مؤتمر الخليج الحادي عشر للمياه

المياه في دول مجلس التعاون .. نحو إدارة فاعلة

The 11th Gulf Water Conference

Water in GCC ..Towards Efficient Management

WSTA 11th
Gulf Water Conference

20-22 October 2014

Muscat, Sultanate of Oman

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WSTA 11th Gulf Water Conference
"Water in the GCC … Towards Efficient Management"
20-22 October, 2014, Muscat, Sultanate of Oman

CONFERENCE INTRODUCTION

In the Gulf Cooperation Council (GCC) countries, situated in one of the driest and most water-stressed region of the world, sustainable water provision to the various development activities has grown to be one of the most challenging tasks faced. This is due to limited available natural water resources on one hand, and escalating sectoral water demands resulting from the fast-paced socio-economic development and its associated rapid population growth on the other. Currently, the GCC countries are experiencing an alarming future of increasing water scarcity and increasing water supply costs, which might not only threaten their future development, but also the preservation and sustainability of their past economic and social achievements.

Addressing water scarcity, both natural and human-induced, is considered now as one of the major and most critical challenges facing the GCC countries. This challenge is expected to grow with time due to many pressing drivers, including population growth, changing lifestyle and consumption patterns, food demand, prevailing general subsidy system, climate change, and many other drivers, forcing these countries into more expensive and costly investments in water supply sources and infrastructures (i.e., desalination, water treatment, dams, and groundwater wellfields) to meet escalating water demands. The heavy financial, economic, and environmental costs, as well as social costs associated with the currently practiced supply-side management approach in the GCC countries cannot be overemphasized.

In general, a sustainable water management system can be defined as **"a system that can supply adequate amount of water with the required quality to the various development sectors, under the lowest financial, economic, social and environmental costs, to achieve maximum socio-economic benefits in terms of use added-value and contribution to the overall national development, on a long term basis."** Strongly embedded in this definition is the issue of "water efficiency", which in the broad sense ranges from use efficiency, recycling and reuse, to supply efficiency and long term planning of resources use, and reflects a major shift in approach to water resources management away from the traditional supply development to demand management. Water efficiency can significantly help reduce wasteful use of the resource, which represents an opportunity lost as well as use of water without an economic or social purpose. Moreover, efficiency measures can often obviate or delay the need for physical infrastructure investments, reducing burden on current financial and energy resources and providing real gain to society.

Currently, in the GCC countries water efficiency in both the supply-side and the demand-side is generally very low. For example, on the supply side the physical leakage component of the non-revenue water in the municipal networks ranges between 30% and more than 40%, which is at odds with the high cost incurred in producing desalinated water varying between 1-2US$ per cubic meter. Moreover, recycling in the GCC countries is negligible, while the collected wastewater on average does not exceed 40% of total domestic water volumes, and the reuse rate is less than 60% of the treated volumes. On the demand side, the per capita water consumption in the domestic sector in most of the GCC countries reaches 500 Liters/day and in some countries exceeds 700 Liters/day, which ranks amongst the highest in the world. Furthermore, in the agricultural sector which consumes on average more than 80% of the total water used in the GCC countries, the predominance of inefficient irrigation practices leads to the loss of more than 50% of the amounts of irrigation water applied. Similarly, in the industrial sector wasteful water practices are common with negligible recycling efforts.

While the GCC countries have spent billions of dollars on water supply infrastructure (i.e., desalination plants, treatment facilities, dams, and drilling of wells) in the provision of water supply, inadequate attention has been given to how efficiently the existing water is being used, being supplied, recycled, or reused. To enhance the sustainability of the water management system and strengthen water demand management policies in the GCC countries, there is an urgent need to reconsider the existing traditional supply-side management approach, and improve water efficiency by reducing wasteful use in all the water consuming sectors, and raise awareness and influence consumers to make behavioral changes to reduce water wastage. In fact, under the currently prevailing political economy in the GCC countries, where a general subsidy system exists that makes the use of economic incentives/disincentives difficult, it is becoming crucially imperative for these countries to focus on improving water efficiency to sustain water supplies with the least costs and minimum risks, and to achieve maximum productivity per cubic meter consumed.

Improving water efficiency by implementing measures that reduce waste, in both the supply and demand sides, is more “cost-effective” than increasing water supply capacity, as available water efficiency options have a lower unit cost than increasing supply. For example reducing water leakage in urban distribution networks is more cost-effective than expanding desalination capacity to augment supply; similarly, increasing the conveyance system and irrigation efficiency is more cost-effective than increasing groundwater abstraction to meet irrigation demands. Therefore, improving water efficiency need to be seen as a viable complement, and in some cases may be a substitute for, investments in long-term water supplies and infrastructure.

At the heart of this concept is an economic standard, where a good water use efficiency program produces a level of benefits that exceed the costs required to undertake the program; for example reducing the desalination plants production or delaying their capacity expansion by implementing water efficiency measures, such as reduction of the leakage in the distribution network, or water-saving devices, or recycling, not only save consumers money and governments financial resources and lower the burden on the national budget, but it also saves natural energy resources assets (oil and gas), the main source of income to the GCC countries. Furthermore, in addition to the increase in the added-value per cubic meter and freeing up water for other uses, this will reduce the environmental costs in terms of greenhouse gases emissions and effluents discharged to the marine environment by desalination plants, thus reducing environmental degradation. Hence, improving water efficiency results in a multitude of successive benefits and contributes directly to the developmental goals of the GCC countries, would help ensure reliable water supplies today and for future generation, and enhance the overall level of water security.

Although the water scarcity problem is well recognized in the GCC countries, water efficiency has not yet become a major priority in the agendas of the governments of the GCC countries. Moreover, in most of the GCC countries, institutions are rooted in a centralized culture with supply driven management and fragmented and sub-sectoral approaches to water management. Hence, it is of paramount importance that efforts are made to incorporate explicitly water efficiency measures within a framework of an integrated and comprehensive water policies and management strategies. Water efficiency must be addressed at all levels in water management, through technical means, improved management practices, and societal behavior changes. **In short, before simply “providing more water” (i.e., a supply management approach), which often implies construction of new and expensive infrastructure, the first and more cost-effective ap-**

proach should be to improve the water efficiency of the water management system, addressing the demand side issues, and as a last resort augmenting supplies.

Through addressing the topic of sustainable water management in the GCC countries, the WSTA Eleventh Gulf Water Conference focuses on the water efficiency of the water sector within a demand management framework, as well as related topics for improving the management efficiency in the various consuming sectors, such as appropriate governance approaches and stakeholders participation, legislative consideration, innovative technologies, awareness raising, capacity development, data requirements and transparent decision making process, economic analysis and benefits, and many other factors relevant to the issue of water efficiency in a scientific forum. The conference will present the experiences and best practices from different countries in improving water efficiency and overcoming the water challenges in the arid GCC and Arab countries.

WSTA wishes that all conference participants have a scientifically fruitful conference.

Prof. Waleed K. Al-Zubari
President, WSTA

CONFERENCE OBJECTIVES

1. Raising awareness and influencing policy and decision making to the importance of improving water efficiency as a cost-effective option contributing to a more sustainable water management in the GCC countries.
2. Identifying challenges and opportunities in improving water efficiency under the prevailing socio-economic, environmental, cultural, and political conditions in the GCC countries.
3. Facilitating an open scientific discussion platform to share knowledge and experiences between researchers, executives, decision and policy makers, private sector, and other stakeholders, on improving water efficiency in the various water supply and consuming sectors in the GCC countries.
4. Identifying scientific and technological research needs and priorities in the field of water efficiency to aid the process of policies formulation and decision making in the GCC countries.
5. Building a research and experience exchange network between individuals, institutes, civil society/NGOs and private sector in the GCC countries, other countries in the Arab region, and beyond in the field of water efficiency.

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DAY 1
MONDAY 20 OCTOBER 2014

SESSION 1
WATER RESOURCES PLANNING AND MANAGEMENT

Keynote

Counting the Cost of Water Resources in the GCC Countries: A Nexus Perspective

Glada Lahn
Senior Research Fellow, Energy, Environment & Resources, Chatham House, UK

Summary
Something that will stand out at this conference is the desire and commitment of Arab Gulf countries to be leaders in solar desalination, water efficient technologies and water saving and storage practices. But is the economic case for investment, policies and incentives that allow the best practices and technologies to emerge being made strongly enough? From the 45 participants from government, universities and technical professions in the Gulf countries who took part in the Chatham House Valuing Vital Resources workshops and dialogue (2013 – 14), the answer was a resounding no.

In a global context, the Gulf stands out as an extreme example of market failure where there is both water scarcity (all Gulf Cooperation Council Countries (GCC) lie below the 'absolute water scarcity' line in terms of 'natural' water availability), yet water is provided free or at negligible cost relative to average incomes; and to make up for the declining groundwater resources, an increasing amount of gas and oil is being burned to produce desalinated seawater – accelerating the depletion of the main source of income of the GCC countries.

The report resulting from the dialogue and regional contributions on counting the costs of current resource trends will recommend that governments in the GCC pay urgent attention to water accounting and disseminate cost accounting models regionally to stimulate greater awareness of the full life-cycle costs of agricultural products using groundwater and desalinated water services. Even where there are reasons for not passing on the costs of water to the consumer, these tools would enable policy planners to make cost-benefit analyses, for example regarding water efficiency investments and demand side programs versus new desalination capacity. It would also make clear the cost to the economies of the current policies.

The production and pricing of energy, water and food are interlinked as will be the solutions. For example, around one third of fuel going into power generation in Qatar and the United Arab Emirates (UAE) can be attributed to desalinated water production. In the UAE, rising gas imports are pushing up these water production costs. Across the region, various government supports for agriculture – including very low diesel prices - have encouraged water intensive crop production thus aiding the rapid depletion of precious groundwater resources. In the last few years, several GCC countries have taken steps to encourage water conservation, including by phase-out of support for wheat production in Saudi Arabia and Rhodes grass in the UAE. The evidence suggests a more integrated understanding of water costs and uses will enhance the policy choices governments have to incentivize its conservation.

This keynote will outline the challenges that water presents for cost assessment and the possibilities for employing shadow prices, reforming water tariffs and using more creative thinking in relation to balancing national objectives in groundwater conservation. It will argue that a better understanding of the interlinked costs of energy, food and water will enable more holistic and socially feasible policies to incentivize sustainable use and good management.

***Biography**: Glada is a Senior Research Fellow with the Energy, Environment & Resources Department at Chatham House (the Royal Institute of International Affairs) in London. Since joining Chatham House in 2004, her research areas have included petroleum sector governance, Arctic extractives investment, sustainable resource use in oil-exporting countries, rethinking energy and climate policy and transboundary water issues in Asia and West Asia. For the last five years she has led work on domestic energy and water management, pricing and policy with partners in the Gulf. From 2002-2004, Glada was Senior Research Fellow at the Gulf Centre for Strategic Studies and has since worked for a number of organizations as a freelance consultant. She has a BA in Arabic and international relations (including a year spent at the University of Damascus), and an MA in Near and Middle Eastern Studies from the School of Oriental and African Studies in London.*

Keynote

Water and Sanitation Services are Fundamental to Health

Hamed A Bakir
Coordinator, Environmental Health Interventions Unit and Regional Advisor Water, Sanitation, Climate and Health, WHO Regional Office for the Eastern Mediterranean/Centre for Environmental Health Action (WHO/EMRO/CEHA)

Summary
The Director General of the World Health Organization (WHO) stated in her keynote address to the Budapest Water Summit in October 2013 that “access to safe drinking water, sanitation, and hygiene is fundamental to health, well-being, and poverty eradication”.

The reliable availability of sufficient and safe domestic water supply is essential for public health. Sufficient water supply is needed for public health purposes including drinking, personal hygiene, food preparation, household cleanness, and sanitation. Insufficient water supply compromises the ability of individuals and households to maintain high hygiene standards that are necessary for the removal of the disease causing pathogens. Unsafe water supplies are also harmful to health. Unsafe water carries disease causing pathogens and chemicals that cause multitude of illnesses including water-borne and water related diseases. At times explosive outbreaks of diseases occur as a result of incidents within the water supply chain causing a decline in water safety.

The provision of adequate means of household sanitation facilities and community wastewater management is also essential for public health. Sanitation and wastewater management are essential for removing human waste from the environment and thus breaking the cycle of diseases within communities. Efficient wastewater management is also essential for pollution control and for facilitating the safe integration of wastewater into the environment as a useable water resource. In fact it is virtually impossible to have a safe water supply in the absence of good sanitation.

WHO is the directing and coordinating authority for health within the United Nations system. It is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to countries and monitoring and assessing health trends. At global, regional and country levels, the WHO works on the following core aspects of water and sanitation:

1. Providing evidence-based normative guidelines on the management of drinking water quality, recreational waters, and the use of wastewater in agriculture and aquaculture. WHO guidelines are intended to protect health and hence they provide WHO’s recommendations for evidence-based policy options and strategies for managing the risks from hazards that may compromise safety and harm health.
2. Monitoring the water and sanitation and reporting globally on the status of water supply and sanitation sector, and supporting countries in improving their monitoring performance to enable better planning and management at the country level. WHO and UNICEF implement the Joint Monitoring Program for Water Supply and Sanitation (JMP). JMP is the official arrangement within the UN System to produce information for the UN Secretary General on the progress of achieving the Millennium Development Goals related to water supply and sanitation.
3. Providing technical support to countries on national policies and program for strengthening the governance and regulatory framework for water and sanitation and the role of the public health agencies in surveillance and monitoring of the water and sanitation sector.

Regionally, the MDG target for access to improved water sources has been achieved and the region is on track for achieving the sanitation target. Within the regain there remain 72 million people without safe drinking water and 182 million people without adequate sanitation facilities, the majority of them live in Yemen, Pakistan, Sudan and Afghanistan (charts 1 and 2).

The MDG indicator for water monitors access to improved water sources, such as piped water and protected wells or boreholes. It does not monitor the microbiological or chemical quality of the water. Piped water supplies in several cities within the region are operated intermittently due to water scarcity that is further aggravated by climate change. Thus achieving the MDG target for access to water sources doesn't necessarily mean that safe water is reliably and continuously delivered in sufficient quantities.

WHO recommends preventative water safety management. Application of new low-cost microbial tests offers an opportunity to greatly expand direct measurement of water safety. At the same time, water quality testing will not solve all problems. By the time contamination is detected, it is too late. Unsafe water will already have been consumed, sometimes by thousands of people. With this reality in mind, the WHO guidelines for drinking water quality, which have been issued since 1958, now place their main emphasis on the prevention of contamination from source top consumer through the concept of water safety planning. Such planning calls for integrated risk assessment and risk management in the full chain of events, from the prevention of pollution in catchment areas, to the reliable performance of treatment works, to the delivery of safe, affordable, and sufficient water to consumers. To date, water companies in more than 50 countries are implementing water safety plans. In more than 20 countries, a water safety plan is either promoted by policy or required by law.

Sound water resource governance is urgently needed to secure water supplies for public health protection. Water is a finite natural resource that is needed to sustain health, agriculture, and ecosystems, and also to fuel industrial development and economic growth. In a world of growing water scarcity and climate change, this situation pits health concerns against the business interests of powerful economic operators. This underscores the importance of the governance issues being discussed.

The institutional infrastructure for regulating, delivering and monitoring the water and sanitation services is multidisciplinary in nature. The delivery of water and sanitation services is entrusted in the specialized national agencies that plan, develop and manage these services in accordance to national regulations and standards. Health agencies with regulatory and surveillance mandate, can issue national standards for water providing numerous practical instruments for the quality and reliability of water and sanitations services. Health agencies can monitor progress and undertake surveillance of the quality, equity, reliability of the services. The health agencies can launch campaigns to promote hygiene, treat the sick, and count the cases and deaths. But the true root causes of these diseases reside in non-health sectors and must be tackled there under an integrated management framework.

Biography: *Mr. Hamed Bakir is a water and wastewater engineer with a career of over 30 years in public health and environment at the World Health Organization and other UN agencies. He Coordinates the Environmental Health Interventions Unit at WHO's Eastern Mediterranean Regional Office Centre for Environmental Health Action. He is also WHO's Regional Advisor on Water, Sanitation, Climate and Health. Under his leadership, the Environmental Health Interventions Unit develops and provides normative guidance, technical and policy support to countries on water quality and safety management; safe wastewater use; climate resilient water and sanitation services; public health adaptation response to climate change; health sector greening; waste management; health in sustainable development; health impact assessment; and environmental health services in healthcare facilities. He pioneered, within the region, the application of water safety management plans, decentralized wastewater systems and reuse, water demand management; and water governance for securing water requirements for health protection.*

Keynote

Agricultural Water Management under Scarcity: from “Efficiency” to “Productivity”

Theib Y. Oweis
Director, Integrated Water and Land Management Program, International Center for Agricultural Research in the Dry Areas (ICARDA), Amman, Jordan

Summary

The Middle East and North Africa is the water scarcest region in the world and agriculture uses over 70% of available resources. In addition it is predicted that in the coming decades, precipitation, and hence water resources, in the MENA region will decline as a result of climate change. There is limited potential to substantially increase water resources in MENA region, because of several constraints, including climatic, technological, economic, and political. Agriculture, the largest user of water, receives a progressively smaller proportion of national water resources. However, food demand continues to rise as a result of rapid population growth and up-scaling of standards. Water availability for agriculture is critical to achieve higher food security and therefore it is essential that countries across MENA region seeking stability and food security to produce more food with less water. The negative impacts of water shortages on sustainable agricultural development and national concerns over food security could lead to socio-political instability and conflicts.

Conventional approaches to development seek to increase crop yields (land productivity) while investing in modern irrigation systems. This approach has major limitations. Higher crop yields generally require more water, which is not available. Modernizing irrigation systems increase productivity but hardly result in substantial and real water savings. Attempts to control water demand in agriculture through water pricing have achieved limited success due to political and socioeconomic constraints.

Improving irrigation efficiency, although necessary for improved performance of irrigation systems, does not reflect many aspects of agricultural water use, especially land and water productivity. Water saved through increasing irrigation efficiency at the field or farm level can largely be captured at the scheme, landscape or basin level. Although water saving at the field or farm levels benefits the farmer it does not provide more water for expansion in irrigated lands or contribute to other sectors as water is recycled within the system. The term “water efficiency” although useful to reflect the performance of irrigation systems is not enough to evaluate water use in agriculture. We here suggest that the term “water productivity” is used to reflect the performance of water use in agriculture.

In water-scarce areas, where water is more limiting than land, the focus must shift from land productivity (yield per unit area) to water productivity, which is the returns or benefits (biological, economic, environmental, nutritional, and/or social) per unit of water consumed. Research has shown that it is possible to double water productivity in many countries of the region in two decades. This is equivalent to doubling the available water resources without improving water productivity. However, this will require major changes in the way we use and manage agricultural water; changes in cropping patterns, irrigation approaches, crop improvement strategies, policies, and institutions; greater investment in research and capacity development is inevitable.

Water productivity can be increased by improving crop water management and technologies, such as deficit irrigation, supplemental irrigation, and water harvesting. Simultaneously, countries

may cultivate highly water productive crops while importing crops with lower water productivity. Policy makers must make painful choices to rationalize water use while ensuring access to the poorest households. Resolving the crisis will require enduring progress towards political, social, economic, and administrative systems that shape the use, development, and management of water resources and water delivery in a more effective, strategic, sustainable, and equitable directions.

Biography: *Dr. Oweis is currently the director of the Integrated Water and Land Management Program at the International Center for Agricultural Research in the Dry Areas (ICARDA), based in Amman, Jordan. Since 1991 he joined ICARDA and worked in several capacities as scientist, principal scientist, team leader and manager. Earlier he joined the University of Jordan in Amman, as an assistant professor in irrigation and drainage engineering and in the 70's worked for Dar Al Handash Consultants (Shaer and Partners). Received his MSc and PhD degrees in Agricultural and Irrigation Engineering from Utah State University, Logan, Utah, USA, in 1979-1983. Has over 30 years of experience in international research and education, development and human capacity building and in the management of water for agriculture especially in the dry environments. Author of over 200 refereed journal publications, books/book chapters and conference proceedings in the areas of water use efficiency, supplemental irrigation, water harvesting, water productivity, deficit irrigation, salinity and the management of scarce water resources. He contributed to promoting at the global level of the concepts of water productivity and water savings practices in agriculture.*

Keynote

Integrated Assessment of the Efficiency of the Water Management System in Bahrain

Waleed K Al-Zubari
Coordinator, Water Resources Management Program, College of Graduate Studies, Arabian Gulf University, Kingdom of Bahrain

Summary

The Kingdom of Bahrain is classified as one of the world's most water-scarce country with acute water poverty (100 m^3/yr/capita). The main water consuming sectors in the Kingdom are the municipal (69%), agricultural (29%), and industrial (2%) sectors, which are met by desalination (60%), groundwater (29%), and treated wastewater (11%). The main water planning and management challenge in meeting the rapid increase in water demands in the various consuming sectors and its increasing associated financial, economic and environmental cost. An integrated assessment of the efficiency of the current water management system in Bahrain is conducted and appropriate management and policy interventions in the three consuming sectors are made to enhance the overall water sector efficiency and sustainability. WEAP dynamic model is used for the integrated simulation of the water management system in Bahrain and assessment of its efficiency and sustainability using a number of selected system cost indicators: cost of municipal water supply (financial), CO_2 emissions (environmental), and natural gas consumption by desalination (economic). The developed model is used to compare these indicators under the business-as-usual scenario to the year 2030 and a number of management interventions scenarios, including leakage reduction in the municipal water supply network, water awareness raising, water saving devices installation in residential units, use of modern irrigation techniques, and use of treated wastewater in industry. Under the business-as-usual scenario, the modeling results indicated that the demand for desalinated water will reach about 350 million cubic meters (Mm^3/y) by 2030, which would be under the "planned" future desalination capacity (372 Mm^3/y in 2030). However, if all the municipal sector management interventions are made, this demand could be reduced to about 217 Mm^3 by 2030, i.e., a potential reduction in municipal water demands by about 38%, with a cumulative water savings of about 4,648 Mm^3, which, if implemented, would have significant and successive impacts in cost reduction: financial cost of desalination plants expansion, production and water supply; desalination plants brine discharge and GHG emissions; financial cost of wastewater plants expansion, treatment; and reduction in treatment plants carryover discharge to the marine environment. Moreover, it would significantly delay the required infrastructure investments for increasing the country's desalination capacity as well as wastewater treatment capacity. Undoubtedly, these demand side and efficiency interventions are more cost-effective than increasing water supply. It is also recommended that institutional reform is an essential to overcome the current fragmented planning of the water sector, and therefore, the activation of the Water Resources Council in Bahrain becomes a necessary step in the formulation of integrated policies, and for the integrated planning and management of the water resources management system in Bahrain to enhance its efficiency and sustainability.

Biography: *Dr. Al-Zubari is Professor of Water Resources Management at the College of Graduate Studies, Arabian Gulf University (AGU), and holds the administrative positions of Coordinator of the Water Resources Management Program, and the Coordinator of the UNU Water Learning Center for the Arab Region. He served as the Dean of the College of Graduate Studies (2010-2013), and AGU Vice-President for Academic Affairs (2008-2010). He obtained his MSc degree from Ohio University in 1987 in the field of Groundwater Mathematical Modeling and his PhD degree in the same field from Colorado State Universityin 1990, and joined AGU. Since joining AGU, he has taught many graduate level courses in Water Resources Management and Planning in Arid Regions, supervised more than 35 Master's Thesis, and has published more than 90 research papers in peer-reviewed journals, conferences, and seminars. He served as the Editor-in-Chief of the Arab Gulf Journal of Scientific Research (2006-2010). He serves as a consultant for many international and regional organizations, including UNESCO, UNEP, UNDP, ESCWA, and FAO.He has been active in the GCC's Water Science and Technology Association (WSTA) and he currently serves as its president. In December 2002, he received the Award of Best Researcher in the Arab World in the field of Water Resources from the Arab League Educational, Cultural, and Scientific Organization (ALECSO). In March 2008, he published his first book on Water Issues and Challenges in the GCC (in Arabic), which received Yousif Bin Ahmad Kanoo Best Authors Prize in early 2012.*

Keynote

Strategies for Efficient Water Management in Nuclear Power Plants: The IAEA Water Management Programme (WAMP)

Ibrahim Khamis
International Atomic Energy Agency (IAEA), Vienna International Centre, Vienna, Austria

Summary

The water and energy nexus is becoming an important issue of concern for policy-makers and planners especially in countries experiencing water scarcity. The availability of water resources is one of the important factors affecting the siting and economics to construct and operate a nuclear power plant. Therefore, the introduction of innovative measures and strategies in design and operation which will enable nuclear power plants to use or consume less water is likely to help such countries introduce nuclear power in their energy supply mix. Whereas harnessing waste heat from nuclear power plants and reusing it for other non-electric applications such as desalination will not only reduce the amount of water needed to operate the nuclear power plant but also increase savings and improve the overall environmental impact of such water and power generation. Based on current cooling water requirements for generic 1000 MW(e) units using once-through cooling, nuclear power plants would require about 26-64 m3/s of water. Water management at nuclear power plants is an important subject during the entire phases of construction and operation of any nuclear power plant. Some identified measures that help reducing water use and consumption in design and innovative strategies in operations of a nuclear power plant include: the selection of optimal cooling systems, treatment of in-house industrial and potable water, introduction of advanced technologies for producing required demineralized water, following specific operating procedures, and recovery of waste heat for other non-electric applications. The optimal choice will require knowledge of various available options and strategies. The IAEA developed and released the Water Management Program WAMP. WAMP can be used for the estimation of water needs in NPPs especially for water cooled nuclear power plants as it estimates both the needs for cooling water and other essential systems, and helps in the selection process of cooling systems by evaluating three different criteria: water resources, environmental, and economic impacts.

***Biography**: Ibrahim Khamis has earned his M.Sc. in 1986 and Ph.D. in 1988 in nuclear engineering from the University of Arizona, Tucson, Arizona, USA. Since 2006, he is the Project Manager of the Non-electric applications of nuclear energy, Nuclear Power Technology Development Section, Division of Nuclear Power, International Atomic Energy Agency (IAEA). His duties involve nuclear desalination, hydrogen production, district heating and other industrial applications of nuclear energy. Before joining the Agency, he was Head, Nuclear Engineering Department, Atomic Energy Commission, Damascus, Syria. An author and coauthor of more than 100 research publications, conference presentations. His main interest is reactor physics, design and simulation, and non-electric applications of nuclear energy.*

Day 2
Tuesday 21 October 2014

SESSION 2A
SURFACE WATER MANAGEMENT

Keynote

Sustainable Management of Surface and Groundwater in the Arab Region

Abdin Salih
Water Management Expert, Interim Director, UNESCO Cairo Office, Egypt

Summary

The Arab Region suffers from indigenous water scarcity that existed for many centuries making it currently the poorest region in the world in this vital resource essential for every aspects of socio-economic development. Traditional water resources (from surface and groundwater) represented the main sources of water supply meeting limited demands which are managed few centuries ago through traditional successful approaches. These past approaches of water resources management (WRM) have proven inadequate for the current regional water challenges created by increasing population and highly enhanced demands as well as fast rising constraints related to pollution, climate change and conflicts related to transboundary waters and competing demands. The sustainability issue became the buzz word as an essential approach that needs to be followed through an IWRM framework that connects water with many conflicting demands (energy, food production, environment, etc.) making it a very complicated process but very important consideration for sustainability. These approaches are mostly reached through sectoral management approach which will not lead to sustainability since water is beyond sectors and is rather a connector. These entire elements will be included in my presentation with focus on the complicated situation of the Arab region and its surface and groundwater development through history.

***Biography**: Prof. Abdin Salih is a Professor of Civil Engineering at the University of Khartoum and Member of the Governing Council of the University. He is also a member of the Governing Council of the Sudan University of Sciences and Technology and the Governing Board of UNESCO-IHE Institute for Water Education, Delft, The Netherlands. His education included a first class honor degree in Civil Engineering from Khartoum University and DIC and PhD from Imperial College in London in 1973. He held various academic positions at many universities in Africa, Middle East, Europe and USA with full professorship since 1982 and served as the Deputy Vice Chancellor of the University of Khartoum in 1991/2. He worked for UNESCO from 1993 to 2008 as regional hydrologist in Cairo, deputy secretary of the International Hydrological Program of UNESCO (IHP) in Paris and Director of UNESCO regional offices in Cairo and Tehran. In September 2011, he was appointed as Secretary of the UNESCO/IHP and the Director of the Water Sciences Division for one year. Prior to that he was elected in 2008 as the President of the Intergovernmental Council of the IHP of UNESCO for two years. He published over 90 scientific contributions in refereed journals and specialized conferences. His research interest includes areas related to water resources management in arid zones. He is a member/fellow of many scientific organizations such as IAHR, IWRA, IAHS, IAH, ICID, and is currently a member of the executive committee of the Arab Water Council.*

An Overview of Flash Floods Events in Jeddah City, KSA (2009 and 2011): their Impacts and Causes

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Abstract: Jeddah city is located in a coastal plain area, in the middle of the western side of the Kingdom of Saudi Arabia, bounded by the Red Sea to the west and foothills and mountains to the east. Jeddah city receives rainfall runoff from the foothills through different drainage pathways (wadis). During intense rainfall events, runoff flows westward from the hills and mountains toward the Red Sea, causing flash floods in the urban areas that face these wadis. Two major flash flood events occurred in Jeddah in November 2009 and in January 2011. These events were characterized by 70 mm and 111 mm respectively, each one has duration of three hours. The impact of these two flood events have been determined as extensive flooding, loss of life (113 persons were dead in 2009) and damage to infrastructure and property (more than 10,000 homes and 17,000 vehicles damaged) plus other commercial and industrial property. The current study deals with the analysis of the situations that have been occurred in the flash flood time of these two events. Our findings indicate that the causes of these floods are related to a number of factors which play as a major contribution to the worsening of the flood disaster. These factors can be classified into the following; geomorphological features, anthropogenic activities, network and catchment factors, and rainfall and climatic changes factors. The climatic changes have a major impact in the increasing the rainfall intensity by 15% to 27.8% and will appear more in the future. The natural factors which related to the wadis as their tributaries, narrow passes, and high slope of the wadi. The anthropogenic activities include the proliferation of slums and construction in the valleys and the lack of suitable water streams to accommodate the amount of water flowing and the presence of dirt led to the transfer direction of flow.

Keywords: Flash floods, Rainfall and Climate changes, wadis nature, Anthropogenic factors, Jeddah, KSA.

Introduction

The Kingdom of Saudi Arabia is classified climatically as a Semi-Arid region according to the "World Map of Kopper-Geiger Climate Classification" (Peel, *et. al.*, 2007). These climates tend to have hot, sometimes extremely hot, summers and mild to warm winters. Semi-arid climates receive precipitation below potential evaporation, rainfalls are little and erratic as well as irregular, precipitations exhibit strong spatial and temporal variability.

The largest rainfall in the Kingdom of Saudi Arabia occurs in the western and south-western region, where Jeddah is located. Rainfall typically occurs during the wet season that spans November through April, although infrequent rainfall events are observed in the transition months of October and May. Most of the annual rainfall is typically received in the form of a few intense thunderstorm events of relatively short duration during the wet season. The annual precipitation is reported as about 52.5 mm/year, with a maximum rainfall of 284 mm occurring in 1996. Subyani (2009) mentioned that the rainfall amounts are generally lowest in the narrow coastal plain region and increase towards the east where foothills and mountain regions are located. Several investigations have confirmed that elevation is the most important factor, effecting both intensity and distribution of precipitation especially in the mountainous regions (Taher and Alshaikh, 1998; Alehaideb, 1985). Temperature generally follows an inverse relation with elevations, with greater temperatures in the narrow coastal plain region and decreasing with increasing elevation in the foothills and mountain regions.

Natural disasters are the main cause of irrecoverable damages worldwide (Vorogushyn *et al.,* 2012). Saudi Arabia embraces flood events annually in different areas (Youssef and Maerz 2013). These flooding have caused considerable damage to highways, settlement, agriculture and livelihood. These consequences can be decreased through an appropriate and accurate susceptibility analysis. Remote sensing (RS) and geographic information system (GIS) techniques have made significant contribution in flood modeling and prediction (Haq *et al.,* 2012; Pradhan and Shafiee, 2009; Pradhan and Youssef, 2011; Saleh, and Al-Hatrushi, 2010; Youssef, *et al* 2010). Variety of data sources, high data quality, day and night data collection capabilities, and rapid analysis were offered by RS and GIS techniques for hydrological studies (Bates, 2012; Wanders *et al.,* 2013). In other hand many authors found that there is a relationship between the landuse changes and the flood hazards by using GIS (Change *et al* 2009). Recently GIS has been used to delineate catchments and compute their morphometric parameters (Dongquan *et al* 2009). Additionally, development of inundation maps to map the vulnerable areas at different flood events has been utilized using GIS (Gogoase et al 2011).

Jeddah city is located near the middle of the Red Sea coast of western Saudi Arabia. This area occupies a stretch of land along the shore, 60 km long and 40 km wide, b-ounded by latitudes 21°15\ 00\\ and 21°55\ 00\\ N, and longitudes 39° 00\ 00\\ and 39° 30\ 00\\ E. (figure 1). The city is bounded to the west by the Red Sea and to the east by several mountain chains that have an average elevation of about 500 meters. The drainage system of this coastal region, which starts form the Sarawat mountain range and proceeds toward the Red Sea, is characterized by steep drainage gradients (Qari, 2009). Many authors investigated various aspects of geomorphology, hydrology and drainage morphometry within and around Jeddah area among them (Sorman and Abdulrazzak, 1993; Abu-Rizaiza and Sarikaya, 1994; Shehata *et al.,* 2001). Most of the drainage systems in this area are directed toward the west. A number of wadis in this region, which run into the shallow coastal waters, have carried sufficient suspended sand and mud to deposit large inshore aprons of soft sediments.

The main objectives of the present research are 1) Investigate the impacts of flash flood events (2009 and 2011) that occurred in Jeddah city. 2) Evaluate the different causative factors of these flash flood events which including a) Anthropogenic effect and urban areas changes, b) Drainage basins distributions and their characteristics, c) Existing Drainage Systems and their characteristics, d) Rainfall analysis and Climatic changes impacts.

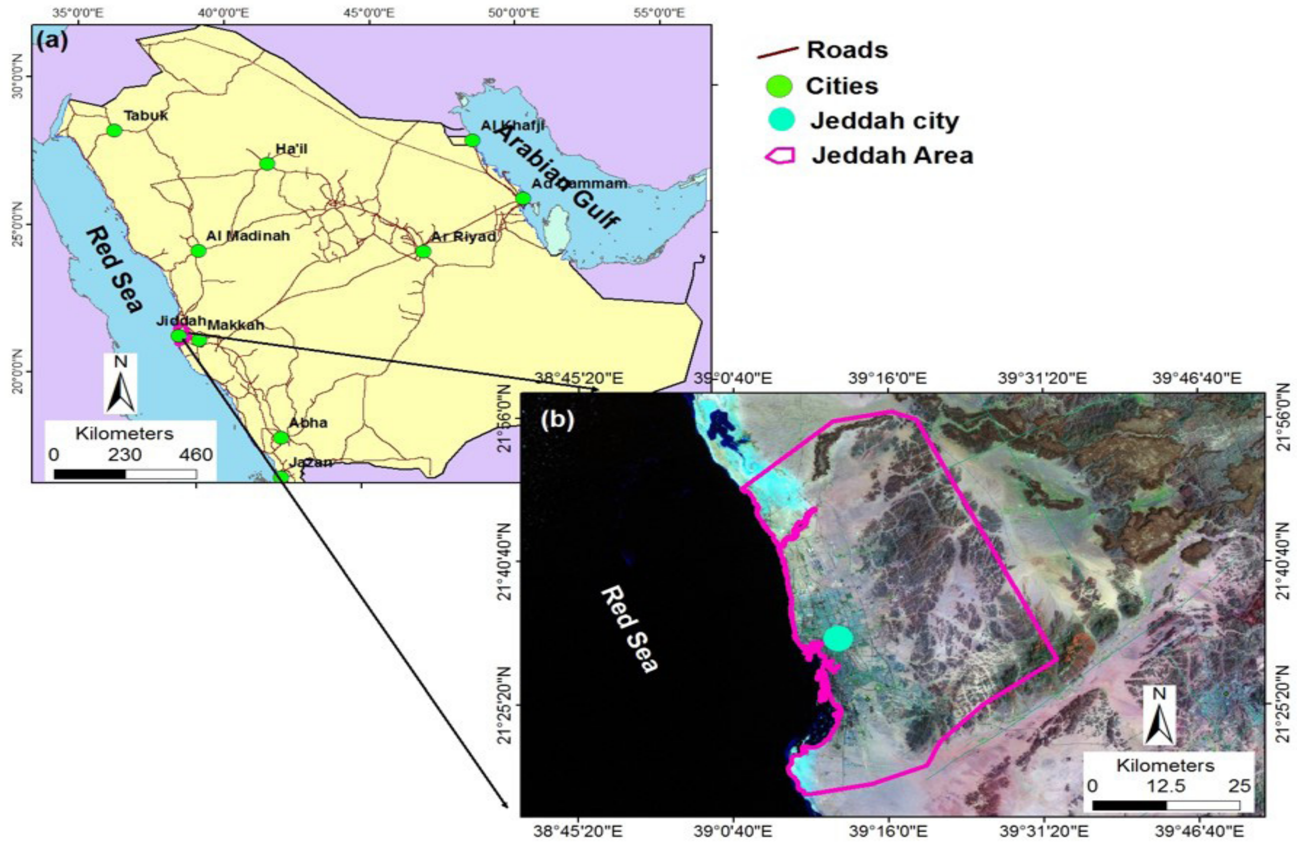


Figure 1: Location map of the study area

1. Geological Features of Jeddah Area

Three distinct geologic units could be distinguished in the study area, these are from oldest to youngest, the Neoproterozoic basement, the Tertiary sediments and lavas, and the Holocene sediments and sabkhas. The Neoproterozoic rocks lie in the eastern part of the area (the area that is occupied by the Red Sea hills and pediments). They consist of volcanic rocks, comprising andesite and dacite, intruded by plutonic rocks including diorite and granite. Shumaysi, Usfan and Hadat Ash-Sham Formations that are covered by basaltic lavas represent the Tertiary rocks recorded in the area east of Jeddah city. The Holocene unit includes the recently emerged marine deposits and corals, the recent basaltic lava flows, the wadi alluvium, sabkha deposits and the Aeolian sands along the coastal plain and pediments (Moore and Al-Rehaili, 1989).

2. Previous Problems in Jeddah Area and their Impacts

In the recent history extreme rainfall events in a few hours were happened causing flash floods one of them occurred in November 2009. This event was characterized by 70 mm of rain in three hours and caused extensive flooding, loss of life and damage to infrastructure and property. These 2009 floods resulted in loss of more than 113 persons, injuries, and damage to more than 10,000 homes and industrial property. The second one happened in 2011 and the rain fall value was 111 mm in three hours, also causing many damages for the properties and infrastructure. Figure (2) some damaged for the infrastructures and properties due to flash flood events in years 2009 and 2011.

Figure 2 a, b, c & **d:** Shows the Damaged to the Infrastructures and Urban Areas Happened in 2009 Floods; / **e, f, g,** & **h** Shows the Damaged Happened in 2011 Floods.

Data and Methodology

Different data types and tools have been used in the current study to understand the flood events that happened in years 2009 and 2011 and even to predict the future impacts. These data includes (1) Rainfall data for all rain gauge stations surround Jeddah basins; (2) digital elevation model and topographic maps to extract all wadis that affect the Jeddah area and determine their morphometric parameters; (3) interpretation of high resolution satellite images to determine the flood impacts and causes; (4) field investigation for the wadis that cause problems in years 2009 and 2011 and determine the causes of these floods; (5) effect of the climate changes on the flood hazards in the future. Different methods and program have been used in the current study including programs to analyze the rainfall data; watershed modeling system to delineate the drainage networks and catchments and to determine the morphometric parameters; Arc GIS 10.2 to analyze different data types, and finally empirical methods to calculate the peak discharge for these wadis.

Causes of Flash Floods in Jeddah Area

1. Geomorphological Impact

Jeddah region has different geomorphological features being a part of the Red Sea coastal area. To the east of the Jeddah area there are a series of hills with drainage sloped towards the Jeddah metropolitan area. This area has a variety of landforms such as low and mid-size rounded hills and flattened foothills in some places. The eastern part of the study region is drained by a network of drainage basins. They have drainage pattern that transports the surface flow towards the city settlement area. Jeddah area is characterized by three distinct geomorphological zones including the Red Sea and its shoreline features; the coastal plain; and the hills and pediments (Figure 3).

