03	Ghayathi	1.23
Seih Ghraba 2	0.01	Delma	0.38
Al Shweib	0.37	Baaya-Sila	0.98
Sweihan	0.39		
Wadi Fiely	0.44		
Sub Total	**28.2**		**196.5**
Total TSE Production in Abu Dhabi Emirate			**244.7**

Source: ADSSC, 2009

Table 2: Future Major Treatment Facilities in Abu Dhabi Emirate (2011-2012).

Location	Catchment	Capacity m^3/day	Commissioning
Al Wathba 1	Abu Dhabi Island & Mainland	345,000	Q1 2011
Al Wathba 2	Abu Dhabi Island & Mainland	345,000	Mid 2012
Al Saad	North Catchment Al Ain City	92,000	Q1 2011
Al Hamah	South Catchment Al Ain City	149,500	Mid 2012
Total Future Additional Capacity		**931,000**	

The irrigation network on Abu Dhabi Mainland is a combination of gravity and pumping mains of medium to large diameters, the primary main being 183 km long plus significantly longer secondary and tertiary irrigation distribution systems. It is not a closed loop system but a series of transmission pipelines discharging to service reservoirs (Figure 4). The main concern is that the capacity of the existing network and associated infrastructure is

insufficient to cope with the ever increasing recycled water production. As on Abu Dhabi Island, a lot of the irrigation scheduling is done manually making for less efficient balancing of supply and demand. Currently, works are underway to construct new, large diameter, transmission mains. All recycled water output from Mafraq is monitored regularly for quality. As noted above, recycled water quality has been deteriorating particularly with regard to high levels of salinity and raised levels of heavy metals. The ADSSC feasibility study cautions that hardware solutions alone will not solve the problem; better planning and management of operations are required. As far as can be determined from available reports there do not appear to be any drainage congestion problems as a result of amenity irrigation. This is primarily because half of available recycled water is disposed of at sea (Figure 4), and that there is good urban drainage – some of it provided by the sewer system and some from surface drainage and shallow groundwater flow to the Gulf.

Figure 4: TSE irrigation network in Abu Dhabi Island

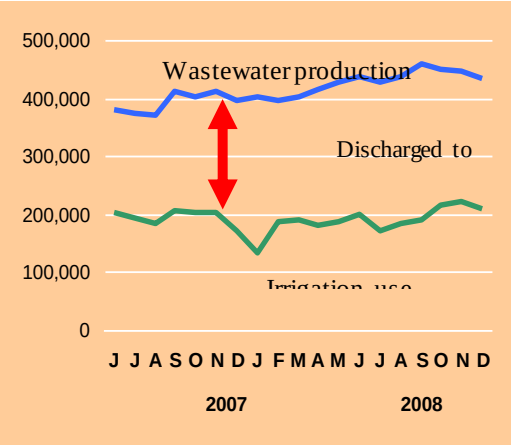

Figure 5: Treated Wastewater Production versus Irrigation Use.

In recognition that the current levels of wastage of unacceptable, ADSSC commissioned a special Assessment and Ownership of Green Water Infrastructure in Abu Dhabi Emirate that was completed in 2008. Subsequently, in response to an instruction from the Executive Council, another consulting firm was engaged to carry out "a feasibility study into the addition of a "fourth stage with the use of fiber" to all large sewerage treatment plants in Abu Dhabi", specifically those at Abu Dhabi and Al Ain. It was proposed in these studies that no desalinated water will be used for irrigation in the future and that this shortfall will be made up with recycled water supplied from both Mafraq and the proposed new plants at Al Wathba. Together these reports' recommendations aim to:

- provide the basis for the upgrading of the irrigation management in Abu Dhabi and Al Ain
- improve the quality of recycled water to remove all risk of biological contamination making it suitable, in principle, for unrestricted use.

The planning horizon for both studies was 2025.

Figure (6) shows all amenity and irrigation demands based upon present water consumption and projected available supplies, and all new proposed future development that will need amenity irrigation. These supply projections by the consultants assume that current total inflow of recycled water will remain unaffected by improvement to the sewer system that could reduce inflow volumes by as much as 30-50%. Thus, under almost all future demand scenarios all the recycled water produced in Abu Dhabi will be fully accounted for in the next 1-3 years.

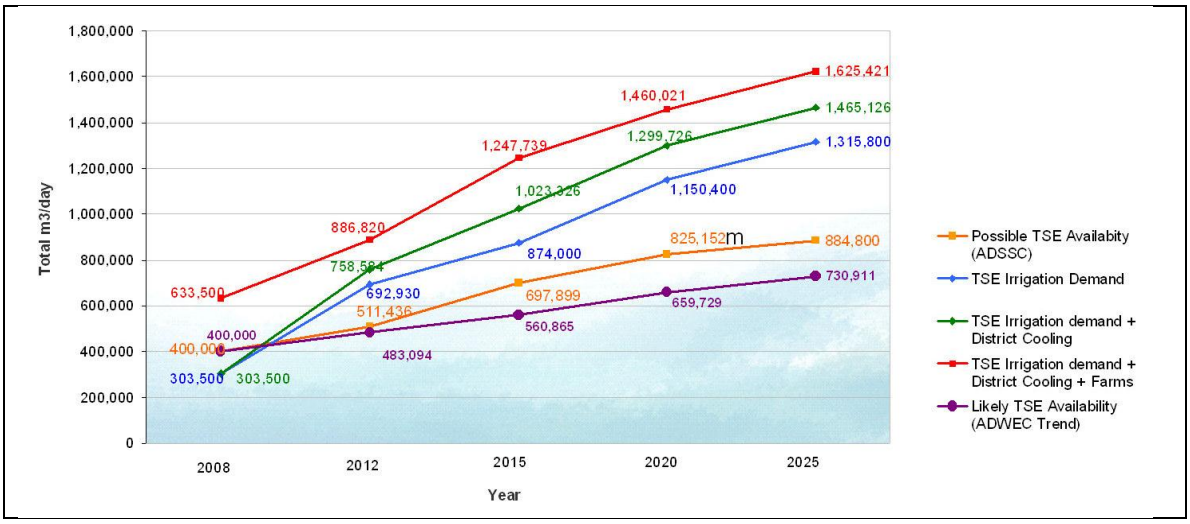

Figure 6: Projection of future wastewater supply and demand.

4. Abu Dhabi Water Reuse Standards

Numerical standards are in the process of being agreed for the use of recycled water and biosolids. However, numerical standards are of little value by themselves unless they are applied and regulated within an effective framework that ensures adequate monitoring, sampling, analysis, reporting and action. Fortunately, the regulations put forward by the RSB provide the basis for effective control as it addresses all of the aspects that would be expected of a modern state of the art system. Two features are worth highlighting. The first is the requirement for a Reuse Safety Plan to be developed by the Disposal Licensee, the Treatment Licensee and the End-User for each reuse scheme. That is certainly a key feature of effective regulation and reflects a modern up- to- date approach. The second is the establishment of a Reuse Review Panel that will review operation, performance and quality standards every two years. Reuse and its regulation is a dynamic process and regular review is an important element. The Abu Dhabi numerical standards have been informed by international opinion and, in particular, the WHO Guidelines for the safe use of Wastewater, Excreta and Grey water (2006). In the WHO's perspective recycled water treatment is one component of an

integrated risk management strategy, and they propose minimum verification monitoring of microbial performance. The latest guidelines aim at preventing communicable disease transmission, while optimizing resource conservation and recycling. They allow incremental and adaptive changes, which are cost-effective in reducing health and environmental risks.

Abu Dhabi RSB's Recycled Water and Biosolids Regulations of 2010 provide in-depth details of standards that will come into force later in 2010. Schedule A provides numerical values for Public Health Standards, P1 (general reuse), P2 (Restricted reuse), P3 (Marine) and P4 (Land percolation system) that are to be applied to specific reuse activities. These define both general physico-chemical characteristics along with three important microbiological standards. It is somewhat surprising, given that the use is mostly irrigation, that there is no standard to minimise the concentration of salts such as TDS, SAR or conductivity. Before comparing these standards with selected international ones it is appropriate to say that an attractive feature of the Abu Dhabi standards is that they are relatively simple and only include relevant parameters that can be readily measured and have meaning; by contrast many national standards include pages of unimportant parameters that have no relevance and are an expensive encumbrance to effective control. Also, the inclusion of the Reuse Review Panel means that additional parameters can be added at a later stage if deemed necessary.

5. Treated Wastewater Reuse Options

Four options were recommended for reuse of treated wastewater in Abu Dhabi:

(1) Direct use amenity plantation, landscaping and forests
(2) Direct use for agriculture
(3) For aquifer recharge
(4) District cooling

Wastewater reuse is not a recent invention. There are indicators that wastewater was used back for irrigation in ancient Greece and in the Minan civilization (ca. 3000 – 1000 BC) (Angelakis et al., 1999; Asano and Levin, 1996). During 1950-60, interests in applying wastewater on land in the western hemisphere as wastewater treatment technology advanced and quality of treated effluents steadfastly improved. Land application became a cost-effective alternative of discharging effluent into surface water bodies (Asano T., 1998).

Figure (7) shows the percentage of total water reuse per sector for California, Florida and Japan. It can be observed that in agricultural irrigation the water reuse overall is highest, but strongly dependent on the regional context. In Japan the reuse for example is highest in the industrial and commercial sector.

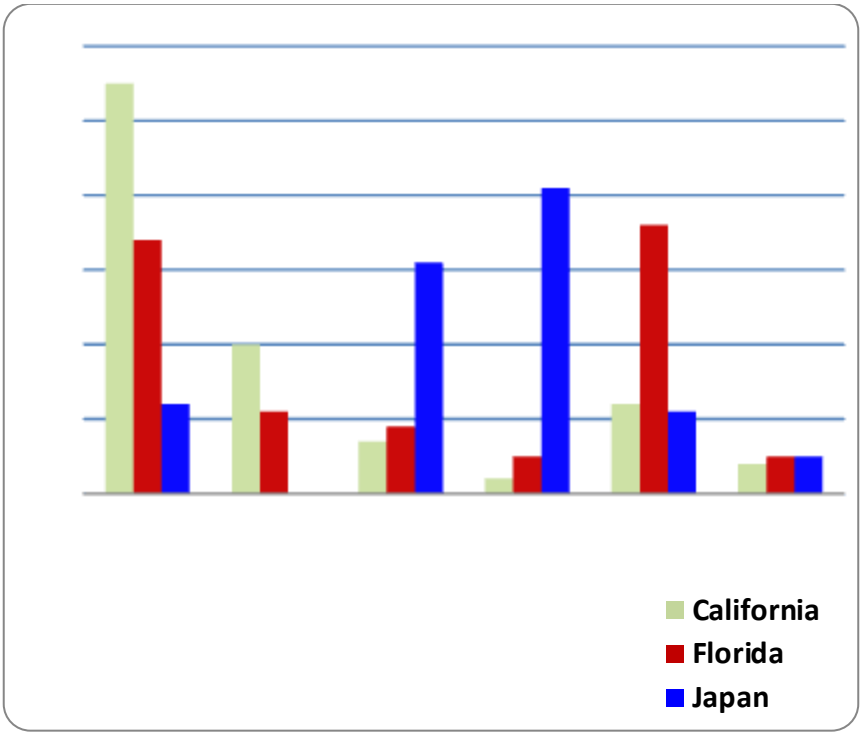

Figure 7: Wastewater applications in California, Florida, and Japan.

5.1 Reuse of treated wastewater in agriculture

The integration of wastewater reuse in the existing water management master plans has been essentially geared towards agricultural irrigation. When considering wastewater reuse for irrigation, an evaluation of the advantages, disadvantages and possible risks has to be made. Table (3) summarizes the advantages, disadvantages and possible risks regarding water conservation, different substances in the water and influences regarding the soil.

Table 3: Advantages, disadvantages and possible risks of wastewater reuse.

Advantages	Disadvantages	Risks
• Improvement of the economic efficiency of investments in wastewater disposal and irrigation • Conservation of freshwater sources • Recharge of aquifers through infiltration water (natural treatment)	Wastewater is normally produced continuously throughout the year, whereas wastewater irrigation is mostly limited to the growing season.	Potential harm to groundwater due to heavy metal, nitrate and organic matter
Use of the nutrients of the wastewater (e.g. nitrogen and phosphate) • reduction of the use of synthetic fertilizer • improvement of soil properties (soil fertility; higher yields)	Some substances that can be present in wastewater in such concentrations that they are toxic for plants or lead to environmental damage	Potential harm to human health by spreading pathogenic germs
Reduction of treatment costs: Soil treatment of the pre-treated wastewater via irrigation (no tertiary treatment necessary, highly dependent on the source of wastewater)		Potential harm to the soil due to heavy metal accumulation and acidification
Beneficial influence of a small natural water cycle		
Reduction of environmental impacts (e.g. eutrophication and minimum discharge requirements)		

5.2 reuse of treated wastewater in aquifer recharge

Where soil and groundwater conditions are favorable for artificial recharge of groundwater through infiltration basins, a high degree of upgrading can be achieved by allowing treated wastewater to infiltrate into the soil and move down to the groundwater as shown in Figure (8). The unsaturated or "vadose" zone then acts as a natural filter and can remove essentially all suspended solids, biodegradable materials, bacteria, viruses, and other microorganisms.

Significant reductions in nitrogen, phosphorus, and heavy metals concentrations can also be achieved.

At present, there is no injection/recharge of the tertiary treated wastewater to groundwater aquifer system in Abu Dhabi. However, this option should be studied in detail in the future. The range of potential groundwater pollutants in wastewater includes pathogenic microorganisms, excess nutrients and dissolved organic carbon, and where significant industrial effluent is present, toxic heavy metals and organic compounds. However, the actual effect on groundwater quality will vary widely with:

- the pollution vulnerability of the aquifer
- the quality of natural groundwater and thus its potential use
- the origin of sewage effluent and thus likelihood of persistent contaminants
- the quality of wastewater, and its level of treatment and dilution
- the scale of wastewater infiltration compared to that of aquifer through flow
- the mode of wastewater handling and land application.

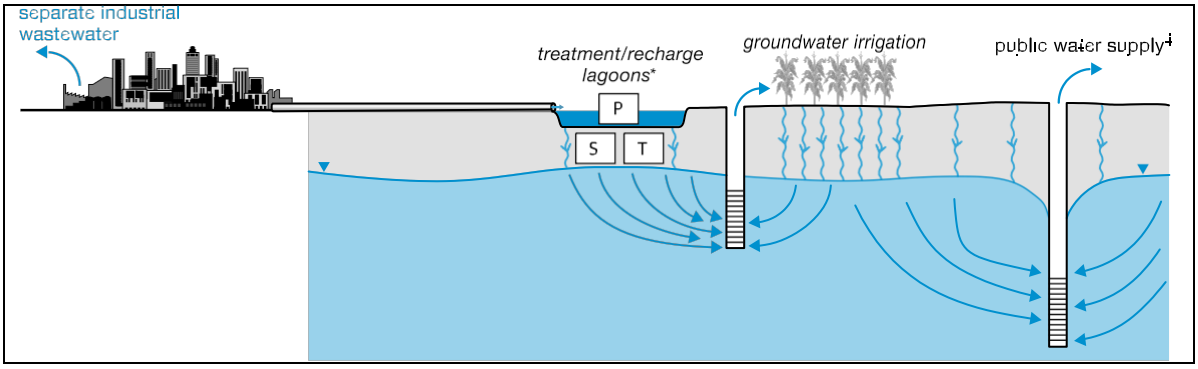

Figure 8: General schemes of wastewater reuse for aquifer recharge.

6. Al Nahda Farm Pilot Project

The Abu Dhabi Sewerage Services Company (ADSSC) has proposed the development of an enhanced TSE Treatment plant on the eastern boundary of the Al Nahda farms area, near Al Wathba (Figure 9). The new plant will provide enhanced treatment of Treated Sewage Effluent (TSE) sourced from the Mafraq Waste Water Treatment Plant (WWTP). The 'enhanced' TSE is intended for irrigation in the Al Nahda farms area, replacing the existing groundwater supply currently in use.

Figure 9: Location map of Al Nahda farms area.

6.1 Groundwater Supply

The irrigation water currently supply for the Al Nahda farms agricultural plots is sourced from groundwater boreholes in Liwa. The water is currently pumped over 130km through pipelines to the Al Nahda farms area. These farms have an economic and cultural value to the Emirati population and the continued maintenance and preservation of this land use is deemed of importance to the UAE. The aquifers in Liwa area are often referred to as the Liwa Crescent aquifers. Over abstraction from aquifers is a major problem in Abu Dhabi emirate, in particular from the Liwa crescent aquifers. Over abstraction of this valuable supply has led to declining groundwater quantity and severe deterioration in groundwater quality.

6.2 Plant and Process

As shown in Figure (10), The Mott MacDonald Feasibility Study (April 2009) identified the minimum necessary treatment processes to achieve the required treated effluent water quality. The minimum treatment processes identified consist of the following:

- Inlet flow balancing tank**:** TSE from Al Mafraq WWTP would first enter the balancing tank to balance flow quantities and prevent surges to ensure effective treatment in the subsequent stages.
- Ultrafiltration membrane treatment**:** The TSE will then be pumped to the ultrafiltration process stage, which will remove particles, algae, protozoa, bacteria, small colloids and viruses. Pre-treatment chemicals for this part of the process are anticipated to

include ammonium sulphate (dechlorination), ferric chloride (coagulation), sodium hypochlorite (pre-chlorination), caustic soda, citric acid (pH control). The ultrafiltration membranes would be cleaned by flushing (referred to a 'backwashing') the membranes with water. Periodically, sodium hypochlorite, citric acid, caustic soda and hydrogen peroxide may be used for chemical cleaning of the membranes.

- Ultra-violet light disinfection**:** In the first stage of ultraviolet disinfection, photons in UV light react directly with nucleic acids in the target organism subsequently killing any organisms present.
- Sodium hypochlorite addition**:** The addition of sodium hypochlorite is the final stage of disinfection.
- Plant and Process Chemicals: All chemicals will be handled, stored and disposed of in accordance with Control of Substances Hazardous to Health (COSHH) best practice and EAD requirements.

Plant Chemical and Reject Flows: The enhanced treatment plant will entail a number of chemical and reject process flows.

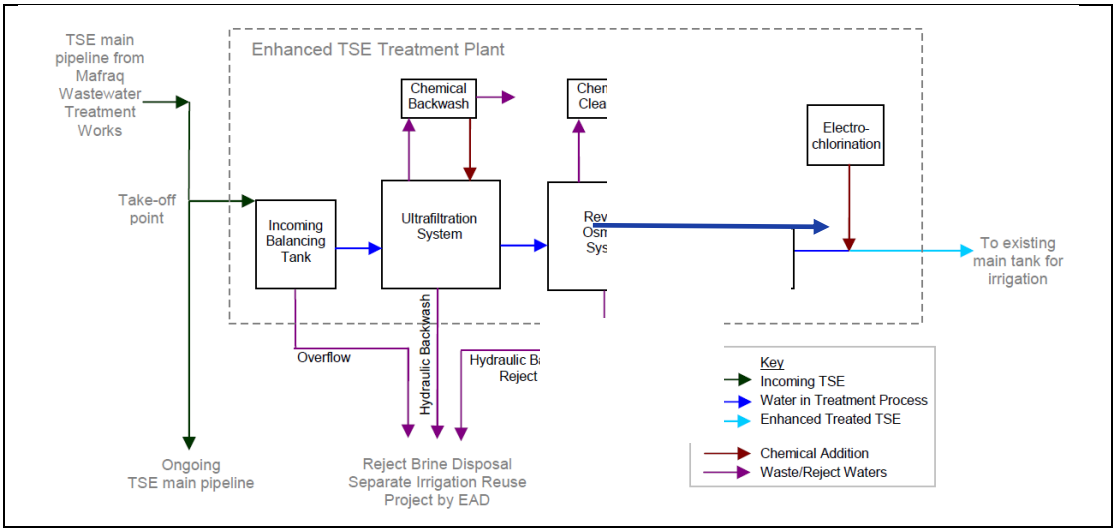

Figure 10: Flowchart of processes for the plant.

6.3 Incoming TSE

The inflow of TSE from the Al Mafraq WWTP transmission main will not exceed 6 mgd, Table (4) shows the average quality of TSE effluent from the Al Mafraq Wastewater Treatment Plant in 2008 to provide an indication of what the incoming TSE quality is likely to be.

6.4 Treated Effluent Water

The design specifications for the proposed plant stipulate that the treated water outflow from the plant will be greater than 75% of the influent at all times, up to a maximum of 4.5 mgd. The final treated TSE quality parameters compared to the influent TSE quality is provided in Table (5).

Table (6) demonstrates that the enhanced TSE quality will be a significant improvement on the quality of the influent TSE from the Al Mafraq WWTP. Parameters with a noted improvement in quality include conductivity (salinity), cadmium, chlorides, chromium, cobalt and zinc. Significant improvements are expected for heavy metal levels in particular. The enhanced treated TSE will then be used for irrigation of the Al Nahda farms.

6.5 Reject Brine Disposals

The expected quantity of reject brine to be utilized for irrigation reuse purposes is 1.5 mgd. Table (7) provides the anticipated quality of the reject brine from the proposed plant.

Table 4: Average Quality of TSE from Mafraq WWTP, 2008

Parameter	Unit	Value	Parameter	Unit	Value
pH	units	7	Total Organic Carbon (TOC)	mg/l	5.7
Alka	mg/l	53	Turbidity	NTU	1.0
Hardness	mg/l	453	Residual Chlorine	Cl2 mg/l	1.4
Conductivity	µS/cm	4700	Calcium (Ca)	mg/l	83
Total Dissolved Solids (TDS)	mg/l	2501	Magnesium (Mg)	mg/l	67
Chlorine (Cl)	mg/l	1466	Sodium (Na)	mg/l	774
Ammonia (NH3N)	mg/l	0.8	Nickel (Ni)	mg/l	0.02
Nitrate (NO2N)	mg/l	0.4	Chromium (Cr)	mg/l	0.03
Nitrate (NO3N)	mg/l	9.1	Cobalt (Co)	mg/l	0.01
Phosphorus as Total P	mg/l	6	Iron (Fe)	mg/l	0.5
Sulfate (SO4-2)	mg/l	169	Zinc (Zn)	mg/l	0.21
Total Suspended Solids (TSS)	mg/l	2.8	Cadmium (Cd)	mg/l	0.05
Biological (BOD) Oxygen Demand	mg/l	1	Copper (Cu)	mg/l	0.10
Chemical (COD) Oxygen Demand	mg/l	10			

Table 5: Typical Enhanced TSE Quality

Parameter	Unit	2008 Annual Average Current Mafraq TSE	Proposed Water Quality from Min. Treatment Process	Required Treated Water Quality	
				95 Percentile Value	Maximum Permissible Value
Conductivity	µS/cm			1000	1200
Total Hardness	mg/l CaCO3	453	23		
Faecal coliforms	cfu/100ml			<1	
Total coliforms	cfu/100ml			<1	
pH				Max 9 Min 6	
Aluminium (Al)	mg/l			0.15	0.10
Ammonia (NH3)	mg/l	0.8	0.8		
Arsenic (As)	mg/l			0.0075	0.005
Boron (B)	mg/l			0.75	0.5
Cadmium (Ca)	mg/l	0.05	0.003	0.00225	0.0015
Chloride (Cl)	mg/l	1466	73	187.5	125
Chromium (Cr)	mg/l	0.03	0.002	0.0375	0.025
Cobalt (Co)	mg/l	0.01	0.001		
Copper (Cu)	mg/l	0.1	0.005	0.750	0.500
Fluoride (Fl)	mg/l			1.125	0.75
Iron (Fe)	mg/l	0.5	0.025	0.15	0.1
Lead (Pb)	mg/l			0.0075	0.005
Manganese (Mg)	mg/l			0.3	0.2
Mercury (Hg)	mg/l			0.0045	0.003
Nickel (Ni)	mg/l	0.2	0.010	0.0525	0.035
Nitrate (NO3)	mg/l	9.1	0.455		
Phosphorus (P)	mg/l P	6	0.300		
Selenium (Se)	mg/l			0.0075	0.005
Sodium (Na)	mg/l	774	39	112.5	75
Zinc (Zn)	mg/l	0.21	0.011	3.75	2.5

During project development, alternative options considered for the disposal of the reject brine included:

1. Disposal into deep aquifers by injection/pumping. This was considered costly and impractical. Through consultation with EAD, it was identified that problems had been encountered previously
2. It is proposed to use the reject brine from the enhanced TSE Treatment plant irrigation of non-agricultural horticulture such as landscaping and forestry planting.

Land adjacent to the proposed enhanced TSE Treatment plant is being developed by EAD into a Wildlife Animal Palace for animals to be relocated from Sir Bani Yas Island. Native Arak and Araf trees will be planted. (Araf trees have salinity tolerance to water with a TDS of around 10 000 ppm and Arak trees have salinity tolerance to water with a TDS of around 20,000 ppm).

Table 6: Expected Reject Brine Water Quality.

Parameter	Unit	Estimate of Wastewater Quality	
		Concentration (mg/l)	Load (kg/d)
Conductivity	µS/cm	18 800	
Total Dissolved Solids	mg/l	10 004	
Total Hardness	mg/l CaCO3	1 812	12 339.7 kg/d
pH		7	
Ammonia	mg/l NH4	3.2	21.8 kg/d
BOD	mg/l	4	
COD	mg/l	40	
Cadmium	mg/l	0.2	1.4 kg/d
Chloride	mg/l	5 864	39 933.8 kg/d
Chromium	mg/l	0.12	0.8 kg/d
Cobalt	mg/l	0.04	0.3 kg/d
Copper	mg/l	0.4	2.7 kg/d
Iron	mg/l	2.0	13.6 kg/d
Nickel	mg/l	0.08	5.4 kg/d
Nitrate	mg/l NO3	36.4	247.9 kg/d
Phosphorus	mg/l P	24.0	163.4 kg/d
Sodium	mg/l	3 096	21 083.8 kg/d
Zinc	mg/l	0.84	5.7 kg/d

6.6 Soils of Al Nahda farms

The main soils commonly existing in Al Nahda agriculture farms, the project area, are classified, according to the USDA Soil Taxonomy (USDA-NRCS, 1999 and 2010) as Typic Torripsamments, mixed, hyperthermic (EAD, 2009b). The soils are deep, sandy soils with mixed mineralogy. They occur on almost level plains to mega transverse and dune fields and are widespread throughout the Abu Dhabi Emirate. They are typically excessively drained or somewhat excessively drained and have rapid to very rapid permeability.

The surface soil is usually loose or soft. Where the soils occur in older landscapes, there may be a surface lag of fine to medium gravels. Complete laboratory analyses including physical, chemical, and mineralogical characterization (USDA-NRCS, 2004) of one soil profile representing the common soils in Al Nahda farm, Typic Torripsamments, mixed, hyperthermic, is presented in Table 6. The texture is fine sand with low electrical conductivity (ECe less than 2 dS/m) and negligible quantities of gypsum and carbonates. Other associated soils in the study area are classified as Typic Haplocalcids, sandy, carbonatic, hyperthermic and consist of very deep or deep sand with a calcic horizon within 100 cm depth. They occur on all landscape positions within level plains to undulating rises. They have also been described in some older sand sheets and interdunal depressions. Soils are well drained or somewhat excessively drained and permeability is rapid or moderately rapid.

7. Conclusion and Recommendation

- The irrigation water currently supplying the Al Nahda farms agricultural plots is sourced from groundwater boreholes in Liwa. The water is currently pumped over 130km through pipelines to the Al Nahda farms area. These farms have an economic and cultural value to the Emirati population and the continued maintenance and preservation of this land use is deemed of importance to the UAE.
- The aquifers in Liwa area are often referred to as the Liwa Crescent aquifers. Over abstraction from aquifers is a major problem in Abu Dhabi emirate, in particular from the Liwa crescent aquifers. Over abstraction of this valuable supply has lead to declining groundwater quantity and severe deterioration in groundwater quality.
- The main soils commonly existing in the project area, Al Nahda agriculture farms, are classified according to the USDA Soil Taxonomy as Typic Torripsamments, mixed, hyperthermic. They are typically excessively drained or somewhat excessively drained and have rapid to very rapid permeability. The texture is fine sand with low electrical conductivity (ECe less than 2 dS/m) and negligible quantities of gypsum and carbonates.
- The enhanced TSE quality will be a significant improvement on the quality of the influent TSE from the Al Mafraq WWTP. Parameters with a noted improvement in quality include conductivity (salinity), cadmium, chlorides, chromium, cobalt and zinc. Significant improvements are expected for heavy metal levels in particular. The enhanced treated TSE will then be used for irrigation of the Al Nahda farms.

- All chemicals will be handled, stored and disposed of in accordance with Control of Substances Hazardous to Health (COSHH) best practice and EAD requirements.
- The EAD irrigation reuse project proposes to install 4-5 piezometers to monitor groundwater in the vicinity of the reject brine irrigation areas. The site has recently had an underground storm water drainage network installed, which is anticipated to collect any excess reject brine infiltrate.
- During project development, alternative options considered for the disposal of the reject brine included:1. Disposal into deep aquifers by injection/pumping. This was considered costly and impractical. Through consultation with EAD, it was identified that problems had been encountered previously, and 2. It is proposed to use the reject brine from the enhanced TSE Treatment plant irrigation of non-agricultural horticulture such as landscaping and forestry planting.
- The key operational activities will include: monitoring TSE output to ensure that it meets the required water quality standard and maintenance measures to prevent ageing/wear and tear of plant items
- Key process maintenance tasks will include: replacing ultra-filtration membrane modules, and, Maintenance of chemical dosing pumps and tanks.
- RSB recommended that establishing a five year monitoring program, which would provide independent and robust data on the performance of the plant and the impact of polished effluent on irrigated land.

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Soil Remediation for Controlling Nutrients Pollution in Water

Gehan A. H. Sallam[6]

Abstract

In Egypt, the optimum economic crop production depends heavily on fertilizers usage, so fertilizer consumption is high and continues to increase. Part of these fertilizers can leach by irrigation water into the drainage water as water flows over land surface and passes through the plant root zone and other parts can leach into groundwater through the soil profile. Therefore, fertilizers are regarded as a potential source of environmental pollution. The nutrients being leached are likely nitrate, ammonia and phosphate forms. Leaching of nutrients is economically and environmentally undesirable because they represent the loss of a valuable plant nutrient and can contribute to pollution of water resources. However, water that has been initially undergone through the soil profile and recharges to subsurface water and groundwater aquifer has rapid infiltration or soil aquifer remediation. Therefore, the main objective of this study is to investigate the extent of soil aquifer remediation taking place in the unsaturated zone during the travel of the natural percolated drainage water from top to soil layer to the interface with groundwater table under a given soil conditions of two different types of soils in the Nile Delta of Egypt. The study was conducted in two Pilot Areas located in the East Delta Region of Egypt. The first one is Mashtul Pilot Area with clayey soil. The study was conducted in this area for two different seasons, winter and summer. The second area is Mit Kenana Pilot Area with sandy soil. The study was conducted in this area for one summer season only.

The data which prevailed in the winter season showed the removal percentage of the three nutrients elements by soil remediation in clayey soil is equal to about 70% for subsurface water and 78% for groundwater for nitrate element, 32% for subsurface water and 80% for groundwater for ammonia element and 16% for subsurface water and 79% for groundwater for phosphate element. However, in the summer season it was found that the removal percentage for clayey soil also is equal to about 4% for subsurface water and 60% for groundwater for nitrate element, 74% for subsurface water and 78% for groundwater for ammonia element and 84% for subsurface water and 95% for groundwater for phosphate element. On the other hand for sandy soil in summer season, it was found that the removal

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percentage is equal to about 2% for subsurface water and 44% for deep groundwater for nitrate element, 45% for subsurface water and 84% for groundwater for ammonia element and 35% for subsurface water and 84% for groundwater for phosphate element. Therefore, it could be concluded that the soil remediation for fertilizers pollution in clayey soil is more effective than in the sandy soil. This depends on the unsaturated zone soil composition. Generally it could be concluded that soil remediation for fertilizers polluted drainage water that naturally percolate in the soil profile is an effective way to provide the equivalent treatment.

1. Introduction

In recent years, serious environmental and natural resources degradation problems have captured the attention of and generated concern in the world community. Agriculture is viewed as a contributor to many of these environmental problems due to application of fertilizers and agrochemical (Hamdy and Kandiah, 1997). Until recently, the foremost priority of the agricultural community globally was to ensure and enhance the productivity and profitability of agriculture. This priority is being re-examined to include environmental considerations. This is because of the concern about the impact of agricultural activities on the ecological system (Ongley, 1996). However, the increasing world population and the increasing demands for food production make the dependence on fertilizers inevitable in the future. This is because of the higher dependence on chemical fertilizers, due to labour shortage, and increased rate of fertilizers application to increase agricultural productivity (Gaballah et al, 2005).

In Egypt, there is a large aquifer in the Nile Valley. The main resource of recharge for this aquifer is indirectly the Nile due to the seepage of irrigation water through the soil profile (Attia, 2006). However, the optimum economic crop production in Egypt depends heavily on fertilizers usage so fertilizers consumption is high and continues to increase. Part of these materials leach by irrigation water into the drainage water as water flows over land surface and passes through the plant root zone and other parts leach to groundwater through the soil profile. Therefore, they are regarded as potential source of environmental pollution. In addition to salts, substances such as nitrates, phosphorus, potassium, and pesticides are the most common pollutants leached (Khalaf, 2004).

Nutrients not taken up by plants can get lost to deeper soil layers. They are also soluble in water and can be transported from soils into ground waters and surface waters by leaching, erosion, or surface runoff. The nutrients being leached are likely in the nitrate (NO_3), ammonia (NH_4) and phosphate (PO_4) forms. Leaching of nutrients is economically and environmentally undesirable because they represent the loss of a valuable plant nutrient and

can contribute to pollution of groundwater aquifers. However, water that has been initially undergone through the soil profile and recharges to the groundwater aquifer has rapid infiltration or soil aquifer remediation (Huang and Iskander, 2000).

Soil aquifer remediation involves renovation of water as it percolates through permeable soil prior to entering groundwater. The renovation mechanisms include a series of physical, biological and chemical processes within the soil profile (El Hattab, 2003). Soil aquifer remediation relies on natural processes to polish water. The performance of Soil aquifer remediation systems are affected by several factors. These include the degree of water quality and certain physical characteristics of the soil system (NCSWS, 2001).

Therefore, the main objective of this study is to investigate the extent of soil aquifer remediation taking place in the unsaturated zone during the travel of the natural percolated drainage water from top to soil layer to the interface with groundwater table under a given soil conditions of two different types of soils in the Nile Delta of Egypt. These two types of soil are clayey soil and sandy soil.

2. Methodology

The study was conducted in two pilot areas with different soil characteristics to obtain the measured data necessary to assess the fertilizers pollution migration to the water and soil and the extent of soil aquifer remediation taking place in the unsaturated zone. The first pilot area is Mashtul Pilot Area with clayey soil and the second one is Mit Kenana Pilot Area with sandy soil.

Mashtul Pilot Area is located in the southeastern part of the Nile Delta (Figure 1) with an area of approximately 260 feddans (1 feddan = 0.42ha). It is characterized with a deep clay layer on top of a sandy aquifer. The clay layer, which is approximately 6.0 m thick, contains about 35 % silt and 65 % clay. The subsurface drainage system in the area was constructed since 1980; it consists of parallel PVC lateral drains, which discharge into buried collector drains. The area is divided into eighteen drainage units. Each unit is cultivated with a single crop each cropping season. On the other hand, Mit-Kenana Pilot area is situated 40 km, North West of Cairo (Figure 1) with an area of approximately 830 feddans. The subsurface drainage system in the area was established in 1992. It represents the sandy soils of the eastern fringes of the Nile Delta. It represents the transient stages between both soils of the desert and the Nile delta. It is divided into seven drainage units. Each unit also is cultivated with a single crop each cropping season.

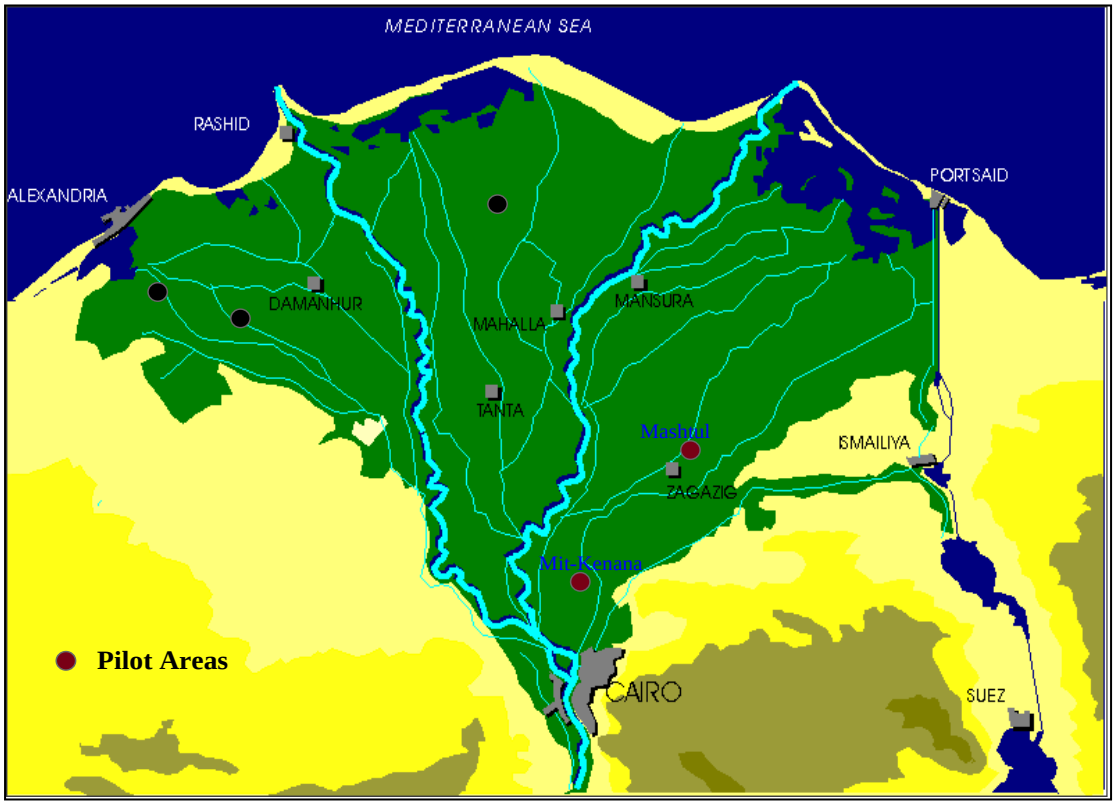

Figure 1: Location of Pilot Areas under Study

The two pilot areas were controlled under the current farming conditions aiming to apply the data measurement program. Mashtul Pilot Area was controlled for two cropping seasons, winter 2005-2006 and summer 2006. However, Mit Kenana Pilot area was controlled for one cropping season only, summer 2006.