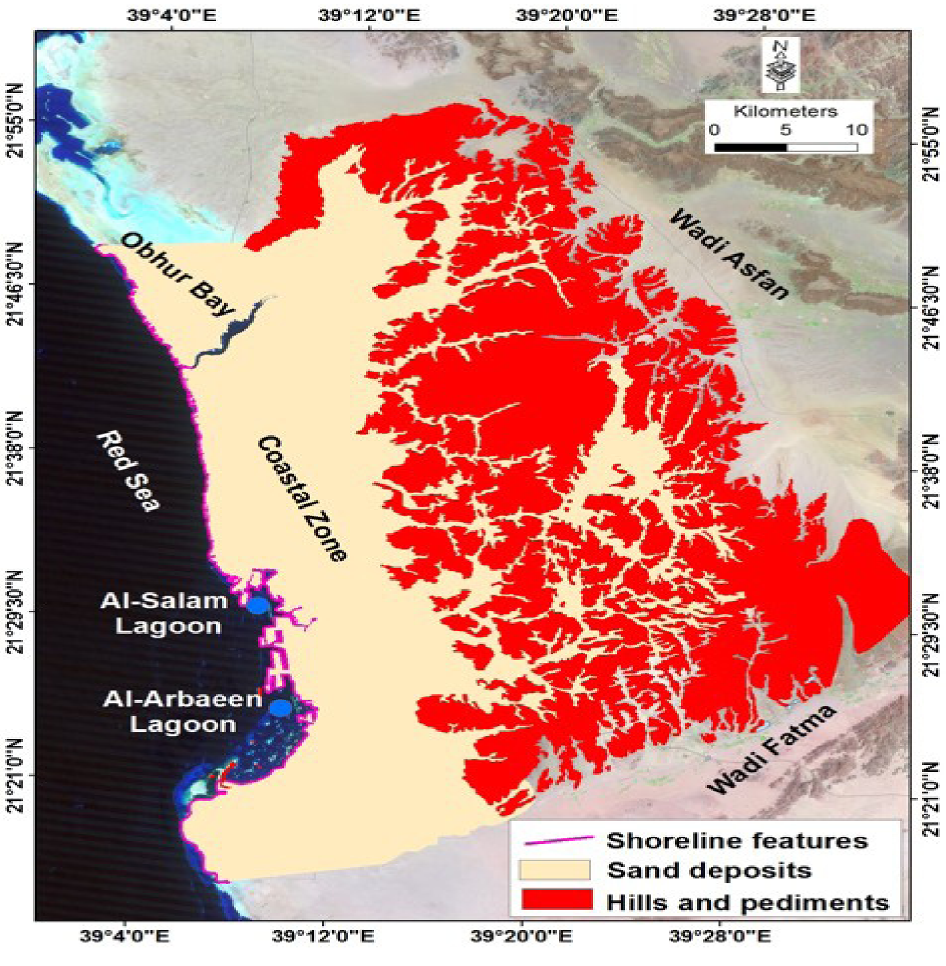


Figure 3: Geomorphological Features of Jeddah Area.

1.1. The Red Sea shoreline features, with upper limit of 0.5 m in elevation is very irregular as it extends inland at some areas to a distance of more than 100 m. It can be divided into two distinct subzones: The northern shoreline is almost straight; it is abruptly broken at the extreme north by Obhur Creek, a narrow linear protrusion of the sea inland. The southern shoreline roughly describes a concave bay, named Jeddah Bay. The shoreline is irregular forming numerous closed and open lagoons, such as Al- Salam and Al-Arbaeen Lagoons.

1.2. The coastal plain zone, which is approximately 10 km wide, lies east of the Red Sea shore and extends in N-NW direction. It is straight at its northern part and is curved towards the southwest at the southern part along Wadi Al-Khumrah. The coastal plain has an almost flat relief, with gradient ranging between 0.002 at the northern part and 0.005 for the southern part. This plain is wider in the north around Obhur Creek and in the south than in the middle part. The coastal plain area is characterized by coralline limestone, alluvial terraces, fluvial deposits, sabkhas and aeolian sands. Many of these areas clearly appear in the satellite images where most of which have now been masked by the residential areas of the rapidly growing Jeddah city.

1.3. The hills and pediments, which extends roughly in N-NW orientation, lies east of the Red Sea coastal plain. This zone constitutes a large number of low-lying hills that are surrounded by flat alluvium covered pediments. The hills range in elevation between a few tens of meters in the west to a few hundred meters in the east side. In this zone different catchments are generated and drain their waters towards the coastal plain zone.

Anthropogenic Effect and Urban Areas Changes

The present study was to outline the diachronic changes of the urban areas in Jeddah area. It is noted that the existent urban pattern consists of residences as well as some industrial facilities, which have remained inside the residential pattern. It is important to compare the growth trend and the changes in the urban areas of Jeddah area. The gradual concentration of population in the Jeddah City and the need for new residences and infrastructure works have led to the expansion of the town boundaries around the old urban limits and in areas that are prone to floods. Different steps for the creation of urban development changes in Jeddah area were used including, 1) Interpretation of different satellite images including MSS 1973, TM 1990, ETM+ 2005, and QuickBird image 2009 that were used to understand the urban expansions. Image processing and GIS techniques have been used to accomplish the changes of urban patterns of the Jeddah city. In order to record the changes of the urban areas, different types of remote sensing maps have been used for the years 1973, 1990, 2005, and 2009 using Landsat MSS, TM, ETM+, and QuickBird. The urban areas were digitized from each map after stack the bands for each image using ERDAS Imagine software. 2) All images were transferred to the ArcGIS environment and bands 123 and 742 (RGB) in order to map the boundaries of urban pattern of the Jeddah city. 3) Overlaying techniques have been used to identify the changes of the urban extent of the town for the years 1973, 1990, 2005, and 2009.

For the time period before 1973, the Jeddah city was concentrated in the old Jeddah town, the expansion occurred toward all directions. For the time between year 1973 to year 1990 the urban expansion continued toward the northern and southern direction as well toward the east side (mountain foots and wadis). During the subsequent periods, from 1990 until 2005, and for the period after 2005 all expansions were in the areas that not developed in the past as well as toward the mountains and wadis course east the Al-Haramein express way. The overall change of urban pattern for all the time periods occurred mainly in North - South direction and to a lesser extent in East direction (Figure 4). These directions coincide with the axes of the Al- Haramine express highway and the Red Sea coast. It is worth to mentioned here that most of the development that occurred toward the North are modernized and most of the expansion to the east and the south are haphazardly and undeveloped urbanization. Figure (5) show the cumulative urban areas with time for the time before 1973 the urban area was 41.2 km^2, before 1990 the urban area was 314.7 km^2, before 2005 the urban area was 459 km^2, and before 2009 the urban area was 635.6 km^2, as well as showing the prediction direction of the urban development in Jeddah area. Different field investigation trips have been done after the flash flood events in 2009 and in 2011. Problems due to human impacts, where the people live in the mountain areas has a negative impact in these flash flood events due to improper use of the land where they close the path of the wadis by building earth dykes, as well as establishing buildings and other things in the wadis paths (figure 6).

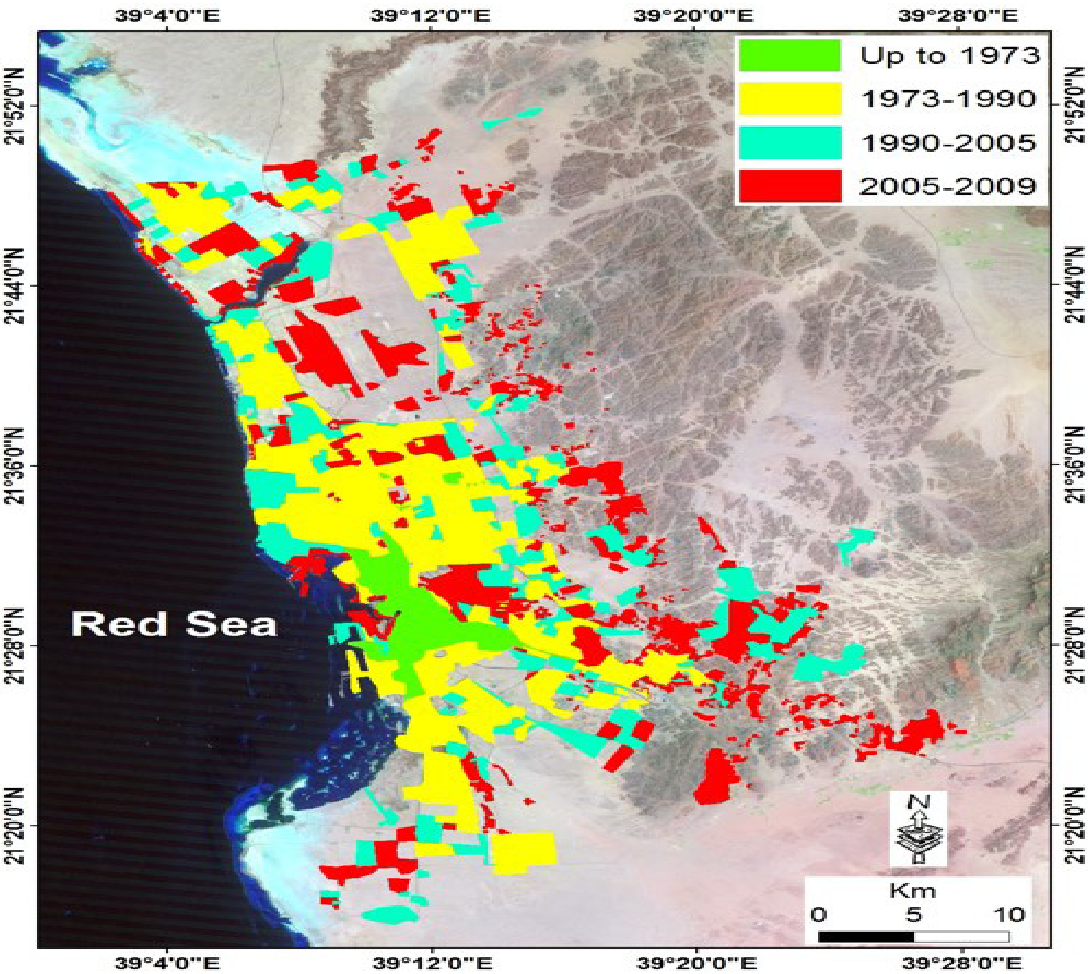


Figure 4: Urban Areas Expansion of Jeddah City from 1973 to 2009.

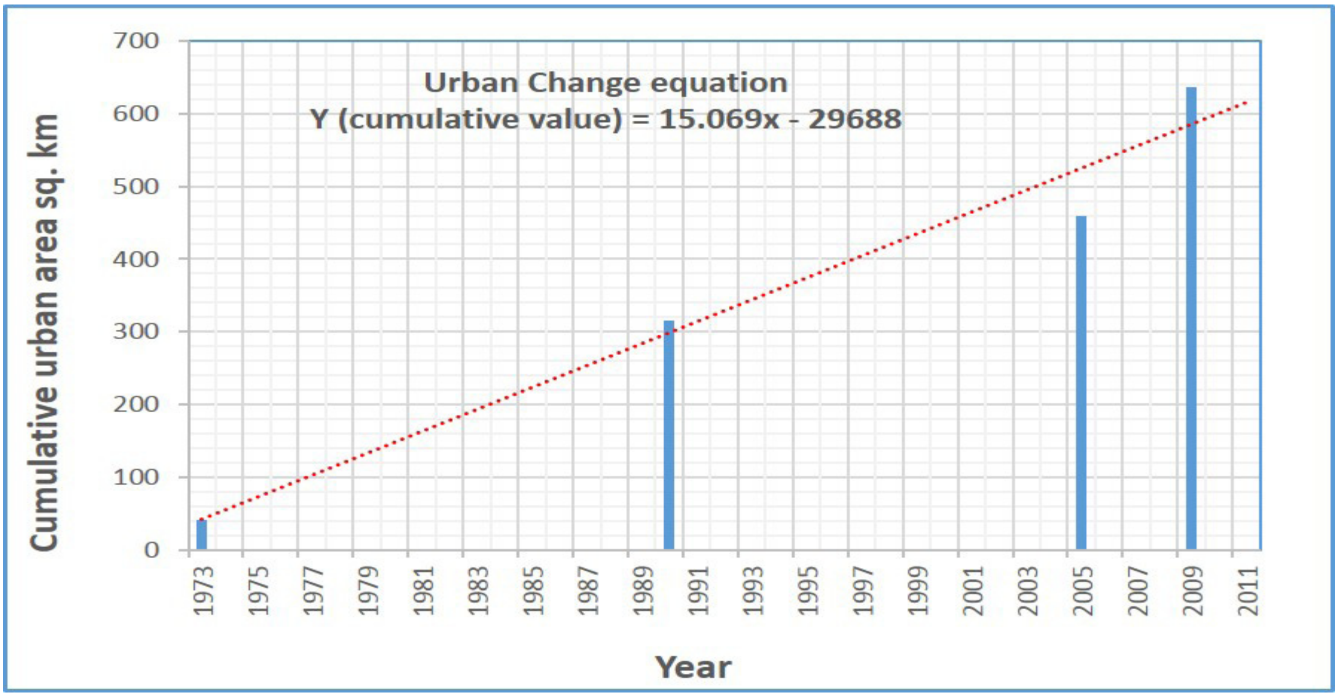
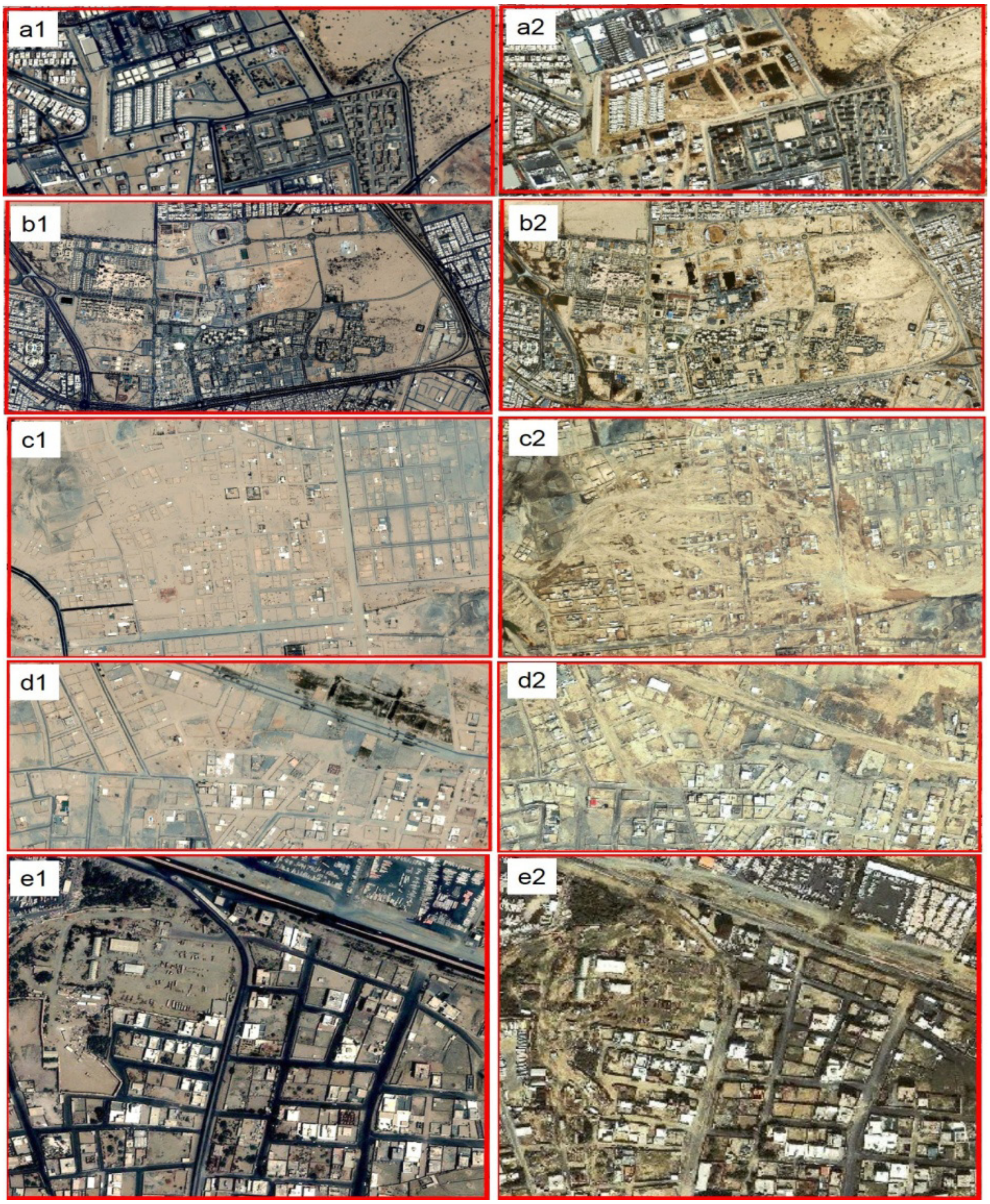


Figure 5: Urban areas Changes with time in Jeddah Area from 1973 to 2009. *Note: red line is the prediction line for future urban development in Jeddah area.*



(**a1**& **a2**): *Um El Khair Area (Wadi Murayikh*)/ (**b1**&**b2**): *King AbdelAziz and Al-Haramine Road (Wadi Qus/* (**c1**&**c2**): *Herazar Area (Wadi Qus)/* (**d1**&d2): *Kilo 14 Area (Methweib Wadi)/* (**e1**&**e2**): *Olya Area (Wadi Ghulil)*

Figure 6: Effect of Uncontrolled Urban Expansion on Floods of Jeddah Area.

Drainage Networks and Catchments Distribution and their Characteristics

Both catchments and streams network together with their morphometric characteristics, that have impact on the Jeddah area, were delineated. This will help understanding the characteristics of surface water movement and their influences. The approach of drainage system delineation for the catchments was obtained by using different types of topographic data sources including 2-meter resolution digital elevation model (DEM) developed by King Abdulaziz City for Science and Technology and data created from the Light Detection and Ranging (LiDAR). These DEMs data captured the most accurate and recent topographic representation of the Jeddah area. Watershed modelling systems (WMS 8.1) was used to extract all these drainage basins and networks as well as their morphometric characteristics (Figure 7 and Table 1). Fifteen catchments were delineated named, Wadi Quraa, Muraygh, Ghia, Um Hablain, Um Hablin south, Daghbaj, Brayman, Brayman south, Al-Asla, Mraikh, Qus, Asheer, methweb, Ghulail, and Al-Khumra. It has been found that there are 15 catchments in Jeddah area, whose areas range from 11.6 km^2 to 3001 km^2. The most morphometric parameters of these catchments have essential role in controlling water flow regime and their impact on flood process including basin area, length, slope, perimeter, and mean elevation; main flow distance (longest flow path) and slope; and main stream distance and slope (table 1).

Table 1: Morphometric Characteristics of the Drainage Basins of Jeddah Area

Basin (No)	Basin Area (Km^2)	Basin Length (m)	Basin Slope (m/m)	Basin Perimeter (m)	Mean Elevation (m)	Main Flow Distance (m)	MFD Slope (m/m)	Main Stream Distance (m)	**MSD Slope (m/m)**
1	142.6	19850.0	0.0278	79905.0	66.0	26090	0.0051	24450.0	0.0036
2	71.7	17363.2	0.0873	62011.5	123.1	22441.3	0.0121	20703.1	0.0072
3	89.3	19461.0	0.0931	79183.0	135.9	28881	0.0166	27540.0	0.0088
4	46.3	19461.0	0.0931	79182.8	135.9	28881.6	0.0166	27540.6	0.0088
5	24.4	8243.2	0.0673	30540.0	89.4	9780.2	0.0241	8222.0	0.0090
6	55.6	16140.1	0.1064	60472.6	140.8	20200.6	0.0188	18896.9	0.0085
7	57.1	18507.9	0.0569	71143.3	119.4	28167.4	0.0089	26736.4	0.0061
8	19.2	6585.4	0.0284	26099.1	73.6	8340.5	0.0096	6804.1	0.0065
9	301	29910.9	0.0513	141305.6	153.4	41284.5	0.0149	38894.4	0.0059
10	40.8	10070.4	0.0501	40183.7	88.5	12502.2	0.0107	10838.5	0.0073
11	68.8	20846.2	0.0372	75758.0	142.3	26081.5	0.0085	23803.3	0.0069
12	11.6	6510.6	0.0471	22132.3	90.4	7623.7	0.0128	6087.3	0.0084
13	57.0	15744.9	0.0463	54687.5	123.8	19310.5	0.0083	17159.5	0.0066
14	40.6	12268.1	0.0520	47208.1	106.8	16088.5	0.0076	14328.4	0.0059
15	164.8	14619.9	0.0219	73933.0	41.4	23506.1	0.0060	21175.1	0.0028

Existing Drainage Systems and their Characteristics

Three drainage systems were previously constructed in Jeddah area to drain the flash floods water that coming from the hill zone towards the west (Figure 7). These systems include 1) the Eastern Channel which is a drainage channel that roughly parallels to Al-Haramain Expressway in the northeastern portion of the city and turns toward the Obhur Creek on the northern side of the airport (see, figure 7). The Eastern Channel drains runoff water coming from eight catchments (Wadi Quraa, Muraygh, Ghia, Um Hablain, Um Hablin south, Daghbaj, Brayman, Brayman south). According to AECOM 2011 work by using Outflow hydrographs for base and future conditions for each catchment, it was determined that the capacity of the Eastern Channel was less than the 10-year flood event.

The Northern Channel is located east of the central portion of Jeddah city. It drains runoff water coming from two catchments (Wadi Al-Asla and Wadi Mraikh). Each wadi flows to a dam that outflows directly to the Northern Channel. These dams include two dams along wadi Al-Asla catchment (the Emergency dam and Al-Samer dam) and Umm Al Khair Dam for Wadi Mraikh. Inflow and outflow hydrographs for base and future conditions have been developed for these dams (AECOM 2011). It was found that the two branches of northern channel coming from wadi Al-Asla dams and wadi Mraikh dam, and the main northern channel part are adequate (Figure 7).

The Southern Channel is located in the southern portion of Jeddah city. It drains runoff water coming from five catchments (wadi Qus, Asheer, methweb, Ghulail, and Al-Khumra) southwards towards the Red Sea. There are two branches of the Southern Channel that come together (Figure 7).

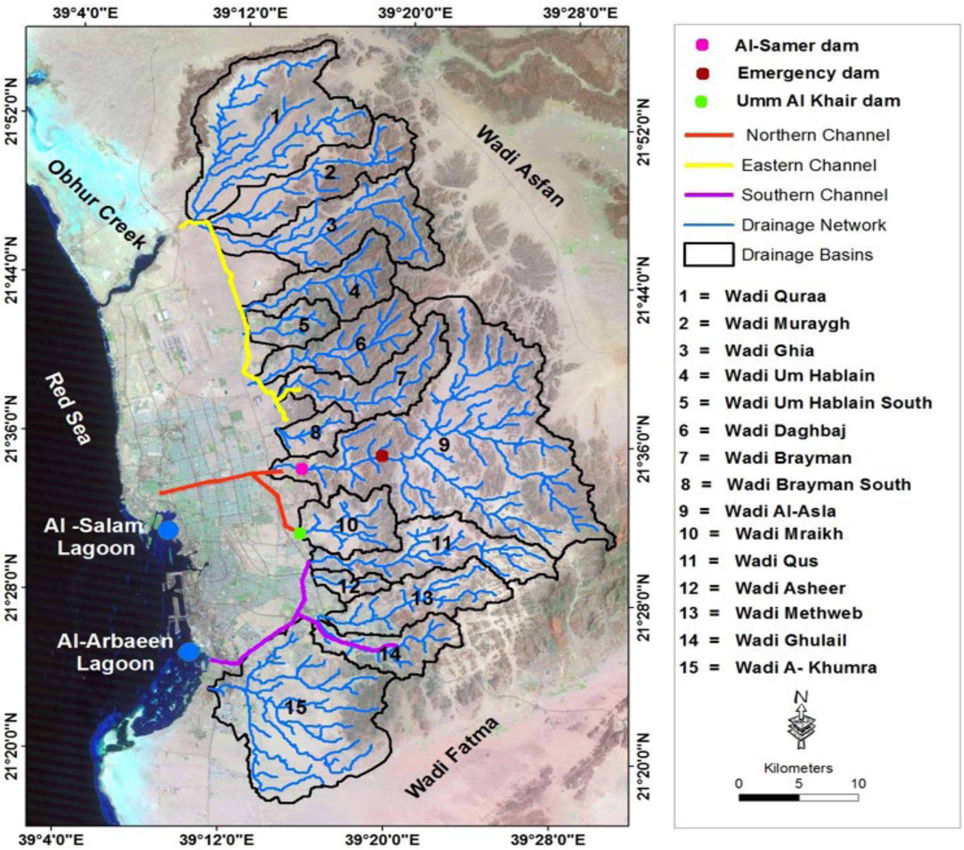


Figure 7: Drainage Basins and Networks as well as Open Channels of Jeddah Area.

The Northern branch receives runoff directly from Wadi Qus just east of the Al-Haramain Expressway. The southern branch receives runoff directly from Wadi Ghulail. However, other three catchments (Wadi Asheer, Methweb, and Al- Khumra) are not connected with the southern channel and most of the flood damages happened in wadi Methweb in 2009). Inflow and Outflow hydrographs for base and future conditions have been developed for these catchments and channel branches and at the outflows into the Red Sea (AECOM 2011). It was found that, the maximum capacity of Wadi Ghulail Channel is greater than the 50-yr event discharge, but less than the 100-year base conditions discharge, due to the overtopping at key points along the channel. For the first 8000 m begins from wadi Qus towards the Red Sea the capacity of this channel portion is nearly as much as the 50-yr base conditions discharge. However, for the last 4500 m till the Red Sea, the Southern Channel is sufficient to contain the 100-year base conditions discharges. Figure (8) shows the northern portion of southern channel where the 2009 flash floods damaged most of the channel.

Figure 8: Northern Part of the Southern Channel by King Abdel Aziz University Showing Inadequate and Damaged during 2009 Flash Flood

Rainfall Analysis and Climatic Changes

There are about 12 rain station are distributed in and surround the study area, among them only three stations namely J221, J134, and 41024 have influence on Jeddah area (figure 9).

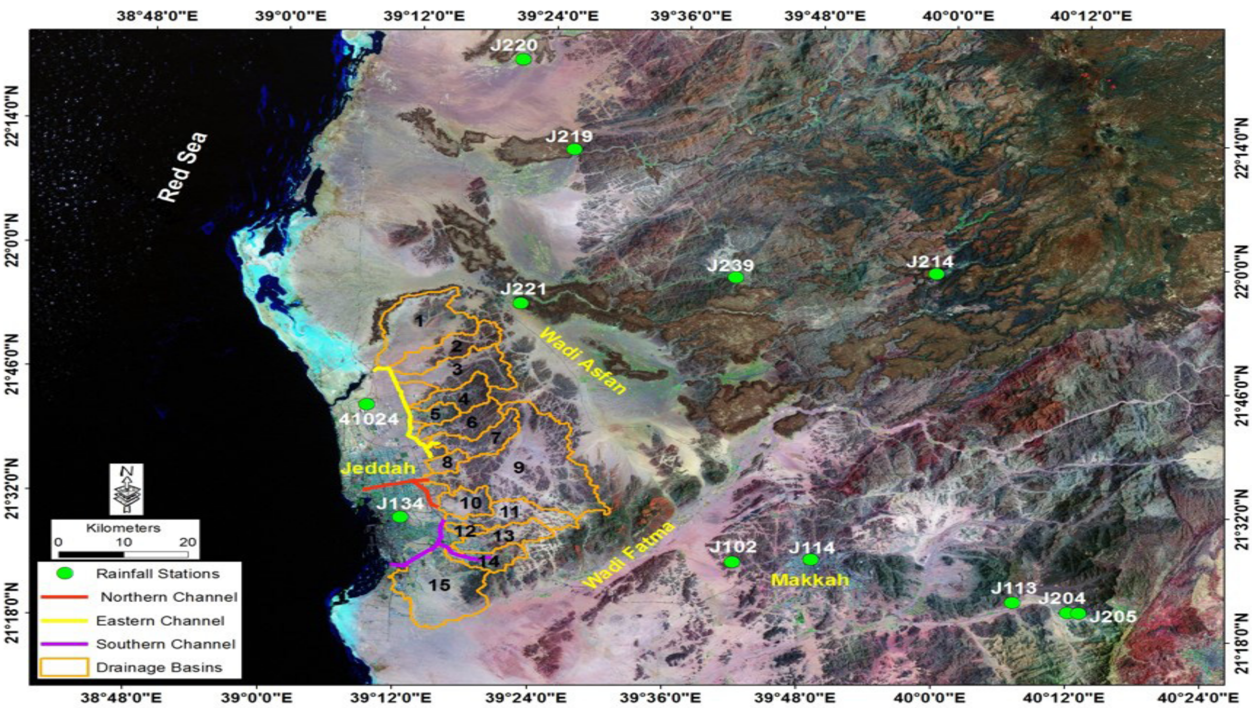


Figure 9: Meteorology Station Locations

However, most of the flash floods were occurred in the southern and central part of Jeddah area, Stations J134 and 41024 were considered for the rainfall analysis. The maximum daily rainfall amounts are given in table (2). The last column in this table is for the aggregated maximum daily rainfall amounts for the stations J134 and 41024, where each value is the maximum of the corresponding year.

Table 2: Maximum Daily Rainfall Amounts at a set of Stations

Year	J134	J221	41024	.Aggr*	Year	J134	J221	41024	.Aggr*
1970	36	-	36	36	1991	38.4	27.4	7.2	38.4
1971	70	8.8	47.6	70	1992	38.4	140.2	51.5	51.5
1972	15	53	83	83	1993	18	24.6	28	28
1973	16	7.6	5.8	16	1994	1	5.6	5.4	5.4
1974	15	10.6	13	15	1995	17.4	7.8	45.2	45.2
1975	13	37.4	9.7	13	1996	46.5	-	55	55
1976	6	2	-	6	1997	52	-	22	52
1977	5.5	67.4	55.5	55.5	1998	27.3	3.7	26	27.3
1978	46.2	56	67	67	1999	21	19.6	28.2	28.2
1979	42.8	52.8	80	80	2000	24.5	24.6	40	40
1980	-	-	4	4	2001	51.2	40	25	51.2
1981	-	13	10.5	10.5	2002	29	18.9	20	29
1982	-	-	0.5	0.5	2003	18.4	25	44.4	44.4
1983	-	2.8	-	2	2004	20	8	6	20
1984	3.7	9	-	3.7	2005	25	-	39	39
1985	49.8	40.4	38	49.8	2006	25	25	3	25
1986	1	-	-	1	2007	10	-	2	10
1987	21	14.5	4.4	21	2008	17	-	12	17
1988	17.4	34.2	23.4	23.4	2009	80	-	70	80
1989	30	33.2	25	30	2010	29	-	41	41
1990	-	12.2	2	2	2011	124	-	29.2	124

(*aggr. = *aggregated values for J134 and 41024 stations*)

The internal structure of maximum daily rainfall amounts at each station is identified by the suitable probability distribution function and the statistical parameters and the pdf parameters are shown in (Table 3). Also, the maximum daily rainfall amount corresponding to a set of return periods of 2-year, 5-year, 10-year, 25-year, 50-year, 100-year were calculated as shown in Table (4). According to the climate changes study in the KSA (Al Zawad, 2008). For the western region, two models were applied 1) under A2 scenario an increase of 40 % in precipitation, 2) under B2 scenario a decrease of 12.2 % in precipitation. In the current study an average value of Model A2 and B2 was used which is increased in precipitation by about 27.8%. In addition, an increase of precipitation of 15 % was used in this study.

Table 3: Statistics Parameters for Probability Distributions of Jeddah Stations

Station name	Distribution type	Distribution parameters	Chi- Squared
J134	Gamma	a=0.05643 lambda =1.501	X^2 = 6.89
41024	Weibull	a=30.46 c=1.1508	X^2 = 4.95
Aggregated	Gen. Extreme Value	k=-0.1078 s=19.33 m=20.981	X^2 = 3.711

Table 4: Maximum Daily Rainfall Amounts at Different Return Periods before and after Climate Change Influence

Station number	25-year			50-year			100-year			200-year		
	BCC	ACC 15%	27.8%	BCC	ACC 15%	27.8%	BCC	ACC 15%	27.8%	BCC	ACC 15%	27.8%
J134	82.4	94.8	105.3	97.6	112.2	124.7	113	129.9	144.4	127	146.1	162.3
41024	84.1	96.7	107.5	99.7	114.7	127.4	115	132.3	146.9	130	149.5	166.1
Aggre-gated	94.8	109.0	121.2	115	132.3	146.9	136	156.4	173.8	159	182.9	203.2

Conclusion

It is clear that the Saudi Arabia is being located under new climatic change conditions, represented mainly by torrential rainfall. This was obviously noticed from the frequent natural disaster events (intensive rainfall) that hit many parts of the region. The degree of impact of these events have negative consequences in people, urban areas, and infrastructures. Great awareness of flash flood hazards are needed. This research develops a detailed analysis of the catastrophic flash flood events which happened in Jeddah area years 2009 and 2011. The study depends mainly on the GIS and remote sensing based approaches for mapping and quantifying urban area changes and determine the flood affected areas. Other software such as those for rainfall analysis and watershed and drainage network delineations were also used. The developed methodology is based on integrating several datasets in a GIS environment. Results show that the main factors affect the flash flood events, are the geomorphology of the study area, anthropogenic activities, drainage catchments and network characteristics, and rainfall and climate changes. The physical setting of study area exhibits its vulnerability to flash flooding process, where dense drainage systems were found (15 basins), basins slope is almost ranges from moderate to high (Table 1) towards the Jeddah urban areas, and narrow valley cross-section along some valleys which has a large contribution on increasing the negative impacts. Anthropogenic activities have large negative consequences on flash floods; especially the haphazard urban expansion along valleys watercourses and floodplains as well as at the outlet downstream where human settlements have been recently constructed without considering any vulnerability assessment for flash flood hazards. In addition, the impact of climate changes has been noticed from the rainfall values changes and the increasing number of the rainfall events.

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Regionalization of Morphometric and Hydrological Characteristic of Small Watershed and their Impacts of the Silting of Tunisian Lakes

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Abstract: In Tunisia, water erosion affects nearly 3 million hectares of agricultural land, and constitutes a threat to the sustainability of small lakes in the hilly regions. Twenty six lakes have been identified in the central part of Tunisia covering the Ridge area and Cap Bon. To predict the siltation in these lakes, we proposed a simple and practical model classification assessing the sediment fluxes at the outlet of the small watersheds and the sediment load of the receiving lakes. We further explored the links between the sediment prediction model parameters and various terrain attributes of the contributing catchments. Three statistical methods are used for the data analysis: the Principal Component Analysis method (PCA), the hierarchical classification method, and finally the step wise linear regression analysis. We identified three different classes of lakes. The first class is less vulnerable to the silting risk and is located on the southern and eastern borders, west of the ridge and the coastal plains. The lakes of this group are characterized by a low rate of silting, a large drainage area, a low relief, a relatively hierarchical hydrographic network and an effect of precipitation and little intense runoff. A second class which is the most degraded environments covers almost the entire semi-arid zone of Central Tunisia. This class has a very abrasive potential watershed, explained by high flow coefficients related, mainly to higher erosive rainfall intensities associated with a moderate or accentuate topography, structure of soil over marl and poor drainage and unimproved surface. The third class exists in the north and south of the Ridge. The catchments of this class are characterized by a moderate to high sedimentation rate which is governed by a more or less marl soil structure and an intense hydrodynamic compounded by the steep slopes of these basins. The represented lake will server to quantify and predict the sedimentation.

Keywords: Silting, Hilly Lake, Principal Components Analysis, Hierarchic Classification, Linear regression, Typology.

Introduction

Dams and reservoirs created behind them have represented a domain of interest for geomorphology and resulted in various economical, hydrological and ecological benefits. However, sedimentation is the major problem which endangers the sustainability of reservoirs resulting in slowing down agricultural development and reducing thereby live storage of many existing reservoirs coupled with the limitations of the existing sediment control measures (Ayadi *et al*, 2011).

Alarming rates of storage depletion have been reported worldwide. The estimated annual loss in storage capacity of the world's water reservoirs due to sediment deposition is around 0.5- 1% (Verstraeten et al, 2003). Nevertheless, for North African countries, annual sedimentation rates are much higher and can go up to 4% or 5%, such that they lose the majority of their capacity after only 25–30 years (Kassoul *et al,* 1997). In Tunisia, the quantity of sediment trapped in the different hydraulic structures of the country occupied 20% of their initial global capacity (Abdelhedi, 2000). Important erosion and sediment transport in this region is highly influenced by the intermittent stream flow and erratic rainfall regimes on a steep topography with fragile soils and sparse vegetation cover.

The phenomenon of filling reservoirs depends on the condition of the soil erosion and deposition processes that are managed by the geological properties, soil, physiographic, hydrographic and anthropogenic watershed as well as hydro- rainfall characteristics. We explain the theory and the results of statistical tools we have used to shape and define the different classes of hill lakes. Our study is done on a sample of 26 hill lakes of different morphometric and hydrological characteristics. The choice of this region is justified by the fact that the study area is considered the heart of Tunisia, which has a remarkable succession of mountainous alignments. It suffers from both low economic development and environmental degradation in association with increased pressure on natural resources (Elise, 2006).

In this study, a multivariate statistical approach was used to identify the dominant factors which contribute to sediment yield variability in various semi-arid mountainous areas located in Central Tunisia. The main objective of this paper is to form different classes of hilly Lakes, by using statistical method, and to define a representative lake of each class.

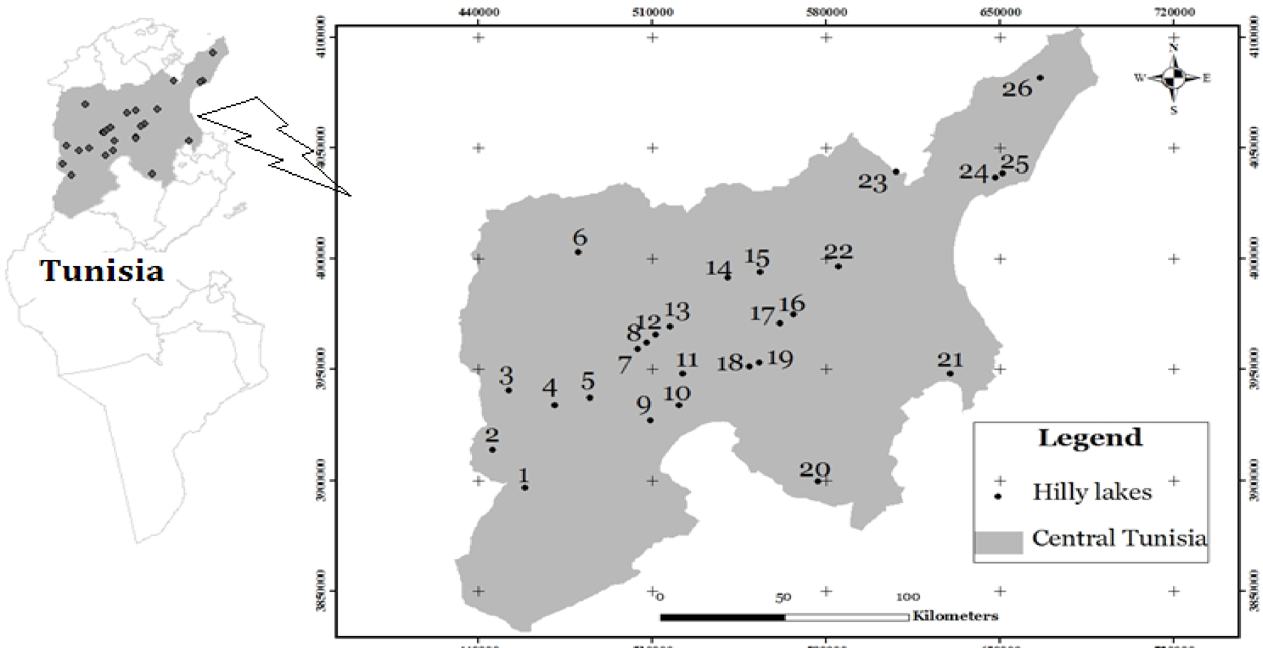
Study Area

The present study focuses on 26 hill lakes in Central Tunisia, along the Dorsal and Cap Bon area of great contrasts on all scales (figure 1). The study area is a semi-arid mountainous region that extends from the Algerian border in the West to the Cap Bon in the North-East. Implemented at the outlets of relatively small mountainous catchments, these artificial reservoirs are affected by water erosion.

The climate of the study area is Mediterranean type characterized by dry summers followed by intense autumn rainfall. The precipitation regime is very irregular and has an erratic distribution combining scarcity with tendency to fall in torrents. Annual rainfall gradient generally varies between 250 mm and 550 mm while mean annual temperature varies between 18 and 20°C. Indeed, the mountains of the dorsal constitute a climatic barrier, where the South Eastern zones are drier than those of the North West.

We conclude from the morphometric study that the majority of sites of hill lakes developed in the semi-arid ridges, mostly defined by topography and mountain terrain, generally have elongated shapes with areas ranging from a few hectares to a few tens of kilometers square and moderated to high relief.

The land watershed consists mainly of farmland (Arboriculture, market gardening, cereal), representing 40-70 % of the area under the watershed. We also note the presence of forests in some regions especially in the Cap Bon and north of the Ridge with a rate up to 35%.



1-Abdeladim	7-Hdada	12-Jannet	17-Dékikira	22-Sadine
2-Arara	8-Sadine 2	13-Sadine 1	18-Fidh Ali	23-Sbaihia
3-Mrir	9-Essenga	14-Hnash	19-Fidh Ali Naser	24-El Maleh
4-Echar	10-Brahim Zaher	15-Mricht El Anze	20-El Mouidhi	25- Ességhir
5-Bouajer	11-Abdessadok	16-El Gouasine	21-Zayet	26- Kamech
6-El Amadi				

Figure 1: Location map of the hilly lakes

The predominance of climate irregularity, torrential flows, moderated to high relief, low densities of vegetation cover and land overuse are all factors that promote soil erosion in our region. Then to reduce this effect, it becomes necessary to implement erosion control facilities whose purpose is to reduce soil loss and keep the soil in place. The density of such arrangements must not affect the good filling reservoirs. Physical factors in our study area are all in favor of an emphasis liquid intake and an acceleration of the phenomenon of erosion.

Statistical analysis of Morphometric and Hydrological Characteristics

Spatial variability of sediment yield in this study is controlled by morphometric catchment characteristics which were derived from digitalized maps (topographic map, drainage network map, geologic map, land use and vegetation cover map) developed within the HYDROMED research program (Albergel *et al,* 2001). Major topographic attributes used are drainage area (A), compactity index (Ci) and a relief parameter known as the overall index slope (Gi).

Another important parameter that may influence sediment yield is the total drainage length (Ltw). Hydro-climatic factors such as maximum rainfall intensity in 30 minutes (I30), runoff depth (Rd), runoff coefficient (Rc) and the ratio of dam initial capacity to inter-annual flow contribution (C/A), were obtained from DGACTA reports (1994-2006) and were considered to characterize the flow erosion potential. Anthropogenic activities and land use pattern are represented in this study by the fraction of cultivated by forest land (Ar/Fr) and the percentage of soil conservation works (WSCW). Finally, soils and surface lithology represented by the fraction of clayish marl area (ERL) could also serve as a proxy to describe the erodibility potential.

In this work, we will rely on statistical analysis of multivariate types to manage the information provided by the used parameters. Multivariate analysis is a useful technique for identifying common patterns in data distribution, leading to a reduction of the initial dimension of data sets and facilitating their interpretation (Castellano et al, 2007). Statistical analyses were carried out by the statistical software (XLSTAT 2013). So after visually interpret the correlations between variables, using the correlation matrix, we will use three methods of analysis. The Principal Component Analysis (PCA) method of descriptive analysis to synthesize the most relevant information of the data used. The Hierarchical Classification method (HC) will, in turn, to quantify the effect of these factors in prioritizing the different watersheds. Then we will use the linear regression of "Step wise" or Type "step by step" to finally get a relationship that expresses the parameters on the erosive process. By comparing the different results, we will try to identify a typology of hill lakes and explain the reasons for such assemblies.

Results and discussion

1. Characterization of Siltation Based on the Hierarchical Tree

The fundamental objective is to define stable and homogeneous groups of small lakes monitored while combining similar elements. Each level represents a class hierarchy (Saporta 1990). It is, in fact, a tree whose terminal elements are the elements classified. Each intersection of this tree is a node. This node represents a class that decomposes itself into two subclasses, the eldest and the youngest, according to the Euclidean distances between them.

The hierarchical classification is applied on 26 lakes hillside reservoirs of Tunisia in central function of 7 variables hydro-morphometric following falling within the physiography of watersheds: the index of overall slope (Gi), the index of compactness (Ci), the length of the settle (Ltw), the nature of runoff and drainage (Rc, Rd) and climatic erosivity of acid (I30) as well as the rate of abrasion (Ta) as the dependent variable.

Of first view, it is clear from the figure 2 below that the taxonomy developed is virtually compatible with the one edited by the analysis of different methods (correlation matrix, ACP and linear regression). In addition, a growing ability and contradictory to the dynamics of the siltation of withholding of lakes hillside reservoirs is observed ranging from the class (1) to (3), of the low to the high potential of abrasion.

The typology unveiled pleaded in favor of the identification of three classes of lakes hillside reservoirs. In effect, the hilly lake 'El Gouazine' (N°16) paints to the larger surface area of drainage and the lowest rate of abrasion. Unlike the hilly lake Dekikira (N°17) is characterized by a catchment whose shape is the more elongated which allows the coalescence of nets of water and the formation of gullies accentuating the ablation of earth. In addition the hilly lake Sadine (N°22) may designate the court or the central core which is governed the spatial variability of the phenomenon of siltation in the study area.

Class I: includes the lakes number 1, 8, 21, 3, 2, 4 and 16, characterized by a low rate of siltation, a low relief and a little intense runoff.

Class II: includes the lakes number 15, 19, 24, 20, 22, 26, 11, 17, 6 and 23, characterized by high rate of sedimentation, high flow mostly associated with most high intensities erosive rainfall coupled to topography moderate or high.

Class III: includes the lakes number 10, 12, 5, 13, 18, 25, 7, 14 and 9, characterized by moderate to high rate of sedimentation. This character is governed by an intense hydrodynamic aggravated especially by the steep slopes of watersheds.

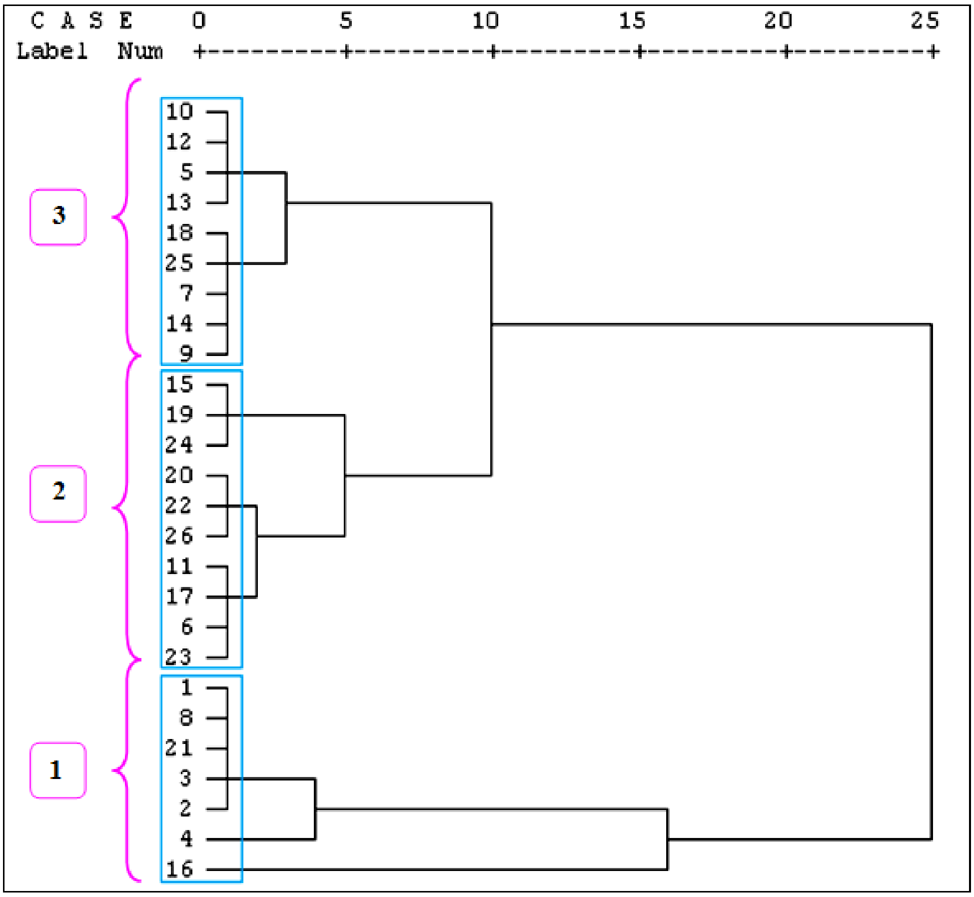


Figure 2: Dendrogramme resulting from the hierarchical classification of hilly lakes

2. Principal Component Analysis

Graphical representations from the principal component analysis allowed to subdivide basins studied in 3 groups (figure 3). First group less vulnerable to the risk of silting locates on the southern and eastern borders of the West Ridge and also on the coastal plains (square mark). It includes the lakes number 1, 3, 4, 5, 16, 21 and 25 which are characterized by a low rate of siltation, a large surface drainage, low relief drainage system relatively hierarchical and an effect of precipitation and runoff little intense . This class is also slightly affected by the various forms of erosion, due to the multiplication of the conservation of soil and water in combination with continuous vegetation cover which contribute significantly to fold the abrasion rate of these lakes. As such, some watersheds (as El Gouazine N°16) show the effectiveness of anti-erosion benches;

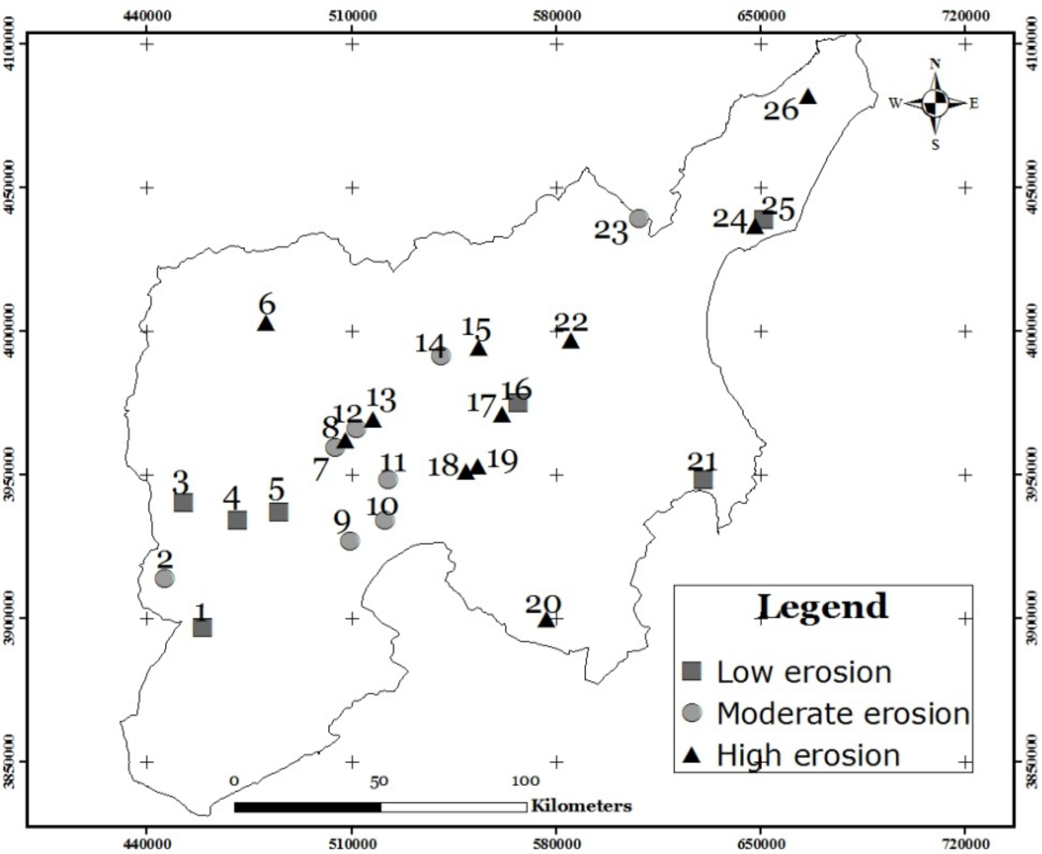


Figure 3: Map of geographical location of 3 groups

First group less vulnerable to the risk of silting locates on the southern and eastern borders of the West Ridge and also on the coastal plains (square mark). It includes the lakes number 1, 3, 4, 5, 16, 21 and 25 which are characterized by a low rate of siltation, a large surface drainage, low relief drainage system relatively hierarchical and an effect of precipitation and runoff little intense. This class is also slightly affected by the various forms of erosion, due to the multiplication of the conservation of soil and water in combination with continuous vegetation cover which contribute significantly to fold the abrasion rate of these lakes. As such, some watersheds (as El Gouazine N°16) show the effectiveness of anti-erosion benches;

A second group comprises the most degraded cover almost all the semi-arid zone of Central Tunisia (triangle mark). This group includes the lakes number 6, 8, 13, 15, 17, 18, 19, 20, 22, 24 and 26. It is characterized by abrasive potential, explained by high flow coefficients related especially at the highest erosive rainfall intensities, moderate or severe topography, soil structure more marl and surface drainage unoccupied and undeveloped. We deduce, therefore, that in this class, raises the erosion and sediment dynamics and yielding large quantities of soil particles to concentrate at a specific core of the Dorsal (case watershed Sadine N°22). Therefore, this class must be taken as a priority area of intervention to fight against the scourge of clogging.

A third group extends on either side of the North and South sides of the ridges, includes the lakes number 2, 7, 9, 10, 11, 12, 14 and 23. It is characterized by moderate to high rate of sedimentation (circle mark). This sedimentation rate is governed by a structure more or less marl soils and intense hydrodynamic compounded by the steep slopes. The evolution of surface exposed to the combined action of traditional farming practices, changes in land use (mechanized farming) and a very variable climate from north to south, may strongly condition the flow, infiltration, erosion and therefore, sedimentation (case of lake El Hnach N°14).

Characterization of the Siltation Based on Linear Regression

After determining the affinities between the sedimentation and the dependent factors by the principal component analysis and the subdivision into groups of the basins studied, another step statistics has been affixed to better examine the effect of weighting of the axis of the PCA and settings that they characterize, a linear regression (or Step wise) has been applied to the pins from the principal component analysis in function of the rate of siltation. In which we share the best regression to a variable, in order to watch if the introduction of new explanatory variables does not justify the elimination of variables already introduced in the model. It stops when no variable brings sufficient reduction of residual variation.

The variables offering the best regressions are the index of slope (Gi) and the runoff coefficient (Rc). The sedimentation rate is given by the following equation:

$Sr = 0{,}993\ Rc + 0{,}466\ Gi$ (With $R^2 = 0.78$ and $N = 26$)

Based on the coefficients from this equation, introducing a coefficient of determination if important to the order of 78 %, it is demonstrated that the siltation rate is more sensitive to the fluctuation of the shape of the watershed and the hydrographic network. In addition, it is by fate that the analysis of the general trend of the siltation is due to natural effects and predominant anthropogenic the hydro-climatic conditions.

This shows that, as the has loosed Walling (1994), the variability of siltation rate depends on the variability of the factors which control the process of silting up (shape of the basin, the density of the hydrographic network, the status of the vegetation cover, nature of the soil, anthropogenic activities and hydro-climatic conditions).

Conclusion

A high spatial variation in area specific sediment yield among the 26 studied small dam reservoirs in Central Tunisia is observed. The average sediment yield is approximately of 15 t ha^{-1} y^{-1}, which is relatively high compared to African average values.

Major factors affecting erosion and siltation were identified. The analysis indicates that there are morphological catchment properties, land use, soil lithology that are useful as aids to predict sedimentation rates. A single criterion cannot determine the erosion of soils on little catchments in the Tunisian mountain range.

Multivariate statistical analyses were performed to assess the role of different catchment variables in the sediment yield of reservoirs and to see the spatial distribution of reservoir sedimentation throughout mountainous areas located in various hydro-climatic, geologic and geomorphologic zones.

In the light of these analyzes, it appears that the study area was divided into three areas of different abilities may siltation:

The first class is less vulnerable to the silting risk and is located on the southern and eastern borders, west of the ridge and the coastal plains. The lakes of this group are characterized by a low rate of silting, a large drainage area, a low relief, a relatively hierarchical hydrographic network and an effect of precipitation and little intense runoff.

A second class consists of the most degraded environments and cover almost the entire the semi-arid zone of Central Tunisia. This class has a very abrasive potential watershed, explained by high flow coefficients related mainly to higher erosive rainfall intensities associated with a moderate or accentuate topography, structure of soil over marl and poor drainage and unimproved surface.

The third class exists in the north and south of the Ridge. The catchments of this class are characterized by a moderate to high sedimentation rate. The sedimentation rate is governed by a more or less marl soil structure and an intense hydrodynamic compounded by the steep slopes of these basins.

Indeed, it turned out that the most degraded areas cover almost all of the semi -arid zone of Central Tunisia and because of the altitude of the mountains, increasing continentality towards the West, increasing aridity southward and finally opposition sides. The semi-arid environment is far from being a homogeneous whole geomorphological and bioclimatic. Although the results generated have clarified the study of conditional factors siltation, it is remarkable that this phenomenon remains as complex as it can only be understood by integrating multiple attributes simultaneously. This suggests not only the complexity of monitoring clogging deductions hill reservoirs, but also its non- linear character. To overcome such a problem, the use of other non-parametric techniques, such as the application of artificial intelligence, is required.

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New Reclamation Mega Projects and Increasing the Pressure on Water System in the Nile Valley and Delta in Egypt

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Abstract: Egypt is an arid country, which covers an area of about 1,001,450 km^2 of which only 4% is occupied by its population. One of the important issues in the future is to redistribute the population over a larger area, therefore, it is essential to reclaim new lands, create new industrial regions, and build new cities. It is expected that there is a real problem that needs to be addressed, analyzed and resolved, where, Egypt has very limited, water resources and yet prepares very optimistic developmental plans. Indeed, many governmental programs have been initiated or planned to rationalize water uses and increase their economic return, and two main land reclamation mega projects have been launched to form the base for population redistribution and further economic development; the first is the El-Salam canal west of the Suez Canal and El-Sheikh Jaber east of the Suez Canal, which is called Sinai project, to reclaim about 620,000 feddans; the second project is the El-Sheikh Zayed canal, which will reclaim some 540,000 feddans in the south of the New Valley (Toshka project). These two projects require huge investments but, the main constraint to implement these projects is the amount of water demands and the effect of these quantities of water availability in old lands and Nile delta. The main objective of this paper is evaluating the impact of the new reclamation projects in Toshka and Sinai on Egypt water resources balance and expected effects on the old lands in Nile valley and Delta, moreover, this paper provides updating about Egyptian Nile water balance and its determinant factors as: population growth, land reclamation, current water uses, agriculture water drainage reuse, waste water reuse, and future water demands. By evaluating the impact of the new reclamations mega projects in Sinai and Toshka on the Egypt water balance, it is expected that the Irrigation improvement, reuse treated waste water, increasing groundwater abstraction and crop pattern projects will not be finalized, to decrease the gap between the resources and demands and save the water requirements for the mega projects in Toshka and Sinai, so, the water requirement for those two projects will be deduced from the released water to the Nile Valley and Delta, which will cause quantitative and qualitative pressures on Nile Valley and Delta water system.

Keywords: Water Resources, Toshka, Demands, Egypt, Mega Projects, Irrigation.

Introduction

Egypt is an arid country, which covers an area of about 1,001,450 km^2 of which only 4% is occupied by its population. According to the 2006 census, the population has reached 79.6 million capita of whom about 99% are concentrated in the Nile Valley and Delta, [2].One of the important issues in the future is to redistribute the population over a larger area, to achieve this objective, it is essential to reclaim new lands, create new industrial regions, and build new cities, hospitals, schools, etc. in order to create new jobs and provide the required food for the new communities. On other hand Egypt is one of the countries facing great challenges, due to its limited water resources represented mainly by its fixed share of the Nile water, and its aridity is the general characteristics of the country.

Water resources in Egypt are limited to the 55.5 BCM/Year share of Egypt in the flow of the river Nile, the deep groundwater in the deserts (mostly non-renewable), and a small amount of rainfall in the northern coastal area and Sinai. Meanwhile, water demand is continually increasing due to population growth, industrial development, and the increase of living standards. The agriculture sector is the largest user of water in Egypt with its share about 80% of the total demand for water. In view of the expected increase in water demand from other sectors, such as municipal and industrial water supply, the development of Egypt's economy strongly depends on its ability to conserve and manage its water resources.

Throughout the last fifty years the population of Egypt has grown by more than three folds while, on the other hand, the available renewable water resources remained the same. Consequently, the annual per capita share of renewable water resources (mainly provided by the Nile) is dramatically reduced from more than 2500 cubic meters at the year 1950 to less than 900 cubic meters at the year 2000, and is further projected to fall to about 500 m^3/cap/yr by the year 2050, [4]as depicted from figure (1).

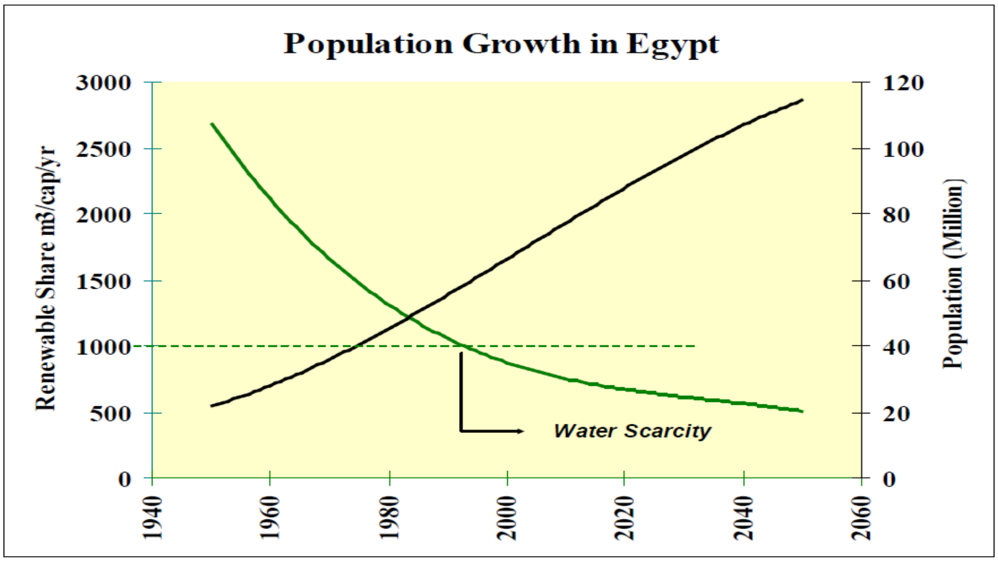

Figure (1) Water scarcity in Egypt [4].

There is a real problem that needs to be addressed, analyzed and resolved. Egypt has very limited, mostly imported, water resources and yet prepares very optimistic developmental plans. Indeed, many governmental programs have been initiated or planned to rationalize water uses and increase their economic return [5],as well as two main land reclamation mega projects have been launched to form the base for population redistribution and further economic development, the first is the El-Salam canal west of the Suez Canal and El-Sheikh Jaber east of the Suez Canal, which is called Sinai project, to reclaim about 620000 feddans, the second project is El-Sheikh

Zayed Canal, which will reclaim about540000 feddans in the south of the New Valley which is called Toshka project,[6]. These two projects require huge investments but they do have major social, economic and institutional benefits. The main constraint to implement these projects is the amount of water demands and the effect of these quantities of water on water availability in old lands and Nile delta. Figure (2)shows the location of two projects in Toshka and Sinai.

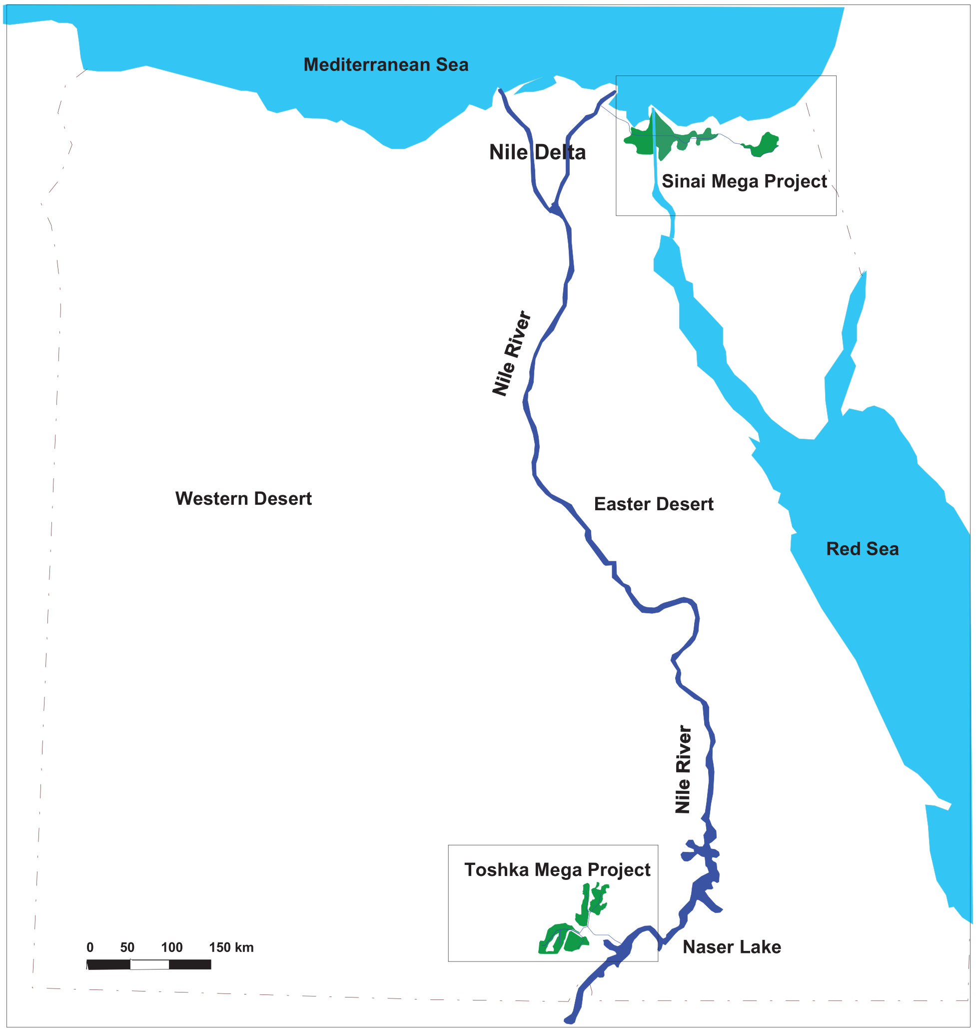

Figure (2): mega projects location map in Toshka and Sinai. Data Source: [6]

Objective and Methodology

In Egypt, many governmental plans and programs have been initiated to development water resources, rationalize water uses and increase their economic return. One of these plans is National Water Resources Plan 2017, (NWRP) which initiated in 1997. Due to some changes in the information, data, assumptions, and factors which relied upon on this plan, It is expected that Egypt will face a great challenges in 2017, the most important of these challenges to provide adequate water resources (quantitative and qualitative) for old lands in the Nile valley and mega projects in Sinai and Toshka. The main objective of this paper is studying the impact of the new reclamation mega projects in Sinai and Toshka on Egypt water resources balance and expected effects on the old lands in Nile valley and Delta, however, this paper provides a review of water resources plans and strategies, and updating about Egyptian Nile water balance and its factors as: population growth, land reclamation, current water uses, agriculture water drainage reuse, and waste water reuse.

Egypt Water Resources Plans and Strategies

Egypt prepared its first water policy after the construction of the Aswan High Dam in 1975. Since then, several water policies were formulated to accommodate the dynamics of the water resources and the changes in the objectives and priorities. The following is a short briefing of examples of the major efforts undertaken by MWRI towards achieving integrated water resources management.

Water Resources Strategy of Egypt until 2017.

In October 1997, Ministry of Water Resources and irrigation (MWRI) prepared a draft of water resources strategy of Egypt until 2017. The strategy analyzed the projected water balance in year 2017 for three scenarios: the first is for reclaiming 612000 ha , the second is for reclaiming 0.9 million ha, and the third for reclaiming 1.36 million ha. Securing the required extra water (about 24 BCM/Year) was to be accomplished through the completion of the first phase of Jonglie canal, an increase of groundwater utilization, water reuse practices, and a reduction of the areas of high water requirement crops [6].

Water Resources Management Policy (2000 – 2017)

The main features of the water resources management policy of Egypt to the year 2017 can be summarized as follows: i) Promoting decentralization within the MWRI, Conducting institutional reform activities at all levels, ii) Enhancing water supply and management, Emphasizing the water quality management, iii) Implementing environmental management systems for the Northern Lakes, and iv)Achieving better integration between agricultural policies and irrigation policies, and Continual cooperation with Nile riparians. The policy depends on the following success factors and instruments for the policy achievements: public awareness, capacity building for all levels of stakeholders, continuous monitoring and evaluation, water quality monitoring programs, drainage water quality monitoring programs, and Groundwater quality monitoring programs. Table (1) summarized the water resources in the year 2000 and the estimated water resources by the year 2017[9].

Table (1): water resources in the year 2000 and the estimated water resources by the year 2017

Source	**2000 (BCM)**	**2017 (BCM)**
Nile River water supply	55.5	55.5
Rainfall and flash flood harvesting	1.0	1.0
Drainage water reuse	4.7	9.0
Shallow groundwater extraction in the Valley and the Delta	4.80	7.50
Reuse of treated wastewater	0.70	2
Deep groundwater extraction	0.57	3.50
Irrigation Improvement projects in 3.50 Million feddans to save		4.0
Cropping pattern shifts to save		3.0
Total	**67.27**	**86.25**

Source: [9]

National Water Resources Plan (NWRP)

This project is hosted in the Planning Sector of the MWRI. The main objective of the NWRP project is: "To develop the National Water Resources Plan (NWRP), that describes how Egypt will safeguard its water resources in the future, both with respect to quantity and quality, and how it will use these resources in the best way from a socio-economic and environmental point of view"[7]. Implementing the NWRP strategy 'Facing the Challenge', as stated in the NWRP, is expected to improve the performance of the water resources system, therefore, more water will be available for the various uses and the water quality will improve significantly, consequently, the agricultural area will increase by 35% as a result of horizontal expansion in two mega projects in Toshka and Sinai, as a result of these projects living space in the desert will be created for more than 20% of the population[6]. The implementation of the strategy will support the socio-economic development of the country and provide safe drinking water to its population, and the access of the population to safe sanitation facilities will double from the present 30% to 60%. It is expected that, , the strategy will safeguard the water supply up to the year 2017.

Water Resources Supply Management Vision for 2050

Ministry of Water Resources and irrigation (MWRI), through its National Water Research Center (NWRC) and other sectors has developed a future vision for the year 2050. This vision is set to safeguard Egypt's demand from currently available water resources which include Egypt's share of the Nile water, as well as the groundwater, and the non-conventional resources. A primarily focus is attributed to increasing sea water desalinization for drinking water purposes in the coastal areas, increasing the efficiency of water conveyance systems and water use, and implementing water reuse programs without relying on the additional increase of Egypt's share of the Nile Water. The principles of the vision include: providing clean drinking water for 100 % of the population, providing adequate water both in quality and quantity for different development purposes; and maximize the economic, social and environmental role of water resources, [11].

Cultivated Land Resources and Available Irrigated Water

Cultivated Land Resources

Most of Egypt land is desert, and cultivated lands are located close to the Nile banks, its main branches and canals, the cultivated agricultural land is about 8.8 Million feddans. Figure (3) shows total cultivated area in Egypt from 2001 to 2012 by million feddans. The per capita cultivated land declined from about 0.23 feddans in 1960 to about 0.115feddans in 2009, [2].The sharp decline of the per capita of cultivated land resulted in the decrease of the per capita crop production; this affects directly the food security at the family, community and country levels.

Losses of Agricultural lands

According to deferent sources, losses per year of agricultural lands due urbanization, ranging from 10,000 to 75,000 feddans, the water master plan report concluded that 45,000 feddans per year, seemed to be fair estimate, there have been varying flocculation of land loss over time varying between 8,771 feddans in 1989 and 4,465 feddans in 1992, the average areas lost in the recorded period is 5,800 feddans per year which is considerably less than the estimate used by the water master plan. Over the 20 years' time period of the plan this results in a loss of 0.52 million feddans [6].

Available Irrigated Water

Table (2) shows Irrigation areas that depend on Nile water in 1997 and 2017, while figure (4) shows the quantities of irrigated water used for the three agriculture seasons and fruits according to field allocation for the period from 2003 to 2011.

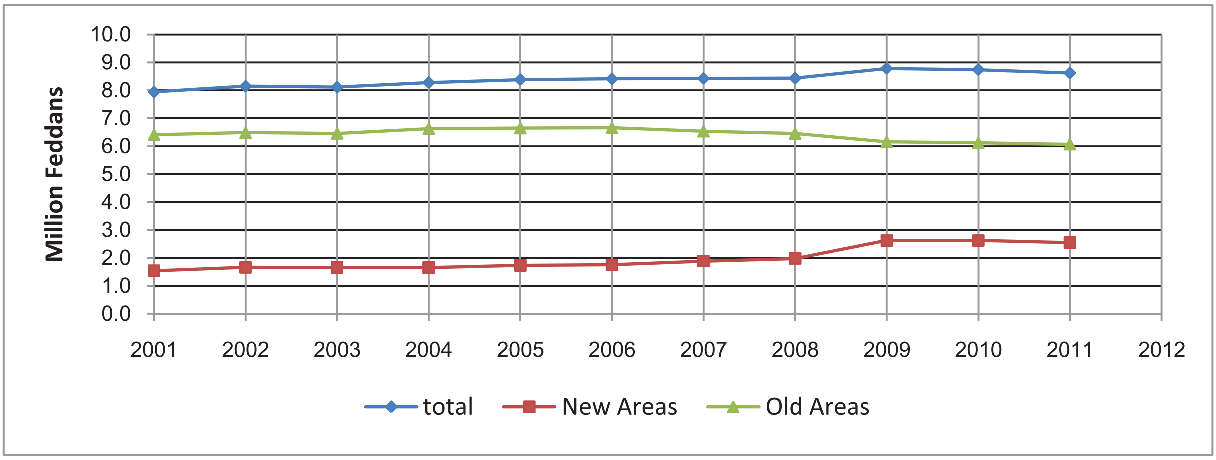

Figure (3) total cultivated area in Egypt from 2001 to 2012 (million feddans). Data source: [1]

Table (2) Irrigation areas that depend on Nile water in 1997 and 2017.

Region	**1997** (feddans 1000)	**2017** fed- 1000) (dans
Upper Egypt	1307	1728
Middle Egypt	1093	10851
Fayoum	360	378
East Delta	2131	2,4461
Middle Delta	1551	1525
West Delta	1473	18861
Sinai (Surface (Water	0	620
Toshka (surface (water	0	540
Total	7915	10208

Source:[6]

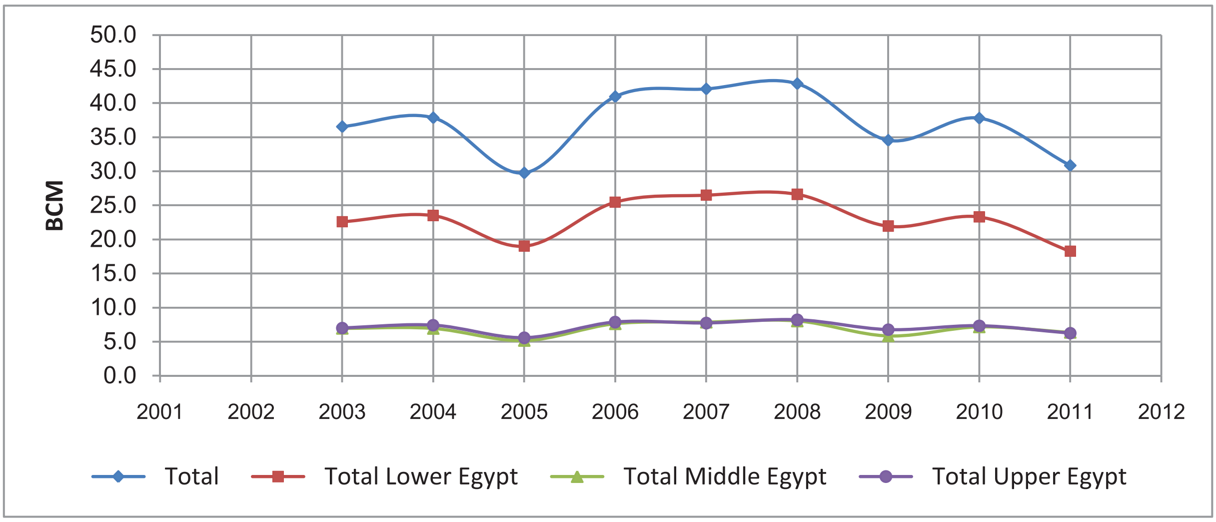

Figure (4) quantities of irrigated water used for the three agriculture seasons and fruits according to field allocation for the period from 2003 to 2011(BCM/Year). Data source: [1]

New Mega Projects

Toshka Project

Toshka project is developed in the Western desert, about 225 km south of Aswan to increase the inhibited area of Egypt. The present plane of the project comprises the development of irrigated agriculture on 540,000 feddans near Lake Nasser through pumping the water from the Lake. In view of the variable levels in the Lake (from 147.5 to 178.5 m above MSL the submerged inlet has been located at about 140 m above MSL, well below the lowest expected level. the water flows through tunnels to the pumping station , built in a deep excavated pit. The water is pumped to a level of about 200 m above MSL to reach the starting point of the canal. The capacity of the pumping station is given as 300m^3/s and the main canal (El-Sheik Zayed Canal) was designed for about 540,000 feddans., “Estimated water requirements needed for reclaiming and cultivating 540 thousand feddans are nearly from 4 to 5 BCM/Year of fresh Nile water” [6].

Sinai Project (AL-Salam Canal Project)

AL-Salam canal is designed to irrigate about 620,000 feddans, it starts from Damietta Branch of the river Nile upstream of the Frascour dam near Damietta it will provide the water to irrigate 220000 feddans in the Eastern Nile delta and 400,000 feddans in Sinai.The project area is extended in governorates of Damietta, AL-Daqahlia, ALI-Sharqia, Port Said, Ismailia and North Sinai. Estimated water requirements needed for reclaiming and cultivating 620 thousand feddans (220 thousand feddans west of the Suez Canal and 400 thousand feddans east of the Suez Canal) are nearly 4.45 billion cubic meters per year of fresh Nile water mixed with agricultural drainage water at a ratio of 1:1 so that salinity ratio would not exceed 1000 ppm (particles per million) along with selecting the proper crops combinations [6].

Egypt Nile Water Resources and Uses

Estimated figures of water resources and uses in Egypt are greatly different from report to another, year to year and from agency to another, even the Ministry of Water Resources and Irrigation (MWRI), that entrusted with the management of water resources; has many estimates for both water resources andwater uses, however, Egypt’s share of Nile River water is the only fixed figure. The following is a brief of water resources of Egypt which has been collected and checked from various resources, where this section will address the Nile water in Egypt, without taking into account groundwater in Western desert and Sinai, as well as their uses for agriculture and domestic, and it will focus only on Nile River water and its uses.

Egypt’s Nile Water Resources

Nile River Water

Egypt’s main and almost exclusive resource of fresh water is the Nile River. Egypt relies on the available water storage of Lake Nasser to sustain its annual share of water that is fixed at 55.5 BCM annually by agreement with Sudan in 1959.

Renewable Groundwater Aquifer

The total available storage of the Nile aquifer was estimated at about 500 BCM but the maximum renewable amount (the aquifer safe yield) was estimated to be only 7.5 BCM/Year. The existing rate of groundwater abstraction in the Valley and Delta regions is about 6.2 BCM/Year in 2010 which is still below the potential safe yield of the aquifer, [2].