The measurement program includes determination of the crop pattern, the fertilizers amount and time of applying for each crop and collecting soil samples at depths of 1.0 m, 1.5 m and 2.0 m from each unit of the pilot areas. Water samples were also collected from each unit including irrigation water, drainage water (from field laterals drains with depth of 1.4 m), subsurface water (from observation wells with depth of 2.0 m) and groundwater (from water pump with depth of 20 m). The samples were collected before and after applying fertilizers and periodically every 10 days. The samples were analyzed in the laboratory to determine the nutrients including the three parameters of nitrate (NO_3), ammonia (NH_4), and total phosphate (PO_4) for soil and water samples to follow the pollution migration and aquifer soil remediation.

3. Results And Discussion

The main crops in the two pilot areas are Rice and Maize in summer season and Wheat and Berseem (Clover) in winter season. Crops need nutrients due to its special functions in the growth and development of them. It may be supplied by fertilizer chemicals such as calcium nitrate (15.5% N), ammonium sulphate (33.5% N) and urea (46% N), animal manures and/or the nitrogen - fixing bacteria associated with legumes.

In Egypt, the fertilizer usage and consumption is high and continues to increase. This is because of the higher dependence on chemical fertilizers, due to labour shortage, and increased rate of fertilizers application to increase agricultural productivity. Table 1 shows the nitrate fertilization types, doses and dates of application for different crops type and the increase in fertilizers application from year 1992 according to Abdel Dayem and Abdel Ghany, (1992) and recent years 2005-2006 according to the collected field data.

Table 1: Nitrate Fertilizers Types, Doses and Dates of Application for Different Crops

Crop Type	Year	Fertilizers Type		
		Calcium Nitrate	Urea	Ammonium Sulphate
Wheat	*1992*		150 kg/fed (Dec-Jan)	
	2005-2006		100 kg/fed (Jan-Feb)	100 kg/fed (Dec-Jan)
Berseem	*1992*	No Fertilization		
	2005-2006		200 kg/fed (Nov-Dec)	100 kg/fed (Oct-Nov)
Rice	*1992*			150 kg/fed (May- Jul)
	2005-2006		200 kg/fed (Jul-Aug)	100 kg/fed (Jun-Jul)
Maize	*1992*	150 kg/fed (Jun-Jul)		
	2005-2006		300 kg/fed (Jun-Jul)	

The data in Table 1 prevailed that there is increase in fertilizers usage for the different crops from year 1992 to year 2006 with percentages of 33%, 300%, 100%, and 100% for Wheat, Berseem, Rice, and Maize respectively. Therefore, it is clear that the fertilizers consumption

is high and continues to increase and consequently they are regarded as potential source of environmental pollution.

The collected water and soil samples were analyzed according to the Standard Methods for the examination of water and waste water (Lenore et al, 1998) to determine the nutrients including the three parameters of nitrate (NO_3), ammonia (NH_4), and phosphate (PO_4) for soil and water samples to follow the pollution migration and qualify aquifer soil remediation.

3.1 Clayey Soil (Winter Season)

The results of the different nutrients parameters nitrate (NO_3), ammonia (NH_4), and phosphate (PO_4) for different variables in the case of clayey soil in winter season are shown in Table 2.

Table 2: Average Nutrients Concentrations for Clayey Soil in Winter Season

Variables	Parameters		
	NO_3	NH_4	PO_4
I W	6.78	1.62	1.60
D W	15.31	6.09	2.73
SS W	4.61	4.16	2.29
G W	3.43	1.25	0.57
Soil 1.0 m	13.72	3.13	2.91
Soil 1.5 m	14.57	3.10	3.23
Soil 2.0 m	12.27	3.01	3.13

I W: Irrigation Water D W: Drainage Water SS W: Subsurface Water G W: Groundwater

The data was prevailed that the average percentage of nitrate decreased from 15.31 ppm in drainage water to 4.61 ppm in subsurface water (Figure 2) with a removal percentage equals to about 70%. However, for groundwater it was decreased to 3.43 ppm with a removal percentage equals to about 78%. The highest concentration of nitrate in the soil was found in the depth of 1.5 m (Figure 3).

The correlation coefficients between different variables for nitrate concentrations in the case of clayey soil in winter season are shown in Table 3. It is clear that there is a significant correlation between nitrate concentration in irrigation water and its concentration in groundwater. However, there is high negative correlation between nitrate concentration in irrigation water and its concentration in soil. The correlation between nitrate concentration in drainage water and subsurface water is positive and negative in the case of soil.

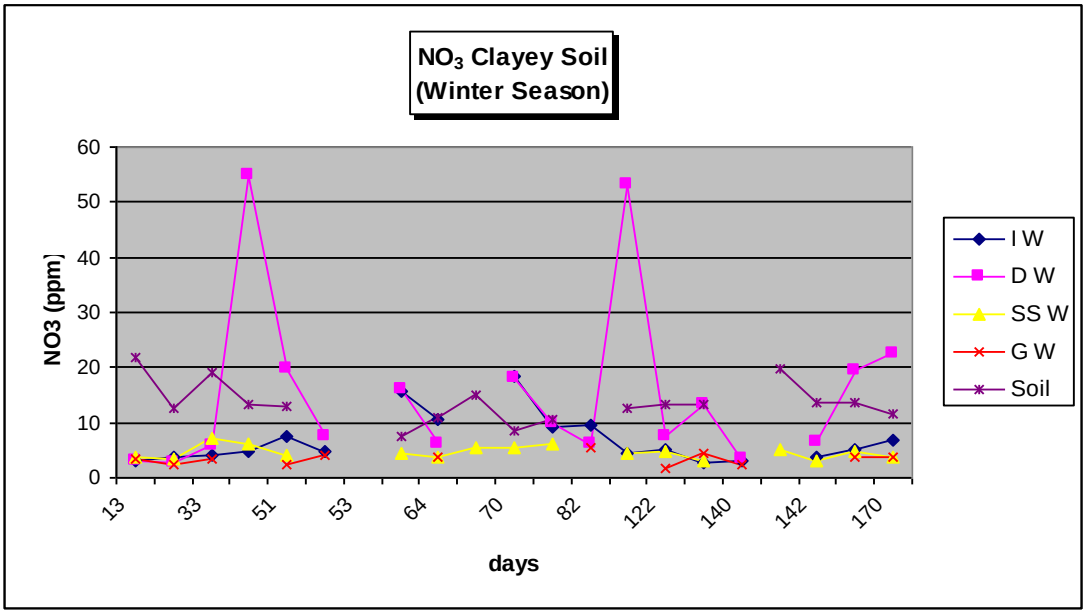

Figure 2: Nitrate Concentrations for Clayey Soil in Winter Season

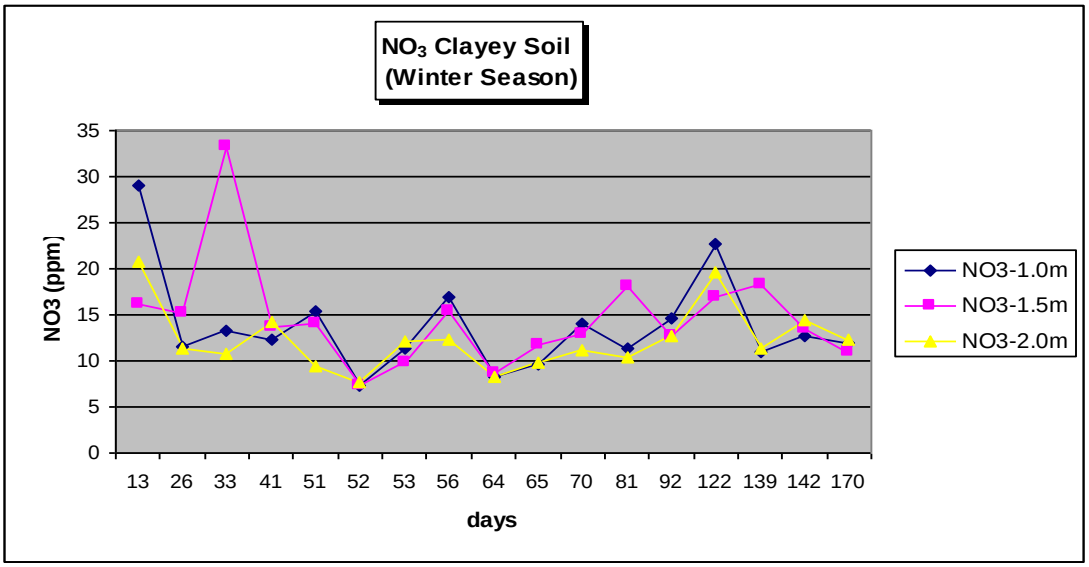

Figure 3: NO_3 Concentrations of Soil Depths for Clayey Soil in Winter Season

Table 3: Correlation Coefficient of Nitrate for Clayey Soil in Winter Season

Variables	I W	D W	SS W	G W	Soil
I W	1				
D W	0.004	1			
SS W	0.179	0.235	1		
G W	0.329	0.083	-0.071	1	
Soil	-0.713	-0.196	0.150	0.128	1

On the other hand, it was found that the average percentage of ammonia decreased from 6.09 ppm in drainage water to 4.16 ppm in subsurface water with a removal percentage equals to about 32%. For groundwater it was decreased to 1.25 ppm with a removal percentage equals to about 80%. Figure 4 shows the variation in ammonia concentrations through the winter season. It is clear that the concentration of ammonia is nearly equal in the three depths of the soil (Figure 5).

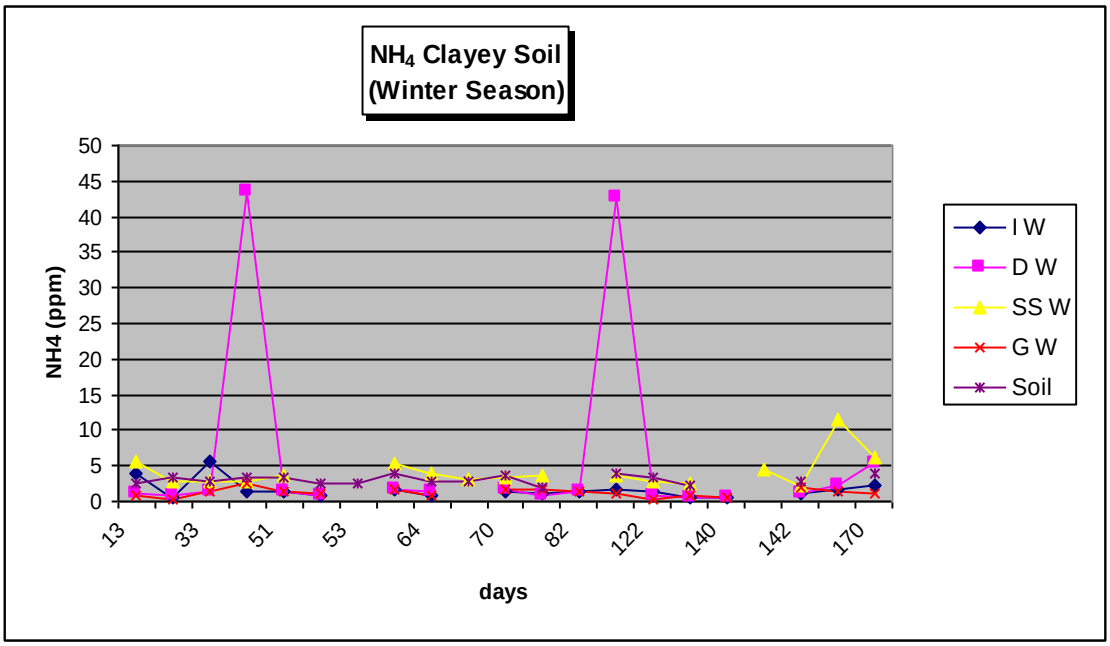

Figure 4: Ammonia Concentrations for Clayey Soil in Winter Season

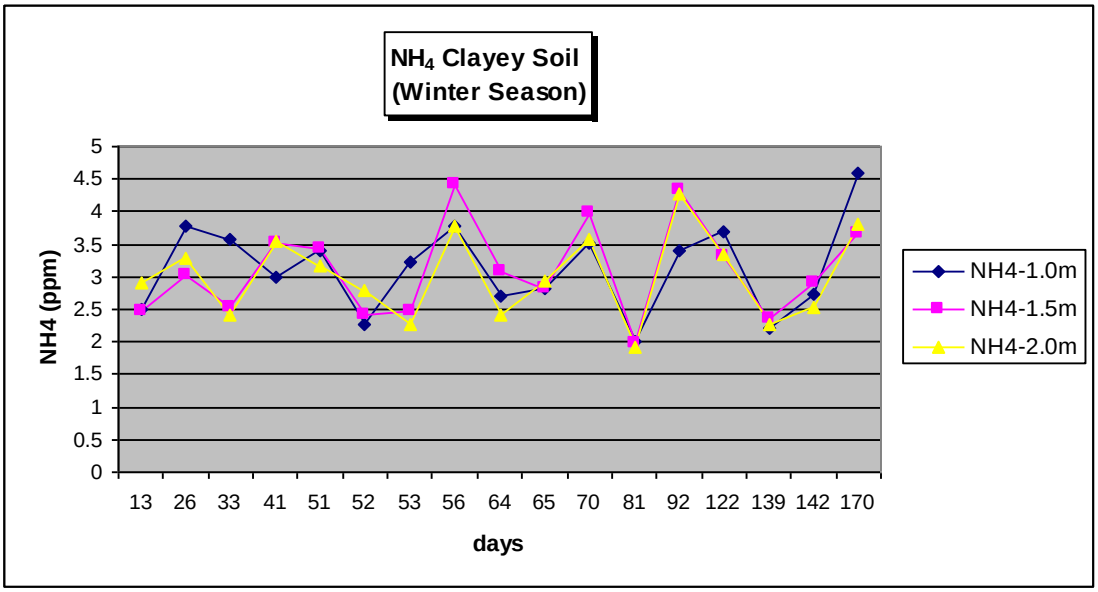

Figure 5: NH_4 Concentrations of Soil Depths for Clayey Soil in Winter Season

Table 4 shows the correlation coefficient between different variables for ammonia concentrations in the case of clayey soil in winter season. It is clear that there is a significant correlation between ammonia concentration in drainage water and its concentration in groundwater and soil. However, there is negative correlation between ammonia concentration in drainage water and its concentration in subsurface water. There is also significant correlation between ammonia concentration in subsurface water and its concentration in soil.

Table 4: Correlation Coefficient of Ammonia for Clayey Soil in Winter Season

Variables	I W	D W	SS W	G W	Soil
I W	1				
D W	-0.038	1			
SS W	0.123	-0.122	1		
G W	0.098	0.372	0.032	1	
Soil	-0.002	0.382	0.356	0.003	1

It was also found that the average concentration of phosphate decreased from 2.73 ppm in drainage water to 2.29 ppm in subsurface water with a removal percentage equals to about 16%. Figure 6 shows the variation in phosphate concentrations through the winter season. It is clear that for groundwater, the average concentration was decreased to 0.57 ppm with a removal percentage equals to about 79%. This is could be attributed to the high concentration of total phosphate in the soil depths of 1.5 m and 2.0 m in comparison to the depth of 1.0 m (Figure 7).

The correlation coefficients between different variables for phosphate concentrations in the case of clayey soil in winter season are shown in Table 5. It is clear that there is a significant correlation between phosphate concentration in irrigation water and its concentration in subsurface water and groundwater. However, there is a negative correlation between phosphate concentration in irrigation water and its concentration in soil. There is also negative significant correlation between phosphate concentration in drainage water and its concentration in subsurface water, groundwater and soil.

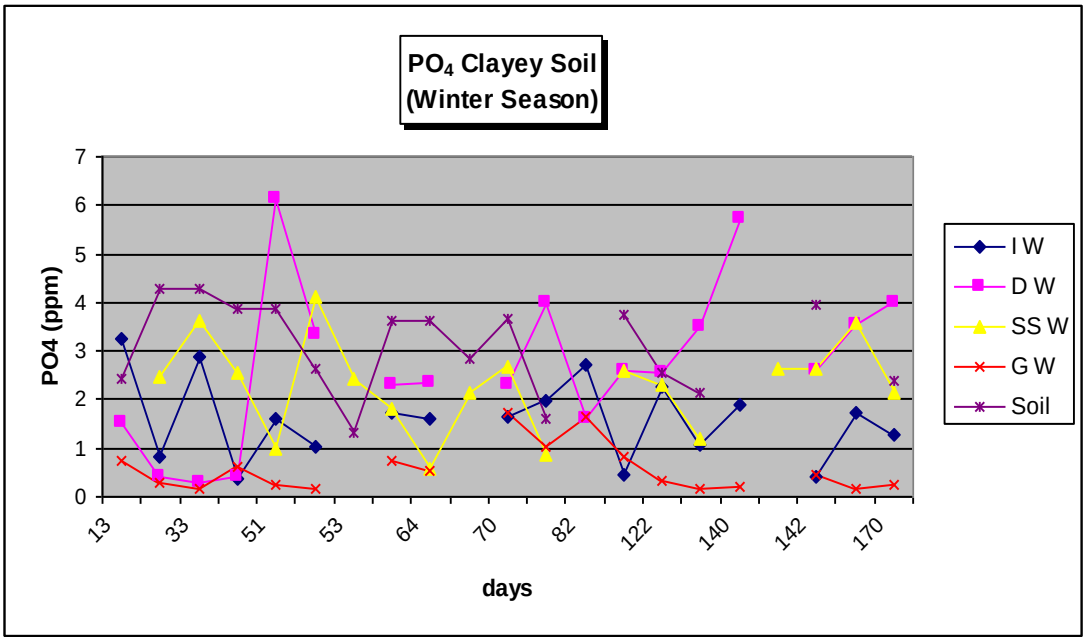

Figure 6: Phosphate Concentrations for Clayey Soil in Winter Season

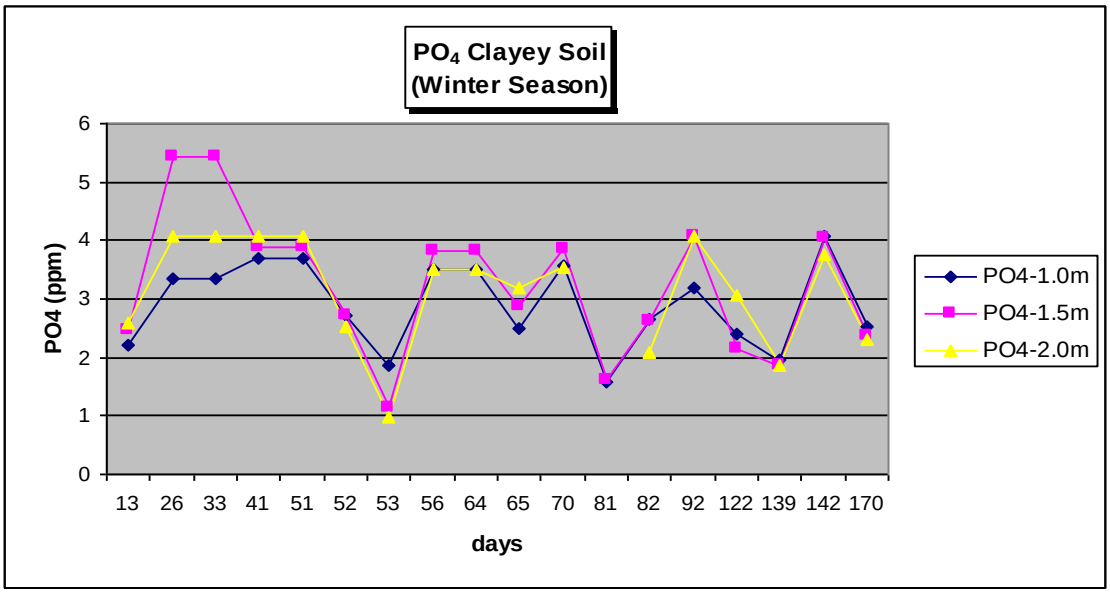

Figure 7: PO_4 Concentrations of Soil Depths for Clayey Soil in Winter Season

Table 5: Correlation Coefficient of Phosphate for Clayey Soil in Winter Season

Variables	I W	D W	SS W	G W	Soil
I W	1				
D W	-0.055	1			
SS W	0.299	-0.421	1		
G W	0.206	-0.257	-0.062	1	
Soil	-0.276	-0.436	0.044	-0.016	1

3.2 Clayey Soil (Summer Season)

The results of the different nutrients parameters nitrate (NO_3), ammonia (NH_4), and phosphate (PO_4) for different variables in the case of clayey soil in summer season are shown in Table 6.

Table 6: Average Nutrients Concentrations for Clayey Soil in Summer Season

Variables	Parameters		
	NO_3	NH_4	PO_4
I W	3.18	0.96	0.71
D W	8.82	4.94	11.87
SS W	8.44	1.30	1.96
G W	3.59	1.08	0.56
Soil 1.0 m	9.92	2.77	2.62
Soil 1.5 m	10.32	2.54	2.56
Soil 2.0 m	11.11	2.78	2.11

I W: Irrigation Water D W: Drainage Water SS W: Subsurface Water G W: Groundwater

The data prevailed that the average percentage of nitrate decreased from 8.82 ppm in drainage water to 8.4 ppm in subsurface water (Figure 8) with a removal percentage equals to about 4%. However, for groundwater it was decreased to 3.59 ppm with a removal percentage equaling to about 60%. The highest concentration of nitrate in the soil was found in the depth of 2.0 m (Figure 9).

Table 7 shows the correlation coefficient between different variables for nitrate concentrations in the case of clayey soil in summer season. It is clear that there is a significant correlation between nitrate concentration in irrigation water and its concentration in groundwater. However, there is negative correlation between nitrate concentration in irrigation water and its concentration in subsurface water and soil. There is high significant correlation between nitrate concentration in drainage water and subsurface water. There is also negative correlation between nitrate concentration in soil and its concentration in subsurface water and groundwater.

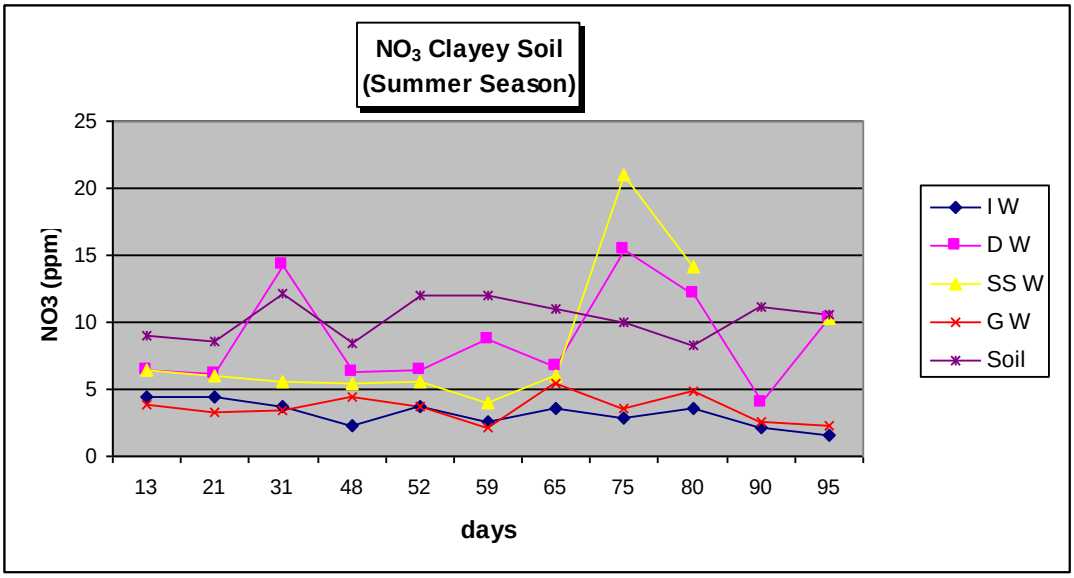

Figure 8: Nitrate Concentrations for Clayey Soil in Summer Season

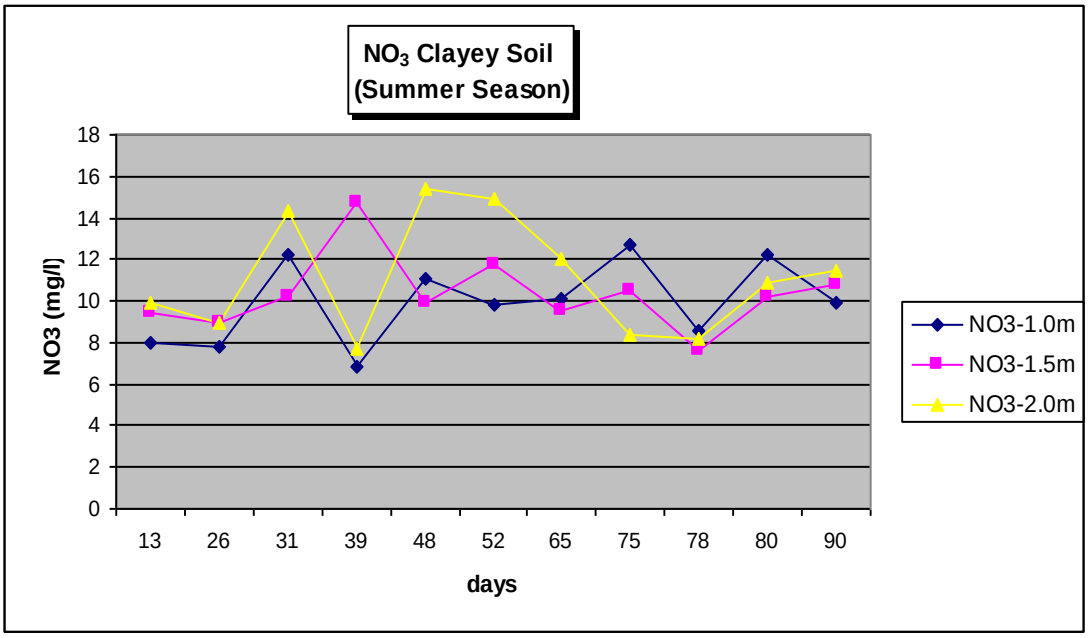

Figure 9: NO_3 Concentrations of Soil Depths for Clayey Soil in Summer Season

Table 7: Correlation Coefficient of Nitrate for Clayey Soil in Summer Season

Variables	I W	D W	SS W	G W	Soil
I W	1				
D W	-0.044	1			
SS W	-0.211	0.710	1		
G W	0.451	-0.011	0.082	1	
Soil	-0.222	0.085	-0.294	-0.388	1

On the other hand, it was found that the average percentage of ammonia decreased from 4.94 ppm in drainage water to 1.3 ppm in subsurface water with a removal percentage equals to about 74%. For groundwater it was decreased to 1.08 ppm with a removal percentage equals to about 78%. Figure 10 shows the variation in ammonia concentrations through the summer season. The concentration of ammonia is nearly equal in the three depths of soil (Figure 11).

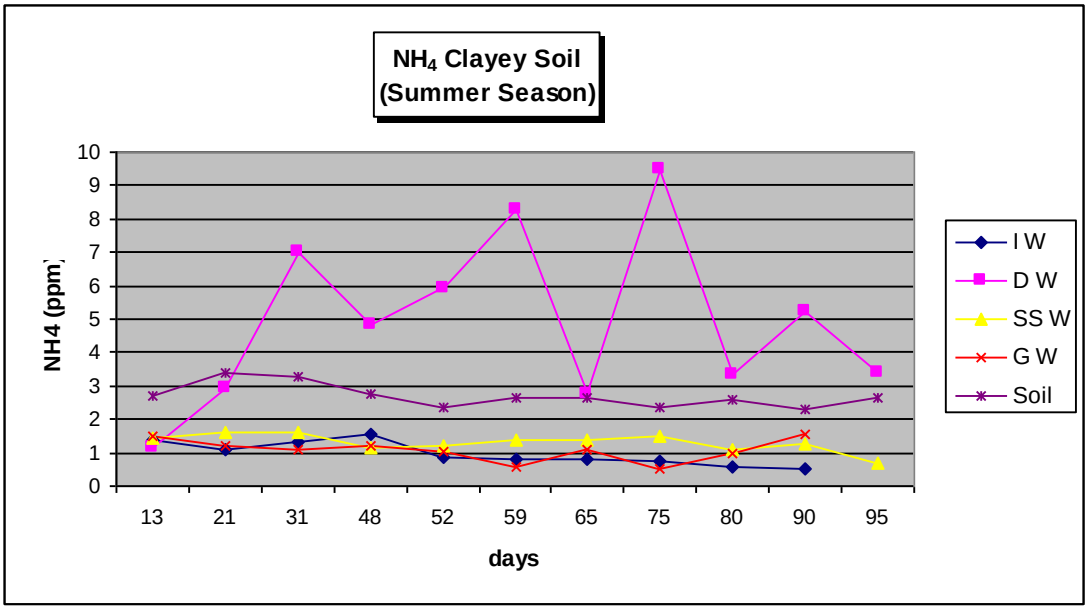

Figure 10: Ammonia Concentrations for Clayey Soil in Summer Season

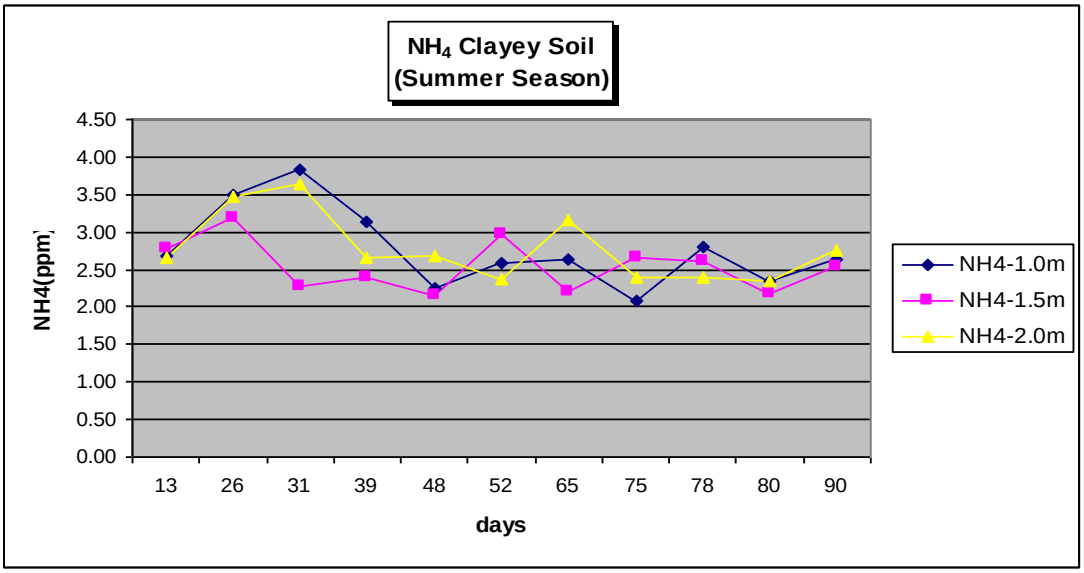

Figure 11: NH_4 Concentrations of Soil depths for Clayey Soil in Summer Season

Table 8 shows the correlation coefficient between different variables for ammonia concentrations in the case of clayey soil in summer season. It is clear that there is a significant correlation between ammonia concentration in irrigation water and its concentration in

subsurface water, groundwater and soil. However, there is negative correlation between ammonia concentration in drainage water and its concentration in groundwater and soil. There is also significant correlation between ammonia concentration in subsurface water and its concentration in soil.

Table 8: Correlation Coefficient of Ammonia for Clayey Soil in Summer Season

Variables	I W	D W	SS W	G W	Soil
I W	1				
D W	-0.258	1			
SS W	0.313	0.201	1		
G W	0.300	-0.724	-0.032	1	
Soil	0.563	-0.231	0.490	0.138	1

It was also found that the average concentration of phosphate decreased from 11.87 ppm in drainage water to 1.96 ppm in subsurface water with a removal percentage equals to about 84%. Figure 12 shows the variation in phosphate concentrations through the summer season. It is clear that for groundwater, the average concentration was decreased to 0.56 ppm with a removal percentage equals to about 95%. It is also clear that the concentration of total phosphate is nearly equal in the three depths of the soil (Figure 13).

Table 9 shows the correlation coefficient between different variables for phosphate concentrations in the case of clayey soil in summer season. It is clear that there is a significant correlation between phosphate concentration in irrigation water and its concentration in drainage water, subsurface water and groundwater. However, there is negative correlation between phosphate concentration in irrigation water and its concentration in soil. There is also significant correlation between phosphate concentration in drainage water and its concentration in subsurface water and groundwater and negative correlation with soil. The correlation between subsurface water and ground water is positive and negative between subsurface water and soil.

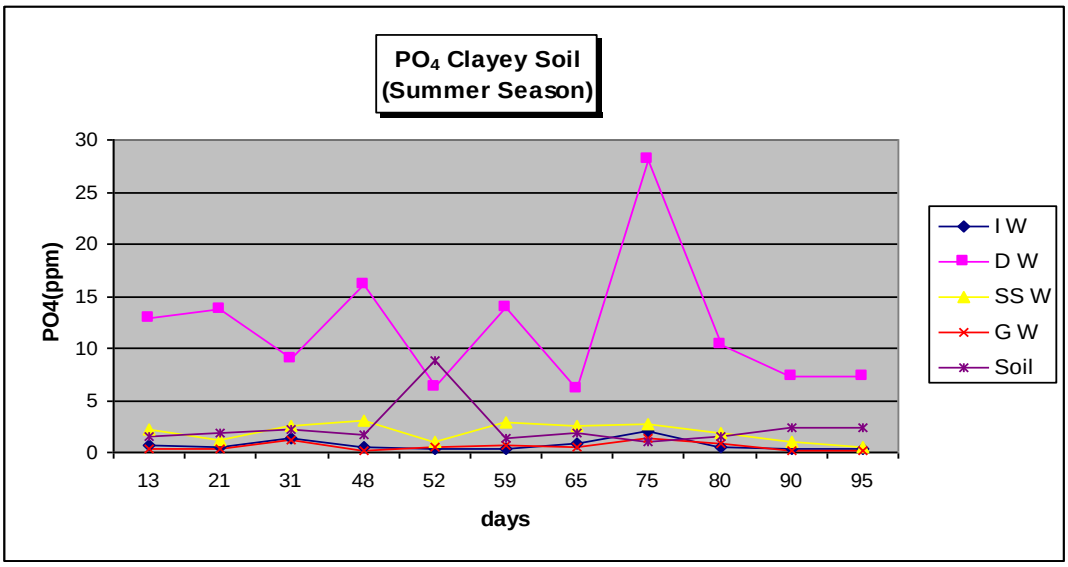

Figure 12: Phosphate Concentrations for Clayey Soil in Summer Season

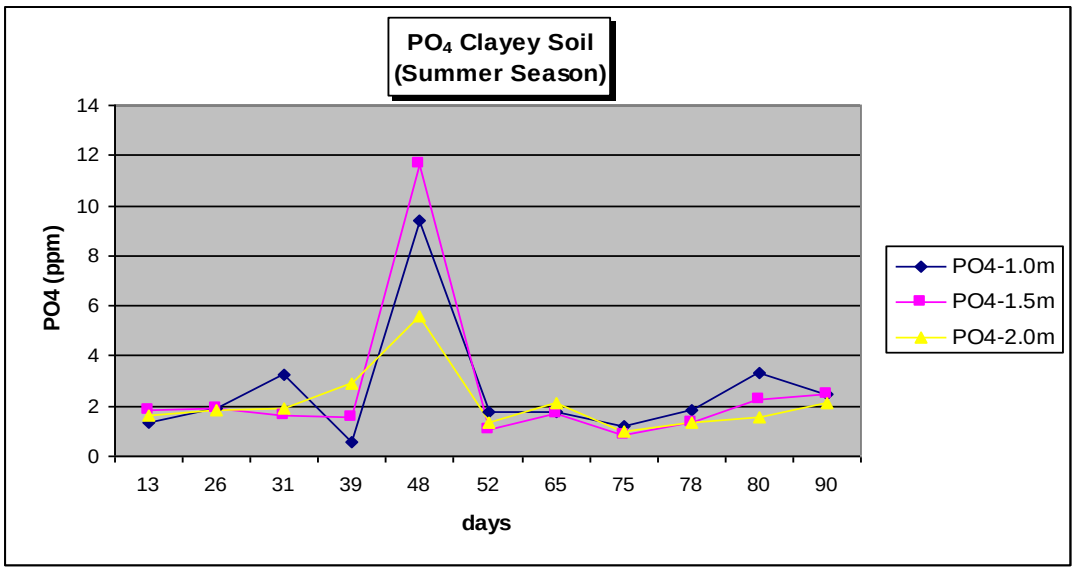

Figure 13: PO_4 Concentrations of Soil Depths for Clayey Soil in Summer Season

Table 9: Correlation Coefficient of Phosphate for Clayey Soil in Summer Season

Variables	I W	D W	SS W	G W	Soil
I W	1				
D W	0.647	1			
SS W	0.513	0.524	1		
G W	0.747	0.517	0.488	1	
Soil	-0.317	-0.433	-0.484	-0.118	1

3.3 Sandy Soil (Summer Season)

Results of different nutrients parameters nitrate (NO_3), ammonia (NH_4), and phosphate (PO_4) for different variables in the case of sandy soil in summer season are shown in Table 10.