Reuse of Agricultural Drainage

The total amount of official drainage reuse increased from 6.86 BCM in 2008 to6.98 BCM in 2010, this amount is expected to increase up to 8.7 BCM in2017, included in this reuse are a number of gravity feeders from drains to tail ends of irrigation canals in the Middle Delta. Direct pumping of nearby drainage water by individual farmers is called the unofficial reuse, which it is impossible to measure because of its spontaneous nature, but it is estimated to be about 2.7 BCM/Year. The unofficial reuse is observed along Bahr Baqar, Bahr Hadus, Gharbia, Edko and Umoum drains, [3].

Reuse of Treated Waste Water

The Egyptian water strategy comprises the treatment and reuse of treated domestic wastewater is either primary or secondary. Currently, Egypt produces an estimated from 5.5 to 6.5 BCM/Year of wastewater. Of that amount, about 2.97 BCM/Year is treated, but only 0.7 BCM/Year is utilized for agriculture (0.26 BCM/Year is undergoing secondary treatment and 0.44 BCM/Year undergoing primary treatment), mainly in direct reuse in desert areas or indirect reuse through mixing with agricultural drainage water,[3].

Rainfall and Flash Floods

Rainfall cannot be considered a dependable source of water, this water could be directly used to meet part of the water requirements or it could be used to recharge the shallow groundwater aquifers, it is estimated that about 1.3 BCM of water on average can be utilized annually by harvesting flash floods,[7].

Egypt's Nile Water Uses

Total water withdrawal in Egypt in 2011 was estimated at 74.8BCM, this included 61BCM for agriculture http://www.eoearth.org/article/Agriculture, 10.4BCM for domestic use and 1.3BCM for industry. The following is a brief of Egypt water demand:

Agriculture Uses

The average annual consumptive use in agriculture uses for 2011was estimated to be 61 BCM, in that year about 8.6194 Million feddans were irrigated[2],this amount represents the crop evapotranspiration, conveyance losses in the irrigation network, seepage, deep percolation loses at the farm level, and outflow to sea.

Municipal Water Requirements

The total municipal water use was estimated to be 5.5 BCM in 2004 and 10.4 BCM in 2010 when the population was 77.8 million will be expected about 11.67 BCM/Year when the population will be 87.4 million capita in 2017,[2].

Industrial Water Requirements

The estimated water requirement for the industrial sector during the year of 1995/96 was in the order of 7.5 BCM/Year,[9]. A small portion of the diverted water for industrial requirement is consumed through evaporation during industrial processes which is estimated about 1.33 BCM in 2008 while most of the water returns to the system.

Navigational Requirements

The river Nile main stream and part of the irrigation network are used for navigation. Water demand specifically for navigation occurs only during the winter closure period (about 3 weeks in January and February), when discharges to meet agriculture demands are too low to provide the minimum draft required by ships. However it is estimated by 0.2BCM/Year, [7].

Out flow to the Sea (Environmental requirements)

Outflow should not be less than the minimum amount required for maintaining the fisheries and the environmental equilibrium in the northern lakes, which was estimated to be approximately 8 BCM/Year; however it has been already included in agricultural uses,[6].

Nile Water Resources Balance in Egypt

This section addresses the water balance equation for Nile water in Egypt, without taking into account groundwater in Western desert and Sinai, as well as their use for agriculture and domestic, however, it will focus only on Nile water and its uses. In summary the actual resources available for use in 2011 are71.77BCM/Year, whereas water demands for all the sectors are in the order of 74.8BCM/Year. Currently, groundwater abstraction from Nile valley aquifer is about 6.2 BCM/Year and an amount of 8.07BCM/Year of drainage water is now reused, moreover, 0.7BCM/Year of treated wastewater is reused for Crops irrigation. At present which still leaves a deficit of demand over supply (about 3.03 BCM), table (3) shows the Nile Water System balance.

Table (3) Egypt Nile Water System.

[**Water Resources 2011**]		**Water Demands 2011**	
Items	**BCM**	**items**	**BCM**
Share of Nile water	55.50	Agriculture	[3]61.00
Groundwater in Valley & Delta	6.20	Evaporation	[6]2.00
Recycling of agricultural water	8.07	Drinking and Healthy uses	[2]10.4
Reuse sewage water in agriculture	0.7	Industry	[2]1.33
Rains &Floods	1.3	River navigation	[7]0.2
Total	**71.77**	**Total**	**74.8**

Updating the Estimation of Nile Water Resources and Requirements By 2017

Egypt confronts is that its renewable water supplies cannot be expanded, while at the same time population is growing and the economy is expanding, with associated increases in water requirements. In summary as in table (4) the estimated resources for use in 2017 will be82BCM/Year, whereas expected water requirement for all the sectors will be more than 83.5BCM/Year.

In 2017 the groundwater abstraction should be increased to about7.5BCM/Year and an amount of 9BCM/Year of drainage water and 2BCM/Year of treated wastewater should be used for irrigation in 2017, moreover crop pattern and irrigation Improvement projects should save about 7.0 BCM/Year, as in table (4), the treated sewage water is currently used in irrigating wooden trees, and is not, officially speaking, to be used in irrigating vegetables and crops. Thus, adding this water to the water balance of the country as a potential water source for the planned agricultural expansions is against the announced policies.

Table (4) estimated Nile water resources and demands in Egypt by 2017.

Water Resources			Water Demands 2017		
Item	**Expected 2017** [BCM [7	**Actual 2011** [2]	**Item**		**BCM**
Share of Nile water	55.50	55.50	Agriculture	[6]	67.8
Groundwater in Valley & Delta	7.50	6.20	Evaporation from Nile &Canals	[7]	2.50
Recycling of agricultural water	9	8.07	Drinking and Healthy uses	[2]	11.67<
Recycling of sewage water	2	0.7	Industry	[2]	1.33<
Rains &Floods	1.00	1.3	River navigation	[6]	0.2
Irrigation Improvement saving	4.0	0			
Crop pattern saving	3.00	0			
Total	**82**	**71.77**	**Total**		**83.5 <**

The Pressure on Water System in the Nile Valley and Delta in Egypt

If the plans, strategies, and projects will not be finalized to save water requirements for the new projects in Toshka and Sinai, the investments that had been spent in those projects will be in risk, and, if the water requirements for those project will be deduced from the released water to the Nile Valley and the Delta, many quantitative and qualitative pressures will be expected on the Nile water system as follows::

Water Quantity Pressures

1. The main increasing in required water in 2017 will be drinking and healthy uses which will use more than 11.67 BCM/Year and about 6.8 BCM/Year additional needed to agricultural sectors only for the new reclamation mega projects in Toshka and Sinai.
2. In 2017 the groundwater abstraction should be increased to about7.5 BCM/Year and an amount of 9 BCM/Year of drainage water and 2 BCM/Year of treated wastewater should be used for irrigation, moreover crop pattern and irrigation Improvement projects should save about 7.0 BCM/Year.
3. It is expected that the irrigation improvement, reuse planed treated waste water , increasing groundwater abstraction and crop pattern projects will not be finalized, to decrease the gap between the resources and demands and save the demandsfor the mega projects in Toshka and Sinai, so, the water requirement for those two projects will be deduced from the released water to the Nile Valley and the Delta.
4. As shown in table (4), there is a gap between expected available water resources in 2017 and the actual water resources in 2011, about 12 BCM , which must be made available to face the expected water shortage.
5. Water requirements for the two mega land reclamation projects, Toshka and Sinai, will be fully provided. the drainage water outflows to the sea and lakes should be the minimum amount required for maintaining the fisheries and the environmental equilibrium in the northern lakes, which was estimated to be approximately 8 BCM/Year,[10].
6. Due to the reallocation of Nile waters to the new irrigation developments (Toshka and Sinai), the existing net availability of irrigation water would drop from 4800 in 1997 to 3400 m^3/year in 2017 per feddans,[6].
7. Mega projects in Toshka and Sinai in are located at the tail ends of the irrigation network,therefore the drainage water of those projects, cannot be returned to the water system. It must be either locally recycled or damped out of the system,[5].

Water Quality Pressures

1. Diverting some of the Nile water to Toshka and Sinai will be deduced from the released water to the Nile Valley and the Delta causing negative impacts on groundwater recharge and on the quantity and quality of the agricultural drainage water.
2. To save about 4 BCM/Year,the irrigation improvement projects, reduction of rice areas and modern irrigation schemes for orchard and fruit farms will reduce the recharge rate of the groundwater, and will reduce the drainage water and may increase its salinity.
3. Expanding the use of groundwater in the Nile Valley and the Delta will lower the groundwater table, and hence reduces the quantity of drainage water available for reuse.
4. The major challenge in increasing the drainage reuse will therefore be to find an optimum mix of main drain reuse and intermediate reuse that in both effective in terms of overall water saving and costs, and that has the least negative impacts on the groundwater and other water uses.
5. The water quality of the River Nile and canals in Egypt is affected by the reused drainage water, containing salts, nutrients, pesticides, and industrial and municipal effluents from all towns and villages.

Conclusion

1. Egypt lacks the necessary data in various sectors, especially water. The only measured resource is the Egypt Nile water quota downstream High Aswan Dam (HAD). There is no accurate measurement for either rainfall or flash floods. As for water quality measurements in Water courses, or for groundwater aquifers, they are very few, even along the Nile River and main canals. The available measurements are both limited and for only a few elements. There are also usually done on distant intervals.
2. It is expected that the irrigation improvement and crop pattern projects will not be finalized to save about 7 BCM/Year for the mega projects in Toshka and Sinai, which cost a lot of money and investments, therefore the water requirement for those two projects may be deduced from the released water to the Nile Valley and the Delta, moreover, Egyptian currently facing a great challenge which represented in constructing a number of dams in Ethiopia, that is expected effect on Egypt's share of Nile water, however.
3. Recent studies indicated that, the use of treated wastewater may not be possible, due to economic reasons, to provide sewerage facilities for all residents of rural and per urban areas, either now or in the near future [3]. So, it should be considered an integral component in country's national water strategic plan.
4. As a result, the focus of the field of wastewater management should change from the construction and management of regional sewerage systems to the construction and management of decentralized wastewater treatment facilities. Given the fact that in the near future, increasing demands are being made on freshwater supplies, it is clear that decentralized systems, will increase the opportunities for localized reclamation/reuse. Also, the use of anaerobic treatment as a first step offers good potentials for both on-site and off-site sanitation.
5. The role of scientific research should take its place to develop new affordable water saving techniques. The same role is significant for introducing new agriculture technologies, seeds and breeds that have high productivity, high diseases resistance and low water consumption.

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Integrated Management of Transboundary Water Resources under Climate Change in the Blue Nile River Basin

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Abstract: There has been a little systematic analysis of alternatives from a regional perspective that include more flexible water allocation, integrated water resources management in the Nile basin. The Blue Nile Basin has a long recorded history of flooding and drought. The region is characterized by highly variable river flows. Emerging and existing hydropower projects in the Nile basin are considered the power pool of the region and may suffer as a result of the impacts of future climate change in the basin. Furthermore, the uncertainty impacts of climate change complicate the integrated operation of the multiple reservoirs in the basin. Therefore understanding the impacts of climate change on both hydropower production and the joint operation of the reservoirs in the basin is essential part of this research. The research will include the major hydropower producing from Grand Ethiopian Renaissance Dam (GERD) through Rosaries, and Sennar dams. Water Evaluation and Planning (WEAP) model will be used for the water resource modeling and identifying potential changes needed to the existing hydropower scheme to reduce the stress due to increased water demand and climate change and variability. The model will take into account the parameter of uncertainty on both supply and demand sides. Currently there is significant potential for expansion of hydropower and irrigation in the Blue Nile River in both Ethiopia and Sudan. However, the likely consequences of upstream development on downstream flows have not been fully assessed and the water resource implications of development in both countries are unclear. Against this background, the Water Evaluation and Planning (WEAP) model was used to provide an assessment of both the current situation and two future scenarios (2015 and 2025). The future scenarios incorporated new irrigation and hydropower schemes on the main stem of the Nile and its principal tributaries. Data for all existing and planned schemes were obtained from the basin master plans as well as scheme feasibility studies, where available. Water use was simulated over a 31-year period of varying rainfall and flow. Finally, the research found out the process for efficient management between upstream and downstream countries.

Keywords: Blue Nile, hydropower, irrigation, Climate Change, WEAP.

Introduction

Reliability of water resources in river basins is challenged by climate change and population growth, the water demands keep increasing. For successful management of available water resources, supply and demand needs to be carefully accounted in the decision-making process, while considering socioeconomic and climate change impacts. With growing scarcity and increasing inter sectoral competition for water the need for efficient and sustainable water allocation policies has also become more important. Efforts to integrate climate change into long-term planning and management of the Nile River Basin have been limited.

Climate change and climate variability by definition implies long-term changes of mean temperatures and of precipitation/evaporation due to Green House Gas (GHG) emissions as well as extremes such as droughts and floods. The integration of climate information into water resource development policies is therefore extremely important because climate is a major driving factor for most economic activities. Unfortunately, climate information has not been easily understood and the same has not been adequately factored into most of the sectors of the economic development. The water sector and other sectors that depend on access to water are invariably impacted. An important aspect of adaptation to climate change is therefore water related adaptation. Planning for adaptation should include water resources planning, as should water resources planning take into account the impacts of climate change on the water resources sector. Mainstreaming climate adaptation into development planning includes integrating adaptation-related policy and activities including with water resources management planning. Adapting to climate change and increased variability will entail dynamic spatial and temporal adjustments.

The Nile represents a crucial resource for the economy of eastern and north-eastern Africa. Water is a critical resource for all countries that share the basin. Water will be even more critical in the future as these countries face larger populations and therefore an even greater demand for water. Agriculture, energy production and livelihood in general depend strongly on the river. There has been little systematic analysis of alternatives from a regional perspective that include more flexible water allocation, integrated water resources management in the Nile basin.

The Nile Basin area is one of the most vulnerable areas to climate change and climate variability, a situation aggravated by the interaction of 'multiple stresses', occurring at various levels, and with low adaptive capacity. The area in the Nile delta is to be flooded due to climate change. On the other hand a large part of the precipitation falling on the Nile watershed is evaporated before reaching surface waters. This implies that there is a high potential for optimizing rainfall use. Drought is the other impact of climate change which may affect huge areas. Therefore adaptation to climate change tools, scenarios and approach is very crucial to be addressed and disseminated. Climate change is likely to aggravate water stress currently faced by some countries in the basin, while some other countries, currently not experiencing water stress, will become at risk of it. The impacts of climate change and other stresses on water resources and changes to flooding risks in the future will require adaptation on the part of governments, water resource management institutions, water users and a host of other stakeholders in the Nile Basin.

Research Overview

This paper is proposed to evaluate sustainability of water resource development in Nile River Basin by considering different climate change scenarios. The research will focus on assessing and analyzing the current state of the spatial and temporal variability of water resource availability in Nile river basin system; the potential development scenarios which has less impact on the availability of water to the Nile river basin countries; the extents of climate change impacts on water availability and transformation of flow regime of the basin; the extents of extreme flows influence on the availability of water and how should these be taken into account in making water allocation decisions for water resource projects. The research will answer the question: where and when could be the competition between water resource users prominent, and what could be the most suitable options/scenarios for meeting the demands and supply in the basin.

Research Objectives

The goal of the proposed research is to provide a basis for sustainable water resource development through establishing appropriate river basin model; studying impacts of climate change and water balance dynamics at different spatial and temporal scales in a river basin. The research will provide an insight into how this synthesis can help in developing sustainable water management strategies that encompasses different sectors of water use.

Case Study

The research considers the hydropower production projects extending from Ethiopian highlands to Khartoum. The reservoirs considered will be Grand Ethiopian Renaissance Dam (GERD), Rosaries and Sennar.

Case Study Description

There are two major basins within the Nile basin. These two major basins are the Eastern Nile that is composed of Abay (Blue Nile), Tekeze (Atbara), Baro Akobo (Sobat) and the Nile Equatorial Lake that is composed of mainly Lake Victoria basins and sudd swamp in South Sudan.

The Abay-Blue Nile sub-basin, Figure 1, located in the Middle East of the Eastern Nile Basin (ENB), is the largest contributor of the system (56 Bm^3/year) accounting for 67% of the inflow at Aswan. The Blue Nile headwaters emanate at the outlet of Lake Tana in the Ethiopian highlands. The Abay-Blue Nile sub-basin covers two countries: Ethiopia and the Sudan. Blue Nile is steeped in the plateau region, and flatter along the low lands. It is joined by many important tributaries, draining the central and southwestern Ethiopian highlands, becoming a mighty river long before it reaches the lowlands and crosses into Sudan.

The climate of the Blue Nile is dominated by two factors: its near-equatorial location and an altitude ranging from below 500 masl at its mouth to more than 4,000 masl in the highland plateaus of Ethiopia. The influence of these factors determines the rich variety of local climates, ranging from hot and desert like along and d/s of the Sudan border, to temperate climates on the highland plateaus and cold climates on the mountain peaks. The climate in the Blue Nile River basin varies greatly between its inception in the highlands of Ethiopia and its confluence with the White Nile River.

As the Blue Nile drops into the lowlands and into Southern Sudan, rainfall decreases and evaporation increases, resulting in a significant net loss. Temperatures also increase in variability, and reach substantially higher levels than at Lake Tana. Temperature and evaporation are observed to have good correlation with altitude in the Abay-Blue Nile sub basin. In summer, peak temperatures are reduced because rainfall, cloudy conditions and energy use for Evapotranspiration rather than sensible heat occur when the highest temperatures would normally be expected (July and August). The hottest period is, therefore, March to May, before the onset of the major rains. This produces a smaller annual range of temperature than might be expected and in some instances results in two cooler and warmer periods. The range in elevation within the basin has a major influence on the climate.

The Main Nile sub-basin covers the area from the confluence of the Blue and White Niles in Khartoum to the delta in Egypt in the North. It is located in the Northernmost portion of the Eastern Nile Basin (ENB). Geographically, it extends from 30^0 30’35’’ to the North down to $13^0$7’ 20’’ in the South. The Merowe dam in the Sudan is located between Khartoum and the Aswan High Dam at the Fourth Cataract.

From Khartoum the Main Nile flows in a general Northward direction before it meets its first tributary, the Tekeze-Atbara-Setite subbasin, and then flows to the general Northwest direction to the Dongola station. Downstream of its confluence with the Tekeze-Atbara-Setite sub-basin at Atbara, the Nile has no significant tributaries joining its system and almost no contribution is generated in terms of runoff all along its downstream reach to its mouth. Temperature in this sub-basin is the hottest owing to the prevalence of the desert climate. Evaporation is considerably high.

Figure 1: The Blue Nile Sub-Basin

Problem Statement

Hydropower production is important, though non-consumptive, water use. Especially Ethiopia has a large potential which is not used so far. The utilization of Hydropower could be combined with the demand to further store Nile floods and to control siltation processes. An interesting question will be how the vast hydropower and irrigation potential will be used to their optimum within the next decades.

The Eastern Nile Basin (ENB) has a long recorded history of flooding. The region is characterized by highly variable river flows and a significant proportion of the annual runoff volume of the Eastern Nile, contributing over 86% of the total River Nile flows, which occur in only three months, July to September. During high rainfall periods, major rivers in the region often give rise to large scale river flooding, particularly in the floodplains of the Sudan and Ethiopia, with devastating effects on lives, livelihoods, and properties. The Eastern Nile Basin (ENB) area is one of the most vulnerable areas to climate change and climate variability, a situation aggravated by the interaction of 'multiple stresses', occurring at various levels, and with low adaptive capacity. The area in the Nile delta is to be flooded due to climate change. Drought is the other impact of climate change which may affect huge areas. Therefore adaptation to climate change tools, scenarios and approach is very crucial to be addressed and disseminated. Climate change is likely to aggravate water stress currently faced by some countries in the basin.

Data

The major input data for the model application will be stream flow data at required points, irrigation water demand data for existing and proposed irrigation schemes, hydropower demand, Reservoirs data, environmental demand, water supply demand, and climate changes scenarios. These data will be prepared on a monthly basis for the study years.

There are few reliable meteorological or hydrologic stations located in the Blue Nile basin due to inaccessibility, remoteness, and economic limitations. Most hydrologic observations started in the early 1970s by the National Meteorological Organization (NMO) (personal communication) and the MOWRE of Sudan (Conway, 2000). Monthly data of precipitation, and discharge have relatively longer observed periods than hourly or daily data. Monthly precipitation data of 8 selected stations, were collected from National Meteorological Organization (NMO). Monthly discharge data for Stations collected from the Nile-DSS (personal communication) and the MWRE, respectively. To analyze and evaluate the future changes in hydrology and water resources of the study area, data-parsimonious, yet reliable, methodologies and models are required.

Methodology and Approach

A better understanding of water supply, demand and its value in different sectors is very much essential in developing any alternate scenarios. The analysis framework consisted of: Hydrologic assessment of the water resources for supply and demand estimation; allocation modeling to allocate water to different nodes; analysis of climate change and variability impacts; and evaluation of sustainability by considering: a. Reliability; b. Resilience; and c. Vulnerability.

Modeling Approach

Water Evaluation and Planning (WEAP) model, developed by the Stockholm Environmental Institute will be used in the of water resources system of the Nile river basin. It is a basin-scale simulation model and accommodates a basin-wide representation of water availability and water demand. The model will be structured as a network model in which the rivers and their main tributaries will be represented by a network consisting of branches and nodes. Once the water availability is estimated, water allocation model can be used to understand the most productive way of distributing the water among different geographical locations as well as different sectors taking into account the climate change impacts.

Monthly simulation will be carried out using hydrological data of record length considering the downstream requirements for hydropower, water supply and irrigation. The model performs a basic water quantity mass balance approach at every node. The simulation criteria will consider: (a) Simulation period (depending on data availability), (b)Time step (monthly)

The outputs from the model describe the response of the basin-system and give a clear picture of the water resources status of the basin. The performance of each reservoir and demand scheme will be then analyzed using the concept of event-based reliability a hydrologic performance indicator. Event-based reliability of each irrigation, hydropower and water supply scheme will be calculated as the probability of non-failure events.

Climate Change Analysis and Sustainability Evaluation

The aim of the research is to evaluate the expected influence of the climate change on the runoff, and its seasonal and spatial variation. The expected climate change in Nile river basin for the scenario can be characterized by an increase of mean annual temperature and precipitation.

In this paper, a two-way ensemble prediction approach will be applied for the evaluation of the future river runoff from the territory of Nile: (A) An ensemble of regional climate models (RCMs) are considered. Comparison of RCM calculated for the reference (or control) time period and for the climate change scenario for selected time period allows ensemble evaluation of run-off change forecast. (B) The ensemble of hydrological models used to calculate the climatic time series of runoff. To proceed with the usage of the ensemble of hydrological models for the runoff forecast, it will employ several steps:

1. An ensemble of river runoff models will be calibrated for the river basins of Nile using observed climatic (temperature, precipitation) and discharge data series.
2. The regional variation (mainly seasonal) of runoff regime will be investigated for contemporary climate.
3. The regional climate models (RCM) calculation results will be prepared to serve as input data for the hydrological models via modification of the regional climate models (RCM) output by histogram equalization method to assure statistical compliance of observed and calculated meteorological data series for the control time period. The downscaling procedure will be employed for temperature, precipitation and relative humidity data series for contemporary climate and climate change scenario
4. The ensemble of calibrated hydrological models used for the calculations of the runoff time. The results of hydrological calculations for contemporary climate will allow evaluation of the usage of (modified) regional climate models (RCM) data as the substitute for the meteorological observation inputs in the hydrological models. The results of hydrological calculations for future climate will allow ensemble evaluation of future runoff regime.
5. Finally, the model water evaluation and planning (WEAP) used to show the expected changes in the regional variation of the runoff regime sustainability of allocation of water will be tested by taking in to account the trends of runoff due to climate change and variability.

Climate Impact Modeling

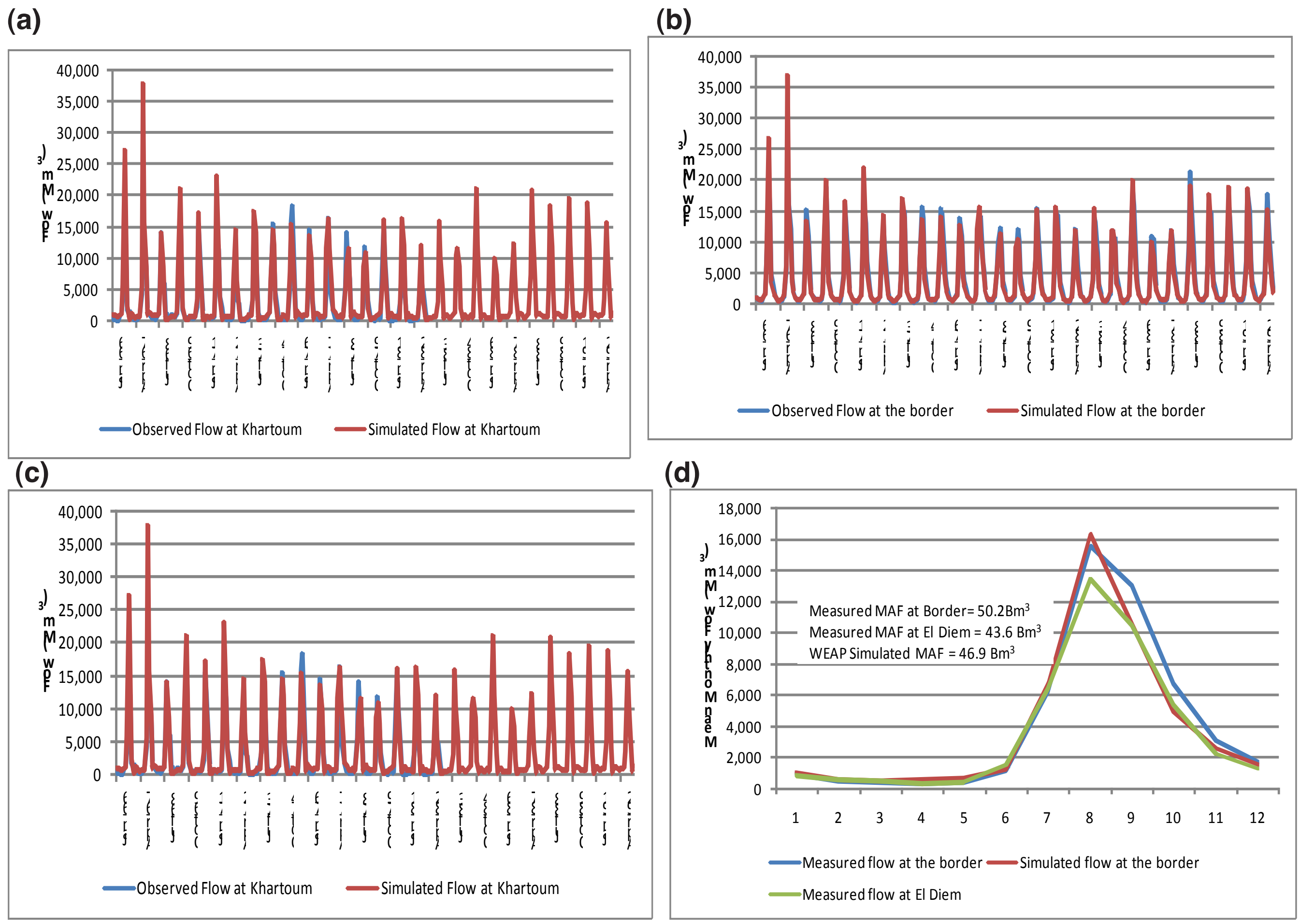
The change factors will be calculated on a monthly basis for the climatic input variables required for the hydrological model. The historical climatic input time-series will be adjusted based on the calculated change factors and the hydrological model will be re-run with the emission scenario data. Comparison will then be made with the control scenario to assess the possible impact of the climate change on the river flow.

Uncertainty analysis

Consideration of uncertainty in data and modeling will be an integral part of this study. The model will take into account the parameter of uncertainty on both supply and demand sides of the system resulting from temporal and spatial variability and inadequate data as well climate change and variability. This will mainly incorporate the uncertainties due to climate change and variability and hydrological approach such as the range of different results obtained by fitting data sets.

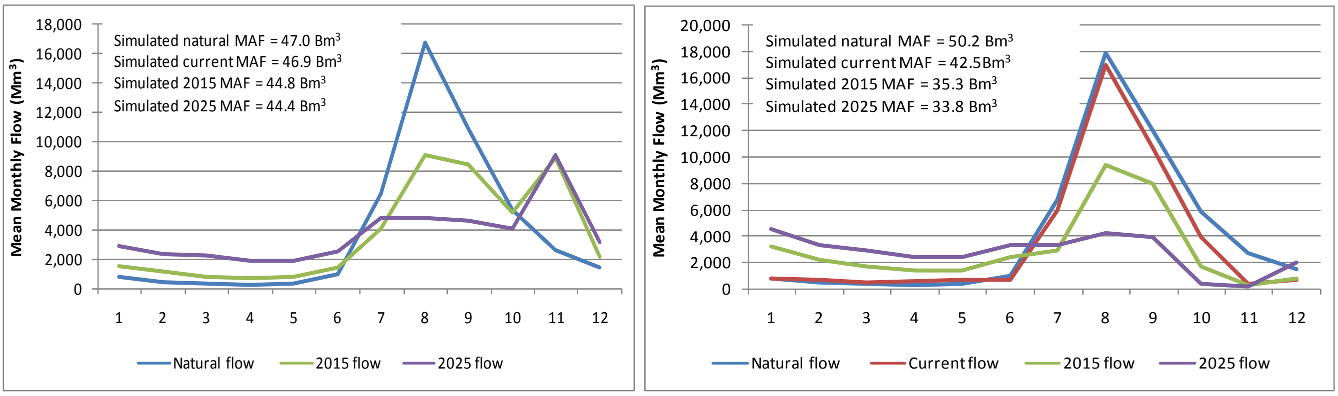
Analysis

Water Evaluation and Planning (WEAP) simulation is reasonably good. At Khartoum, observed data (obtained from Ministry of Water Resources) were only available for the period 1980-2010. Over this period the percentage error in the simulated mean annual flow was 12.8%. As a result of current abstractions, primarily for irrigation in Sudan, the flow at Khartoum is estimated to be approximately 7.7 Bm3y-1 less than would have occurred naturally over this period (*i.e.* 42.5 Bm^3y^{-1} rather than 50.2 Bm^3y^{-1}). At the border there are two flow gauging stations, as seen in figures below (figures 2 & 3). One is operated by the government of Ethiopia and just a few kilometers downstream another is operated by the government of Sudan. Possibly because of differences in periods of missing data, observed flows at these two stations differ and there is a 13% difference in mean annual flow over the period 1980-2010; 50.2 Bm^3 measured by Ethiopia and 43.6 Bm^3 measured by Sudan. Without detailed analyses, beyond the scope of the present study, it is not possible to know which of the two flow series is the more accurate. The WEAP model simulation falls exactly half-way between the two with a mean annual discharge of 46.9 Bm^3.



a) *Simulated and observed flow series flows for the Blue Nile (current situation) at Khartoum /* **(b)** *Simulated and* **)** *observed mean monthly flow series for the Blue Nile (current situation) at Khartoum/* **(c)** *Simulated and observed flow series for the Blue Nile (current situation) at the Ethiopia-Sudan border/* **(d***) Simulated and observed ,mean monthly flow series for the Blue Nile (current situation) at the Ethiopia-Sudan border*

Figure 2, a, b, c, d: Simulated and Observed Flow Series Flows & Mean Monthly Flow for the Blue Nile (Current Situation) at Khartoum and at Ethiopia Sudan Border.



(a) **(b)**

a) *Comparison of Simulated Mean Monthly flow Derived For Natural, Current, 2015, and 2025 Scenar-***)** *ios at Khartoum/* **(b)** *Comparison of Simulated Mean Monthly flow Derived for Natural, Current, 2015, and 2025 Scenarios* at *Ethiopia, Sudan Border*

Figure 3, a, b: Comparison of Simulated Mean Monthly Flow Derived for Natural, Current, 2015, and 2025 Scenarios at Khartoum and at Ethiopia, Sudan Border.

Currently irrigation water demand in Sudan greatly exceeds that in Ethiopia. Total irrigation demand in Sudan is estimated to average 8.45 Bm^3y^{-1}. This compares to an average of just 0.26 Bm^3y^{-1} in Ethiopia. With the planned irrigation development, demand is estimated to increase to 13.39 Bm^3y^{-1} and 3.65 Bm^3y^{-1} by 2015 and to 13.83 and 5.13 Bm^3y^{-1} by 2025 in Sudan and Ethiopia respectively. If all planned dams are constructed total reservoir storage in Ethiopia is estimated to increase to 70 Bm^3 (i.e. 1.5 times mean annual flow at the border) by 2015 and to 167 Bm^3 (i.e. 3.6 times mean annual flow at the border) by 2025. Hydropower generated in Ethiopia, from the Tis Abay and Finchaa power stations, is currently estimated to be 1,383 $GWhy^{-1}$. With the construction of the Tana Beles transfer, the Karadobi dam and other smaller schemes this is estimated to increase to 12,908 $GWhy^{-1}$ by 2015. With Border, Mendaya and Mabil on line, as well as additional smaller schemes, electricity production by 2025 could increase to 31,297 $GWhy^{-1}$. A significant proportion of the additional electricity produced is likely to be sold to Sudan and possibly other countries in the Nile Basin. Hydropower generated in Sudan is currently estimated to be just over 1,000 $GWhy^{-1}$, but there are no publicly available data to confirm this estimate. Because of the additional head and increased storage, the raising of the Roseries dam will result in a very small increase to 1,134 $GWhy^{-1}$ in 2015 and 1,205 $GWhy^{-1}$ in 2025. The increase in 2025 is due to entirely to more regular flows as a consequence of increased regulation upstream in Ethiopia.

Comparison of the mean monthly flows at Khartoum for the simulated natural condition, current situation and the 2015 and 2025 scenarios indicates how the mean annual runoff is progressively reduced as a consequence of greater upstream abstractions. Wet season flows are reduced significantly but flows in the months January to May are increased as a consequence of flow regulation. Under natural conditions 73% of the river flow occurs in the wet season months (July – September). In the 2015 and 2025 scenarios this is reduced to 58% and 35% respectively.

At the Ethiopia-Sudan border the current situation is almost identical to the natural condition so this not shown. Mean annual flow is reduced from 47.0 Bm^3 to 44.8 Bm^3 and 44.4 Bm^3 in the 2015 and 2025 scenarios respectively. Similar to Khartoum there is a significant reduction in wet season flows, but significant increases in dry season flows as consequence of flow regulation. Under natural conditions 72% of the river flow occurs in the wet season but this decreases to 61% and 35% in the 2015 and 2025 scenarios respectively. Interestingly the total decrease in border flow in the 2025 scenario is less than might be expected given the increased irrigation demand in Ethiopia. The reason is partly that less water is diverted from the Tana to the Beles catchment and more flow is routed down the main stem of Blue Nile. Shortfalls in meeting irrigation demand in Ethiopia also increase.

Concluding Remarks

Water Evaluation and Planning (WEAP) model has been configured to simulate the impacts of water resource development in the Blue Nile basin. Currently Ethiopia utilizes very little water but does regulate some flow for hydropower production. In contrast Sudan uses some water for hydropower production but also abstracts large volumes for irrigation. Both countries plan to develop water resource infrastructure substantially in the near future. The results in this paper are preliminary and based on many assumptions. Lack of flow and water demand and use data, particularly from Ethiopia, make it very difficult to validate the model for the current situation. Where it has been possible to verify them the model results are reasonable. Nevertheless, the current results must be treated with caution. In future the model will be refined using improved estimates of irrigation water demand and better estimates of dates at which schemes will become operational.

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SESSION 2B
GROUNDWATER MANAGEMENT

Keynote

Water Well Design and Groundwater Development in the Gulf Region

Bruce D. Misstear
Department of Civil, Structural &Environmental Engineering, Trinity College, Dublin, Ireland

Summary
Groundwater is the main source of water supply for people and agriculture in the Gulf region. Traditionally, *aflaj* and hand-dug wells have been used to extract groundwater from shallow groundwater sources, especially the wadi gravel aquifers that occur widely throughout the Gulf States. In recent decades there has been a huge increase in the number of boreholes drilled in countries such as Saudi Arabia, UAE and Oman. Modern drilling techniques have enabled deeper sedimentary rock aquifers to be exploited in addition to shallow wadi gravels. This paper addresses some of the key issues in the design of water wells in both alluvial and bedrock aquifers. Good well design is essential for efficient management of groundwater resources. Wells in wadi gravel aquifers must be lined for stability (even though the gravels may sometimes be cemented), and the paper demonstrates how material sizes can be chosen so as to minimize unnecessary head losses in the well, thereby avoiding unnecessary pumping costs. The intake sections of boreholes drilled into stable bedrock aquifers are often left unlined: in these situations, one of the most important issues is to provide a proper annular seal around the pump-chamber casing, so as to reduce the risk of ingress of contaminants from the surface. The paper also explains how the collection of routine water level and discharge data in production wells can help in diagnosing the causes of changing well performance, with examples from Oman and the UK.

__Biography__: Prof Bruce Misstear is an Associate Professor in the School of Engineering and a Fellow of Trinity College Dublin. He is a hydrogeologist with over 30 years experience in groundwater resources development. Prior to joining the Civil Engineering Department in Trinity College in 1995, Prof Misstear worked as a consultant hydrogeologist, becoming head of the Groundwater Department of international consultancy Mott MacDonald. During this period he undertook groundwater projects in many parts of the world, including the Gulf region. His current research includes amajor project on water pollution pathways in Ireland. He is also part of the Uganda Water is Life research team. Prof Misstear is the author or co-author of more than 100 publications, including the international textbook Water wells and boreholes. He is both a Chartered Geologist and Chartered Engineer. He is currently Vice President (Finance and Membership) of the International Association of Hydrogeologists.

Groundwater Management of the South Al Batinah, Interior Governorates, Sultanate of Oman

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[2]Sultan Qaboos University, Oman, Director of Water Research Center, Associate professor, Earth Science Dept., College of Science.

Abstract: Groundwater is the primary source of water supply for many arid countries in the globe. Quantifying such resources is crucial for effective water resources management sustainable agriculture and environment. The present study investigates appropriate management strategy in the northern Oman that occupies the south-eastern corner of the Arabian Peninsula. Most of the water demand in the study area is covered by groundwater and consequently, groundwater levels have dropped in many wells and a deficit between recharge and discharge has been created. The absence of alternative water resources leaves groundwater as the primary source for agricultural, domestic and industrial uses. Groundwater in the study area is present in different aquifers and under varying conditions. Proper management requires pollution control, aquifer protection, future planning and prediction. Moreover, hydrologic monitoring is essential as it provides information related to the hydrologic system, and can be used to signal necessary adjustments to the management plan. The present study discusses groundwater management options and clarifies groundwater role in the region. It also acquires good understanding to manage water resources and reduce pressure on aquifers by resorting to ingenious ways of utilizing the available water resources. This implies to make judicious use of available water resources and reduce waste. This paper provides a brief overview of the history of depletion of groundwater in the study area and discusses problems associated with groundwater salinization. The study concludes that, with respect to the set achievements, future use should be reduced by applying alternative water resources such as desalinated and treated water and controlling the intrusion. To achieve these objectives we have to extend the research capabilities of groundwater models by developing and applying a large-scale groundwater balance model which is a logical solution to improve knowledge about present and future groundwater resources.

Keywords: Recharge/discharge, hydrologic monitoring, alternative water resources, groundwater balance, Oman.

Introduction

Oman with an area of almost 310,000 km² is located in the northern tropical arid zone where water resources are very scarce. It is one of the driest and hottest countries of the world. The present day climate of northern Oman is arid, characterized by hot summer months (June to September) and dry warm winter months (November to April). The mean annual air temperature is 17°C in the mountainous area of the Jabal Akhdar, 28°C for the coastal areas and between 25° and 28°C in the alluvial plains just south of the Jabal Akhdar [1]. Mean monthly temperatures are between 33° and 35°C during the summer months and between 20° to 25°C during the winter months. Long term mean annual rainfall is about 300 mm on the Jabal Akhdar and approximately 90 mm on the alluvial plain. Potential evapotranspiration varies from 1,660 mm/year in the Salalah plain, with lower temperature and seasonal fogs, to 2,200 mm/year in the interior.

The total renewable resources replenished from rainfall and stored in aquifers is estimated to be about 1,300 Mm3/yr with a recovery level of about 70% underground currently. Whereas, the non-renewable resources comprise underground fossil water which would mostly not be replenished if it's not yet been exploited and abstracted. The convention water in Oman is about 84% whereas the non convention is about 16%,the source of the renewable convention water is surface water which represent around 6% (Ghaili Aflaj and baseflow of few wadi 98 Mm³per year) and groundwater which represent around 94% (Wells, Dawoodi Aflaj and Springs 1,186Mm³per year). Desalination plants supplies total of 196 Mm3/yr and the Virtual water is estimated to import about 1,700 m3/capita/yr through imports of food and other consumer products, the reuse of treated waste water is about 22.77 Mm3/year. Almost 78% of the extracted water is used in the agricultural sector, 12% as potable water and 2% for industrial usage [2] as shown in figure (1).

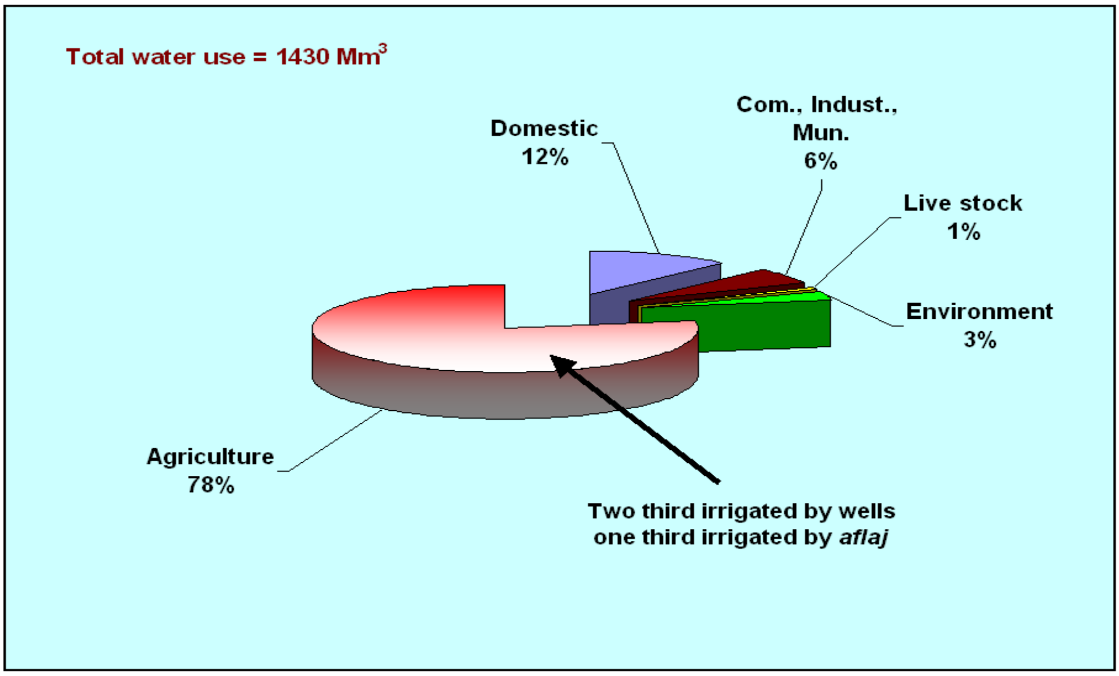

Figure (1): The water use by sectors in Oman. (MRMWR, 2011)

In most areas of the Sultanate of Oman the renewable water resources are believed to be fully utilized, and in some areas heavily overdrawn as shown in Figure 2. The Ministry of Regional Municipalities and Water Resources (MRMWR) have responsibility for the general plan for the development of water resources and their conservation. If maximum benefits are to be obtained from scarce water resources an assessment of the resource is necessary to determine the sustainable level of water use and, in deficit situations, controls necessary to bring an area into a balanced condition [3].

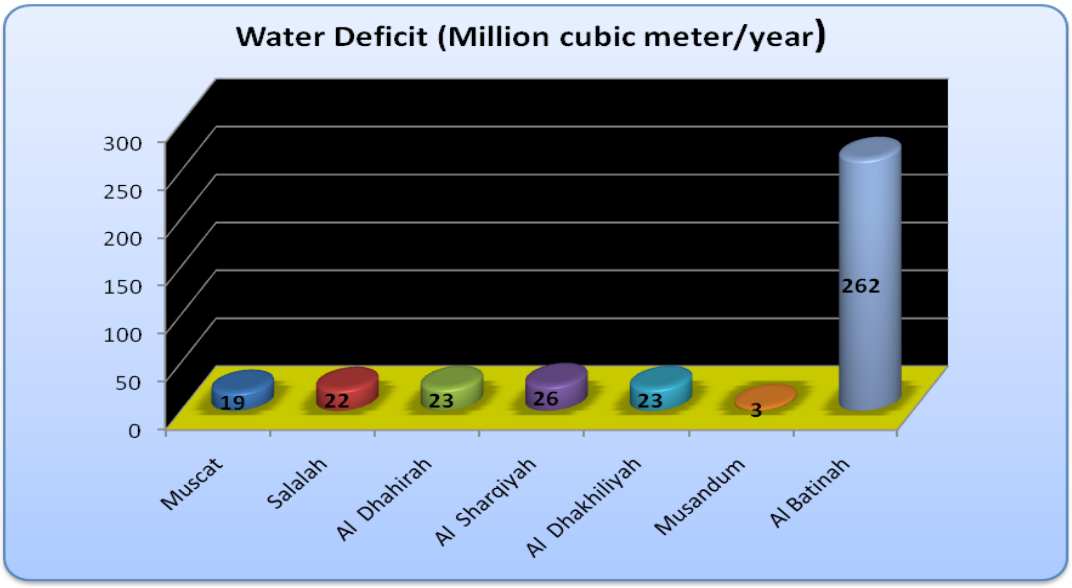

Figure 2: Water Deficit in different governorates in Oman (adapted by MRMWR, 2010)

The primary requirement for management of water resources in any region is an accurate water balance and in turn, requires estimation of groundwater recharge and discharge rates and, where possible, knowledge of their spatial distribution [4].

Problem Statement

Water is the most precious and scarce natural resource in arid regions. Quantifying the available water is very crucial for effective water resource management, sustainable agriculture and stable environment. Most of the water demand in the study area is supplied by groundwater resources. As a result of increased water consumption during the past three decades mostly for the agricultural purposes, deficit of the groundwater recharge, climatic and land use change, the groundwater levels have dropped in many wells which led to the creation of a gap between recharge and discharge. The absence of alternatives water resources leaves groundwater as the primary source of water to fulfil the demands for agricultural, domestic and industrial uses. These problems raise the question to study the groundwater conditions in the area by applying an integrated assessment, prognosis, planning and Management tool (APPM) for sustainable water management in the study area. It is necessary to determine the sustainable level of water use and, in deficit situations, controls necessary to bring an area into a balanced condition. . The progressive deterioration of groundwater quantity and quality poses a serious to all agriculture along the coast of the study area, causing concern about the long-term prognosis for water quality and quantity in the area. There is a pressing requirement to assess available groundwater resources and to develop a sustainable water management plan.

Study Area

According to the title of the study groundwater management of the South Al Batinah/Interior governorates in North of Oman, this study focuses on a 36,400 km² which represents only 11.7% of a Sultanate of Oman total area which is 309,652km², the study area (South Al Batinah) located northwest of the Capital city Muscat whereas Dakhiliya governorate, located approximately 150 km to the southwest of the capital Muscat. The Gulf of Oman forms a natural border to the north of the study area, while the southern limits are defined by the discharge area of Um as samim, to the west the area is limited by the Hamrat Duru range and the eastern limit are from the Semail Basin water divide to south of Sinaw. The study area can be divided in two parts south and north according to the Jabal Akhdar Mountain range. There are six catchments have been chosen for intensive studying from the north side; Wadi Al Fara, Wadi Bani Kharus,Wadi Ma'awil ,Wadi Taww and from the south part: Wadi Al Omairy and Wadi Halfayn. , the Wadi Halfayn system including the surface wadi systems of Wadi Halfayn, Mu'aydin and Abyadh-Nizwa and the Bahla system including Wadi Bahla and Sayfam (Figure 3).

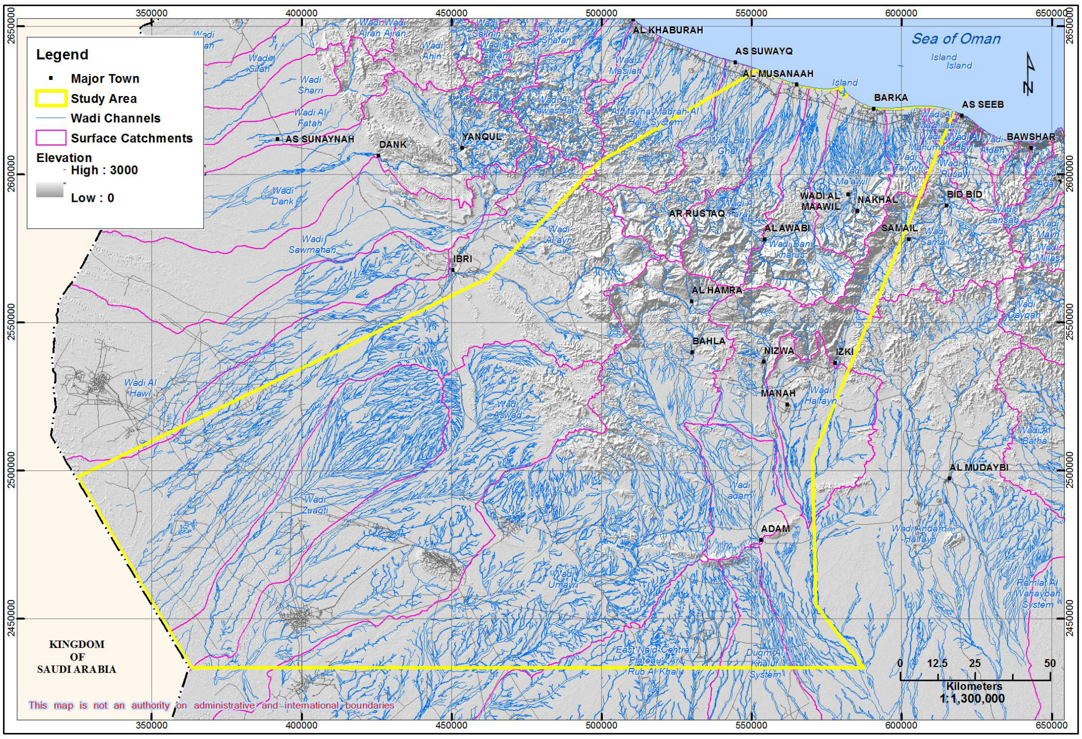

Figure 3: Location of the study area and six catchments.

The main reason to select this area for this study is the availability of necessary data required and its importance for agriculture. As shown on the study area map, Jable Al Akhdar is divided the study area to south toward to the interior and to the north toward to the Gulf of Oman. Potential recharge areas are the high altitude regions of the Jabal Akhdar where the amount of the rainfall is highest comparing to any region in Oman as shown in the figure (4) below.

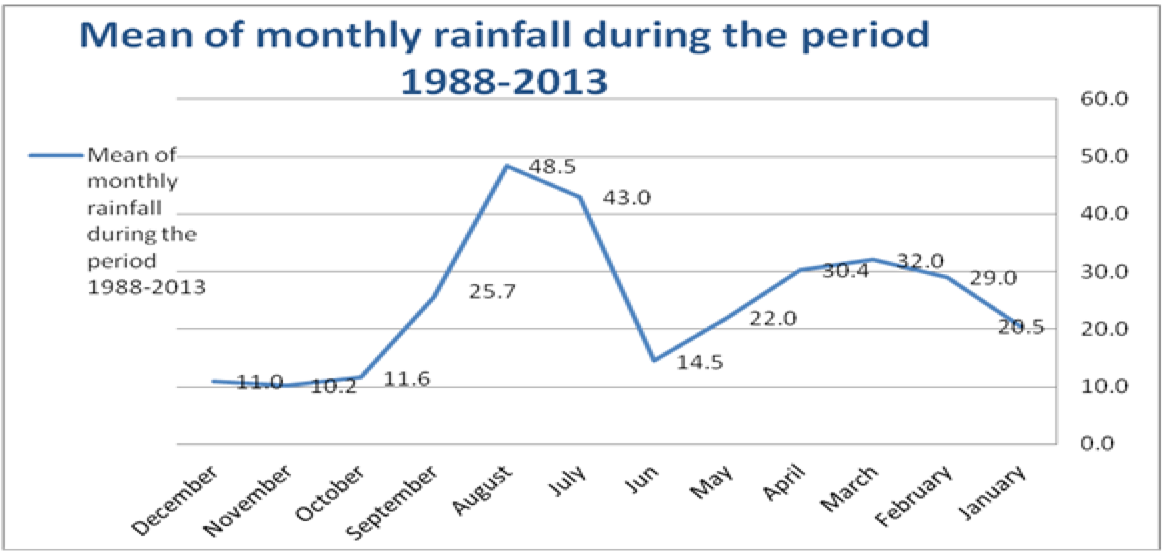

Figure (4): Average Monthly Rainfall for the last 25 Years in Jabal Al Akhdar

In recent years, water has become increasingly scarce and the study area basin has shown signs of salinization of agricultural land especially in the lower part close to the sea. Most of the irrigation techniques till date are insufficient which leads to excess water pumping from the aquifer. Because of the uncontrolled pumping from the coastal side of the region, water table in those places has declined alarmingly. In some part of the region, there is almost a drawdown of 4 to 5 m within a time period of about 30 years starting from 1974 to 2004 [5].

Regional Geology

A simplified geological map of the study area is shown in Figure (5) and schematic geological cross sections from Batinah to southern flank of Jabal Akhdar and from southern flank of Jabal Akhdar to southern of Jabal Salakh displayed respectively in Figure (6) and (7).

Groundwater in Oman is present in many different aquifer formations and under varying conditions. Several important aquifers exist in Oman. The main aquifer systems include the alluvial aquifers, the regional quaternary aquifers, the aquifers of the Hadramawt Group and the aquifers of the Fars Group. A first distinction can be made between aquifers in unconsolidated Quaternary alluvial and Aeolian deposits, and aquifers in order, more consolidated rocks. Flow of groundwater in the later group is mainly through fissures (fissure aquifers), whereas it is through the pores in the former category (pore aquifer). Furthermore, the size of the different aquifer systems varies considerably, from small narrow wadi fills to extensive platform aquifer systems hundreds of thousands square kilometers in aerial extent. Fresh groundwater is common in many zones of the country, but brackish groundwater occurs in coastal zones and in vast inland regions [2].

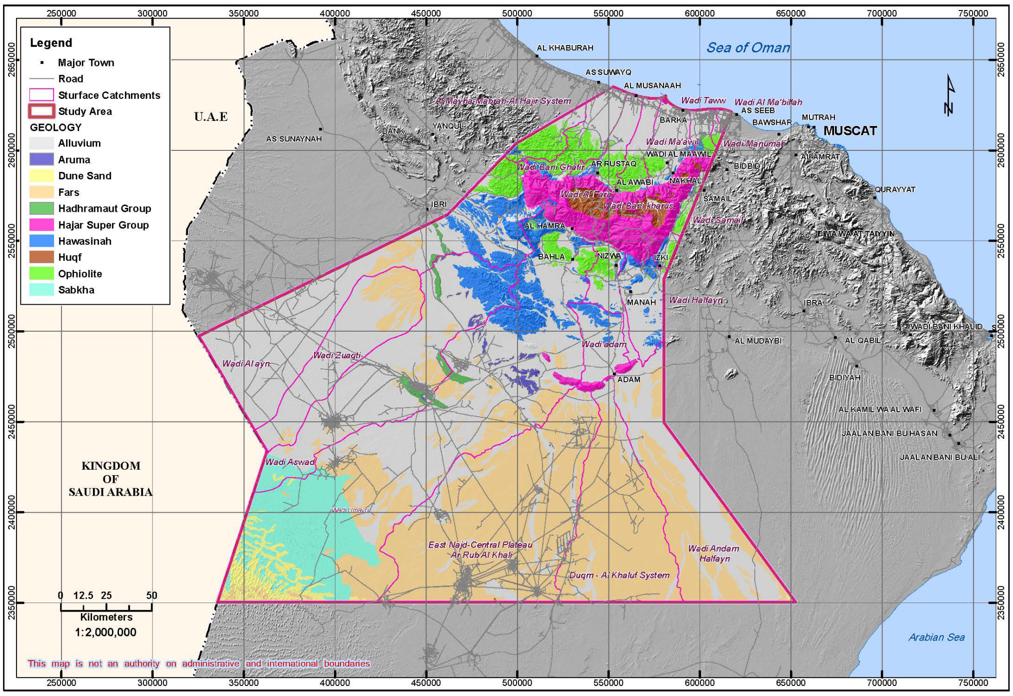

Figure 5: Simplified Geological Map of the Study Area

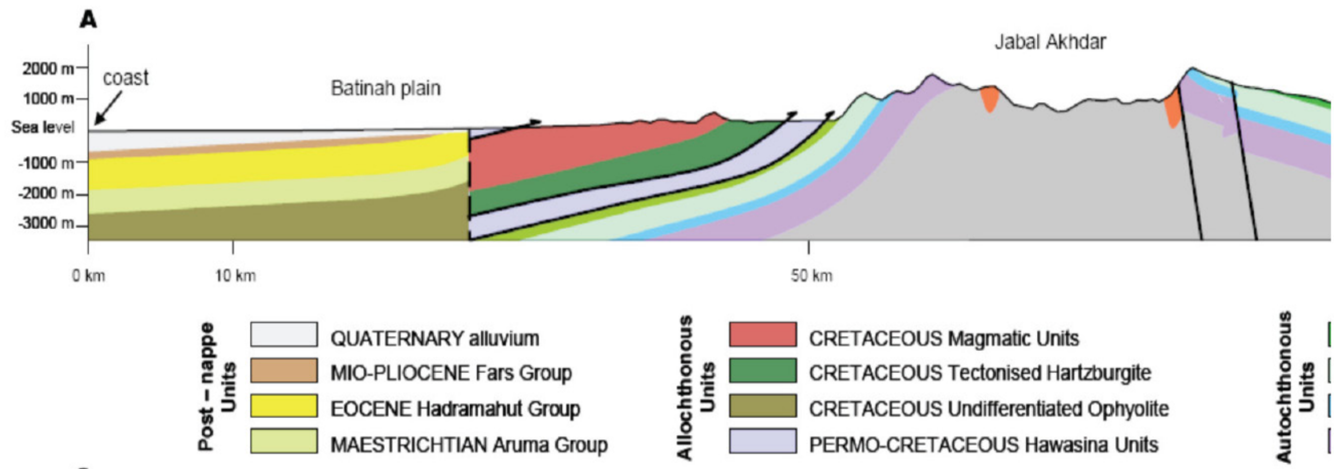

Figure 6: Schematic geological cross sections from Batinah to southern flank of Jabal Akhdar (*After MRMWR, 2011*)

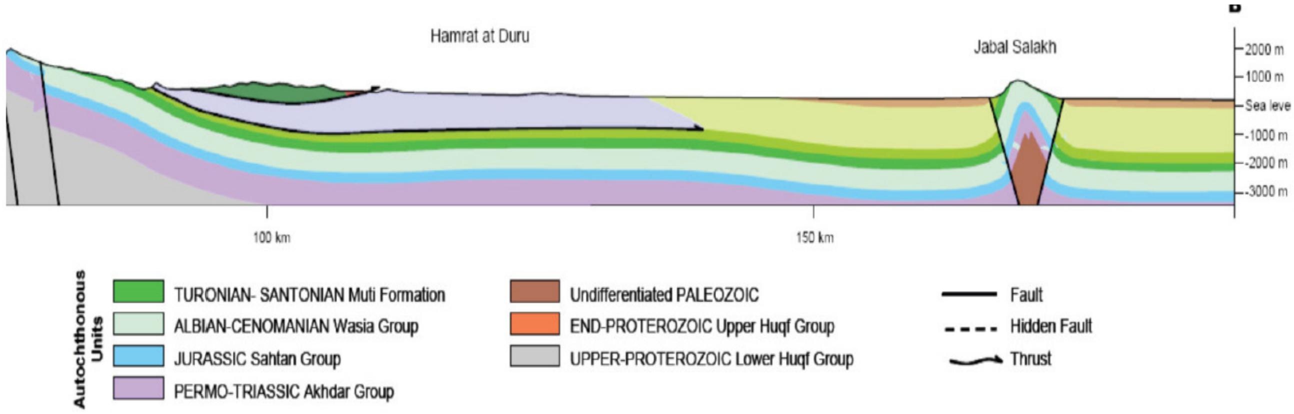

Figure 7: Schematic geological cross sections from southern flank of Jabal Akhdar to southern of Jabal Salakh (*After MRMWR, 2011*)

Data Availability in the Study Area

Based on the figure (8) which shows distribution of the monitoring points such as rainfall stations, Wadi gauge, observation and monitoring wells, dams gauge and monitored aflaj. It can be seen that the monitoring points not covered all the study area and concentrated in some catchments more than other. For example in the Jabal Al Akhdar there is a rare of monitoring points and that area is the main recharge source of the study area .Moreover, deficit of the monitoring points in the south part of the study area close to discharge area is much clarified in the map below.

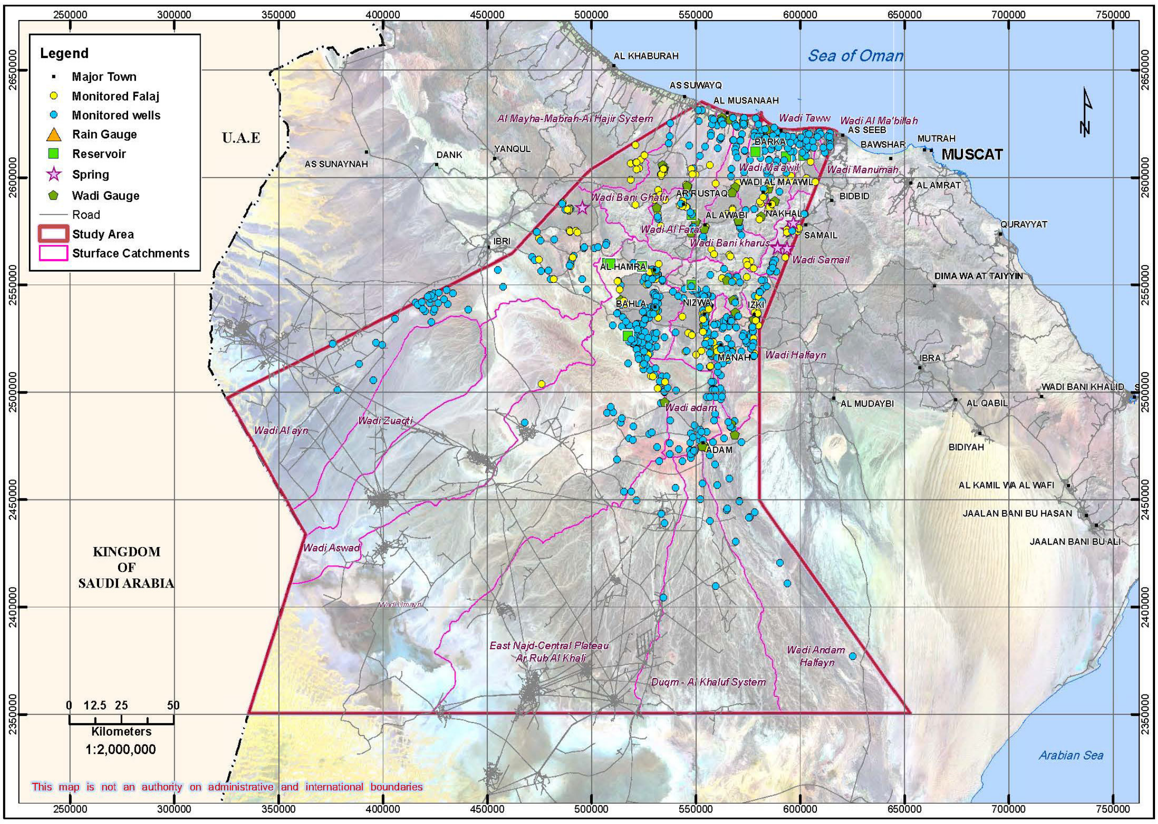

Figure 8: Distribution of the monitoring points in the study area

Problems Associated with Groundwater in the Study Area

Groundwater is a major source of drinking water across the world and plays a vital role in maintaining the ecological value of many areas [6]. However, the quantity and quality of groundwater are changing due to human activity [7]. Managing the groundwater resources is vital in order to reserve this valuable bounty for long-term use. Therefore, management requires the selection of the best tools and policies to determine policies expected to achieve the goals of preserving this resource [8].

Depletion of the Groundwater

To show the groundwater depletion in the study area we selected 11 monitoring wells located in the north and south part of the study area and each well located in the center of the catchments that have been chosen. From the figure (9) which represent the north part of the study area it can be seen that there is no stability of water table in the all wells except well TD-10 located in mabilah close to the costal line and downstream of Al Khoudh dam. On the other hand figure (10) represent southern part of the study area and the groundwater depletion is clear in some wells especially well NSA-4A and BAH-37.

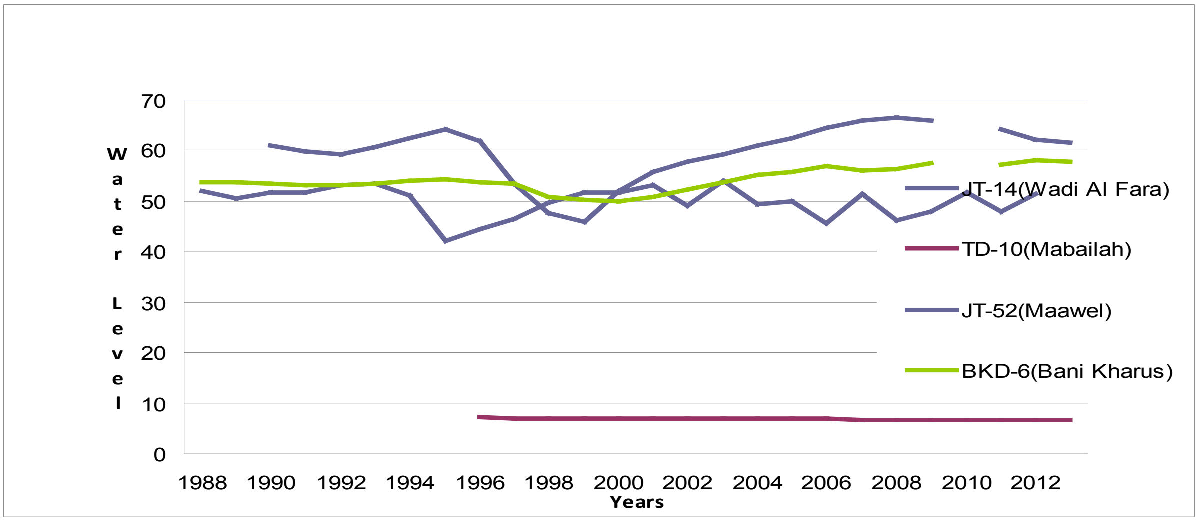

Figure 9: Groundwater Level in different monitoring wells in the North part of the study Area

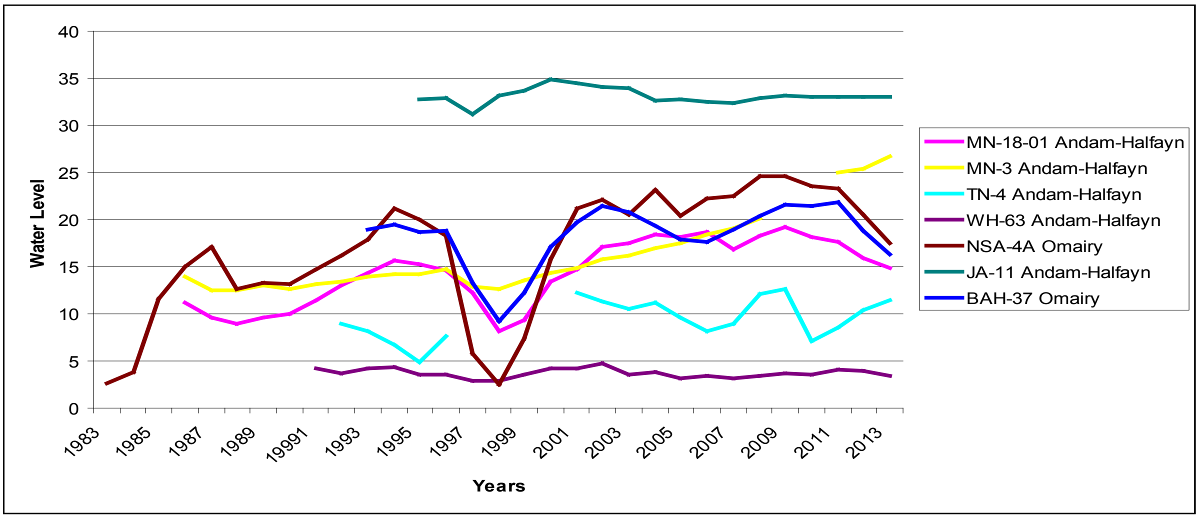

Figure 10: Groundwater Level in different monitoring wells in the South part of the study Area

Saline Intrusion

Groundwater extraction is the primary cause of saltwater intrusion. It is the main source of the irrigation use in the study area, and extraction has increased over time. Many studies and research projects in the study area related to water salinity taken place in different tasks of monitoring, assessment, and mapping. The Ministry of Agriculture and Fisheries produced Oman Salinity Strategy in 2012 which revealed that agriculture uses 93 percent of the nation's renewable water and detailed water balance calculations show that groundwater use in Al-Batinah governorates is about 54 percent higher than renewable supplies. Figure 6 shows results for intrusion length and spatial variability along the coast during the period between 1995 and 2010[9]. However, the 2000 National Water Resources Master Plan estimated that agricultural water use was 16 percent more than renewable supplies [10]. In 2010, Barka was the most affected by sea water intrusion (MAF).

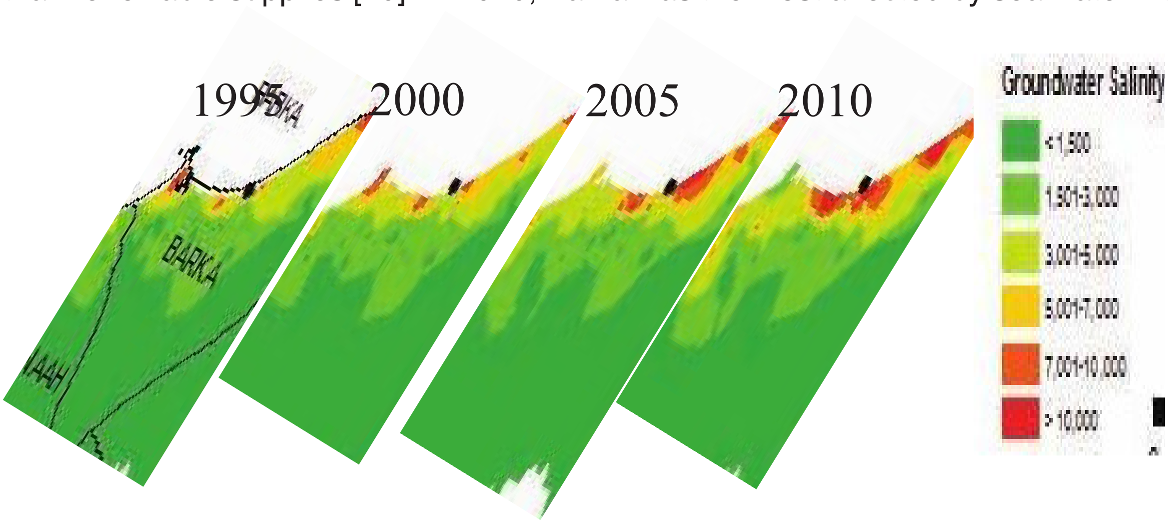

Figure 11: Salinity Measurements after Oman Salinity Strategy in 2012.

Al-Barwani and Helmi (2006)[11].used Geographical Information Systems (GIS) and Autocad techniques to map groundwater salinity levels in the coastal area of Al-Batinah plain based on water electrical conductivity surveys conducted by the Ministry of Regional Municipalities and Water Resources for 20 years since 1984. They found that lands suitable for agriculture have been reduced by 7 percent in the period of 2000 - 2005. They also reported that the salinity water moved 12 km towards inland in areas like Barka as showed that in figure (12a) 2005.whereas the salinity water moved more towards in land in 2012 as seen in figure (12b).

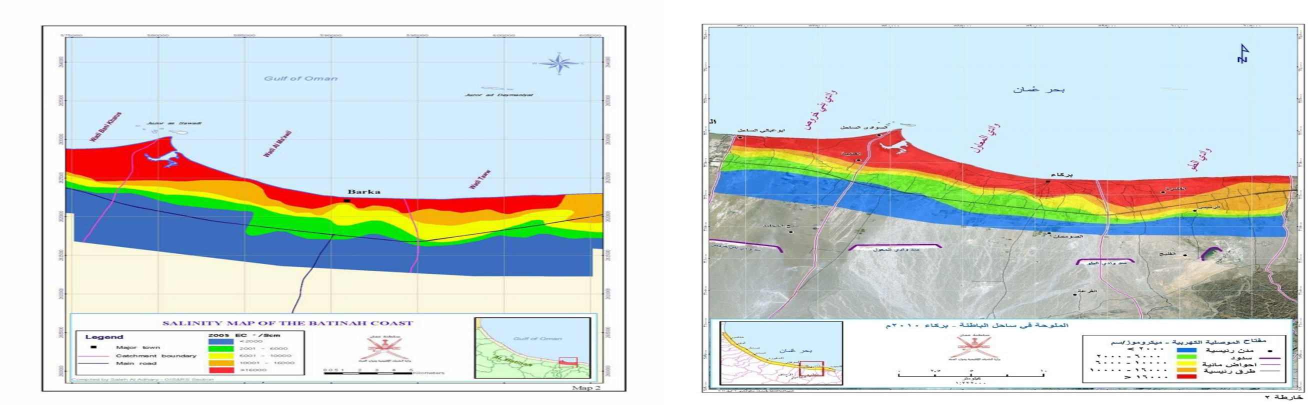

Figure 12a and b: Salinity water Measurement in 2005 and 2012 in Barka Area.

Walther, M, 2014, and other [12] used numerical model OPENGEOSYS to give information on the time scale for remediation activities. They found that Salinity simulation output of marine intrusion (Fig. 13a, b) shows results for intrusion length and spatial variability along the coast similar to reported measurements (Ministry of Agriculture and Fisheries 2012).Mean intrusion length and the general trend of saltwater intrusion increase from 2–4 km in 1975 to 5–7 km in 2005. Groundwater flow paths are indicated by stream tracers, originate in the southern mountainous areas and, in 1974, still partly reach the sea. As freshwater discharges into the sea, the intrusion interface is still retained near the coast. In 2005 (Fig. 12b), all recharge plumes are completely captured by pumping activities. High abstraction rates lead to immense drawdown and accordingly excessive saltwater intrusion of up to 3 km.

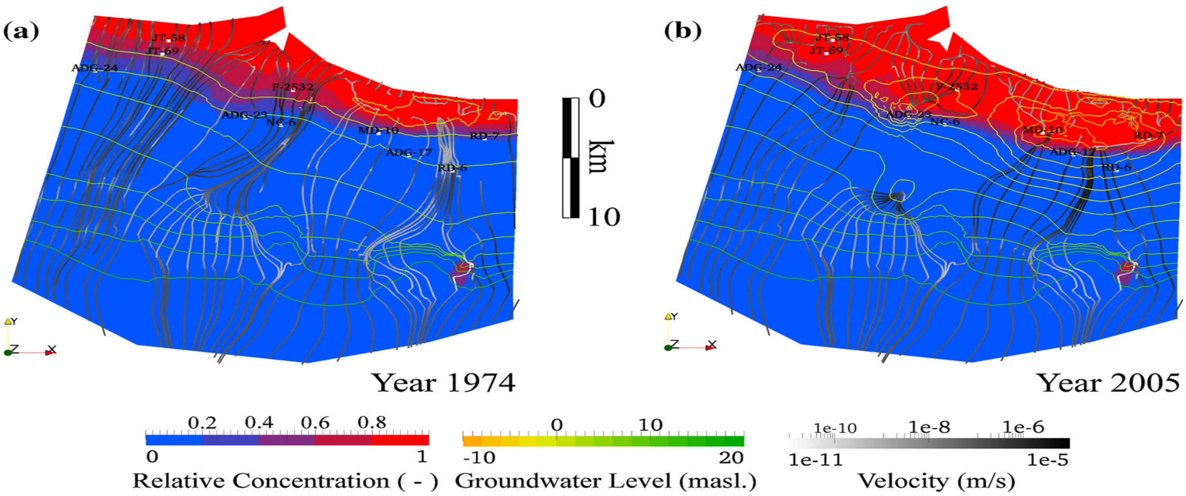

Fig. 12 a, b Salinity (at 10 m below groundwater level), groundwater levels (isolines) and stream tracer for initial and final state of transient simulation (1974 and 2005), after Walther et al. (2013). Groundwater Pollution

The increase in groundwater abstraction over the last twenty years, as a result of uncontrolled withdrawn led to groundwater quality deterioration at some location of the study area such as Barka water assessment area. Study area is facing groundwater pollution from microbial and chemical contamination in the densely populated areas because of the lack of wastewater sewerage systems and the extensive use of septic tanks.

A remediation study in the Rustaq area revealed that groundwater in fractured rock formations was contaminated with volatile organic compounds. It took five years to bring the level of hydrocarbon contamination below detection limits. [13].The use of agrochemicals, fertilizer and pesticides, is widespread and is a serious hazard to groundwater quality as most aquifers are unconfined and soils are sandy loams with low organic content. Nitrates, phosphates, and sulphates in groundwater have been reported where agriculture is widespread such as in the Batinah Plain. [13].

Many sources of groundwater contamination surrounded or in the study area such as storage tanks of gasoline and oil, Septic systems that are not connected to a city sewer system, uncontrolled hazardous waste sites, landfills and atmospheric Contaminants Since groundwater is part of the hydrologic cycle, contaminants in other parts of the cycle, such as the atmosphere or bodies of surface

Alternative Water Sources in the Study area

To reduce the dependence on groundwater resources and minimize the deficit in the study area, searching for an alternative source of water for irrigation use which consumed more than 90% of pumped groundwater. There are more than 12 of treatment plants operated by the Ministry of Regional Municipalities and water Resources distributed in the towns located in the study area and according to capacities and outflow of these treatment plants there is a surplus of water can be used for the irrigation purpose.

There is one main water desalination plant located in Barka operated by the Public Authority of Electricity and Water supplied most Wilayates of the study area. The project of water supply for domestic use is still under progress and by the completion of the project, pumped water from the well fields will stop and that will reduce the pressure on the groundwater aquifers.

Using rain water harvesting technology by constructing more number of recharge and storage dams in the upstream of the catchments or by storing the rain water collected from the roof or runoff and then uses it for irrigation especially in the mountainous area where the evapotranspiration is very low. Rain water harvesting is already implemented in the Al Jabal Al Akhdar area and the people saved a lot amount of metering water to irrigate their house garden.

Development and Application of a Large-Scale Groundwater Balance Model in the Study Area

To define the water budget in this region more precisely and to evaluate the existing groundwater resources and to develop realistic water management strategies applying the groundwater flow model is most important. Because quantifying groundwater resources is a key issue for the management of the limited water resources in arid regions, it is essential to better understand the nature of groundwater recharge in the study area, as well as to identify the major flow paths and residence times of the water recharging the aquifers.

To achieve these objectives we have to extend the research capabilities of groundwater models by developing and applying a large-scale groundwater balance model which is a logical solution to improve knowledge about present and future groundwater resources.

In this study we will use a Model Muse which is a graphical user interface (GUI) for the U.S. Geological Survey (USGS) models MODFLOW–2005 and PHAST. This software package provides a GUI for creating the flow and transport input file for PHAST and the input files for MODFLOW–2005. In Model Muse, the spatial data for the model is independent of the grid, and the temporal data is independent of the stress periods. Being able to input these data independently allows the user to redefine the spatial and temporal discretization at will. [14].

MODFLOW-2005 (Harbaugh, 2005) simulates steady and nonsteady flow in an irregularly shaped flow system in which aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated.