Table 10: Average Nutrients Concentrations for Sandy Soil in Summer Season

Variables	Parameters		
	NO_3	NH_4	PO_4
I W	4.80	4.56	0.28
D W	10.87	11.82	0.57
SS W	10.62	6.47	0.37
G W	6.08	1.91	0.09
Soil 1.0 m	8.60	3.47	0.42
Soil 1.5 m	5.92	3.46	0.36
Soil 2.0 m	6.03	3.95	0.37

I W: Irrigation Water D W: Drainage Water SS W: Subsurface Water G W: Groundwater

The data prevailed that the average percentage of nitrate decreased from 10.87 ppm in drainage water to 10.62 ppm in subsurface water (Figure 14) with a removal percentage equals to about 2%. However, for groundwater it was decreased to 6.08 ppm with a removal percentage equals to about 44%. The highest concentration of nitrate in the soil was found in the depth of 1.0 m (Figure 15).

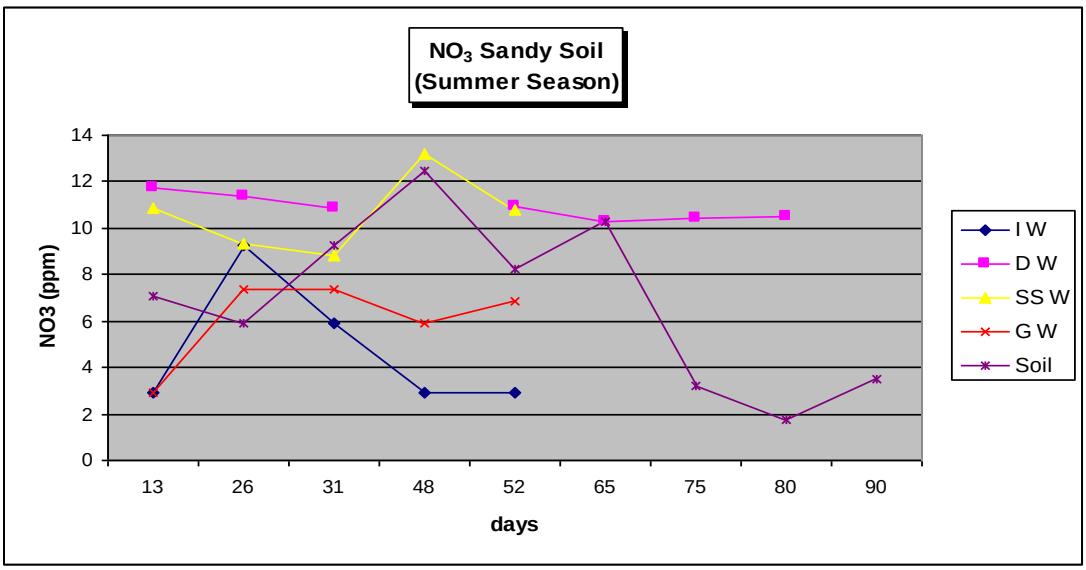

Figure 14: Nitrate Concentrations for Sandy Soil in Summer Season

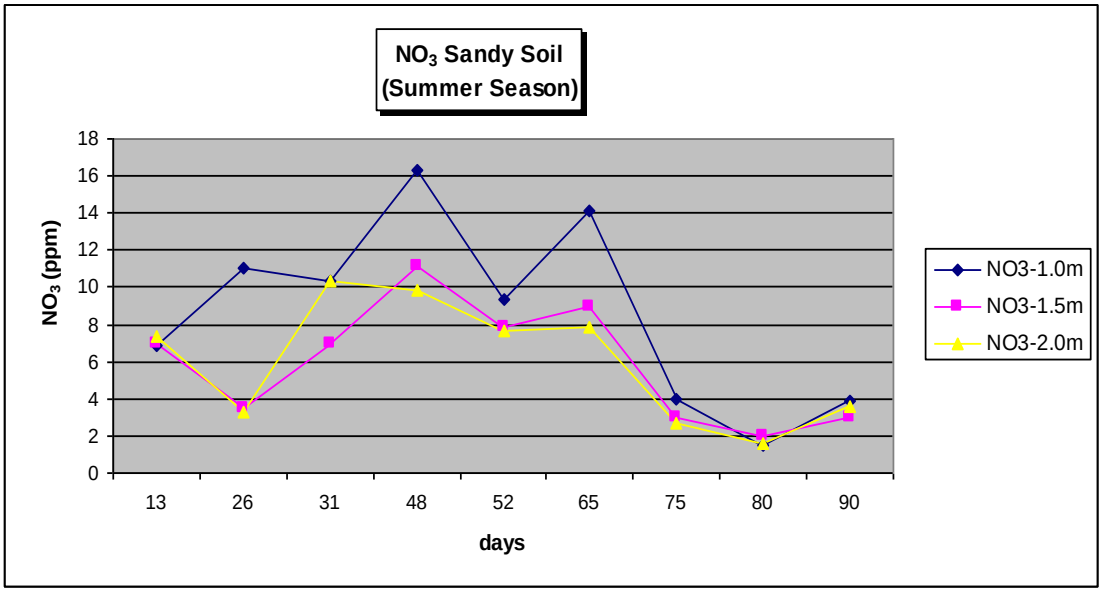

Figure 15: NO_3 Concentrations of Soil Depths for Sandy Soil in Summer Season

Table 11 shows the correlation coefficient between different variables for nitrate concentrations in the case of sandy soil in summer season. It is clear that there is a significant correlation between nitrate concentration in irrigation water and its concentration in groundwater. However, there is negative correlation between nitrate concentration in irrigation water and its concentration in drainage water, subsurface water and soil. There is high positive correlation between nitrate concentration in drainage water and its concentration in subsurface water and soil.

Table 11: Correlation Coefficient of Nitrate for Sandy Soil in Summer Season

Variables	I W	D W	SS W	G W	Soil
I W	1				
D W	-0.431	1			
SS W	-0.492	0.954	1		
G W	0.565	-0.156	0.023	1	
Soil	-0.534	0.608	0.964	0.066	1

On the other hand, it was found that the average percentage of ammonia decreased from 11.82 ppm in drainage water to 6.47 ppm in subsurface water with a removal percentage equals to about 45%. For groundwater it was decreased to 1.91 ppm with a removal percentage equals to about 84%. Figure 16 shows the variation in ammonia concentrations. The concentration of ammonia is nearly equal in the three depths of the soil (Figure 17).

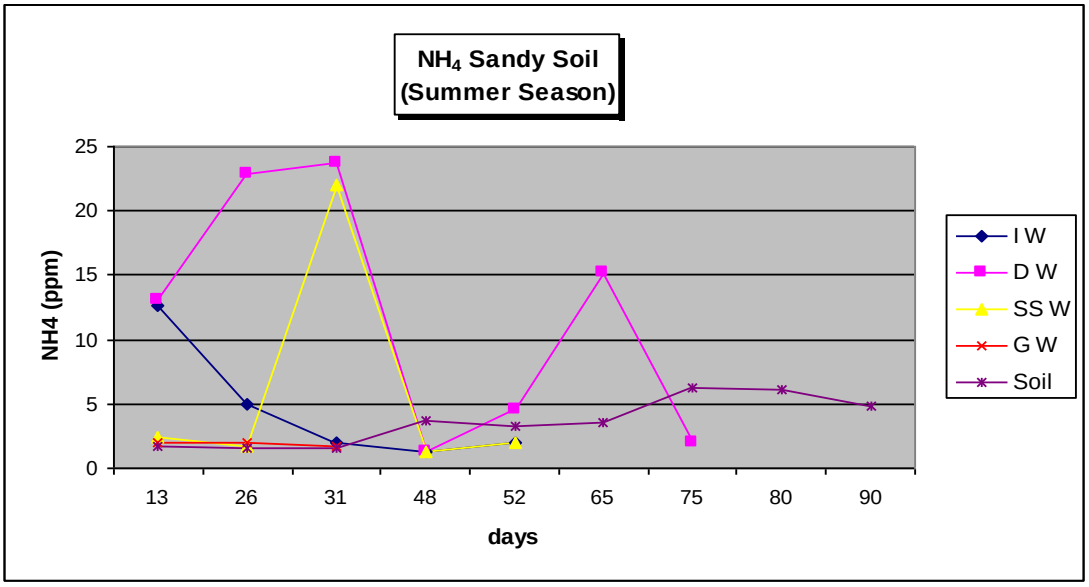

Figure 16: Ammonia Concentrations for Sandy Soil in Summer Season

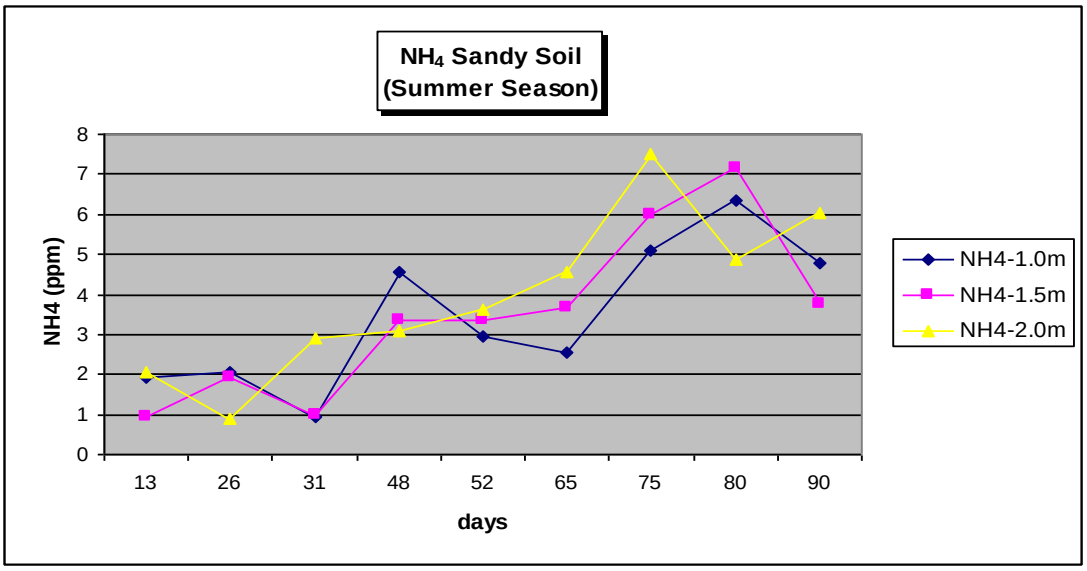

Figure 17: NH_4 Concentrations of Soil Depths for Sandy Soil in Summer Season

Table 12 shows the correlation coefficient between different variables for ammonia concentrations in the case of sandy soil in summer season. It is clear that there is high correlation between ammonia concentration in irrigation water and its concentration in groundwater. However, there is significant negative correlation between nitrate concentration in irrigation water and its concentration in soil. There is also negative correlation between ammonia concentrations in drainage water and its concentration in groundwater and soil and positive significant correlation with subsurface water. The correlation between ammonia concentration in groundwater and its concentration in subsurface water is highly negative. On the other hand, it is highly positive with soil.

Table 12: Correlation Coefficient of Ammonia for Sandy Soil in Summer Season

Variables	I W	D W	SS W	G W	Soil
I W	1				
D W	0.196	1			
SS W	-0.261	0.586	1		
G W	0.710	-0.559	-0.999	1	
Soil	-0.565	-0.761	-0.437	0.904	1

It was also found that the average concentration of phosphate decreased from 0.57 ppm in drainage water to 0.37 ppm in subsurface water with a removal percentage equals to about 35%. Figure 18 shows the variation in phosphate concentrations through summer season. It is clear that for groundwater, the average concentration was decreased to 0.09 ppm with a removal percentage equals to about 84%. It is also clear that the highest concentration of total phosphate in the depth of 1.0 m (Figure 19).

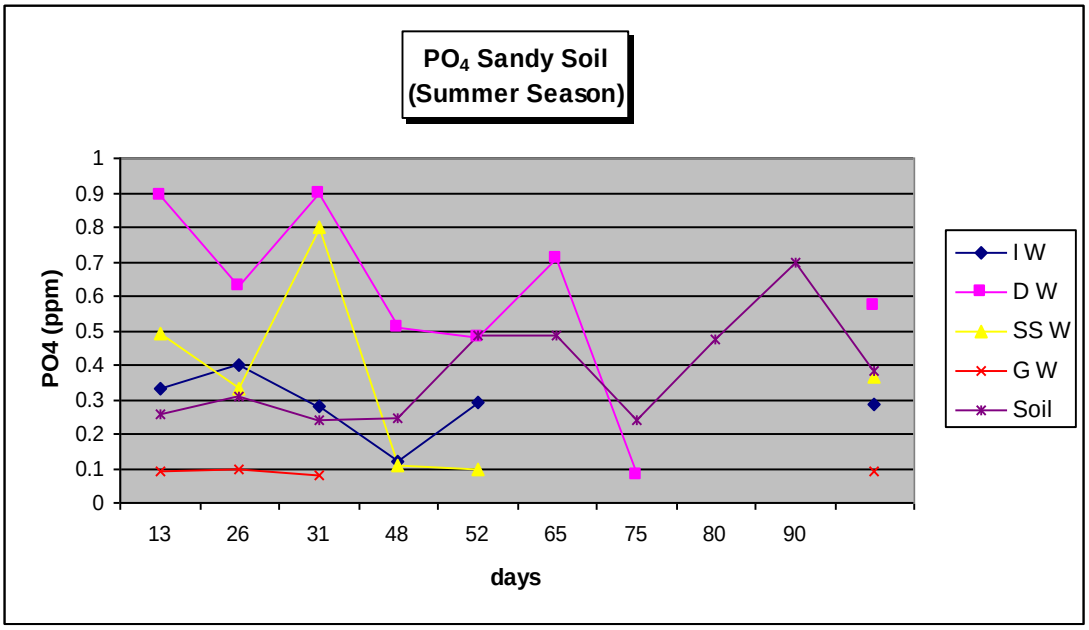

Figure 18: Phosphate Concentrations for Sandy Soil in Summer Season

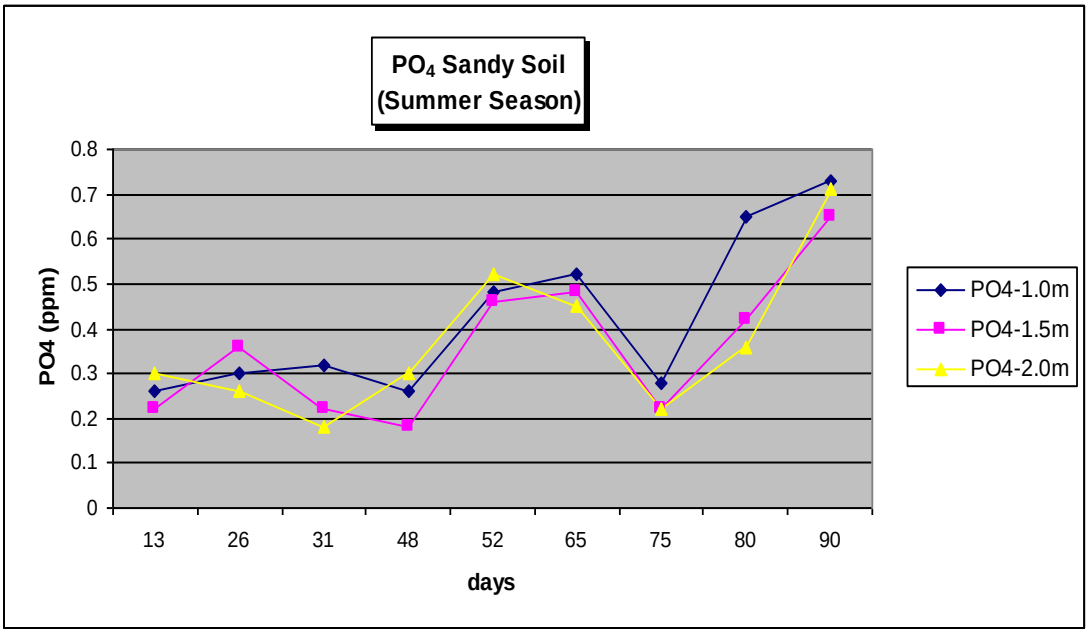

Figure 19: PO_4 Concentrations of Soil Depths for Sandy Soil in Summer Season

Table 21 shows the correlation coefficient between different variables for phosphate concentrations in the case of sandy soil in summer season. It is clear that there is significant correlation between phosphate concentration in irrigation water and its concentration in drainage water, subsurface water and soil. There is also high correlation between phosphate concentration in irrigation water and its concentration in groundwater. There is a highly positive correlation between phosphate concentrations in drainage water and its concentration in subsurface water. On the other hand, there is high negative correlation between groundwater and drainage water and subsurface water. The correlation between phosphate concentration in soil and its concentration in subsurface water is negative and positive with groundwater.

Table 21: Correlation Coefficient of Phosphate for Sandy Soil in Summer Season

Variables	I W	D W	SS W	G W	Soil
I W	1				
D W	0.355	1			
SS W	0.334	0.930	1		
G W	0.995	-0.882	-0.983	1	
Soil	0.212	0.023	-0.558	0.974	1

4. Conclusion

It could be concluded that in the case of clayey soil the removal percentage of nitrate (NO_3) by soil remediation in winter season is equal to about 70% for subsurface water and 78% for groundwater. The highest concentration of nitrate in the soil was found in the depth of 1.5 m. On the other hand, it was found that the removal percentage of Ammonia (NH_4) by soil remediation in winter season also is equal to about 32% for subsurface water and 80% for groundwater. The concentration of ammonia is nearly equal in the three depths of the soil. However, in the case of total phosphate (PO_4) it could concluded that the removal percentage by soil remediation in winter is equal to about 16% for subsurface water and 79% for groundwater. This is could be attributed to the high concentration of total phosphate in the soil depths of 1.5 m and 2.0 m in comparison to the depth of 1.0 m.

Moreover, in the summer season for clayey soil it was found that the removal percentage of nitrate (NO_3) by soil remediation is equal to about 4% for subsurface water and 60% for groundwater. The highest concentration of nitrate in the soil was found in the depth of 2.0 m. It also could be concluded that the removal percentage of Ammonia (NH_4) by soil remediation is equal to about 74% for subsurface water and 78% for groundwater. The concentration of ammonia is nearly equal in the three depths of the soil. It was also found that for the total phosphate (PO_4) the removal percentage by soil remediation is equal to about 84% for subsurface water and 95% for groundwater. It is also clear that the concentration of total phosphate is nearly equal in the three depths of the soil.

However, in the summer season for sandy soil it was found that the removal percentage of nitrate (NO_3) by soil remediation is equal to about 2% for subsurface water and 60% for groundwater. The highest concentration of nitrate in the soil was found in the depth of 1.0 m. It also could be concluded that the removal percentage of Ammonia (NH_4) by soil remediation is equal to about 45% for subsurface water and 84% for groundwater. The concentration of ammonia is nearly equal in the three depths of the soil. It was also found that for the total phosphate (PO_4) the removal percentage by soil remediation is equal to about 35% for subsurface water and 84% for groundwater. The highest concentration of total phosphate in the soil was found in the depth of 1.0 m.

Generally it could be concluded that the soil remediation for fertilizers pollution in clayey soil is more effective than sandy soil. It is undoubted that the adoption and utilization of soil remediation for the natural percolated drainage water before recharge to groundwater is worth considering as an alternative due to its efficacy in reducing the fertilizers pollutants. The drainage water is renovated as it percolates through the soil prior to entering groundwater. The soil remediation mechanisms include a series of physical, biological and chemical

processes within the soil profile. The main evaluation for soil remediation relies on natural processes to polish drainage water. This depends on the unsaturated zone soil composition.

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تعزيز المعارف التقليدية في إدارة الطلب على المياه للمقاشم والبساتين التاريخية بصنعاء القديمة

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ملخص:

تعتبر مقاشم وبساتين صنعاء القديمة ضمن التراث الإنساني العالمي في صنعاء القديمة التي اعتمدتها منظمة اليونسكو عام 1986م، وقد تم استغلالها لأغراض الزراعة باستخدام مياه الوضوء (أو كما اصطلح عليها حاليا بالمياه الرمادية) الخارجة من المساجد في ري الخضروات كمحاصيل تقليدية وكذا الفواكه وذلك منذ أكثر من 500 سنة. هذه المقاشم عبارة عن أراض وقف وهبتها الأسر الغنية لمصلحة المساجد بحيث تكون تحت إدارة وزارة الأوقاف وينتفع من زراعتها الفقراء مقابل خدمتهم للمسجد. أصبحت مشكلة نضوب المياه في الآبار اليدوية التي تغذي المساجد تهدد بقاء واستمرارية هذه المقاشم والبساتين البيئية التقليدية التي كانت تدار بآلية متميزة لإدارة الطلب على المياه بطريقة مستدامة، وقد أفضى ذلك إلى ظهور مشكلة اجتماعية واقتصادية كبيرة لدى الأسر الفقيرة المستفيدة من تلك المقاشم والبساتين مما أدى إلى فقدان المزارعين المحليين لأعمالهم. تهدف هذه الورقة الى دراسة الوضع الحالي لمقاشم وبساتين صنعاء القديمة والمعارف التقليدية المرتبطة بها وبالتالي تعزيز تلك المعارف التقليدية ورفدها بحلول ومقترحات علمية للتغلب على المشاكل التي تعاني منها وإعادة إحيائها بناءً على مبدأ الإدارة المتكاملة للموارد المائية بغرض الحفاظ على هذا النموذج التاريخي الفريد لإدارة الطلب على المياه. قام الفريق البحثي متعدد التخصصات خلال الفترة 2006-2008م بإتباع منهجية البحث على مرحلتين، في المرحلة الأولى تم النزول الميداني للمقاشم والبساتين ومقابلة المزارعين القائمين على المقاشم والمجتمع المحلي من خلال استبيان تم تصميمه لهذا الغرض، أعقب ذلك تنفيذ نقاش بالمشاركة(PRA) في مقر المشروع بمنطقة الطبري داخل صنعاء القديمة وذلك بالتركيز على المعارف التقليدية ومن ثم حصر المشاكل التي تعاني منها المقاشم والبساتين وتحديد أسبابها وكذا حصر وتوثيق المقاشم بتحديد حدودها ومساحاتها. في المرحلة الثانية تم اقتراح الحلول للتغلب على أسباب تلك المشاكل، حيث تم تقسيم هذه المرحلة إلى أربعة مكونات، في المكون الأول تم البحث عن مصادر مياه تكميلية آمنة وتصميم وتنفيذ وتشغيل منظومة المياه الرمادية. في المكون الثاني، تم التحقق من مدى اختلاف ميول الرصف المنفذ حديثاً في الشوارع الداخلية عن الطريقة التقليدية، وكذا التحقق من أثر رصف السائلة على تسارع هبوط مستوى منسوب الآبار اليدوية في مقاشم وبساتين صنعاء القديمة وذلك من خلال دراسة هبوط مستوى المياه في أربعة آبار داخل صنعاء القديمة خلال الفترتين الزمنيتين قبل وبعد رصف السائلة. أما المكون الثالث، فقد ركز على دراسة وحصر المحاصيل التقليدية والتركيز على المحاصيل الزراعية التقليدية الأكثر اقتصاداً وتطبيقها في المساحة المحددة في المقشامة المستهدفة كجزء من منظومة المياه الرمادية. في المكون الرابع تم التركيز على ربط المزارعين القائمين على المقاشم في إطار قانوني من خلال تشكيل الجمعية العامة للحفاظ على مقاشم وبساتين صنعاء القديمة. خلصت نتائج المرحلة الأولى إلى رسم خريطة لصنعاء القديمة وتوقيع المقاشم والبساتين عليها بمساحاتها وحدودها وتصنيفها زراعياً

وتوثيقها كخطوة للحفاظ على الموروث الثقافي الحضاري. كما تم تحديد أهم المشاكل التي تعاني منها المقاشم والبساتين التقليدية واقتراح الحلول التي تستند على المعارف التقليدية وتعزيزها بالحلول العلمية المبنية على مبدأ الإدارة المتكاملة للموارد المائية. أوصى الباحثون بتمويل تنفيذ مخرجات هذا البحث بغرض إعادة إحياء المقاشم والبساتين، ومن ثم نشر تطبيق نموذج المقاشم في المناطق الأخرى من الجمهورية اليمنية من خلال إدخال تحسينات متعددة التخصصات تتناسب مع ظروف كل موقع على حده.

كلمات دالة: مقاشم وبساتين، صنعاء القديمة، إدارة الطلب على المياه، المعارف التقليدية، منظومة المياه الرمادية، الإستدامة

Abstract

The Traditional gardens (Maqashim) of Old Sana'a city is considered as one of the World Heritage, adopted by UNESCO in 1986. It has been exploited for agriculture using ablution water (as termed currently graywater) emerging from mosques in the irrigation of traditional vegetables as well as fruits, since more than 500 years. The lands of these Maqashim were donated by wealthy families as endowment (Waqf) for the benefit of the mosques so that they are under the administration of the Ministry of Awqaf, cultivated by and for the benefit of the poor against their service at the mosque. The problem of depletion of water in the hand-dug wells feeding the mosques is threatening the survival and sustainability of these Maqashim, which was administered by distinguished mechanism of water demand management in a sustainable manner, has led to the emergence of social and economic problems for the poor benefiting from these Maqashim leading to the loss of business of the local farmers. This paper aims at studying the current situation of Maqashim of Old Sana'a and its associated traditional knowledge and thus enhances those of traditional knowledge by supporting them with scientific solutions based on IWRM to overcome the problems experienced in order to maintain this historical uniqueness model of water demand management. This research project was implemented by multidisciplinary team during the period 2006-2008 by applying the research methodology in two stages. In the first stage, field visits was conducted to Mqashim, and designing questionnaire and applying it in interview with farmers, followed by discussion based on participation approach (PRA) at the rented project office at Al-Tabari district in Old Sana'a city focusing on traditional knowledge and then listing the problems facing Al-Maqashim and determine their causes, as well as inventory and documentation of Al-Mqashim by determine its borders and areas. In the second phase, solutions were suggested to overcome the causes of those problems, where this stage has been divided into four components, the first component has concentrated in searching for alternative and safe water resources. As a complementary, design, implementation and operation of gray water system was conducted. In the second component, the difference of traditional versus recent pavement slopes of Interior streets has been verified, as well as verification of the effect of the

paving on the drawdown of the water level of hand-dug wells in Mqashim of Old Sana'a city, through the study of the water level in four wells in old Sana'a during the time periods before and after the paving of the streets and Wadi Sailah. The third component was focused on the study and inventory of traditional crops and focuses on the most economical traditional crops, and then applied in the selected area in Al-Washali Meqshamah targeted by as part of the gray water system. The fourth component was focused on linking farmers of Al-Maqashim at old Sana'a city within a legal framework through the formation of the General Association to maintain Mqashim of old Sana'a. The results of the first stage was drawing a map of Old Sana'a city and the locating of Al-Mmqashim with its boundaries, areas and classification of existing agricultural situation, documented as a step to preserve the cultural heritage. The identified problems of Almqashim were solved by proposing solutions based on traditional knowledge and promotion of scientific solutions based on the principle of integrated water resources management. Researchers recommended that funding for implementation of findings of this research to revive Al-Mqashim, and then apply such solutions to Al-Mqashim in other governorates of the Republic of Yemen through adaptation of multi-disciplinary solutions based on the circumstances of each site separately.

Keywords: Maqashim, Old Sana'a, water demand management, traditional knowledge, gray water system, sustainability

مقدمه:

تميزت مدينة صنعاء القديمة إلى جانب طرازها المعماري التاريخي الفريد بمساحاتها الزراعية الخضراء التي سميت بالمقاشم والبساتين والتي تعتبر اليوم أحد المعالم الحضارية التاريخية التي تتميز بها مدينة صنعاء القديمة المسجلة من قبل منظمة اليونسكو ضمن التراث العالمي الإنساني عام 1986م. هذه المساحات الخضراء عبارة عن أراض بجانب المساجد أوقفتها الدولة وبعض الأسرالغنية على تلك المساجد منذ أكثر من 500 عام، وبذلك أصبحت أراضٍ لايجوز بيعها أو البناء عليها أو استخدامها في غير الغرض الذي أوقفت من أجله وخصصت له، وهو حكم تنص وتشدد عليه الشريعة الإسلامية، ويعتبر ذلك سبباً رئيسياً في دعم بقائها واستمرارها والحفاظ عليها طوال القرون الماضية. حيث تم تخصيصها لزراعة وإنتاج الخضروات الطازجة معتمدة في ذلك على ابتكار نظام الاستفادة من مياه الوضوء الخارجة من المساجد في ري تلك المقاشم والبساتين، وتعتبر بذلك نموذجاً تاريخياً فريداً لتطبيق مبدأ إدارة الطلب على المياه وترشيد استخدامها بطريقة مستدامة بتطبيق المعارف التقليدية المرتبطة بها والمتراكمة لعقود عده، كما تكتسب خصوصية أكبر تتجاوز تطبيق مبدأ الطلب على المياه إلى تجسيد نظام الإدارة المتكاملة للموارد المائية التي تشمل الجوانب البيئية الحيوية ودعم النظام الاجتماعي والاقتصادي للمجتمع المحلي. تدار هذه العملية كمنظومة متكاملة مكونة من مسجد ومقشامة وبئر ويمكن أن نطلق عليها "منظومة المقشامة"، حيث يتم حفر بئر يدوية لكل مسجد لتزويده بمياه الوضوء وملء المطاهير، وعند تبديل هذه المياه المستخدمة في الوضوء والغسل يتم إخراجها عبر قنوات إلى بركة تجميعية ومنها إلى المقشامة أوالبستان. وقد تحولت تلك المقاشم والبساتين التقليدية منذ ذلك الحين إلى مصدر دخل أساسي للقائمين عليها من الأسر الفقيرة الذين عملوا في زراعتها والانتفاع بمردودها الاقتصادي مقابل رفع المياه من البئر لتغذية المسجد وسمي القائم بذلك ب "الساني" ، وبفضل هذا النظام المائي والإدارة الرشيدة في إعادة استخدام مياه الوضوء في الزراعة، ظلت تلك المقاشم والبساتين التقليدية طوال القرون الماضية محافظة على هيئتها ونظامها الزراعي ووظيفتها الأساسية في تأمين احتياجات سكان المدينة من الخضروات الطازجة إلى جانب دورها الحيوي الاقتصادي والاجتماعي والبيئي، كما تميزت من الناحية الزراعية باعتمادها حتى يومنا هذا على نمط الزراعة العضوية واستخدام محدود جداً للأسمدة الكيميائية وعدم استخدام المبيدات.

ركزت معظم مشاريع إدارة الطلب على المياه في اليمن على إدخال تقنيات الري المرشدة للمياه اضافة الى الإعتماد على إدارة المجتمع المحلي ممثلا بمجموعات أو جمعيات مستخدمي المياه التي تم تكوينها بهدف ترشيد استخدام المياه الجوفية والقضاء على الممارسات الخاطئة التي تؤدي الى هدر المياه .بينما ركزت فقط بعض المشاريع الصغيرة المتفرقة على إعادة استخدام مياه الوضوء الخارجة من المساجد في الري، بينما تمثلت المبادرات التي قدمتها بعض الجهات مثل الصندوق الاجتماعي للتنمية في تسوير بعض المقاشم، وتعميق بعض الآبار الضحلة في بعض المقاشم، وترميم وإعادة تأهيل البرك في بعض المقاشم، كما قام الصندوق في مواقع أخرى خارج صنعاء القديمة وبعض المحافظات الأخرى باستغلال المياه الرمادية لتحسين وتجميل البيئة المحيطة بالمساجد والمدارس المجاورة بغرض استغلال الكميات الكبيرة من المياه الرمادية الخارجة من المساجد .كما أن هناك مشروعاً فازت به الجمهورية اليمنية ممثلة بوزارة المياه والبيئة بتمويل مشروع اعادة استخدام مياه الوضوء من المساجد من البنك الدولي في الملتقى السنوي التنافسي (Development Market Place, 2005) قامت بتنفيذه شركة إنجليزية (Parsons Brinckerhoff, 2006)، تم في ذلك المشروع تجميع المياه الرمادية الخارجة من ثلاثة مساجد في

اليمن (مسجد بدر في صنعاء، مسجد بير زبوط في ذمار، الجامع الكبير في عمران) وإدخال المرشح الرملي لمعالجتها ومن ثم الاستفادة من المياه المعالجة في ري البساتين والمقاشم القريبة من هذه المساجد الثلاثة. إلا أن هذه المبادرات لم تتطرق للجوانب الاجتماعية والاقتصادية (فيما يتعلق بالزراعة والمحاصيل والتسويق) أو حتى التحديات الاجتماعية والثقافية لإعادة استخدام مياه الوضوء غير المعالجة .وقد لوحظ خلال السنوات الأخيرة أن إعادة استخدام المياه الرمادية ومياه الصرف الصحي والجوانب ذات الصلة البيئية تحظى بإهتمام كبير من قبل واضعي السياسات والأوساط الأكاديمية عن طريق البحث عن معلومات واستخدامها في التعليم والتوعية بهذا الموضوع والمؤسسات الفقهية.

المشكله:

باتت ندرة المياه تهدد بقاء واستمرارية هذه المقاشم والبساتين البيئية التقليدية والذي أدى إلى جفافها وتصحرها وتعطل النشاط الزراعي فيها ، وأصبحت مرمى للقمامة إضافة إلى زحف البناء على هذه البساتين. واثر ذلك فيما يلي: فقدان الكثير من الأسر الفقيرة لمصدرها الاساسي ما أدى إلى تدهور الحياة المعيشية لهذه الأسر، ظهور بعض التوترات الاجتماعية والنزاعات داخل المجتمع، والتخوف من فقدان حقوق الماء والأرض، تزايد المنافسة على المحاصيل المنتجة من المزارع المحلية خارج صنعاء القديمة والرخيصة الثمن مقارنة مع الإنتاج من المقاشم التي تعاني من عدم كفاية المياه و الإنتاج. ويمكن تلخيص أهم أسباب هذه المشاكل فيما يلي: نضوب الآبار اليدوية التي تغذي المساجد بالمياه في صنعاء القديمة بسبب قلة الأمطار، رصف الشوارع الداخلية لصنعاء القديمة بطريقة مخالفة للوضع التقليدي، رصف السائلة (المجرى الرئيسي للسيول) دون الأخذ في الاعتبار تغذية الاحواض المائية. كل ذلك أدى الى عدم تغذية الآباراليدوية ونضوبها مما أدى إلى تأثير سلبي على الدور الحيوي التي تقوم به من الناحية الاجتماعية والاقتصادية خصوصا لدى الأسر المستفيدة من تلك البساتين، والمعتمده على زراعتها كمصدر دخل أساسي لحياتهم المعيشية. كما أن تصريف مياه الوضوء إلى شبكة الصرف الصحي قد ساعد في تدهور الوضع الزراعي في تلك المقاشم والبساتين التقليدية وتصحرها (بروسلو وآخرون، 2006) كما توضحه الصور المأخوذة لمقشامة الوشلي التي تصحرت سنة 2004 م مقارنة بوضعها الزراعي عام 2002 م (صوره 1، 2).

صوره (1) مقشامة الوشلي قبل التصحر (2002)

صوره (2) مقشامة الوشلي بعد التصحر (2004)

أهداف البحث.

تهدف هذه الورقة الى دراسة الوضع الحالي للمقاشم والبساتين التاريخية الحضرية في صنعاء القديمة والمعارف التقليدية المرتبطة بها وتعزيزها بالحلول والمقترحات العلمية للتغلب على المشاكل التي تعاني منها بغرض إعادة إحيائها بناء على مبدأ الإداره المتكاملة للموارد المائية والحفاظ على هذا النموذج التاريخي الفريد لإدارة الطلب على المياه، وتطويرمنظومة المقشامة المكونة من المسجد، البئر، المقشامة وذلك لتلبيةمتطلبات المستقبل مع الأخذ في الإعتبار الجوانب الإجتماعية، التقنية، الإقتصادية، الزراعية والبيئية من خلال تطوير منظومة فرعية فيها تسمى منظومة المياه الرمادية واعادة توجيه السيول الى المقاشم بالطرق التقليدية واعادة تغذية الآبار الضحلة في المقاشم، حصر وتوثيق المحاصيل الزراعية التقليدية في المقاشم بغرض حمايتها من الإنقراض والتركيز على المحاصيل الإقتصادية منها، و تشكيل الجمعية العامة للحفاظ على مقاشم وبساتين صنعاء القديمة بغرض اشراك المجتمع المحلي في الحفاظ على هذه المقاشم.

المنهجيه:

تم تنفيذ المشروع وفق منهجية متسلسلة اشتملت على مرحلتين رئيسيتين، تضمنت المرحلة الأولى منها حصر وتصنيف وتوثيق المقاشم والبساتين التقليدية، بينما اشتملت المرحلة الثانية على أربعة مكونات تناولت أربعة محاور رئيسية هي: تطوير وتنفيذ وتشغيل منظومة المياه الرمادية وري المساحة المستهدفة، التحقق من تأثير رصف الشوارع والسائلة على جفاف المقاشم والآبار، واختيار المحاصيل التقليدية الاقتصادية وزراعة المساحة المستهدفة، تشكيل الجمعية العامة للحفاظ على مقاشم صنعاء القديمة. وقد تضمنت كل مرحلة على مجموعة من الأعمال كمايلي:

المرحلة الأولى:

تم تشكيل فريق العمل الأساسي والفريق النسائي المساعد، ضم الفريق الأساسي التخصصات المختلفة التي تغطي مكونات الإداره المتكاملة للموارد المائية حيث تكون من: أخصائي في الجوانب الاجتماعية والتراثية والثقافية من منظمة ايديال الفرنسية غيرالحكومية– رئيس الفريق، أخصائي معالجة مياه رمادية وتحسين نوعيتها من مركز المياه والبيئة – جامعة صنعاء، أخصائي أنظمة الري واستخدامات المياه الرمادية في الري التكميلي من وزارة الزراعة والري، أخصائي تغذية المياه الجوفية من الأمطار من أمانة العاصمة، أخصائي زراعة وحصاد محاصيل زراعية تقليدية من مركز الأصول الوراثية - كلية الزراعة- جامعة صنعاء.

فيما يخص الفريق النسائي فبحسب العادات والتقاليد المتعارف عليها، كان من الضروري الاستعانة بمهندسات لكي يقمن بالتحاور والنقاش مع النساء المستفيدات من هذه المقاشم فقد تم تشكيل فريق نسائي من المهندسات الزراعيات وتم التواصل مع النساء المستفيدات وعقدت اجتماعات من قبل الفريق النسائي المساعد مع النساء المستفيدات من المقاشم.