Conclusions:

An understanding of the main sources and sinks of water and their spatial variability aids the management of water resources in Oman. It is important that more accurate data are obtained on all aquifers for a more detailed assessment of the groundwater balance.

The main challenges facing groundwater in the study area are scarcity and depletion, sea water intrusion, and anthropogenic pollution.

High demands and over abstraction have led to saline intrusion along the Batinah coast and predicted population growth means that pressure on water resources is increasing. Searching for an alternative water resources like treated water for irrigation and desalination water for urban use beside constructed of recharge dams to increase the infiltration, constructed of storage dams to harvest water and use it for irrigation purpose will reduce the salinity intrusion and groundwater depletion.

The study concludes that, with respect to the set achievements, future use should be reduced by applying alternative water resources. To achieve these objectives we have to extend the research capabilities of groundwater models by developing and applying a large-scale groundwater balance model which is a logical solution to improve knowledge about present and future groundwater resources.

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A Modeling Study of Aquifer System in South Batinah, Oman

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Abstract: The groundwater system of Quaternary and late Tertiary along south Batinah catchments on the northern coast of Oman has undergone overexploitation since the 80's. The area faced problems with lowering hydraulic heads and salt water intrusion. Since eighties, large amounts of water have been extracted for agricultural purposes resulting in a spatiotemporal evolution of water level depletion as well as degradation of groundwater quality due to seawater intrusion in such valuable ecosystem. Therefore, sustainable management of the aquifer system in this area is crucial. The main objectives of the work are better understand the hydrogeology of the region; assess the recovery of groundwater level following the water injection into the aquifer system, and decreasing abstraction rate in addition to assess the effect of both interventions on the progress of seawater intrusion in the area. The results showed that the groundwater abstraction severely exceeds the total average input by about 5 fold. Therefore, largely groundwater for this abstraction comes from storage and seawater intrusion and this will not be sustainable into the long term. Following the decreasing of abstraction by 20% as well as introducing treated wastewater starting from 2016 simulated groundwater levels begin to rise noticeably in the area of the well field. It was noteworthy that applying both interventions would have a great effect on the recovery of water level and decreasing salinity. With both interventions; the water level appears to be recovered by about 7 m in the area of the well field and there has been a decrease in salinity reaches about 5.5 g/l near the injection wells. It is highly recommended that the region should be well distributed installment of gauges to improve the accuracy of the model and thus groundwater management. New observation wells are drilled in the southern part of the area which has low density of data and also enhancement of salinity monitoring especially along the coastal zone. Public awareness and incentives are paid to the land owners in the catchment convincing them decreasing their abstraction.

Keywords: Simulation, Coastal aquifer, Sea intrusion, Sustainable management, Oman.

Introduction

With the expansion of agricultural activities, water demand has been increased and the groundwater resource has become worse, especially in most coastal regions where over-exploitation of groundwater occurs. The south Batinah coastal plain, the subject of this work, is located in the northern part of the Sultanate of Oman (Fig. 1). The plain represents a part of the Barka Water Assessment Area as classified by the Ministry of Regional Municipalities and Water Resources (MRMWR) and includes lower catchments of three wadis namely; wadi Bani Kharus, wadi Ma'awil and wadi Taww. The area has been subjected to a heavy groundwater abstraction, which is concentrated along the coastal strip and has increased substantially since the early eighties. Consequently, groundwater levels more and more are getting declined as well as saltwater intrusion is common problems in near-coastal zones. Four recharge dams have been constructed in the lower catchments across the tributaries of four Wadis to increase the recharge to the groundwater system and to minimize the surface flow going to the coast. The volume of tertiary treated wastewater is 36.5 Mm^3/year where most of it is used for irrigation of parks and landscaping. This volume is expected to reach 54.8 Mm^3/year by 2015. It was assumed with providing the expected excess of treated wastewater to artificially recharge the aquifer system by an amount reaches 11.6 Mm^3/year. Total natural recharge to the aquifer system is relatively small compared with the amount of abstraction due to an accentuated variability of climate in space and time. Therefore, injection wells to the groundwater system using the treated wastewater have been introduced as an alternative method to cope with and alleviate salinity increasing along the coastal zone. Many groundwater studies have been reported on the study area. We may specifically notice among them: Tetratech (1980), PAWR (1982, 1988), MMP (Sir MacDonald and Partners) (1983, 1985), Bhatnagar and Orpe (1986), Dames and Moore (PAWR), (1986b), JICA, (1986), Mott MacDonald International (1991), BRGM (1992), MWR (1992), Heathcote (Hydrotechnica), (1993), Lakey et al (1995), MWR (Macumber) 1998), CACE (2004), Al-Shoukri (2008), Kacimov et al (2009), ICBA (2011), Walther, et al (2012). The key component of this paper is to develop and calibrate a numerical groundwater model based on the understanding developed in the conceptual model to simulate the groundwater heads and the extent of seawater intrusion. The numerical code used was MODFLOW compatible MT3DMS and SEAWAT utilizing the graphic user interface GMS. Using the calibrated model, some predictive runs over 25-year period were provided. The broad objective of this work is to build and calibrate a numerical model for the aquifer system in the coastal plain area. The specific objectives can be stated as: 1) Quantitative understanding the hydrogeology of the area; 2) Assess the historical impact of utilizing abstraction on the groundwater levels and salinity and 3) Evaluate the recovery of groundwater levels and the reduction of water salinity following injected tertiary treated wastewater and/or reducing abstraction quantity which they are both starting from 2016 up to the year 2035. A conceptual model was used to build an understanding of the aquifer system, its properties and the main components of recharge and discharge prior to the construction of the numerical groundwater flow model.

Conceptual Model

A conceptual model of the groundwater flow regime of the south Batinah catchments has been constructed on the basis of data provided by the MRMWR as shown in a schematic diagram (Fig. 2). The study area is divided into two distinct zones; southern mountainous and northern coastal plain. Southern mountainous or Hajar Super Group Mountains (HSG) attains elevations generally above 300 masl rising to over 2,500 masl at Al Jabal Al Akhdar (Fig. 1). Catchments of this zone drain inland southwards and to the Sea of Oman northwards. Northern coastal plain attains elevations generally below 300 masl with catchments draining to the Sea of Oman.

Climate

Rainfall is subject to orographic effects, which resulted in variable rainfall patterns over relatively small distances. Consequently, they cause higher average annual rainfall amounts at the Hajar Mountains than at the coastal plain. Rainfall often occurs as short and intense localized showers. It attains an average value reaches to 350 mm/year at higher elevation mountainous zone. Meanwhile, it ranges between 50 and 100 mm/year at the coastal plain.

Average temperatures vary between 17 and 37 °C over the whole country. The average winter temperatures range between 20 and 28 °C in the study area, while average summer temperatures range between 27 and 37 °C. Evaporation is very high throughout the country. Where temperatures are lower at higher elevations, the potential evaporation is also lower. The average humidity is higher at the coastal plain leading to lower potential evaporation rates. The high temperature range recorded over the study area result in potential evaporation values reach to 2,300 mm/year.

Figure 1: Geologic map (modified after Macumber.

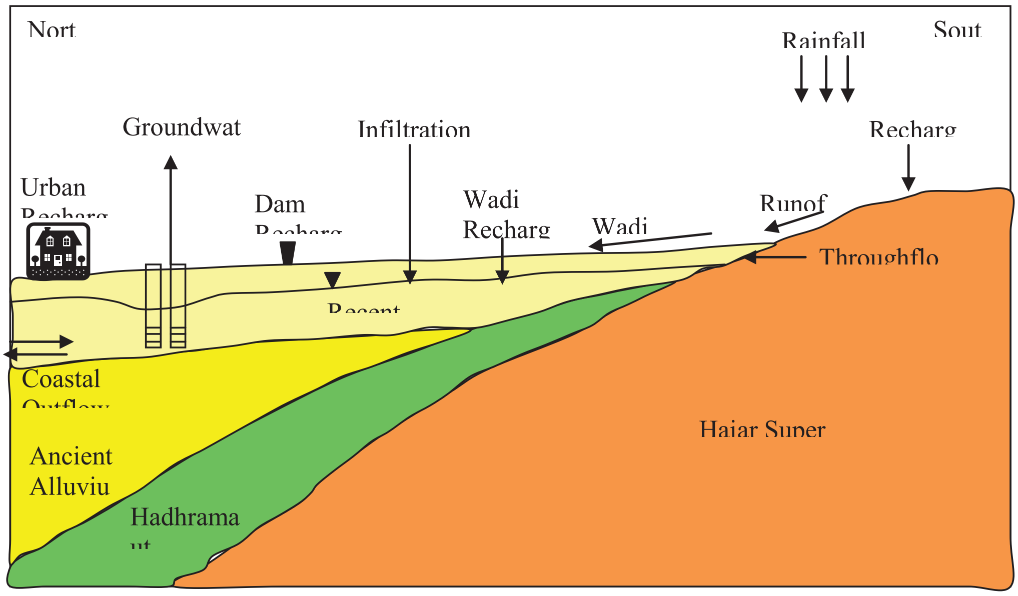


Figure 2: Schematic conceptual

Geology

The HSG consists mainly of limestone and dolomite representing different formations ranging in age from Permian to Late Cretaceous (Autoch. unit A and unit B). Hawsinah Nappes and Samail ophiolit were deposited contemporaneously with the upper part of HSG. Hawsinah Nappes are formed of shale, limestone, chert and basalt. Samail Ophiolite is a sequence of rock that is representing marine volcanic rocks. It consists of peridotite, gabbros, mafic dikes and basalt. It was formed by the obduction of oceanic crust and part of the mantle from the ocean onto the Arabian Platform.

The formations of Tertiary carbonates (Paleocene – Early Eocene) known as Hadramaut group (Powers, 1966) are mainly formed of strong limestone interbedded with silty shale. After the deposition of these formations the area was uplifted in the mid-Tertiary resulting in rapid erosion which detaches the Tertiary outcrop into isolated remnants where they currently outcrop (Fig. 1) and lie unconformably beneath the conglomeratic units (ancient alluvium) along the northeastern flank of the HSG Mountains.

It was noticed from the interpretation of the TDEM surface geophysics and borehole logs that the carbonate formations have an electrical resistivity ranges from 50 to 100 ohm/m. However, it is difficult to delineate the subsurface mapping for the Tertiary units. TDEM has delineated a major low-resistivity (<5 ohm/m) along the sea coast of Oman. Drilling and sampling indicate that this low resistive unit is a marl unit (Gibb, 1976) comprising very high saline groundwater more than seawater.

The coastal plain forms a subsiding continental margin and presents a well-developed sequence of alluvial fans and fan remnants (Abrams and Chadwick, 1994). Alluvium starts deposition with uplift in the mid-Tertiary by conglomeratic facies overlying carbonate units. Abrams and Chadwick, 1994 divided the alluvial deposits in the area into eight units. While, Mann et al 1990 stated that the eight units are correlated to the cemented gravel unit throughout. The lower older four units as described by Abrams and Chadwick correlate with ancient alluvium of late Tertiary described by BRGM (1986a, 1986b) as a conglomerate with a clay-sand matrix. These units will be delineated as layer 2 in the modeling section. On the other hand, the other upper younger four units are associated with Quaternary recent alluvium of less cementation materials and will be delineated as layer 1 in the modeling section. Low permeability HSG formations delineate the southern boundary of the coastal plain aquifer where they restrict the flow between them except a window at Nakhl.

Generally, both recent and ancient alluvium having variable thickness and variable elevations, the reported thickness of the recent alluvium varies from 52 m to 312 m recorded in borehole logs (MWR, 1995) while it varies from 72 to 420 m thick for the ancient alluvium. The ancient alluvium unit thins towards the east until it pinches out in the eastern half of the study area which may explain the range of reported thicknesses.

Groundwater Levels

There are 61 observation boreholes in the coastal plain area (Fig. 3). Groundwater levels are only available at 18 borehole locations for 1974. Groundwater level contours for 1974 (Fig. 4) showed that groundwater flow is generally from the south towards the north. Water levels range from 270 masl in the south to zero masl along the coast. The gradient of the water level is steeped in the southern part (0.0133). In the northern part, however, it becomes progressively gentle (0.0004). Groundwater contours have been drawn perpendicular to the catchment boundaries which indicates that there is little or no lateral groundwater flow across these boundaries. In the southern region of the study area, the absence of observation boreholes makes it difficult to show the groundwater flow regime in this area.

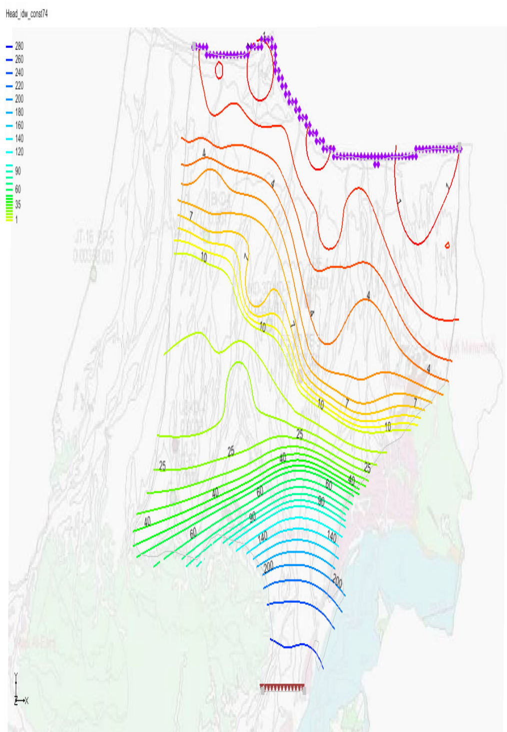


Fig. 3: Observation boreholes

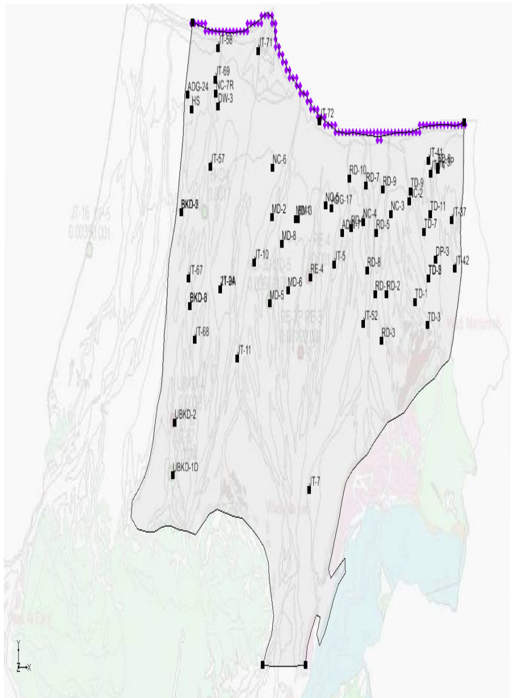


Fig. 4: Groundwater level for 1974

Throughflow

The amount of throughflow from the Hajar southern catchments to the coastal plain area through the southern window (Fig. 1) can be calculated by multiplying (extent of southern window, average hydraulic conductivity, thickness of aquifer and hydraulic gradient). The extent of this window is considered by (~6 km) for calculations. Using an estimated hydraulic conductivity between 8 m/day and 11.5 m/day, average aquifer thickness of 19.6 m near this window, and calculated hydraulic gradient of 0.0133, the throughflow amounts of 15,250 m^3/day on average or 5.6 Mm^3/year. This amount of throughflow then will be adjusted during the model calibration.

Abstraction

National Well Inventory (MWR, 1995) provides an estimate of crop area based upon the volume of water used. It has been used to estimate the gross water demand for agriculture. However, there is considerable uncertainty in the estimations of the amount that is actually used by crops based upon the gross demand. Calculations of net demand require detailed information concerning the efficiency of different irrigation practices, crop types and distribution systems. The locations of all the known groundwater abstraction locations in the study area are shown in Fig. 5. These comprise 2,697 governmental and private water wells and most of them are private wells. The owners drilled their wells tapping layer 1 (recent alluvium) to reduce the costs. Mott MacDonald, 2013 undertake a water balance computation study for all Oman. During the study, they analyzed the USGS landsat satellite imagery for 2005 to provide estimates of agricultural demand and to allow comparison with the agricultural census undertaken by the Ministry of Agriculture and Fisheries, 2005. Landsat satellite imagery is considered to provide the most accurate means of estimating the net crop demand. The method uses crop area, the estimated evaporation and the crop coefficient. Coefficients for the crops have been considered based on the Food and Agricultural Organization guidelines (FAO, 1998). The net water demand undertook by Mott MacDonald, 2013 is summarized in the water balance section.

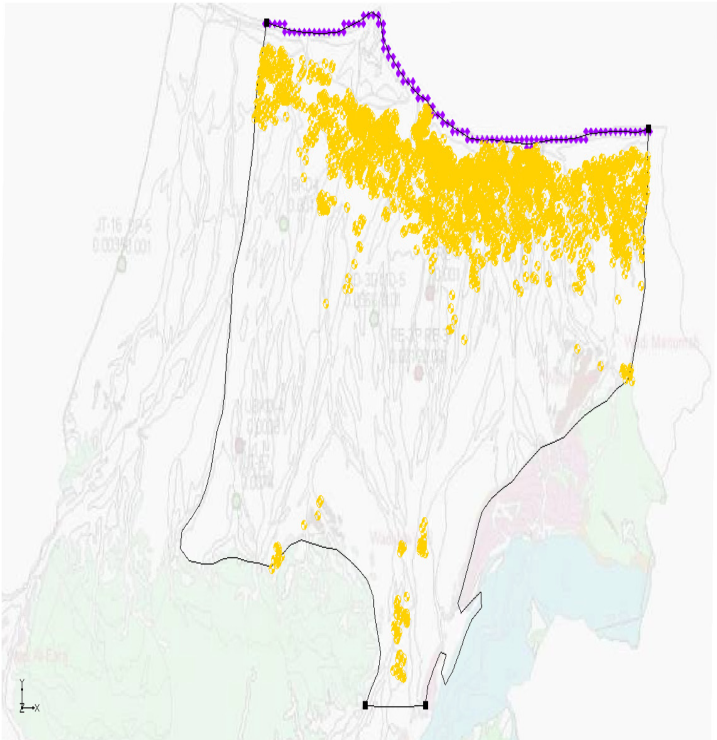


Fig. 5: Abstraction wells

Aquifer Properties

Pumping tests were conducted at some locations to define the aquifer parameters; transmissivity (T), hydraulic conductivity (K) and specific yield (Sy) or storativity (S). Given the uneven distribution of data, it is difficult to identify any significant patterns in the T distribution especially in the southern parts of study area. There is a relative absence of appropriate values of S to represent realistic conditions within the study area. The calculated K values recorded in the aquifer database (MWR, 1995) range from 0.5 to 47.8 m/day. Storativity values are difficult to be interpolated over the study area, their values also recorded in the aquifer properties database range from 10^{-2} to 6×10^{-4}.

Recharge

During their water balance computation study Mott MacDonald, 2013 also calculated various recharge components over the catchments of study area. These components include recharge from rainfall, wadi system, urban network, and dams. The methodology of rainfall recharge is derived from the SCS modeling (Soil Conservation Service, 1971). An assessment of the amount of water lost to wadi recharge was also made using the SCS methodology to determine the amount of rainfall which is converted to runoff and consequently wadi flow. As the wadi flows downstream, it loses water based upon a leakage rate. Urban recharge is a direct result of urban water supply and includes leakage losses from water supply distribution systems and return flows from sewage effluent. Recharge dams are used to increase the amount of recharge from wadi flow. The calculation of recharge from the dams is based on rating curves and the relationships of flows to the volume. All the calculated amounts of different recharge components (Mott MacDonald, 2013) are summarized in the water balance section.

Water Balance

A water balance has been used to assess the contributions of each flow component to the flow regime in the south Batinah coastal plain catchments. Total and average flows for 1992 to 2010 are provided in Table 1. The water balance changes over time were presented as shown in Fig. 6.

There is an inbalance between the inflows at (35 Mm^3/year on average) and the outflows (126 Mm^3/year on average). The balance is met by abstraction from aquifer storage and inflow from the sea amounts to 91 Mm^3/year. As can be seen from Fig. 6, rainfall is variable from year to year with the maximum amounts of 34, 66, and 63 Mm^3/year in 1995, 1997, and 2007 respectively. Wadi recharge is dependent on the amount of rainfall and subsequent runoff from the HSG mountainous areas. Agricultural abstractions, which are used to meet the irrigation demands, are calculated to be 123 Mm^3/year. Inputs to the catchments in the study area from rainfall recharge 16 Mm^3/year, wadi recharge 9 Mm^3/year, urban recharge 3 Mm^3/year, and 1 Mm^3/year for dam recharge. The calculated groundwater throughflow as previously stated is 6 Mm^3/year.

The conclusion that can be drawn from this water balance is that the exploitation of the aquifer has been heavily dependent on the release of water from aquifer storage, and that water use cannot be sustainable in the long term.

Table 1: Water balance between 1992 and 2010

Flow component	Total flow (Mm^3)	Average flow (Mm^3/year)
Rainfall recharge	290.8	16.15
Wadi recharge	161.1	8.95
Urban recharge	47.5	2.63
Dam recharge	24.5	1.36
Throughflow	101.3	5.63
Total Inflow	625.2	34.72
Abstraction – agricultural	2208.6	122.7
Abstraction – urban	67	3.72
Total Outflow	2275.6	126.42

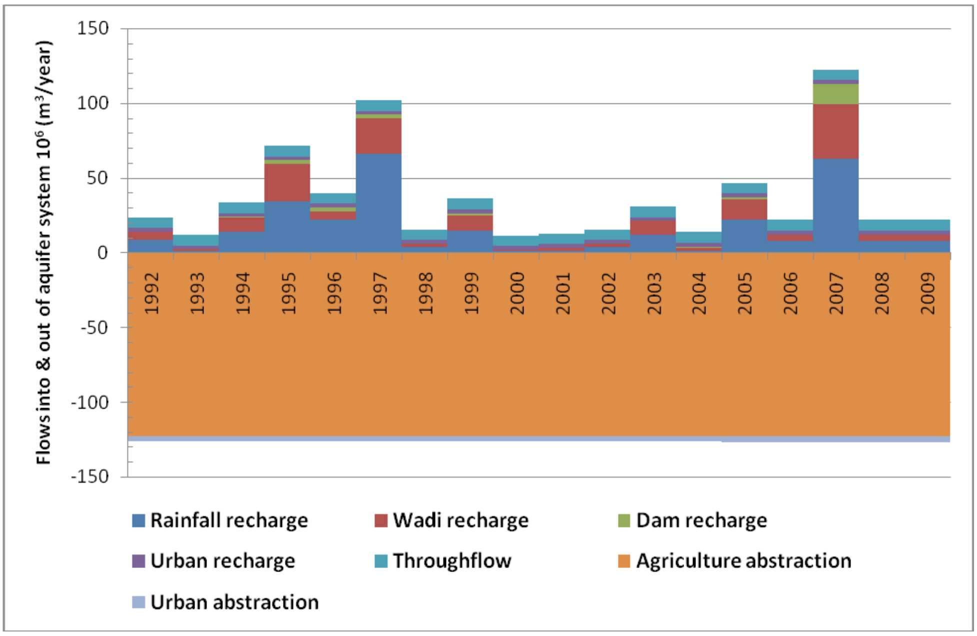


Fig. 6: Water balance for coastal plain catchments

Water Quality

Electrical conductivity (EC) values were measured for production wells existing in the study area. Not all wells have continuous records but only seven wells. These wells, located more than 5 kilometers from the sea coast, have records from 2002 to 2010. Total dissolved solids (TDS) have been used as the measurements of salinity. From the data, it is evident that TDS values have then been transformed by multiplying the provided EC values with coefficient 0.73 by applying the following general relationship (Ministry for Hydraulics and Energy of Mauritania, 2000) which only gives an approximate value for TDS: TDS (g/l) = EC (µS/cm)/10^3 x 0.73

Numerical Model

1. Model Package

The selection of the modeling software was governed by the hydrogeological conceptual model and the dominant physical processes of the aquifer system. The MODFLOW compatible MT3DMS and density-coupled SEAWAT modeling package (Harbaugh et al, 2000), developed originally by the USGS, and is well supported by commercially available, user friendly graphical interface GMS will be used in this modeling work.

2. Time Discretisation

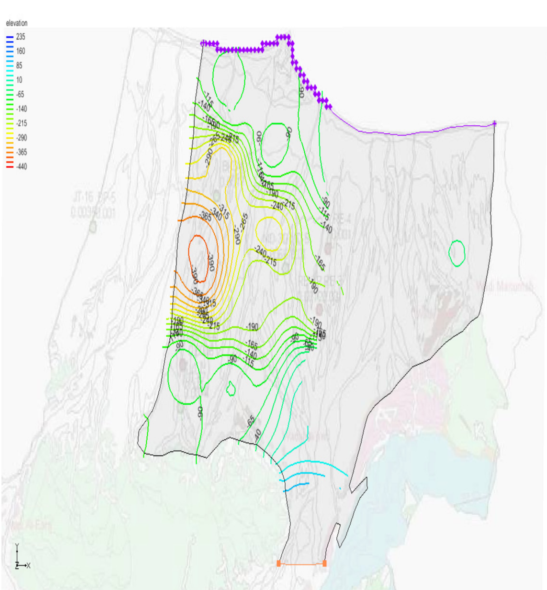
There are four models which have been used to calculate the groundwater flow in the study area. A steady state model was used to calibrate the throughflow from the HSG mountainous catchments into the coastal plain. The second model, transient from 1985 to 1992, is used to calculate the initial conditions for input into the third main model which has been used for transient calibration against historic observed groundwater levels during the period from 1992 to 2010. The last model has been used for the predictive scenario runs from 2010 till 2035.

Time variant components such as recharge and abstractions are included in the model with constant annual values. This time period where the input values are constant is known as a stress period. The stress period is divided discretely into time steps to obtain an accurate solution and result in smoother head versus time curves. A ten time steps in each stress period with a time step multiplier of 1.2 were used which produced smaller time steps at the beginning of a stress period resulting in better representation of the changes of the transient flow field. The predictive runs have been descretized into annual time period.

3. Model Domain and Boundary Conditions

The model domain of the coastal plain (Fig. 7) comprises an area of 1,116 km^2. It covers the extent of the aquifer system includes two layers which represent the Quaternary recent alluvium and the Tertiary ancient alluvium. The model area includes three catchments of wadi Bani Kharus in the west, wadi Ma'awil and wadi Taww in the east. A 500x500 m grid has been used for all models. In total there are 85 rows and 98 columns.

Based upon the borehole subsurface data; the base elevation of the two layers (Figs. 8 and 9) has been delineated using subsurface characterization model. The top of the model is set to be the topography, taken from the DEM provided by MRMWR. The base elevation of layer 1 varies from 135 masl to -140 masl, while it varies from 110 masl to -390 masl for layer 2 which truncated by the Hadramaut carbonate sequence in the eastern half of the study area. More layers may be needed to achieve the required accuracy when both flow and solute transport simulations are undertaken than when flow simulation alone is involved (Anderson and Woessner (1992), Zheng and Bennett (1995), USGS (2002)) therefore; each model layer is subsequently divided into 4 units to sum-up with a total of 8 layers.



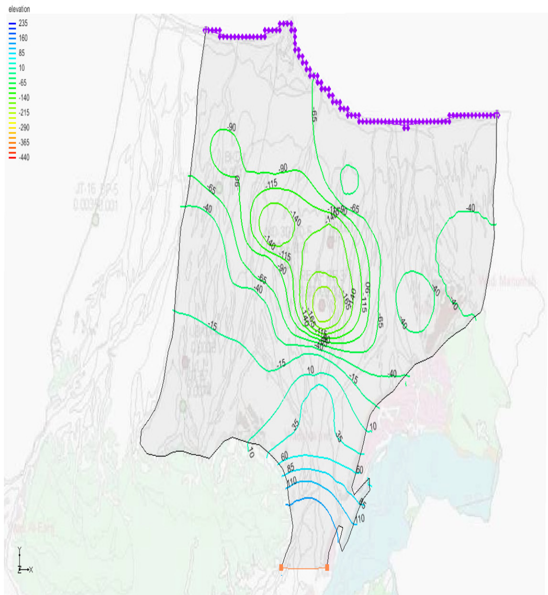
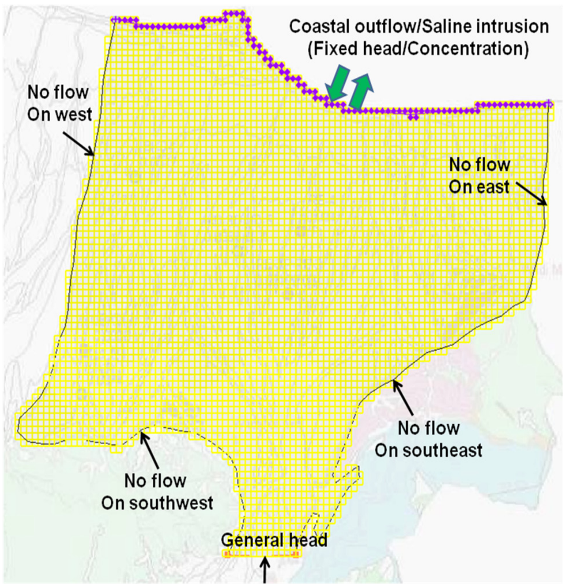


Fig. 7: Model domain and boundary conditions **Fig. 8:** Base elevation of layer 1



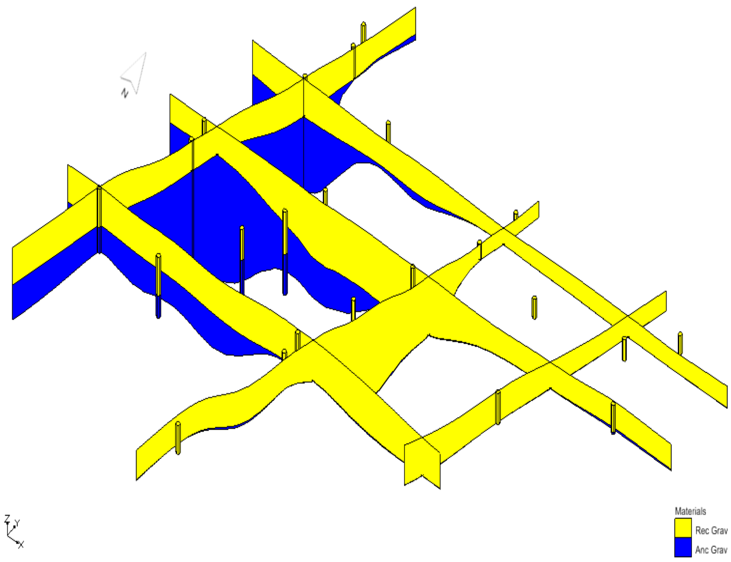


Fig. 10: Fence diagram **Fig. 9:** Base elevation of layer 2

A fence diagram of the two layers (Fig. 10) shows a trough in the central zone for the layer 1 and also occurred in the layer 2 in the western central zone as well.

The following boundary types were applied within the flow model (steady state and transient) where they represent the physical and hydraulic conditions on the external boundaries of the aquifer (Fig. 7): constant head boundary, head-dependent flux boundary, and constant flux boundary. The constant head boundary type assumes uniform hydrologic stresses. This boundary was applied to the Sea of Oman coastline cells. It was also applied to represent the saltwater interface at the Sea coast. A constant hydraulic head value of zero was given to all cells for both layers.

General Head Boundary (GHB) was applied in the model along alluvial part at the southern entrance window of lower wadi Ma'awil to allow for a flux to or from a model cell, governed by the hydraulic gradient between the boundary and the model cell, and a hydraulic conductance term. The flux was determined through iterative calibration which contributes throughflow to the coastal plain.

Special case of constant flux boundary (zero flow boundaries) was represented to the low impermeable rocks of Samail ophiolite in the southwestern side, HSG and Hawasinah nappe in the southeastern side along the contact between these rocks and the alluvium. They also applied to the western and eastern boundaries of the model domain where the flow lines are parallel to the groundwater flow from the south towards the north.

Point and areally distributed constant flux features were used to represent the following hydrological stresses to the flow regime: groundwater abstraction from wells, annual precipitation on the plain, infiltration from municipal network beneath urban areas, infiltration from wadi flow, and infiltration beneath the recharge dam sites.

Well Abstraction

For the purpose of steady state model case, a long term average abstraction volume (26.5 Mm^3/year) was applied. However, for the transient case there were two abstraction volumes applied to the model; 151 Mm^3/year during the period (1992 to 2000) based on abstraction sensitivity analysis undertaken during this period, while the volume of 126 Mm^3/year (2000 to 2010) based on the annual net crop demand according to Mott MacDonald's computation study. The abstraction amount of 151 Mm^3/year was reasonable since the agricultural activities at a maximum level during the corresponding period. The total number of abstraction wells included within the model domain comprised 2,297 wells. A proportion factor has been used that converts abstraction values initially estimated at every well location into the obtained abstraction volumes during each period. As is clear from abstraction well location map (Fig. 5), the majority of the wells are located in a narrow strip along the coast. Most of these wells are shallow-dug boreholes that are tapping the recent alluvium.

Aquifer Properties

Although considerable aquifer testing has been conducted, aquifer properties demonstrate that most of the testing has been designed to evaluate the bore itself, as opposed to testing particular geological units. Hydrogeological analysis is further constrained by the facts that bore construction details are unknown; and many lithological descriptions lack stratigraphic interpretation. Zoning of the hydraulic conductivity (K) was created using the data determined at 26 borehole locations (Fig. 11). It was used an average values of K in each zone. The obtained K zones can be realistic in the northern part of the study area as most of the test locations exist. It can be concluded from the data that K values for the recent alluvium aquifer varies between 0.5 and 48 m/day, while it attains a low value of 0.2 m/day for the ancient alluvium aquifer since only one or two boreholes tested in this aquifer layer. Due to the uncertainty with the parameter values the initial K will be adjusted during the model calibration.

There are insufficient data available on the storage coefficient (S) to be able to create zones. Specific yield and storage coefficient applied in the final calibrated transient model is uniform across the layer, at 2×10^{-1} and 6×10^{-3} consistent with values determined from aquifer testing for layer 1 and layer 2 respectively. During model calibration it was concluded that these values have been maintained unchanged as any variation greatly affect on the model calibration.

Recharge

Recharge to the model domain has been taken place through various components. It comes through direct recharge from rainfall, infiltration of wadi flow and urban recharge due to network leakage. It also comes from recharge dam zones. The model domain was divided into zones representing each recharge component. The recharge components have been introduced to these zones as constant annual values. The zones of various recharge components are presented as shown in Fig. 12.

Initial Conditions

Initial conditions for the main transient groundwater model have been provided by a transient model which runs from 1985 to 1992, the period of time prior to the start of calibration of the main model. Initial conditions (groundwater heads and boundary throughflow) obtained from a steady state model run simulating 'pre-abstraction' conditions were imported into the preceding transient model.

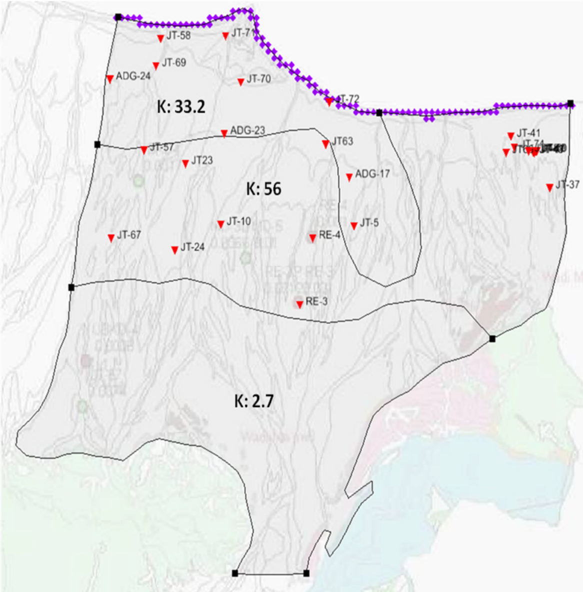


Fig. 11: Hydraulic conductivity zones (m/d)

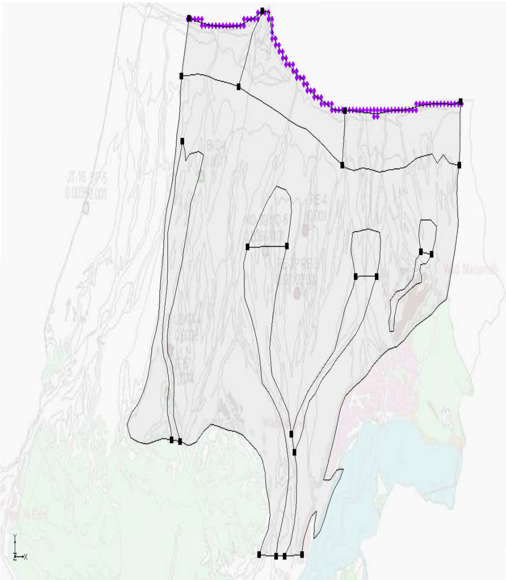


Fig. 12: Recharge flux zones

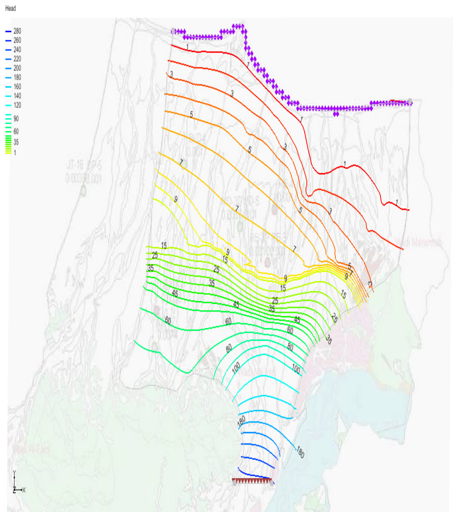
Initial conditions for the main transient groundwater model have been provided by a transient model which runs from 1985 to 1992, the period of time prior to the start of calibration of the main model. Initial conditions (groundwater heads and boundary throughflow) obtained from a steady state model run simulating 'pre-abstraction' conditions were imported into the preceding transient model.

Steady State Calibration

The steady state flow model simulates the pre-abstraction groundwater system and provides initial condition for the transient simulation which begins in the period preceding the main transient model. The model water level configuration is presented in Fig. 13. The steady state groundwater balance component values are presented in Table 2. The groundwater balance shows that the total input to aquifer system is 36.5 Mm^3/year, of which almost all input to the layer 1. The calculated throughflow was 7.5 Mm^3/year which is in close agreement with preliminary throughflow calculation of 5.6 Mm^3/year (see Table 1).

Transient Calibration

The transient model simulates the period from January 1992 to December 2009. Groundwater level hydrographs from observation wells are compared with the simulated water levels through time to assess the calibration. A scatter plot of the average simulated groundwater levels versus the average of the observation levels (Fig. 14) demonstrates a generally close match; except boreholes in the immediate vicinity of the dams (the circled areas in Fig. 14) are less well calibrated owing to uncertain water levels due to the proximity of dam zones. The model calibration performance shows that initial conditions are simulated well. It is therefore it can be used to make predictions.



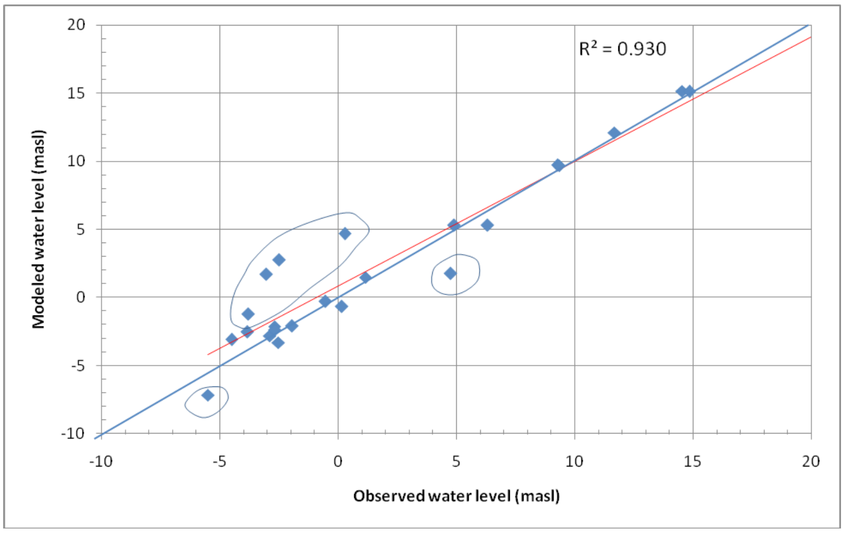


Fig. 14: Calibrated water level compared with observed

Fig. 13: Steady state groundwater level

Table 2: Steady state water balance components (Mm³/year)

Aquifer layer	Coastal boundary Outflow	Throughflow	Recharge	Abstraction
Layer 1	10	7.2	29	26.5
Layer 2	---	0.3	--	--
Total	10	7.5	29	26.5

Simulated groundwater level contour maps have been produced for 1995, and 2010 (Fig. 15). The left map is representing more abstraction period (1992-2000), whereas the right map is representing less abstraction for the subsequent period (2000-2010).