وتم افتتاح مقر المشروع في منطقة الطبري بقلب مدينة صنعاء القديمة وعقدت الاجتماعات مع الجهات ذات العلاقة والمستفيدين وتم اكتساب ثقة المجتمع حيث خصص فريق المشروع اجتماعات أسبوعية وحلقات عمل تشاركية وتم تنفيذ ورش عمل واجتماعات ونقاشات جماعية بطريقة PRA مع ممثلي الجهات ذات العلاقة (على رأسهم ممثل وزارة الأوقاف بأمانة العاصمة، والأشخاص المستفيدين من المقاشم وممثلي المجلس المحلي.

قام الفريق بتنفيذ زيارات ميدانية لدراسة الوضع الراهن للمقاشم والبساتين التقليدية بصنعاء القديمة من خلال تصميم استبيان عام متعدد التخصصات حيث تم حصرها وتحديد مساحاتها وحدودها وتصنيفها زراعيا ومائيا وتحديد المشاكل التي تعاني منها، اختيار خمس مقاشم رئيسية ووضع معايير لإختيار مقشامة واحده منها كنموذج بحثي لتنفيذ التدخل.

المرحلة الثانيه: وتم تقسيمها الى أربعة مكونات كمايلي:

المكون الأول: البحث عن مصادر مياه تكميليه آمنه من خلال دراسة موقعية وتطوير وتنفيذ وتشغيل منظومة المياه الرمادية.

المكون الثاني: دراسة أثر رصف الشوارع الداخليه المنفذ حديثا والمخالف للطريقة التقليدية في تغيير توجيه السيول لري المقاشم وتغذيه الابار اليدويه فيها وكذا تأثير رصف السائله على عدم تغذية الآبار اليدويه في صنعاء القديمه من خلال دراسه هبوط مستوى المياه في خمسة ابار واقتراح حلول لذلك.

المكون الثالث: التركيز على المحاصيل الزراعيه التقليديه الاكثر اقتصادا لتعميم وتنوع الإنتاج الزراعي في المقاشم وذلك من خلال حصر وتوثيق المحاصيل الزراعيه التقليديه وتطبيقها على المساحه المستهدفه في المقشامة التي تم اختيارها للتدخل كجزء من منظومه المياه الرماديه.

المكون الرابع: ربط المزارعين القائمين على المقاشم في اطار قانوني من خلال تشكيل الجمعيه العامة للحفاظ على مقاشم صنعاء القديمه.

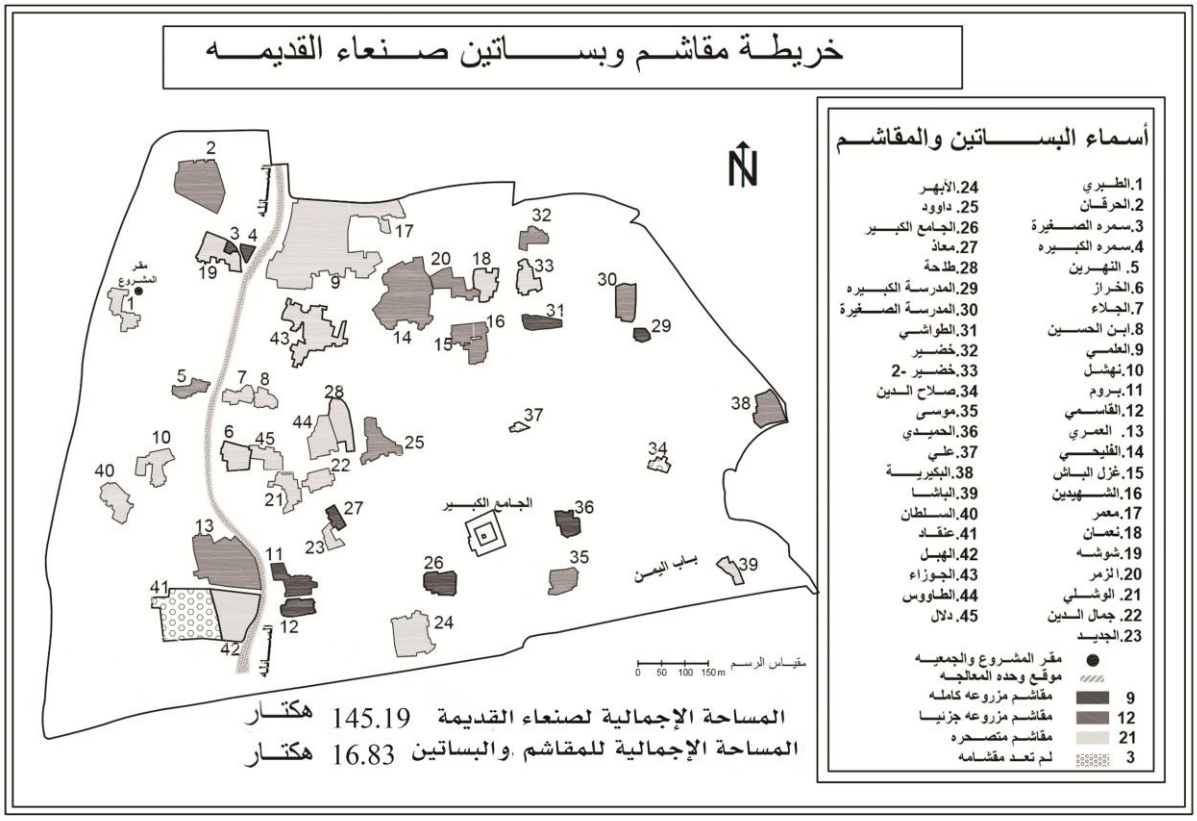
النتائج والمناقشة:

نتائج المرحله الأولى: توثيق وتصنيف المقاشم والبساتين

تم تحديد حدود ومساحة مدينة صنعاء القديمة حيث بلغت 145.19 هكتار وبمقارنة مساحة صنعاء القديمة بما ورد في الوعيل (2004) و برسولو وآخرون (2006) يتضح أن مساحة صنعاء القديمه 156هكتار و 160 هكتار، على التوالي ويظهر من كلا المرجعين أن المساحه الزائده فيهما تعتبرا خارجه عن سور صنعاء القديمه.

وتم حصر المقاشم والبساتين التقليدية فيها وتحديد مواقعها ومساحاتها وإتضح أن عددها 45 مقشامة وبستاناً وباستخدام برنامج جوجل (Google Earth,) تبين أن إجمالي مساحتها 16.83 هكتار أي

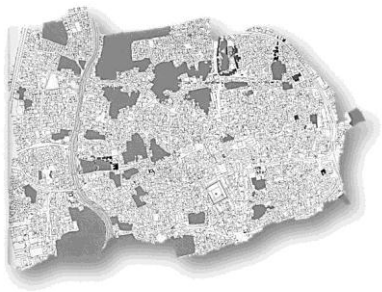
بنسبة 11.6% من مساحة صنعاء القديمه وتم رسم خريطه توضح حدود صنعاء القديمة ومواقع وحدود ومساحات المقاشم والبساتين التقليديه عليها (شكل 1)



شكل 1. خريطة صنعاء القديمه وعليها المقاشم والبساتين

بينما ورد في كتاب منظمة العواصم والمدن الإسلاميه (2005) أن نسبة المقاشم والبساتين كانت 33% طبقا لفيسمان (1929) في منتصف القرن العشرين (شكل 2، 3) وانحسرت تلك المساحه الى 12.2% (16.9 هكتار) في بروسلو وآخرون (2006).

شكل (2) خريطة صنعاء القديمه عام 1929 بعد فيسمان (كتاب العواصم الإسلامية)



شكل (3) خريطة صنعاء القديمه عام 2005 (كتاب العواصم الإسلامية)

تم تصنيف هذه المقاشم من حيث وضعها المائي والزراعي واتضح أن مايزيد على نصف هذه المقاشم متصحره وثلاث منها تم البناء عليها أواستخدمت كمواقف للسيارات ولم تعد كمقاشم بينما الجزء المتبقي اتضح أنها ماتزال مزروعه إما كليا أو جزئيا (شكل 1). ومن خلال الزيارات الميدانيه والإستبيانات تبين أن أهم المشاكل التي تهدد استمرارية المقاشم والبساتين هي: السطو عليها من خلال البناء، جفاف الابار، ربط مياه الوضوء بشبكه الصرف الصحي، رمي المخلفات الصلبه فيها.

تم وضع معايير لاختيار مقشامة متنوعة المشاكل لتحديد إمكانية التدخل في تطبيق منظومة المياه الرماديه فيها كنموذج بحثي يمكن تطبيقه في المقاشم المشابهه وتلخصت فيما يلي:

تصحر المقشامة، نضوب البئر، المزارع عضواً في الجمعية، وجود رغبة لدى المستفيدين في تخصيص المساحة اللازمة في المقشامة لتنفيذ المنظومة، مخرج مياه الوضوء من المسجد موجه إلى المقشامة، إمكانية تجميع المياه الرمادية من المنازل المجاورة، موافقة القائمين على المقشامة بالإهتمام بوحدة المعالجة وتشغيلها وصيانتها والحفاظ عليها، التعاون مع فريق المشروع بأخذ القياسات وتنفيذ البرامج الإيضاحية والإرشادية، مدى توفر شبكة ري في المقشامة. وهذه المعايير تم تطبيقها على المقاشم الخمس المقترحه للتدخل وهي: الوشلي، الحرقان، العمري، الطواشي، برروم، حيث تم اختيار مقشامة الوشلي لتنفيذ التدخل عليها لتنفيذ منظومة المياه الرمادية فيها كونها المقشامه الأكثر تطابقا مع المعايير.

نتائج المرحله الثانية:

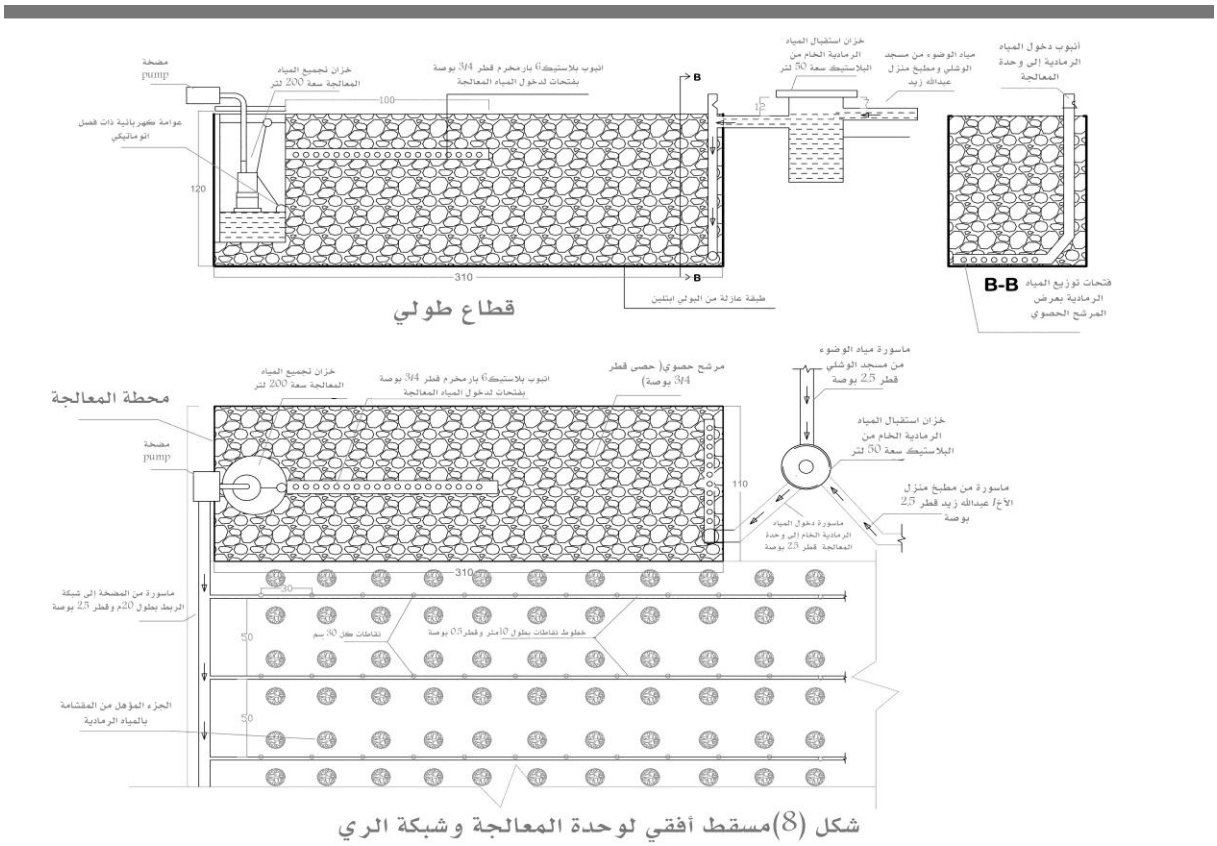
المكون الأول:

من المعروف سابقا أن استخدام المياه في المساجد يشمل الغسل والوضوء وكذا نقل كميه منه للمنازل للشرب والاستخدامات المنزليه غير انه بعد توصيل شبكات المياه العامه إلى المنازل انتقلت بعض هذه الإستخدامات من المساجد إلى المنازل واقتصر استخدام المياه في المساجد على الوضوء فقط مما جعل مياه الوضوء الخارجة من المساجد غير كافية لري هذه المقاشم. ونظرا لتزامن هبوط مستوى المياه وجفاف معظم الابار مع قله احتياج استخدام المياه في المساجد اتجهت وزارة الاوقاف الى تقنين تغذية المساجد بالمياه وذلك بتنفيذ خزان علوي وحنفيات وضوء وعدم تشجيع ملئ المطاهير مما ساعد على تصحر المقاشم.

لذا اتجه هذا المكون إلى تعويض النقص الحاصل في مياه الوضوء وذلك بربط المياه الرماديه الخارجه من المنازل واعادتها الى المقاشم كمصدر تكميلي ليساعد على ري واعادة احياء المقاشم وزراعتها. و نظرا لأن استخدام المياه الرمادية مباشرة يعتبر غير آمن للإنسان والتربه لإحتوائه على الميكروبات والمواد العضوية عالية التركيز ويتطلب لإعادة استخدامه بحسب فقهاء الشريعة الإسلامية أن يتم معالجته حتى يذهب لون ما خالطه من النجاسة ويجوز استعماله في سقي المزارع والأشجار إلا إذا كانت هناك أضرار صحية تنشأ عن استعمالها فيمتنع ذلك محافظة على النفس وبعدا عن الضرر لا لنجاستها (مجلة البحوث الإسلامية، 1999) لذا تم دراسة نوعية تلك المياه واختيار طريقة لمعالجتها بحسب طريقة الشبكه الإسلاميه لإدارة وتطوير الموارد المائيه، عمان، الأردن (INWRDAM)، التي تم تنفيذها في دول الشرق الأوسط وشمال افريقيا (Mcllwaine and Redwood, 2010)، حتى تصبح آمنه لإستخدامها في ري الخضروات في المقاشم. تكونت منظومة المياه الرماديه من أربعه أجزاء رئيسيه (شكل 4) هي:

المصدر المائي والمكون من: شبكة أنابيب صرف مياه رماديه من المنزل ومياه الوضوء من المسجد إلى وحدة المعالجة،

وحدة المعالجه والمكونه من: خزان استقبال، مرشح بيولوجي، خزان المياه المعالجه،
شبكة الري والمكونه من:مضخه وعوامه كهربائيه تعمل آليا، شبكة الري بالتنقيط،
الزراعه والمكونه من: تحديد جزء من المقشامه بمساحة 200 متر مربع بحسب كمية المياه المتاحه.



شكل (8)مسقط أفقي لوحدة المعالجة وشبكة الري

شكل (4). منظومة المياه الرماديه

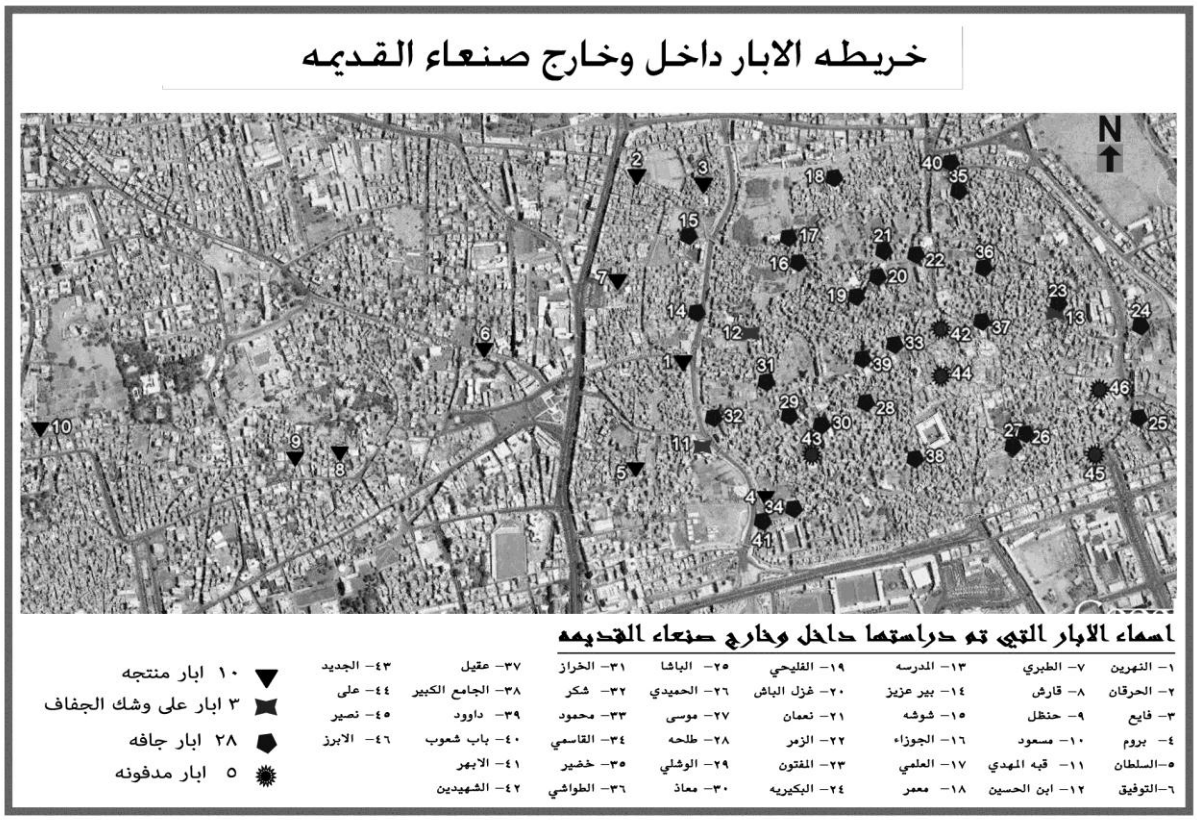
ويمكن تلخيص آلية تشغيل المنظومه كمايلي:
توجيه مياه الوضوء من المسجد إلى خزان الاستقبال مباشرة دون المرور بالبركة لتفادي تبخرها، توجيه المياه الرمادية من مطبخ المنزل إلى خزان الاستقبال، خروج المياه الرمادية من خزان الاستقبال إلى المرشح الحصوي ليتم معالجته بيولوجياً ثم يمر إلى خزان تجميع المياه المعالجة ثم ضخها من داخل الخزان إلى المساحة المطلوب زراعتها عبرشبكة الري بالتنقيط. بغرض تهيئة المرشح البيولوجي للمعالجة يتم ملأه بالمياه الرمادية ويترك لمدة أسبوعين وذلك لتوفير بيئة ملائمة لنمو وتكاثر البكتيريا اللاهوائية على الحصى.

من خلال تشغيل المنظومه خلال الفتره يونيو حتى أغسطس 2007م اتضح مايلي: كمية المياه التي يتم ضخها كل يومين من وحدة المعالجة عبر شبكة الري هي 500 لترأي بإجمالي 22.5 متر مكعب خلال فترة الموسم الزراعي المحدد ب 3 أشهر. كما هطلت أمطار خلال فترة الموسم بمعدل 33 مم (16.5 متر مكعب) (محطات الرصد المطري في الوحدة المركزية لمراقبة المياه، 2007م) والتي عملت على تغطية الكميه المطلوبه بشكل كامل لتصبح كمية مياه الري 39 متر مكعب أكثر مما هو مطلوب بطريقة بنمان (28 متر مكعب) (هيئة البحوث الزراعيه، 2003)، أي أن موسم هطول الأمطارساعد على إضافة كمية كبيره من المياه مما جعل الإنتاج المحصولي كاملا، كما أنه عند توصيل منزل آخر سيتم تغطية الكميه المطلوبه. ومن خلال تحاليل عينات المياه الداخله والخارجه من الوحده اتضح ان وحدة المعالجه قد خفضت المواد العضويه من 288-1340 الى 232-472 مجم/لتر (أقل من 500مجم/لتر) ونسبة ادمصاص الصوديوم (SAR) من 2.8- 3.0 الى 2.1- 2.6 (أقل من 3) والبكتريا من 340-1500 الى أقل من ذلك اي الى الحدود المسموح بها للزراعه المقيده Tarawneh, Z.F. and (Uleimat,A.A.,2008). ومن خلال تحاليل التربه اتضح أنها قد تحسنت بعد زراعتها واستفادت من المواد العضويه في المياه الرماديه كمخصب للأرض حيث زادت نسبة الماده العضويه من 0.13-0.20% الى 0.44-0.54%.

كما تم تدريب مزارع المقشامه على تشغيل وصيانة المنظومه عن طريق الإستمرار في ضخ المياه للري وعدم تركها في الخزان مده طويله حتى لا تتعفن. كما بلغت التكلفه الإجماليه لمنظومة المياه الرماديه والمنفذه لري مساحة 200متر مربع مبلغ 175,450 ريال يمني (900 دولار أمريكي تقريبا) خلال الفتره التي تم تنفيذ المشروع فيها (سنة 2007).

المكون الثاني:

من المعروف أن النظام التقليدي لشوارع صنعاء القديمة كان مبنياً على أساس توجيه ميول الشوارع نحو المقاشم والذي بدوره يؤدي إلى توجيه مياه الأمطار لري وتغذية آبار المقاشم بشكل متوازن وبسبب طريقة تنفيذ الرصف الخاطئ لشوارع صنعاء القديمة بشكل مخالف للرصف التقليدي المتبع سابقاً، فقد أثر سلباً على توجيه مياه السيول إلى بعض المقاشم دون الأخرى وبصورة غير متوازنة. لذا تم في هذا المكون تسليط الضوء على تسارع ظاهرة جفاف الآبار في المقاشم والبساتين في صنعاء القديمة خلال السنوات الأخيرة للتحقق من ذلك، حيث باتت هذه المشكلة تهدد الوضع الزراعي والاجتماعي لهذه المقاشم، حيث تم دراسة عدد 46 بئراً يدوية أخذت خلالها البيانات والقياسات المختلفة واتضح من خلالها أن أكثر من نصف هذه الآبار أصبحت جافه وتركزت في الجزء الشرقي من صنعاء القديمة والسائلة وتم توقيع الآبار التي تم دراستها على خريطة صنعاء القديمه على خريطة (شكل 5) باستخدام برنامج Google Earth



شكل (5). خريطة الآبار داخل وخارج صنعاء القديمه

وللتأكد من تأثير الرصف على هبوط مستوى المياه في الآبار، تم مقارنة منسوب المياه في أربعة آبار (العمري، ابن الحسين، النهرين، الحرقان) تقع جميعها حول السائلة تم قياس منسوب المياه فيها ومقارتها بمعلومات مراقبه لنفس الآبار تم جمعها لسنة 2002 (الصندوق الإجتماعي، 2002) و لسنة 1970 م (Serjeant and Lewcock,1983) حيث أظهرت النتائج أن متوسط معدل هبوط المياه سنويا في الآبار الأربعه التي تم مراقبتها قد تضاعف أكثر من مرتين ونصف خلال الفترة 2002-2007م (بعد رصف السائله) مقارنة بالهبوط خلال الفترة 1970-2002 (قبل رصف السائله) كما هي موضحه في جدول (2).

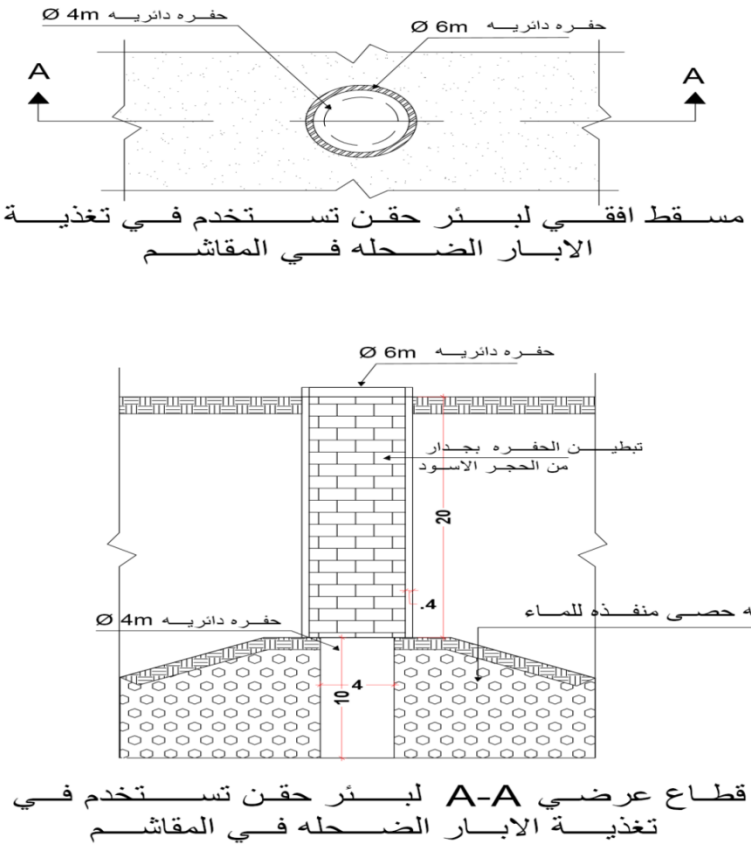
جدول (2) متوسط عمق مستوى المياه في الآبار ومعدل الهبوط السنوي خلال الفترتين قبل وبعد رصف السائله

اسم البئر	عمق البئر (متر)	سنة القياس وعمق مستوى الماء في البئر (متر)			معدل الإستنزاف السنوي (متر/سنه)	
		1970*	2002**	2007***	خلال فترة 32 سنه 2002-1970	خلال فترة 5 سنوات 2-2007200
بئرالعمري	65	10	42	59	1.00	03.4
ابن الحسين	57.5	10	50	57	1.25	01.4

النهرين	64	10	42	59.4	1.00	3.48
الحرقان	56	10	41	51.7	0.97	2.14
متوسط هبوط منسوب المياه (متر/سنه)				61.0	2.	61

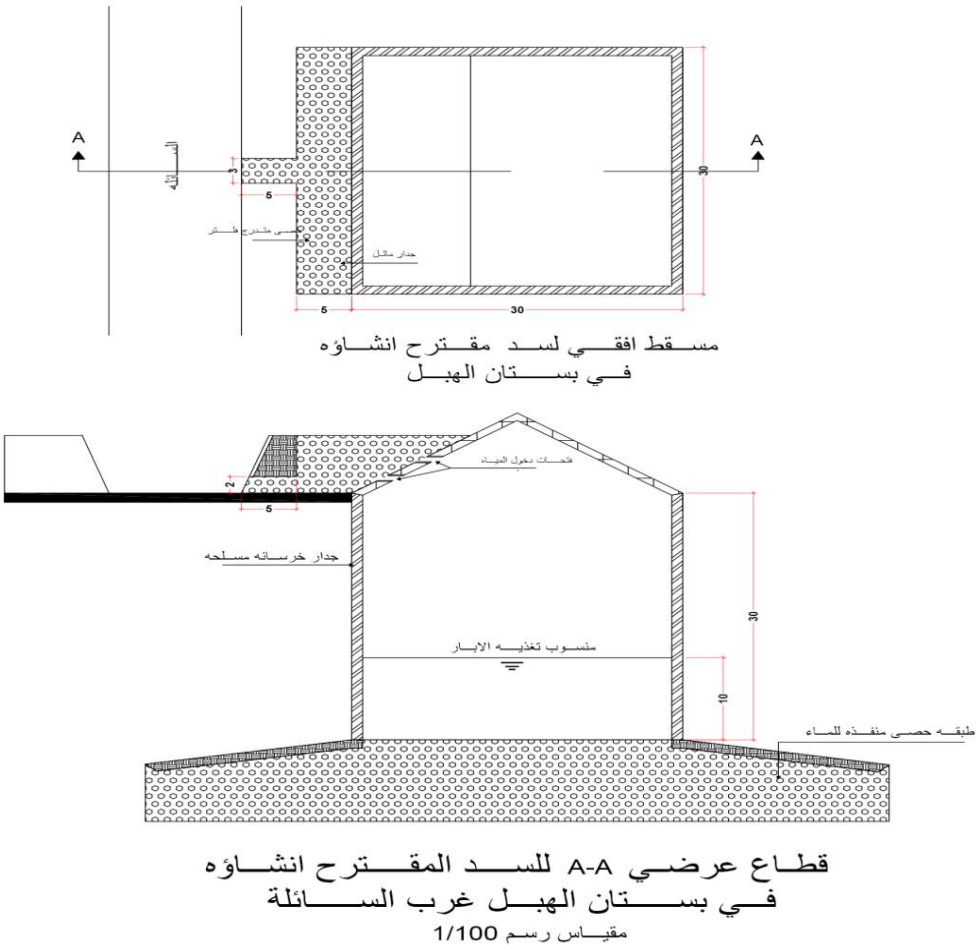
(Serjeant and Lewcock,1983) *
** (الصندوق الإجتماعي للتنميه-صنعاء، 2002)
*** هذا البحث

الحلول المقترحة لإعادة تغذية الآبار في السائلة وفي المقاشم داخل صنعاء القديمة.
حفر آبار حقن يدوية بعمق 30 متراً في المقاشم بحيث يتم تبطينها بالحجر حتى عمق 20 متراً ثم الاستمرار بالحفر بعمق 10 أمتار بدون تبطين للسماح بتغذية البئر الضحل (شكل 6)



شكل (6) تصميم بئر حقن في المقاشم

حفرنقاط تغذيه (سدود) على طول السائله بعمق 30 متر و طول 30م وعرض 30م وعلى مسافات بينيه 500متر والتركيز على المقاشم المحاذية للسائله مثل قبة المهدي أو بستان الهبل (شكل 7).



شكل (7) تصميم نقاط تغذية على طول السائله

المكون الثالث: حصر المحاصيل التي تزرع في مقاشم صنعاء القديمة.

من المعروف أن مقاشم صنعاء القديمة تتميز بتعدد النباتات الزراعية فيها الأمر الذي استدعى القيام بحصر هذه النباتات التقليدية سواءً كانت حولية أو دائمة ومعرفة قيمتها الغذائية والطبية المختلفة إضافة إلى توثيق مواسم زراعتها وفترات حصادها بالتركيز على المحاصيل الأكثر اقتصاداً وبالتالى التوصية بالمحافظة عليها وتوثيق تلك المعارف التقليدية المرتبطة بها للحفاظ عليها من الاندثار،حيث اتضح انه يوجد 37 نوعاً من النباتات الحولية و28 نوعا من النباتات الدائمه.

من خلال المعارف التقليديه والدراسه الميدانيه للنباتات الاكثر شيوعا اتضح ان نباتات (البيعه ،السلطه ،الجرجير،القشمي، البقدونس، العصفر) الاكثر انتاجا وبالتالي إقتصادا.

صوره (3) زراعة مساحة 200متر مربع في مقشامة الوشلي

المكون الرابع: تشكيل الجمعية العامة للحفاظ على مقاشم وبساتين صنعاء القديمة.

لتعزيز الدعم لمواجه المشاكل التي تعاني منها المقاشم كان لابد من جمع المزارعين المستفيدين في اطار واحد يمكنهم من البحث عن الحلول من خلال النقاش فيما بينهم والتواصل مع الاخرين سواءا مع الجهات المشرفه او الجهات البحثيه مثل جامعه صنعاء (مركز المياه والبيئه)، وبدرجه كبيره العمل على دمجهم في المجتمع في محاول لتلاشي تهميش هذ الطبقه لذلك تم تأسيس جمعيه سميت بـ "الجمعية العامه للحفاظ على مقاشم وبساتين صنعاء القديمه".

وتم تأسيس هذه الجمعيه واعلانها رسميا بتاريخ 25 يونيو 2007م وتحديد اهدافها بما يتناسب مع الحاجه لإنشائها وخاصة أن نطاق الجمعيه هي صنعاء القديمه حيث أن العمل فيها وتحقيق اهدافها يعني الحفاظ على التراث الحضاري التي تتمتع به مدينة صنعاء القديمه كمدينه تاريخيه. وبشكل عام الاستفاده من توصيات ومخرجات هذا المشروع.

وتتلخص أهم نشاطات الجمعية فيمايلي:

- إطلاق حملات توعية لدعم وسائل الاتصال بين الجمعيه والمجتمع، وتم طبع بروشور تعريفي للجمعيه.
- إقامة معرض خاص بالمنتجات الزراعيه الخاص بالمقاشم وكذا بالمجسمات التي تجسد أهم مكونات هذه المقاشم.
- عقد دوارت تدريبية تهدف الى كيفية الإستفادة من مخرجات المشروع البحثي شمل التدريب على تشغيل وصيانه منظومة المياه الرمادية، معرفه توزيع مياه الامطار من الشوارع الداخلية الى المقاشم وكذا تغذية الابار اليدويه من خلال بركة المقشامه او من السائلة، التدريب على الأنشطة الزراعية المختلفة كالتقليم وتكوين السماد البلدي وزراعة الشتلات واعداد مشاتل لأصناف الأشجار التي تتميز بها صنعاء القديمة.

التوصيات:

أولاً: فيما يخص التوثيق والمحافظة على المقاشم. توثيق مساحات المقاشم رسميا وتسليمها كأمانة للمزارع وتوقيع عقود خاصة تحدد فيها مهام ومسئوليات كل من وزارة الأوقاف والقائمين على المقاشم تجاه تلك الأراضي حتى يتم المحافظة عليها والاستفادة منها في نفس الوقت.

ثانياً : فيما يخص تعميم استخدام المياه الرمادية بعد معالجتها. توفير المياه للمساجد بشكل مستمر مع الاستغناء عن المطاهير والاكتفاء بالخزان العلوي الذي يغذي حنفيات الوضوء في المسجد وإعادة توجيه شبكة مياه الوضوء إلى المقشامة بدلاً عن شبكة الصرف الصحي، بينما يقوم المزارع ضمن مهامه بالحفاظ على المقشامة وعدم السماح برمي المخلفات الصلبة فيها، كما تقوم وزارة الأوقاف بالتعاون مع الأهالي المحيطين بكل مقشامة في دعم فصل المياه الرمادية من منازلهم وتوجيهها إلى المقاشم وتنفيذ منظومة المياه الرمادية فيها كمصدر تكميلي للمنظومة للتمكين من زراعة المقاشم وخاصة في غير فترات الأمطار و تعميم كود فصل المياه الرمادية عن المياه السوداء في الشبكات الداخلية للمباني حتى يسهل استخدام المياه الرمادية. استخدام البركة الخاصة بالمسجد لتخزين مياه الوضوء الخارجة من المسجد وكذا المياه الرمادية المعالجة بغرض خلطها وتخفيفها لمنع التعفن وكذا لعمل توازن في تغطية فترات الإحتياج للري مع تنفيذ مصيده قبل البركه لمنع دخول المواد الصلبة التي تحملها مياه الأمطار، وتعميم وحدة المعالجة على المناطق المختلفة للاستفادة من المياه الرمادية بعد معالجتها باتباع تعليمات المراقبة والتشغيل للمنظومه وتحديد المساحة الزراعية بحسب كمية المياه الواصله الى المقشامه بناء على دليل المنظومه مع التأكيد على استخدام شبكات الري الحديث (بالتنقيط) لترشيد استهلاك المياه.

ثالثاً: فيما يخص إعادة تغذية الآبار اليدوية في مدينة صنعاء القديمة. قيام أمانة العاصمة بإعداد خريطة طبوغرافية من خلال المعارف التقليدية المتعارف عليها وإعادة رصف الشوارع بغرض توجيه مياه السيول من الشوارع الداخلية إلى المقاشم بالتوزيع التقليدي، وذلك لتعزيز كفاءة مساهمة الميول الطبيعية لجريان المياه السطحية في ري المقاشم. وبهدف تغذية الآبار الضحله التي جفت نوصي باستغلال هذه المياه من خلال حفر آبار حقن يدوية في المقاشم (شكل 6) أو استغلال البركة الموجودة في المقشامة لإستقبال مياه السيول ومنها يتم توجيه المياه الى الآبار اليدوية الجافة مباشرة إما بالجريان الطبيعي أو باستخدام مضخة لرفع المياه إلى البئر مع الأخذ في الاعتبار تحاشي حصول تلوث مباشر لمياه البئر. للتغلب على الآثار السلبية لرصف السائلة إذ أنه لم يتم الأخذ في الإعتبار تغذية المياه الجوفيه، يوصي هذا البحث الجهة المسئولة عن مشروع السائلة بحفر نقاط تغذية (سدود) على طول السائلة (شكل 7)على مسافات بينية 500 متر والتركيز على أن تكون هذه النقاط عند المقاشم المحاذية للسائلة مثل بستان الهبل ومقشامة العمري.

رابعاً : فيما يخص توثيق النباتات التقليدية وزراعتها في المقاشم . الاستمرار في زراعة مساحة التدخل في مقشامة الوشلي بالمحاصيل الاقتصادية التي تم دراستها بغرض رفع مستوى المزارعين اقتصادياً ومحاولة التوسع في الأرض المزروعة بناءً على التوسع في توصيل المنازل المجاورة والفندق المجاور ومحاولة تطبيق هذه المحاصيل الاقتصادية في المقاشم الأخرى.

خامساً : فيما يخص تفعيل "الجمعية العامة للحفاظ على مقاشم وبساتين صنعاء القديمة": تطبيق التوصيات السابقه بالتعاون مع وزارة الأوقاف والجهات ذات العلاقة والتركيز على توثيق المقاشم والبساتين التقليدية في السجل العقاري، محاولة الحصول على تمويل لتنفيذ مخرجات هذا المشروع البحثي.

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