The average groundwater balance for the model period is shown in Table 3. In general terms, the largest flow component presented is groundwater abstraction where it is about 137 Mm³/year. The saltwater intrusion flux represents a considerable amount where its average annual was 46 Mm³/year and substantial amount (55 Mm³/year) is also taken from storage as expected. The total average annual inflow (throughflow and various forms of recharge) is about 36 Mm³/year.

The simulated annual groundwater recharge in the period 1992 to 2010 indicates that the annual groundwater recharge to the aquifer system is ranging from 4-15 Mm³ in dry years 2000, 2001, 2002, 2004, and 2006 to 65-97 Mm³ in wet years (e.g. 1995 and 1997) to more than 117 Mm³ in the wet year 2007 with an average of 28.5 Mm³ per year. The rate of abstraction to groundwater recharge varied from 16 folds in the dry years to only 2 folds in the wet years. The average annual abstraction rate over the whole period (1992-2010) attains an amount of 137 Mm³ and thus it is 5 fold the average recharge rate (28.5 Mm³/year).

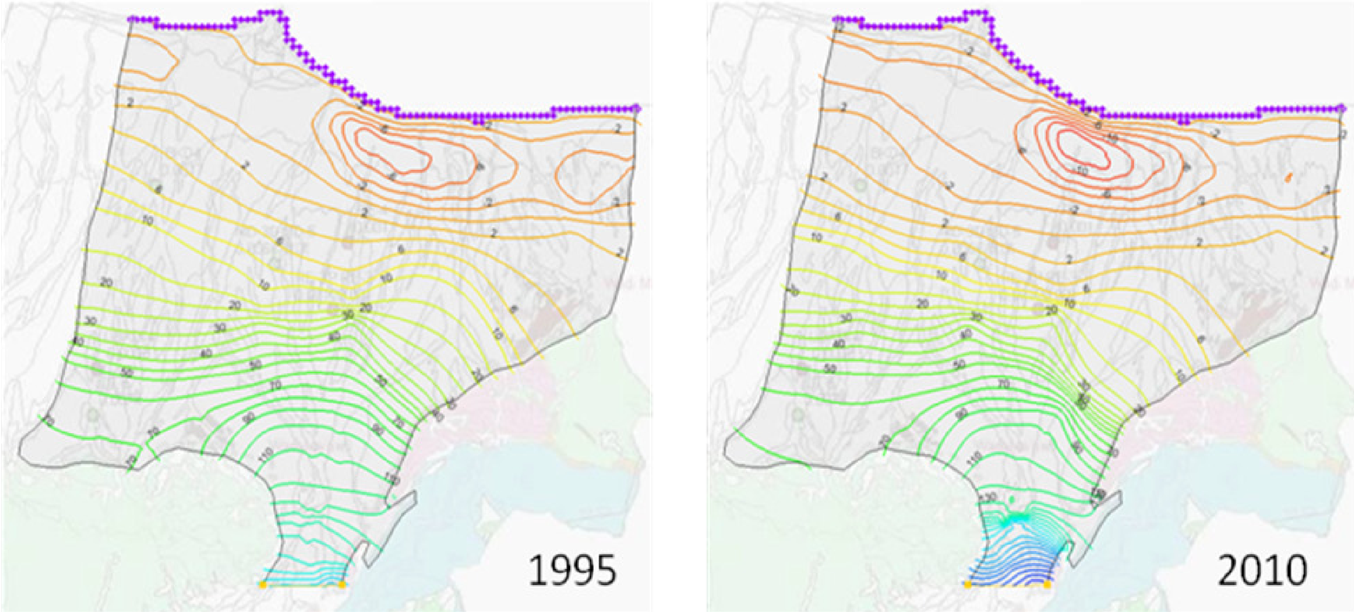


Fig. 15: Simulated water level

Table 3: Average simulated groundwater balance for the model period (1992–2010)

Flow component	Inflow		Outflow	
	m³/day	Mm³/year	m³/day	Mm³/year
Storage change	150,496.3	54.9	--	--
Coastal boundary	126,890.7	46.3	--	--
Throughflow	19,368.5	7.1	--	--
Recharge	78,140.7	28.5	--	--
Abstraction	--	--	374,896	136.84
Total	374,896.2	136.8	374,896	136.8

Sensitivity Analysis

Parameter sensitivity was tested during the model calibration process and testing the sensitivity of the other water balance components. Each of the key model parameters were varied to review the criticality of this parameter on simulated water level. The model calibration process demonstrates that the model results are not greatly affected to recharge parameter. However they are sensitive to variations in aquifer property parameters as well as abstraction quantity. The analysis shows that it can reduce the sum of squared residuals by multiplying the K parameter values in the northern two property zones with 1.8. This is confirmed by analysis of the model results. However, in the southern property zone it has to greatly reduce its amount reach 27% of the initial value. This is consistent with the higher water level in the southern area, where reducing the conductivity generally results in significant increases in the simulated water level. The aquifer storage was deemed to have a negligible influence. It is apparent that increasing in the abstraction rate by 20% in the first half of simulation period (1992-2000) would be required to appropriately improve the model calibration and simulate observed water level in this period.

Transient Flow Prediction

There are a number of scenarios for future aquifer system utilization. In order to understand the long term effects of changes to the assumed treated wastewater injection and/or proposed reduction of abstraction amounts, the model runs from 2010 until 2035. It was assumed that, for each predictive run, the groundwater flow and the hydrogeology remain the same as the calibration model.

Changes have been made to some aspects in the model to adapt it for predictive runs. As recharge is highly variable through time; it is therefore difficult to produce a recharge time series for the future. Steady state recharge values have been used for each recharge zone. The predictive scenarios run over annual stress periods meaning that time variant parameters are averaged on a yearly time bases. Initial heads for the predictive model are the heads at the end of the calibrated model in 2010. The predictive scenarios are summarized as follows:

i. Base case: Evaluate the current aquifer utilization with no any interventions
ii. Pred. 1: A scenario to evaluate the current utilization plus tertiary treated wastewater injection from 2016;
iii. Pred. 2: A scenario to evaluate reduction of the current utilization to 80% from 2016 plus tertiary treated wastewater injection from 2016;
iv. Pred. 3: A scenario to evaluate reduction of the current utilization to 80% from 2016 but excluding treated wastewater injection.

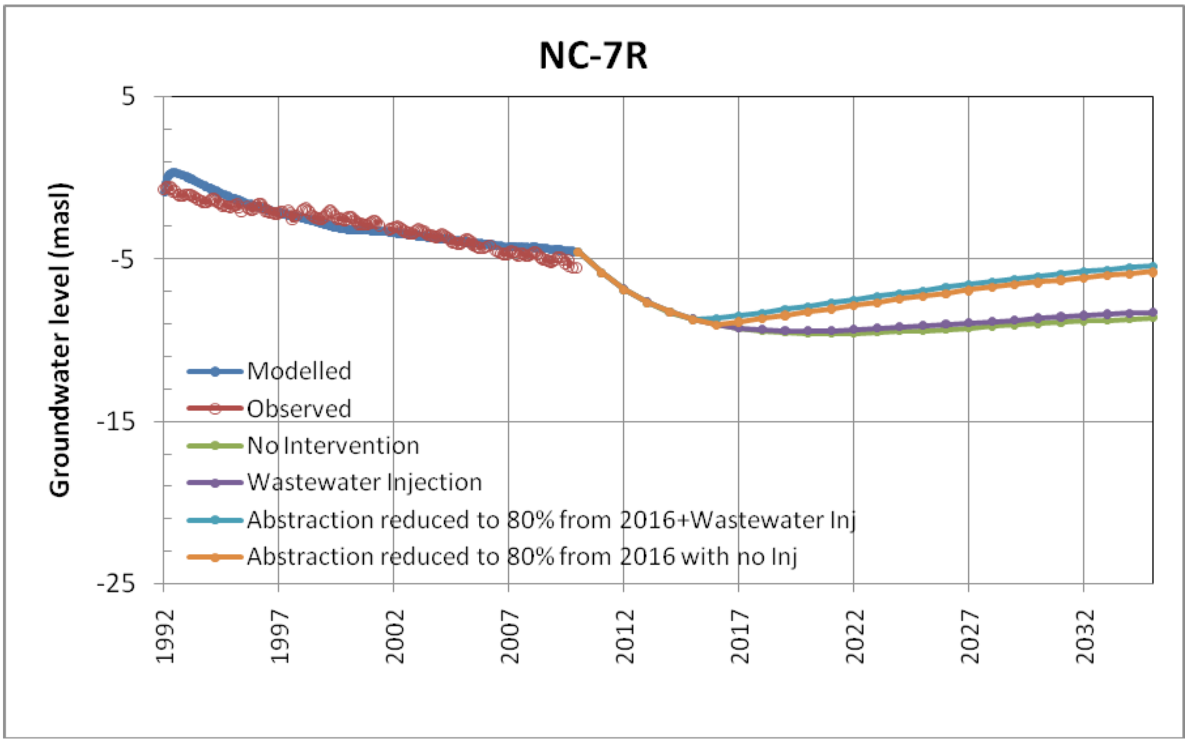


Fig. 16: Groundwater level hydrograph

The base case simulates the water level of current utilization to 2035, without any interventions. Water level hydrograph for the well NC-7R (fig. 16) shows the predicted water level changes, along with the measured water level and model calibration performance. The predicted water level for the base case for 2035 is illustrated on fig. 17 where it decreases to more than 35 m below sea level in the northeastern side.

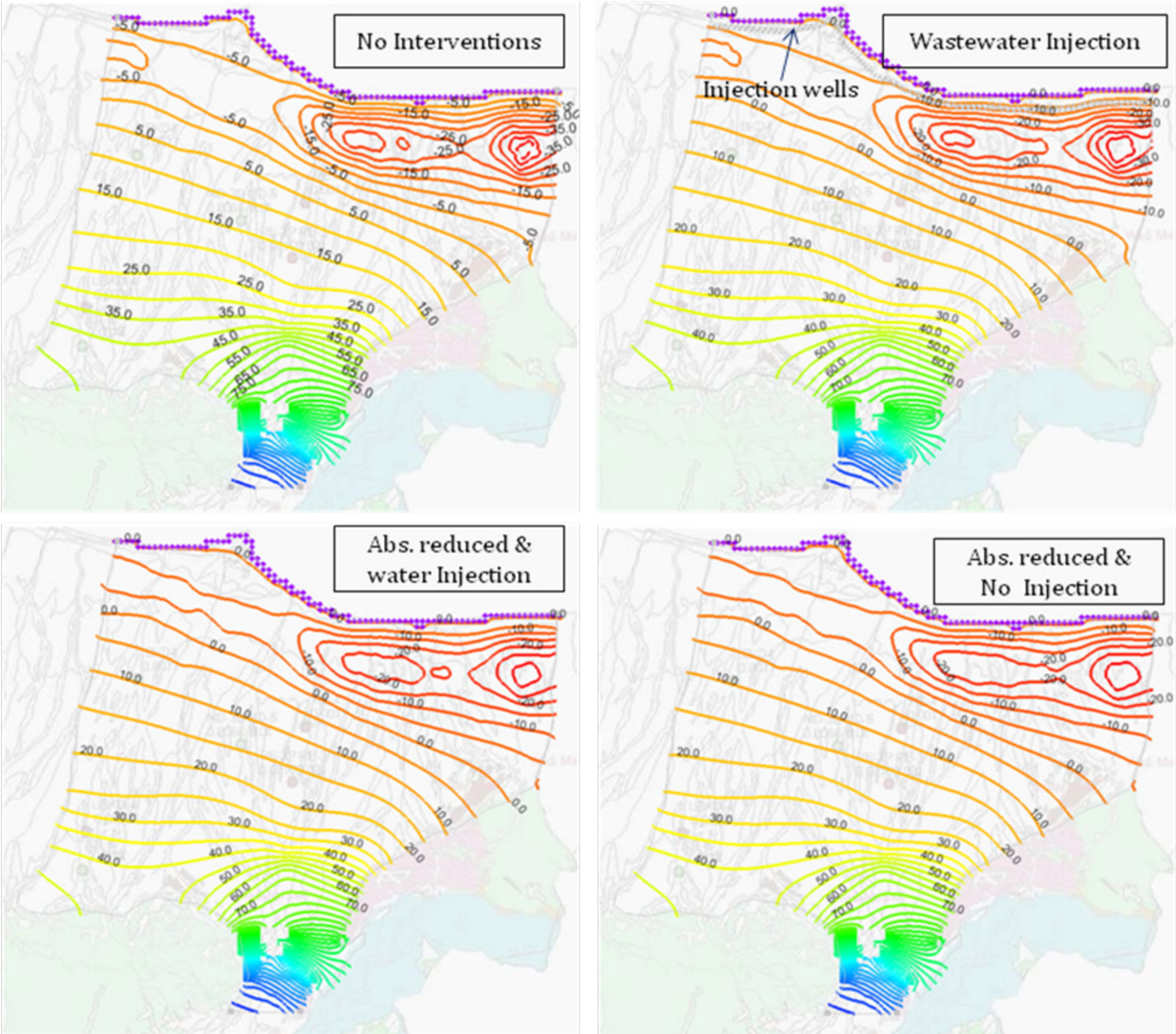


Fig.17: Simulated water level for 2035

Wastewater treatment is undertaken by Haya Water Company (http:/www.haya.com.om). The treatment is carried out to the tertiary level. The tertiary treated wastewater volume is 36.5 Mm^3/year which represents 46% of the urban water. Most of it is used for parks irrigation and landscaping. This volume is expected to reach 54.8 Mm^3/year by 2015 (Al Wahaibi, 2011). However, Zekri, et al, 2013 expected an excess of the tertiary treated wastewater of 31 Mm^3/year by 2015. It was proposed with providing the expected excess of tertiary treated wastewater to artificially recharge the aquifer system by an amount about 11.6 Mm^3/year. The artificial recharge is supposed to be via 79 injection wells distributed 500 m apart along the coastal zone (Fig. 17) to cope with and alleviate salinity increasing along the coast.

Zekri*, et al,* 2013 evaluated the cost estimation using quaternary treated wastewater to artificially recharge groundwater aquifers. The fixed costs include wells, pumps, pipes, treatment system, basin construction and land acquisition. The variable costs include basin cleaning, basin skimming, pumping and management costs. The total cost varies between USD 0.353 and USD 0.55 per cubic meter, depending on the cost of electricity, the interest rate and the life span of the project.

Pred. 1 is identical to the base case except for the inclusion tertiary treated wastewater injection from 2016 onwards. The treated wastewater injection has a small effect on the lowering of water level due to abstraction except a narrow strip along the coast (fig. 16). However, it has a remarkable influence of saline inflows from the coast, as discussed in the next section. The predicted water level for Pred. 1 is illustrated on fig. 17.

Pred. 2 is Pred. 1 however; current abstraction utilization has been reduced to 80% from 2016 onwards. The groundwater level hydrograph (fig. 16) also shows the response to both interventions where some increase of water level has been noticed. The predicted water level for Pred. 2 is presented on fig. 17, where it shows the response through the abridged water level contours. The recovery of the water level reaches 7 m in Taww catchment in the eastern side of the study area.

Pred. 3 is Pred. 2 however; treated wastewater injection has been excluded. The response to wastewater injection is fairly small compared with that of abstraction reduction (Fig. 16). The predicted water level for Pred. 3 is also presented on fig. 17.

Seawater Intrusion

Based on the calibrated transient flow model, a coupled-density transport model was developed. The transport solves the advection-dispersion equations in three dimensions based on calculated heads and flows derived from the transient groundwater flow model.

Groundwater salinity data plays an important role for developing the transport model. The salinity data obtained are imperfect because measurements were taken at the top of water column inside the well. In addition to mostly electrical conductivity (EC) measurements rather than laboratory analysis determined Total Dissolved Solids (TDS). The boundary conditions for salinity include seawater concentration (TDS 35 g/l) at the coastal boundary for both layers. Tertiary treated wastewater injection wells near the coast for post-2016 simulations (TDS 1.5 g/l). According to (Zheng and Bennett, 1995) when using the transport model, sufficiently small time steps are recommended to reduce numerical dispersion. In the present work, 10-days time steps have been applied.

Trials have been undertaken to estimate the longitudinal dispersivity. Value of 1,250 m was found to give an acceptable match with field salinity distribution. Smaller value of longitudinal dispersivity (125 m) was chosen for the lesser transmissive layer 2. The horizontal transverse dispersivity was set to 0.1 of the longitudinal values, consistent with best practice approaches (Zheng and Bennett, 1995). Vertical transverse dispersivity was set to 0.01 m.

1. Transport Model Results

The model simulation of groundwater salinities at January 2005 is compared with the field data at January 2005 as shown in Fig. 18 (salinities presented as contours of TDS). The model results and the field data show a reasonable match.

To illustrate the predictive utility of the model, some predictive runs (2010-2035) were devised based on the calibration model for the period 2002-2010. The Pred. 1 includes the simulation without any interventions. Salinity contours are presented in Fig. 19. The Pred. 2 includes the simulation of a proposed tertiary treated wastewater injection in 2016 onwards. Wastewater injection boreholes (79 wells) located along the coast at an average rate 32,000 m^3/day and with a concentration of 1.5 g/l TDS.

The salinity is also illustrated with the injection scheme from 2016 in Fig. 19. It also shows contour plots for the same time with abstraction reduction to 80% from 2016 plus injection scheme (Pred. 3). Pred. 4 includes the simulation of the abstraction reduction to 80% from 2016 but without the injection scheme as provided in Fig. 19.

It was clearly noticed more salinity reduction with applying wastewater injection than that with applying abstraction reduction owing to the effective role of water injection. It was also noticed that applying both interventions there has been a reduction in salinity reaches about 5.5 g/l near the injection wells. Even applying both interventions, then by the year 2035, the eastern coastal zone still will be affected to some degree by salt intrusion. Similar effects but to a lesser extent can be noticed for western coastal side. Providing an extra amount of treated wastewater to artificially recharge the aquifer system is forcing the saline intrusion to retreat especially in the eastern side.

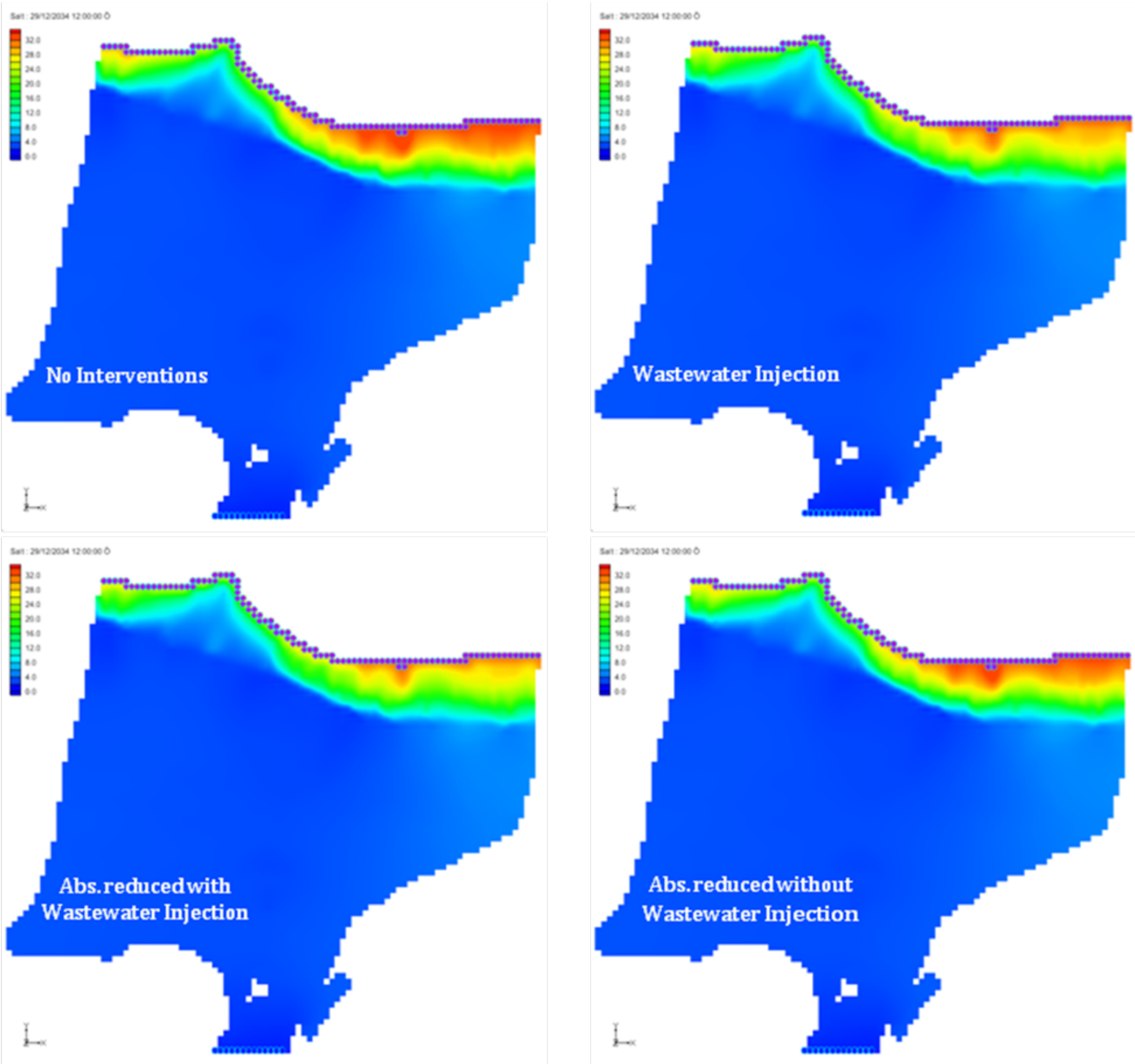


Fig. 18: Modeled and observed salinity for 2005 (g/l)

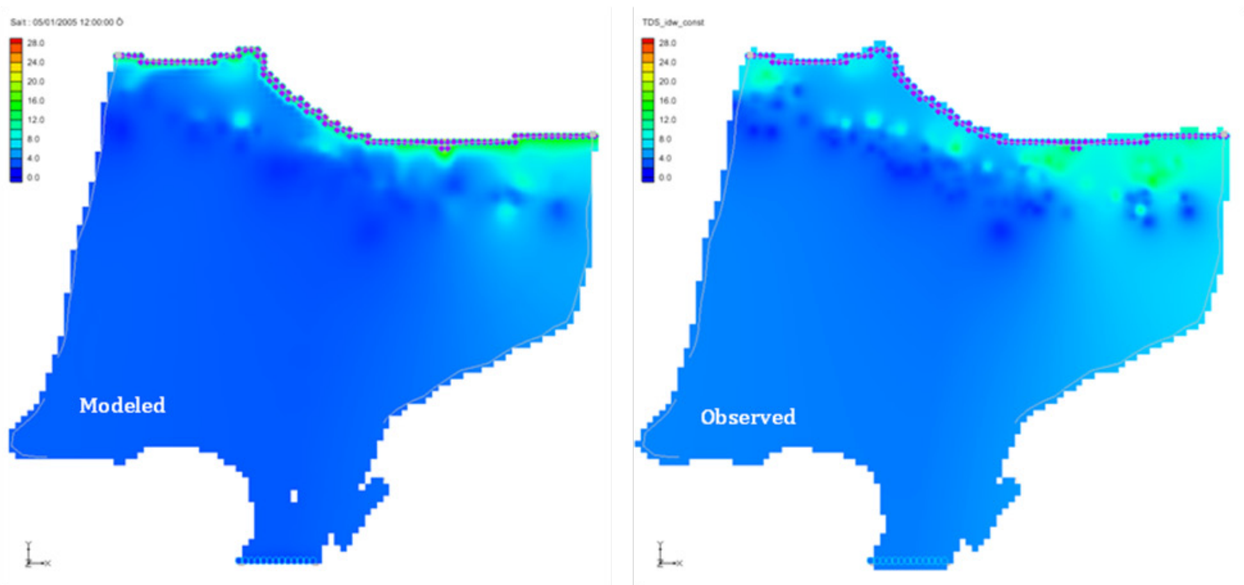


Fig. 19: Predictive salinity for 2035 (g/l)

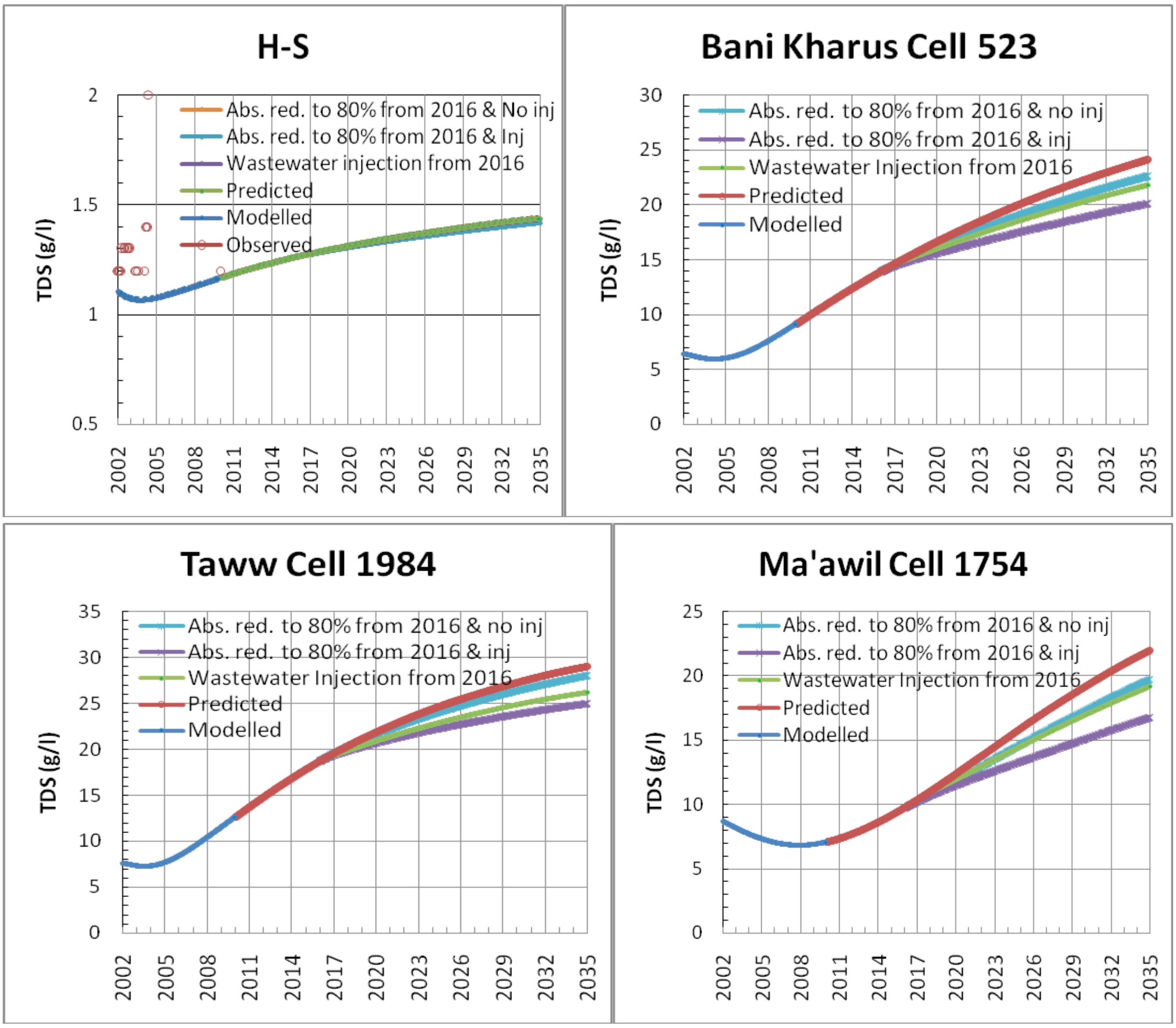


Fig. 20: Salinity hydrograph

To further illustrate the performance of the model, the simulated salinity hydrographs for selected borehole and selected cells in Bani Kharus, Ma'awil and Taww catchments are provided in Fig. 20. The salinity hydrographs show range of salinities: from low range (1.1 – 1.4 g/l TDS covers most of central and southern areas, to mid-range (6 – 10 g/l TDS and high range (10 – 30 g/l TDS) near the coastal zone.

Conclusion and Recommendations

The Quaternary and late Tertiary is the main aquifer system existed in south Batinah catchments. The area faced problems with lowering hydraulic heads and salt water intrusion. There is a need to better understand the hydrogeology of the region; assess the recovery of groundwater level following the wastewater injection into the aquifer system and proposed decreasing abstraction rate in addition to assess the effect of both interventions on the water level and progress of seawater intrusion in the area.

The aquifer system is conceptualized in two layers namely the recent and ancient alluvium. Recharge occurs by various components; direct recharge from rainfall, recharge through active wadis, dam recharge and urban recharge. Recharge also occurs by throughflow from HSG in the south. The abstractions mainly used for irrigation. It largely exceeds the total inputs to the system, therefore largely water abstraction comes from storage and seawater intrusion as well and this will not be sustainable into the long term.

A MODFLOW model has been constructed, based on the understanding developed in the conceptual model with a total area of 1,116 km^2. The boundaries of the model are represented by no flow boundaries in the west, southwest, east and southeast; constant head in the north and general head in the south. A steady state model was developed to represent the pre-abstraction conditions using long term average flow, and to develop the initial water level to be used in transient model (1985 to 1992) prior to the start main model calibration.

A transient model is developed from 1992 to 2010. In transient model, two parameters have been used for calibration hydraulic conductivity and abstraction. These parameters were varied to match the model simulated heads with the observed heads. Recharge is applied to the model as variable flux into eight flux zones. A good match of modeled heads compared to the observed was achieved.

The simulated annual groundwater recharge to the aquifer system is ranging from 4-15 Mm^3 in dry years to 65-97 Mm^3 in wet years with an average of 28.5 Mm^3 per year. The rate of abstraction to groundwater recharge varied from 16 folds in the dry years to only 2 folds in the wet years. The average annual abstraction rate attains an amount of 137 Mm^3 and thus it is 5 fold the average recharge rate (28.5 Mm^3/year). This explains the seawater intrusion which represents a considerable amount 46 Mm^3/year. There is a substantial amount 55 Mm^3/year is also taken from storage.

Prediction scenarios have been run using the same input parameters as for the calibrated model. Four predictive simulations have been carried out from 2010 to 2035 in order to understand the long term effects of changes to the assumed wastewater injection and/or 20% proposed reduction of abstraction amounts from 2016 onward. The predicted water level, with no any interventions for 2035, decreases to more than 35 m below sea level in the northeastern side. Applying both interventions is reflected on the recovery of the water level. It reaches 7 m in Taww catchment in the eastern coastal side.

A coupled-density transport model was developed based on calculated heads and flows derived from the transient groundwater flow model. Constant head boundary was also assigned seawater concentration (TDS 35 g/l) at the coastal boundary. Tertiary treated wastewater injection boreholes (79 wells) near the coast for post-2016 simulations at an average rate 32,000 m^3/day and TDS 1.5 g/l.

More salinity reduction is noticed with applying wastewater injection than that with applying abstraction reduction owing to the effective role of water injection. It was also noticed that applying both interventions there has been a reduction in salinity reaches about 5.5 g/l near the injection wells.

Some recommendations can be stated as follows: 1) Good gauges distribution to improve the accuracy of the model and thus groundwater management. 2) New observation wells drilled in the southern part of the area which has low density of data. 3) Enhancement a salinity monitoring program which will be based on periodical measurements including laboratory analyses, especially along the coastal zone, using bottomed bailers to sample screened zone of monitoring wells. 4) Public awareness and incentives to the land owners in the catchment and convincing them decreasing their abstractions, which could be undertaken through either the introduction of modern irrigation system or the introduction of water pricing and thereby giving water a monetary value. 5) Providing an extra amount of treated wastewater to artificially recharge the aquifer system, which is forcing the saline intrusion to retreat especially in the eastern side.

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SESSION 2C
GROUNDWATER MANAGEMENT

Keynote

Principles and Challenges of Integrated Water Resources Management: How a Concept can be Transferred into Practice for Coastal Arid Regions

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Technische Universität Dresden, Institute of Hydrology and Meteorology, Germany

Summary

Water scarcity, rapid population growth and climate change adaption strategies imperatively require a more efficient and sustainable management of water resources. Coastal systems in arid or semiarid regions are particularly at risk because they are mainly relying on limited groundwater resources. Continuously increasing water abstraction due to growing water demands tighten the hazard of sea water intrusion into coastal aquifer systems if it exceeds considerably the natural rate of groundwater replenishment. In this case, intrusion of salty water does not only menace the water quality of the aquifer but also the productivity of soils since they are then strongly affected by salinity. Integrated water resources management (IWRM) has been widely accepted as an overall strategy to come up with best long term solutions for such complex water related problems. It promotes a process for coordinated development and management of water, land and related resources, considering economic, social and environmental aspects. However, decision makers and experts around the world facing several reasons why the technical implementation of the IWRM concept is challenging, among them: (i) an integrated approach needs to consider different sectors and resources with their relevant players and stakeholders. Each of them having different interests and mostly contradicting objectives which have to be formulated in a multi-objective, multiple-decision maker water management problem; (ii) tools for decisions support are required which allow for evaluating the outcome/impact of different management options under future conditions and uncertainties. Numerical integrated models may help if they are able to portray processes and interactions between sectors and resources reliably and computationally efficient; (iii) best possible management strategies and measures should be developed. Optimization techniques might be helpful but challenging if the number of decision variables increases; and (iv) management decisions and derived measures for implementation should be accepted by local people and stakeholders. Participatory approaches of IWRM can support this acceptance and contribute to increased awareness.

Since the IWRM concept only offers a guideline or framework, specific solutions are needed to implement an IWRM process successfully. Those solutions have to be tailored to fit the individual hydrological, economic, cultural, and ethic characteristics of a region. Besides a discussion of those general issues of IWRM an example of a joint Omani-German cooperation project will be given within the keynote, which shows, how the IWRM concept can be transferred into practice from a technical point of view. The project focuses on the south Batinah region in Oman which is affected by saltwater intrusion into the coastal aquifer due to excessive groundwater withdrawal for irrigated agriculture. It aims to 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 for ensuring a sustainable management of arid and semi-arid regions. The APPM unites process modeling with artificial intelligence tools and evolutionary optimization techniques for managing both, water quality and water quantity of agricultural coastal regions. A few technical insights as well as its tailored application on the south Batinah region will be presented.

***Biogrpahy**: Dr.rer.nat. Jens Grundmann studied Hydrology at Technische Universität Dresden and received his Diploma in 2001. He worked as a research associate at the Institute of Hydrology and Meteorology and received his PhD in 2009 for a study about uncertainties in spatial distributed rainfall-runoff modelling. Afterwards he worked for the International Water Research Alliance Saxony founded by the Federal Ministry of Research and Education, Germany, as scientific coordinator of the Oman – German IWRM cooperation project and conducted research in the field of integrated water resources management of coupled groundwater-agriculture hydrosystems. Currently, he holds the position of the senior research associate at the chair of Hydrology of Technische Universität Dresden and is responsible for teaching and research. He is a lecturer for watershed management, hydrometry, and catchment modelling. He is also member of IAHS, EGU, and the German Hydrological Society and works as reviewer for several scientific journals.*

Groundwater Quality in Oman: Investigation of Arsenic Concentrations

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Abstract : Several samples of groundwater and plants have been collected from an area in Sohar (Batina region, NE Oman) where the water quality is affected by various activities such as mining, agriculture, and sewage. To characterize the quality of the groundwater, investigations have been made for As and Cu concentrations in waters collected from different wells and compared with local and international standards. Investigation of As and Cu concentrations in plants collected from mining and sewage areas revealed an important accumulation of these elements in leaves, the decomposition of which may explain partly the enrichment of As in the shallow groundwater relative to the deep groundwater. Comparison of the data with local and international standard values revealed that groundwater in the Sohar region is characterized by low concentrations in As, which implies that As poses no threat to water quality in the study area.

Keywords: Batina, arsenic**,** arid, sediments, standard, Sohar, mining.

Introduction

Arid areas with high temperatures 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. In the Sultanate of Oman, where there are more than 128,000 wells tapping the major aquifers, the total annual rainfall averages 100 mm/year with 0 and 350 mm extremes. Groundwater quality degradation is quite common in many arid countries, and Oman is no exception. Mining, oil industry, and salt-water intrusion are the most important sources of degradation of groundwater in Oman. Copper mining activities are well developed in Batina area (North Oman). Several studies have been made that focused on the quality of groundwater in Oman (Sharma and AL-Busaidi, 2001; Jamrah *et al.*, 2004; Yaghi, 2007). Jamrah *et al.*, (2004), established vulnerability map for Barka region (North Batina, Oman) using DRASTIC vulnerability index method in GIS environment by using groundwater quality data such as chemical and biological parameters. These authors concluded that this region is partially highly vulnerable to pollution especially the central part. A recent study by Yaghi (2007) on the chemical characterization of groundwater in the Batina area revealed a widespread contamination in Pb and Cr, which prompted different state agencies in Oman (the Ministry of housing, the Ministry of Health, the Ministry of Commerce and Industry and the Ministry of Regional Municipality and Environmental and Water Resources) to initiate programs for testing and monitoring on the chemical quality of waters in Oman.

The programs have already made some significant strides in gaining information about distributions and sources of a number of trace chemical elements which presence in some excess levels in surface and ground waters can be a serious health problem for the people. They have yet to start looking in natural processes (weathering of materials in the Earth's crust and geothermal fluids) or via human activity such as mining or mining-related activities (Eisler, 2004; Garelick *et al,* 2008). The main objective of the present study is to investigate the concentrations of As and Cu in waters collected from wells in the Batina area, where human activity has ranged from mining to sewage to agriculture. Plants have been known to be a significant source of dissolved metals in surface waters (Chaudhuri *et al.,* 2007). Hence, to gain an insight as to potential influence of natural plant debris on As contents in the well waters, an assessment has been made for As contents of the same species of a commonly occurring plant grown in the vicinity where well water samples were also collected.

The quality of groundwater collected during this study was analyzed in the context of the standards for the safe maximum concentration limits established by both the Oman government and the World Health Organization (WHO, 1999, 2001). Arsenic contamination of ground waters is found in many countries, particularly in Bangladesh, India, China, Taiwan, Japan, Thailand and a few others with less severity (Ahmad et al. 1997, Chowdhury and Jakariya, 1999; Guha Mazumder *et al,* 2010; Yiqun *et al,* 2014) The range of such variations in the As contamination remains still unclear.

Geology and Hydrology of the Study Area

The geological formations of Batina, which form part of a basin, have widespread signatures of tectonic activity involving faulting and thrusting. The basin rests on crystalline bedrocks, mainly ophiolites, that are mantled by unconsolidated alluvium deposits and sedimentary rock deposits, primarily limestones. The ophiolites impede groundwater flow and define the base of the hydrogeologic system. The crystalline rocks dominated by ophiolites formed when the Tethyan oceanic crust obducted against Arabian Plate in the Late Cretaceous between 90 and 105Ma. (Robertson et al, 1990; Hanna, 1995). Ophiolites consist in sequences of dunite, harzburgite, gabbros, sheeted dykes and pillow lavas. They make the main source for the alluvium resulting from weathering. The limestones are deposited during the Tertiary under shallow marine environment consequent to sea transgression.

The alluviums, formed during the Quaternary and unconformably rest on the ophiolites and which represent the main aquifers of the groundwater in the region, comprise gravelly poorly sorted sedimentary units that directly overlie the ophiolites in the major drainage system. The area is generally arid with varying rainfall. Total annual rainfall averages 100 mm/year with 0 and 350 mm extremes.

Material and Methods

During this study, waters were collected from several wells in different locations penetrating the alluvium-aquifer in Sohar (North of Muscat area) (fig. 1). These locations include sewage treatment areas, agriculture areas and copper-mining areas. Waters were also collected from two wells at downstream of these different areas and are considered a control area.

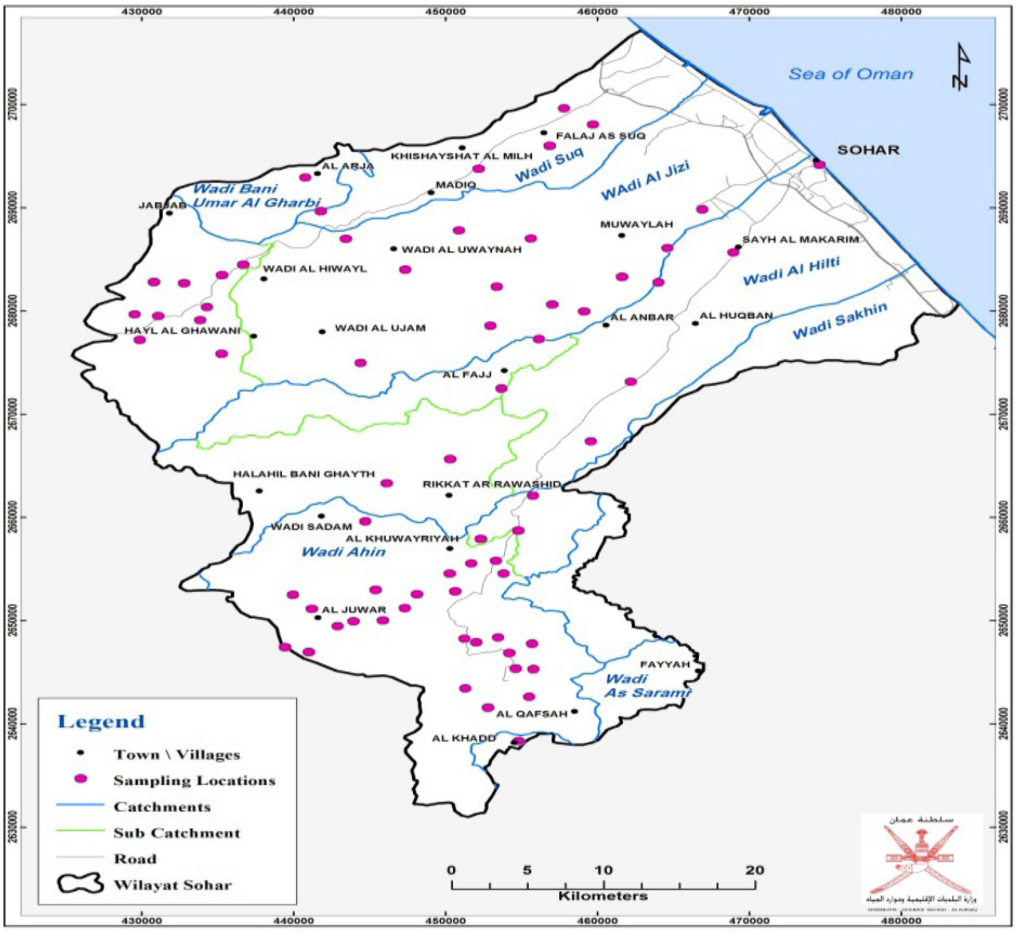

Figure 1: Batina Sampling Location

The different water samples have been collected in 500 ml polypropylene containers. Field analyses were carried out for pH, conductivity and temperature measurements. For the laboratory analysis, water samples were kept stored at 4 degrees C immediately after the field collection. To prepare the samples for the laboratory analyses, they were vacuum filtered through a membrane filter with 0.45 mm pore size. Laboratory analyses were conducted within 3 days of sample collection.

Plant samples were collected from mining and sewage areas. The leaves of about twenty individual plants from each plant sample were removed randomly and grouped in five separate batches. The plants of each batch were processed and analyzed separately, so that the chemical data of plants collected from each area represented an average of five sets of plant individuals in each case. In other words, instead of repeating the analyses for control of the analytical uncertainty, we managed the analytical reproducibility in analyzing systematically five batches of each plant at each step and averaged the data within a 2s error. In summary, each plant data in Table 2 represents actually an average measure of 100-125 individual plants that were grouped into 5 independent batches.

The collected plants were first washed five times with demineralized water. This washing was followed by a gentle ultrasonic treatment in a bath for about 10 minutes to remove any solid mineral particles that could have adhered at the surface of the plants. After removing from ultrasonic bath, the plants were washed again with demineralized water.

The procedure of digestion of plant sample followed the method of Semhi *et al.* (2009). The analyses started with drying the plant batches at 60°C for 24 hours and weighed them afterwards. Then each weighed plant amount was ashed in a Pt crucible at about 600°C for 45 minutes. The ash was transferred into a Teflon beaker and digested in ultrapure concentrated HNO_3 at a temperature of about 70°C for 24 hours and more if needed. The solution was then slowly evaporated to dryness by closing the beakers. Ten drops of $HClO_4$ were added afterwards to ensure dissolution of all remaining organic material, and the aliquot was evaporated again to dryness. The obtained solution was then prepared for analysis by dissolving the dried material with a known volume of 1N HNO_3. While waters were analyzed for As and Cu, plants were also analyzed for both As and Cu. Metal contents were determined using Inductively coupled plasma optical emission spectrometry (ICP-OES). Analytical precision ranged between 5 and 10%.

Results and Discussion

1. Groundwaters

Table 1 lists the pH, temperature (T), electrical conductivity (EC), and As and Cu concentrations of groundwater from different parts within the Batina area. As listed in table 1, concentrations of As in waters collected from wells in the copper-mining area ranged from 0.21 to 3.85 micrograms/liter, whereas that of waters from wells in the sewage area ranged from less than detection limit to 0.32 microgram/liter.

Table 1: Lists the pH, Temperature (T), Electrical Conductivity (EC), and As and Cu Concentrations of Groundwater from Different Parts within the Batina Area.

ID of groundwater from:	EC (µS/cm)	T(°C)	pH	Depth (m)	water level (m)	Cu (ppb)	As (ppb)
Cu mining							
1	3900	31.3	8.6	17.8	16.4	6.6	0.86
2	1357	33.6	7.32	15	12.5	19.3	1.26
3	8700	34	7.5	18.7	11.7	5.3	0.43
4	3900	31.3	8.6	17.8	16.4	O	0.21
5	3400	30.9	7.92	17.4	15.7	3.4	0.42
6	nd	nd	Nd	Nd	Nd	5.1	1.77
7	nd	nd	Nd	Nd	Nd	32.1	0.66
8	nd	nd	Nd	Nd	Nd	82.0	1.69
9	nd	nd	Nd	Nd	Nd	19.4	3.85
Sewage							
1	1000	31.1	8.4	17.5	16	Nd	0.26
2	5400	30.4	7.7	16.5	15.4	Nd	0.23

3	9000	31.1	7.6	17.8	16.5	Nd	0.32
Agriculture							
1	5200	30	7.6	7	5.1	ND	0.40
2	6400	30.3	7.6	8.5	6.2	ND	0.44
Contro	nd	nd	Nd	Nd	Nd	10.5	0.09
	nd	nd	Nd	Nd	Nd	2.7	0.07
1	670	30	8.38	18.5	15	Nd	0.21
2	365	33	9	25	12	0.20	0.64

(Nd*; not determined*)

In comparison, the waters from wells in the agricultural area had As concentrations between 0.07 and 0.44 microgram/liter. The concentrations of As in waters collected from control areas are from 0.21 to 0.64 microgram/liter. Taking the As concentration data collectively, it appears that the mining area groundwaters generally have relatively higher As concentrations, having concentration as high as 3.8 micrograms/liter, than those from the agricultural and sewage areas. What is significant here is that even in the mining area within the Batina region where the groundwaters were found with As concentrations as high as about 3.8 micrograms/liter, the groundwaters in the Batina region remained well below the limit of As concentration that is safe for drinking waters as the guideline set by either WHO, which suggested a maximum upper limit of 10 microgram/liter (Yamamura, 2003), or the US EPA (2001) recommending an upper limit of 5 microgram/limit (fig. 3). These recommended values are not strictly adhered by different agencies and organizations. Many countries still operate with 50 micrograms/liter upper limit (Gaus *et al.,* 2003; Hoque *et al.,* 2008). Oman has even a very strict upper limit of less than 0.1 microgram/liter As concentration for drinkable water. In the context of the Oman standard with regard to the safe upper limit for As in drinkable waters, the groundwaters in the mining districts and some ground waters in the agricultural areas could be considered as being unsafe for drinking unless prior steps are taken for the reduction of the metal to a safe level in the waters.

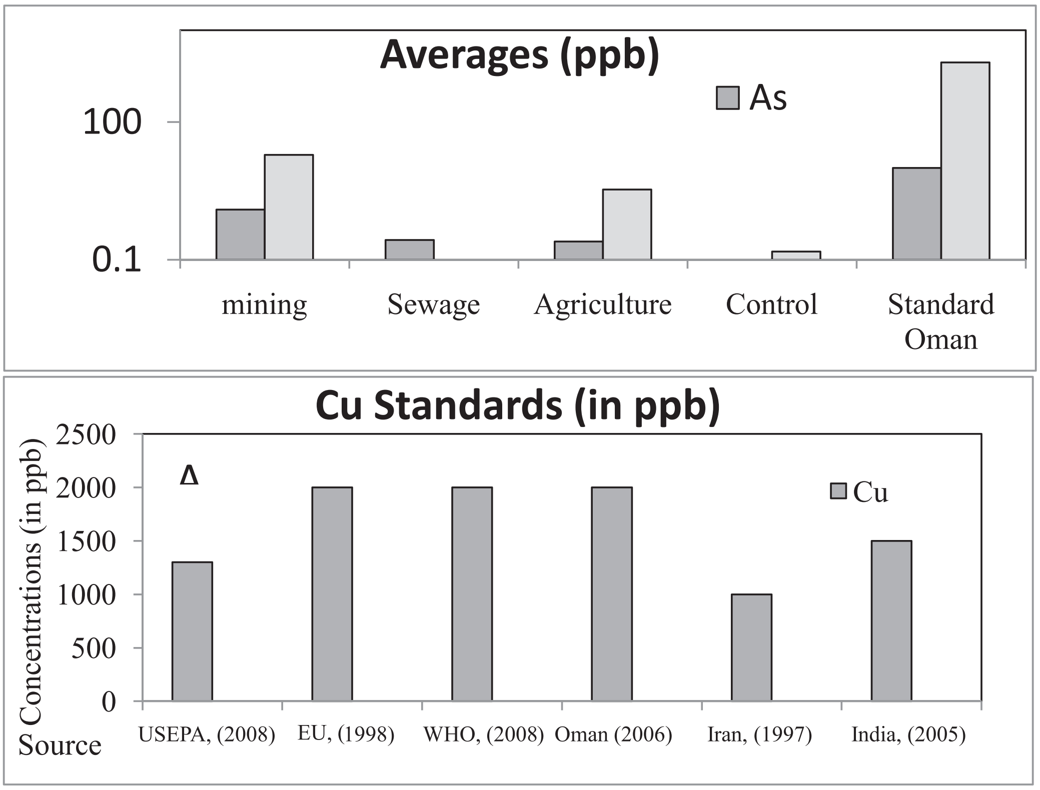

Figure 2: Average Concentrations of as and Cu in Groundwaters Collected During This Study

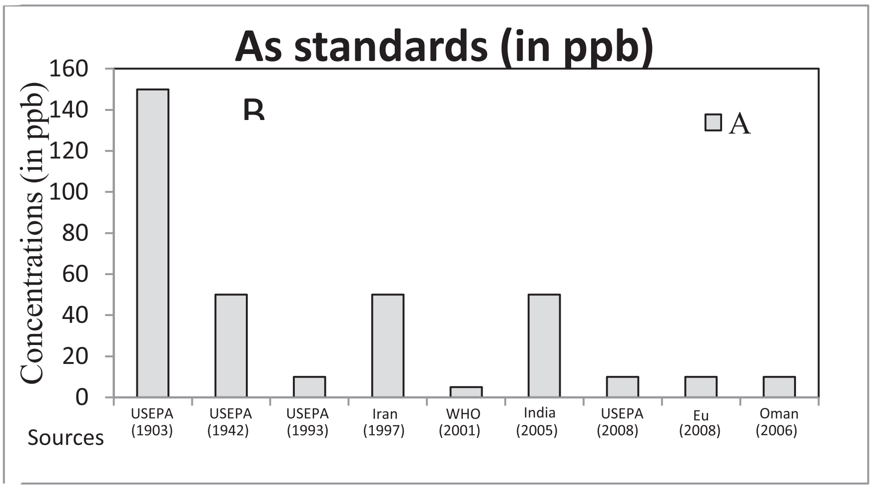

Figure 3: Standard Data of (a) Cu Standard in ppb, and (b) As,Standard in ppb

Regardless of differences in the perspectives about the safe upper limit for the As concentrations in groundwaters for their use for drinking and irrigation purposes, knowledge of the spatial distributions of As in groundwaters and understanding of the basis of such distributions are important to finding a means to alleviate any potential pollution threats to the natural water resources. The As loads in groundwaters are consequences of combined effects of the concentrations of the metals in the aquifer mineral media, solubility of the inorganic mineral matrices as may be influenced by pH and redox conditions and temperature, and living and dead organic constituents. The release of As from their organic and inorganic sources leading to their transport through the aquifer media may be highly influenced by the co-ordination of the metal with available ligands under the pH and redox conditions of the aqueous medium in contact with the aquifer surfaces. An examination of the electrical conductivity data with the As concentrations of the groundwaters in the mining area reveals that the two parameters are very poorly correlated, suggesting that a simple dissolution mode would not explain the spatial distributions of As in ground waters in the mining area. Geochemical complexities become increasingly apparent by looking at the spatial distributions of As in the groundwaters. In the mining region, shallow groundwaters were found with higher As concentrations than deeper groundwaters. This pattern of relationship in the As concentrations between the shallow and the deep groundwaters, with the shallow groundwaters being higher in As concentrations than deep ones in the copper-mining districts in Batina area, has been known as a globally common phenomenon (Hoque *et al,* 2008).

The sewage area groundwaters had a vertical profile of As concentrations which was unlike the mining area groundwater profile. In the sewage area, the deep groundwaters appeared to be higher in As concentrations than the shallow ones. For a lack of an adequate number of samples for analyses in this study, relationship of As concentrations to depth for groundwaters from the agriculture dominated area could not be defined.

The pH of groundwaters collectively within the mining district ranged widely from about 6 to 8.6 (see, table 1). The As concentrations appeared to be negatively correlated, but poorly, with the pH (Fig 4). The pH of groundwaters from the sewage area ranged between 7.6 and 8.4 and no relationship was found between the pH and the As concentrations of the ground waters. Only a single sample of groundwater from the agriculture was measured for the pH and it was found to be 7.6.

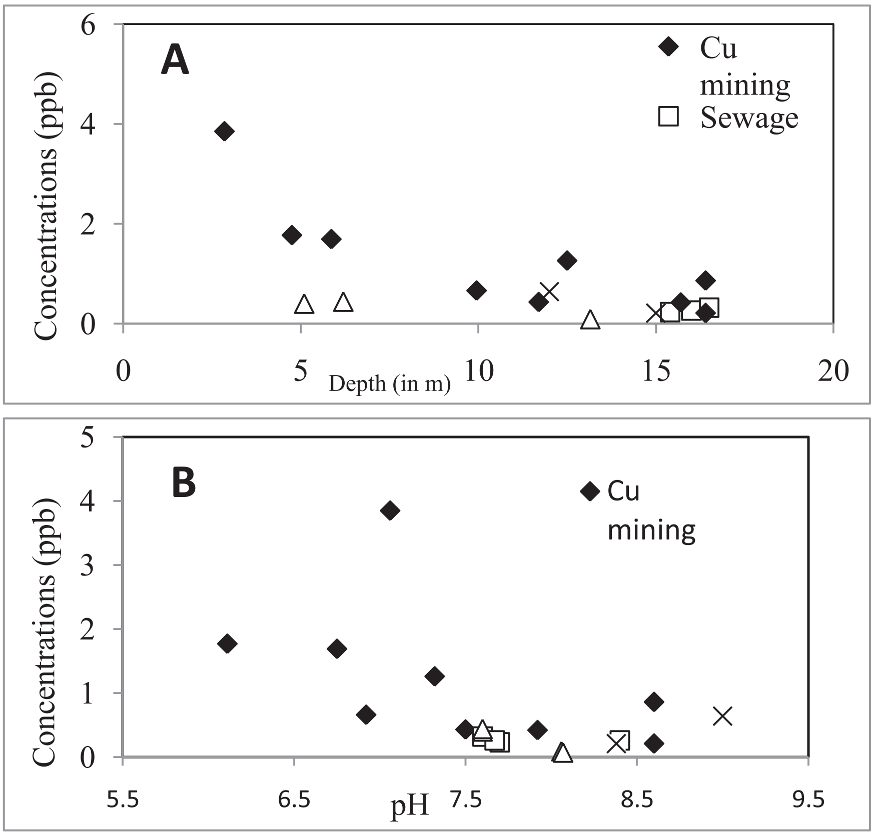

Figure 4: Variation of As Concentrations in Waters with (a) Depth and (b) pH

Conductivity data for groundwater from the mining district ranged from 1,357 μS/cm to 8,700 μS/cm, whereas that from the sewage area ranged from about 1,000 μS/cm to 9,000 μS/cm (see, table 1). In this regard, the groundwater between the two areas did not differ much in their dissolved chemical contents. Only two samples of groundwater from the agriculture area were analysed for their electrical conductivity. The data for the two samples were 5,200 and 6400 μS/cm. The As concentrations of groundwater from these different areas did not appear to have any dependence on the dissolved chemical contents as reflected by the electrical conductivity data.

The dissolved Cu concentrations in groundwater were obtained only for samples from the mining and the agriculture areas. In the mining district, the copper concentrations in groundwater varied widely, ranging from below detection limit to as high as 82 micrograms/liter (see, table 1). Copper concentrations varied widely with depth, making very poor correlation between the concentration and the depth of the groundwater. In the agriculture area, two groundwater samples were analysed for their Cu concentrations and they were found to be with 3 micrograms/liter and 10 micrograms/liter. Except for the one groundwater sample with below detection level for the Cu content, all other groundwater from the mining area analysed in this study were found with Cu concentrations that far exceeded the maximum upper limit for Cu concentration in waters set by both the Oman Government and the WHO (1999, 2001), which defined the upper limit at 0.2 microgram/liter.

Plants

The As and Cu contents were collected from the same species of plants Rhazya *stricta*. Leaves of these plants appear to contain much higher amounts of these two elements than either the stems or the roots (table 2). In the copper-mining area, leaves contain as much 1.2 microgram of As per /gm of dry material, while the stems and roots have about 0.08 and 0.09 microgram of As per gram of dried material, respectively. In the sewage area, leaves contain about 0.07 microgram of

As per gram of dry material with about half the concentration of As for the roots. Leaves in the agriculture area contain the least amount of As, with concentration no more than 0.04 microgram per gram of dry material. The Cu concentrations of the plants follow nearly the same pattern as the As concentrations. They are characterized by relatively high Cu concentrations for the mining area plant materials with leaves having as much as 61 micrograms of Cu per gram of dry material and roots having relatively low Cu concentrations of about 9.8 micrograms per gram of dry material. By contrast, leaves of plants from the sewage area had Cu concentration of about 10 microgram per gram of dry material and those from the agriculture area were found with Cu concentration of about 5 micrograms per gram of dry material.

Table 2: Average Chemical Composition of Plants Collected from Batina, Concentrations are Expressed (in ppm) for the Whole Plant, and in ppb for the Concentrations of Cu and As in Leaves, Stems and Roots.

	(in ppm)								(in ppb)					
Plants from:	Cd	Co	Cr	Fe	Mn	Ni	Pb	Zn	Cu			As		
									Leaves	Stems	roots	Leaves	Stems	roots
Cu mining area	0.05	0.189	0.805	91.74	7.308	1.384	0.201	33.86	61473	6696	9856	1196	78	87
Sewage area	0.095	0.13	0.639	61.07	14.75	0.9	0.107	12.23	10132	nd	5530	71		40
agricultural	Nd	nd	nd	nd	nd	Nd	Nd	nd	4930	nd	nd	40	nd	nd
area	Nd	nd	nd	nd	nd	Nd	Nd	nd	Nd	nd	nd	nd	nd	nd

(*Nd; not determined*)

Arsenic-Copper Relative Distributions between Plants And Ground Waters

It has been very commonly stated that in the literature, as the statement of Singh (1994) illustrates, that availability and uptake of metals by plants do not depend only on their content in the soil, but also on pH of soil, organic matter and amount of clays in the soil (Singh, 1994). We believe, that such an expression is highly oversimplification, although all these parameters included in such a statement are highly important (Gadd, 2007). Nonetheless, it fails to underscore the importance of microbial community composition and activity in the rhizosphere on the characteristics of metal accumulation by plants. The mineralogic framework of soil appeared very similar between the copper-mining and the sewage areas. The difference in the amount of elements uptake by the same species of plants collected from these two areas may reflect differences in physicochemical properties, especially pH rather than in the amount of organic matter in the soil since sewage soils contain important amount of organic matter (Lindsay and Logan, 1998; Zhang *et al.*, 2007) Organic matter is known to immobilize heavy metals in soils and reduce their uptake by plants. The organic matter can also complex with heavy metals found in soils (Weng *et al.*, 2002; Silveira *et al.,* 2003; Tukura *et al.*, 2007; Ashworth and Alloway, 2008) reducing heavy metal pollution. Several authors have studied the effect of sewage sludge on soil physical, chemical and biological properties (King and Morris, 1972, Melo *et al.*, 1994, 2002). The study of Melo *et al.* (2002) revealed that sewage increased soil organic matter and pH and enzyme activities in soils. Investigation of effect of sewage on soils by Al-Wabel *et al.*, (1998) revealed that the pH values of treated soils by sewage sludge decreased and the concentrations of heavy metals increased in the treated layers of soil compared to the untreated layers. Our results may reflect a change in the pH, but they could be explained in terms of the influence of variations in the character of the microbial communities. A close look at the plant to root metal ratios may shed some light on this. The ratio of Cu concentration of leaf to that of root for the plant in the mining area is about 6, whereas the same ratio for the plant in the sewage area is about 2. A similarly significant difference exists in the ratio of As concentration of leaf to that of root between the mining area plant and the sewage area plant, the former having a ratio of 14 while the latter with a ratio of about 2. The relative differences could at least in part be attributed to plant enzyme activity for the aboveground parts of the plants, where the enzymatic framework is heavily influenced by the rhizosphere microbial community. The construction of microbial community may change with time, which in turn may make the difference in the availability of metals from the same mineral components of the soils to the plants and also to the soil solution and to groundwater. Future research should incorporate studies of microbial communities to the investigation of plant-soil-water systems in Batina region.

Conclusion

Comparison with standards showed that there is currently no threat of As pollution in groundwater of Sohar area. The study reaffirms that Cu pollution of groundwater in the Sohar area is prevalent, especially severe in the copper-mining district. Plant influence on metal pollutions of groundwater in this region should be more thoroughly investigated. Understandings from such investigations may play an important role in finding a means to alleviate threats of copper and other metal pollutions in groundwater in the Sohar area.

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Biography: *Dr. Khadija Semhi is a Geochemist, has a doctorate in geochemistry from Louis Pasteur University (Strasbourg, France). She has been a consultant in geology department (college of science, SQU, Oman) from 2005 to 2010. The main research interest is chemistry (of waters, rocks, plants and soils) and environmental Geochemistry. The used tracers consist in heavy metals and isotopes. The interest is to investigate the quality of waters, soils and plants in stressed systems such as polluted soils, soils irrigated with recycled water, soils irrigated with magnetized waters etc.. These investigations are established through the transfer of heavy metals (including rare earth elements) and isotopes from soils to plants and to waters. Dr Semhi works in collaboration with scientists from SQU (Oman), scientists from Regional Municipalities and Water Resources (Oman), scientist from France, and a scientist from USA. She published over 20 publications, and she participated in several conferences. She is often invited to review articles for international journals.*

Monitoring of Salinity Changes along Al-Batinah Coastal Aquifer 1983-2010, Northern Oman

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Abstract: In Oman, Al Batinah coastal plain is flat and fertile so it is the most favorable place for human settlement and activities were 50% of the Sultanate agriculture production is coming from Al Batinah Plain. Groundwater is the primary source of agriculture water. During the 1970's and 1980's groundwater pumpage from Al Batinah coastal aquifer increased dramatically, which resulted in large water-level declines and associated environmental impacts, including groundwater deterioration and sea water intrusion. Agriculture sector has the lion share on water abstraction, constitutes 84% of the total water use. Currently, the coastal aquifer is under stressed as water consumed increased by 29% to the water available reflecting deficit in water balance. This deficit is recovered through pumping of the aquifer storage resulting in lowering of water table below sea level near the coast at some pocket areas and sea water intrusion. The Ministry of Regional Municipalities and Water Resources as a part of an integrated water resources management programme carried out a regular monitoring of salinity changes along Al Batinah coastal aquifer in order to understand the ongoing situation, to get better future prediction and to improve management plans. On 2010, the field survey includes measurements of an 1150 wells, 90% of them are productive wells, located along the study area (3000 km^2) on both sides of the Batinah Coast highway. Electric Conductivity (EC) was measured using a calibrated EC meter at 25°C. In addition, and for the first time 700 water samples were collected from productive wells and tested on the laboratory for complete physical and chemical analysis. The objectives of this paper are threefold: to provide a summary of the extent and modes of saltwater intrusion along the coastal area of Al Batinah plain, to monitor the groundwater quality changes at productive wells along the Al Batinah coast and to set up the first bottom line of the chemical characteristics (cations and anions) database for groundwater at Al Batinah coast. The study shows that few areas are highly affected by sea water intrusion and on the other hand, few areas (catchments) were showing slight improvement. However, groundwater quality improvements at some parts and/or deterioration of others along Al Batinah coast on 2010 survey is controlled by both hydrological and socio-economical conditions prevailing during the last five years.

Keywords: Salinity changes, Al Batinah coastal aquifer, Electric conductivity, Oman

Introduction

The Batinah coastal zone stretches for more than 270 km along Sea of Oman starting from Seeb in the southeast to Shinas in the northwest crossing three governorates, 9 wilayats and more than 10 towns and villages. Because it's flat and fertile, it is the most favorable place for human settlement and activities were 50% of the Sultanate agriculture production is coming from Al Batinah Plain. Groundwater is the primary or sole source of agriculture water were it constitutes about 84% of the total water demand. Groundwater withdrawals for public supplies, agriculture, industry, and other uses in Al Batinah coastal region of the Sultanate of Oman exceeded 1.7 million cubic meters per day in 2006. Since early 1980's, there was a remarkable increase in water demand for agriculture uses. The average abstraction was 95.58 x 10^6 m^3/year withdrawn from alluvium coastal aquifer in 1982 (El Behairy, 2010), while on 2006 the average abstraction doubled seven times to reach about 696 x 10^6 m^3/year. This situation leads to great deficit (289 x 10^6 m^3/year) in water balance and consequently lowering of water table at the coastal discharge area resulting in groundwater deterioration of the coastal aquifer and saltwater intrusion.

In general, the extent of saline water intrusion is influenced by nature of geologic settings, hydraulic gradient, rate of groundwater withdrawal and rate of recharge (Choudhury et al., 2001). In addition, the morphologic and geologic setting of an area governs the occurrences, movement and quality of groundwater to a large extent (Roy, 1991). Although groundwater overuse and contamination are not uncommon, the proximity of coastal aquifers to saltwater creates unique issues with respect to groundwater sustainability in coastal region (Barlow and Reichard 2009). These issues are those primarily related to saltwater intrusion into freshwater aquifers and changes in the amount and quality of fresh groundwater discharge in Al Batinah coast. This paper focuses on the first of these issues-groundwater changes of the Al Batinah coastal aquifer, which was first reported as a problem in Oman as early as 1984 (PAWR 1984). Different quantitative methods can be adopted for investigating groundwater flow and deterioration in coastal aquifers.

Different quantitative methods can be adopted for studying the salt water intrusion in coastal aquifers includes geophysical survey methods, geochemical tracers, water sampling studies, GIS techniques and numerical flow modeling studies (Poulsen et al. 2009). A Prediction of salt water intrusion is vital for the management of arid coastal catchments (Kacimov and Sherif, 2006). Therefore, regular monitoring of groundwater salinity changes in coastal aquifer is essential for understanding the ongoing situation, better future prediction and help in improving the water management plans.

The objectives of this paper are threefold: to provide a summary of the extent and modes of saltwater intrusion along the coastal area of Al Batinah plain, to monitor the groundwater quality changes at productive wells along the Al Batinah coast; and to set up the first bottom line of the chemical characteristics (cations and anions) database for groundwater at Al Batinah coast.

Study Area

The Al Batinah coastal plain is one of the key regions for agriculture, industry and settlement in Oman, and covered an area of about 15025 km^2. The study area is a part of Al Batinah coastal plain, located at the most downstream coastal strip. The area experienced a groundwater deterioration and saltwater intrusion during the last 30 years. The area consists of 29 surface catchments covers a land area of about 3000 km^2 located in the northern Oman coastal area and stretched as a strip of 5-10 km width as shown in figure 1. The twenty nine catchments originating from Al Hajar Al Gharbi range which runs parallel to the coast and separates the fertile Al Batinah governorate from the Interior. Groundwater is the only source of water use for all water supplies, except in recent years a desalination plants are built to cover most of the drinking and domestic water demands.

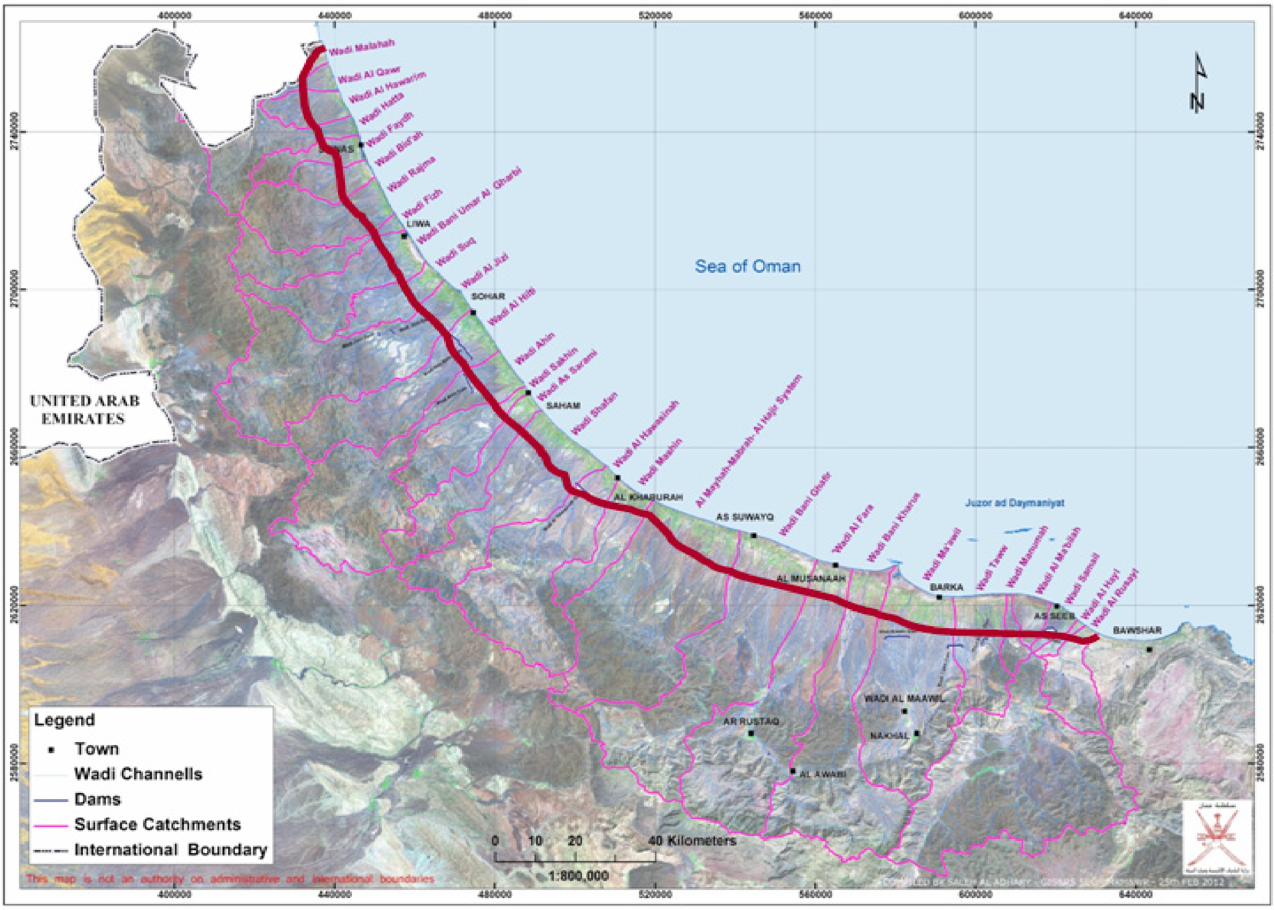


Figure 1: Study Area

Settings

Geography and Geology

The topography of the area is shown on Figure 1. The satellite image and simplified geology shown of figure 2**,** illustrate the major physiographic characteristics of the study area. Two distinct geomorphological zones are recognized by its geological setting, hard rock and soft rock (Gibb, 1976): Mountain/piedmont**:** elevations along the northern and eastern boundary of Al Batinah rise to 2,500 m and are mostly above 2,000 meters above mean sea level. Between the high limestone Jabal Akhdar Mountains and the coast, a much lower range of Ophiolite hills (up to about 900 m), intervenes and is cut through by Wadis. The soft rock: Alluvial fan/plain**:** the alluvial plain occupies, the northern part of Al Hajar Al Gharbi mountains series. The Batinah plain narrows from 30 km at the middle part to 15 km at eastern part, approaching Muscat and 10 km at western part approaching Shinas. In upper alluvial fan systems, older gravel and sand ridges are interspersed with and incised by more recent wadi channels. Towards the coast, the terrain becomes flatter and wider old and new channel systems interlink. Much of the wadi flow infiltrates on the plain. Wadi channels tend to narrow towards the sea sometimes forming multiple, small outlets. Adjacent to the coast, aeolian and beach sand deposits occur juxtaposed with sabkha, clay and silt deposits.

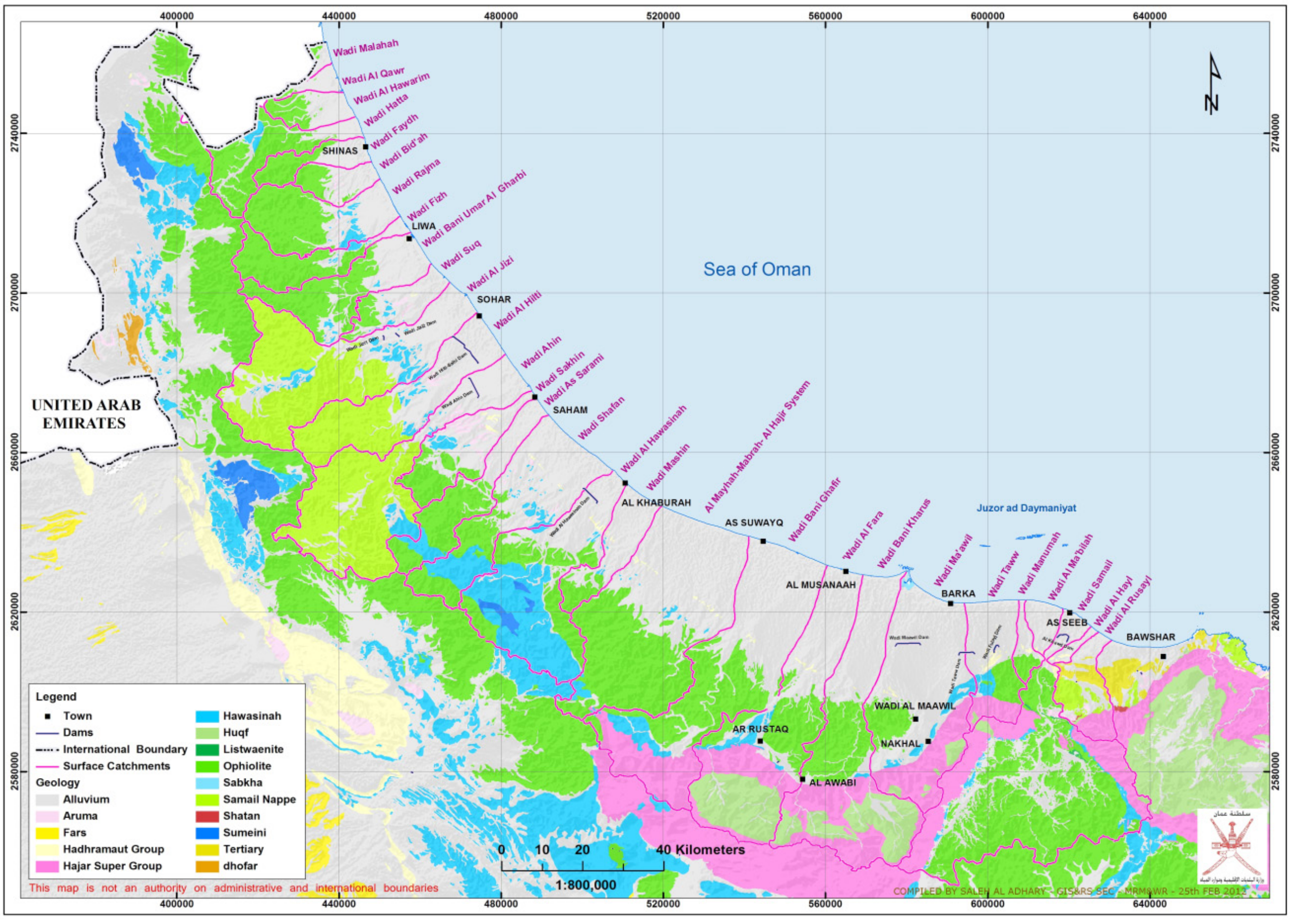


Figure 2: Simplified Geology of Al Batinah

Geologically, there are different geologic units of varying Hydrogeological significance encountered within the study area. The geologic units can be summarized from oldest to youngest (see, figure 2) as follow:

i. Haushi to Hugf Group: These rocks formed of limestone, sandstone and siltstone, Stanger (1986) named as metasediments.

ii. Hajar Supper Group (HSG): They consist mainly of limestone, dolomite, sandstone and siltstone.

iii. Sumeini Nappes: Over-thrust the *HSG* and composed of thinly bedded fine-grained grey calcarenite, shale and chert of Permian to cretaceous.

iv. Hawasinah Nappes: Formed of variety of rocks including shale, limestone, chert and basalt.

v. Samail Ophiolite Nappes: Representing a sequence of marine volcanic rocks. It consists of peridotite, gabbro and basalt outcropping cover all the southern area and reach to altitude about 1,000 m.asl (MRMWR, 2010).

vi. Arume Group: Formed of late cretaceous dark grey shale with thin layers of mudstone.

vii. Hadhramaut Group: This group found under the coastal plain and they are outcropping at the frontal mountains particularly at North Al Batinah. They first described in Saudi Arabia by (Powers R.W., 1966) composed of strong grey limestone interbedded with grey silty shale.

viii. Fars Group: Not exposed in the study area (Al Batinah region), it contains three principle subdivisions of Neogene's age lower, middl e and upper Fars (MWR, 1993a, GRC, 2004 and GRC, 2006). The Fars Group lies unconformable above Hadhramaut Group, composed of shale and mudstone/claystone at the lower and middle part and dolomitic cemented conglomerate and chalky limestone at the upper part Upper Fars".

ix. Alluvium: Representing the recent or Quaternary-aged sand and gravel deposits described as a conglomerate with clay-sand matrix with thickness ranges from 8-147 m (BRGM, 1986a, 1986b).

Rainfall and Wadi Flows

Average monthly and annually rainfall and wadi flow in Mm^3 recorded at 31 and 39 sites respectively within the study area. The annual average rainfall for Al Batinah area estimated to 113 mm, with higher average at the mountains 156 mm and 80 mm at the coastal areas. The highest computed annual average rainfall is 163 mm recorded at both of wadi Al Fara and wadi Bani Kharous. The total flow gauged area is about 9,019 km^2 which is equal to 60% of the total area (15,000 km^2). The annual average flow is varying considerably, between 102 Mm^3 at the upper mountainous catchments area to 16 Mm^3 at the coastal catchment areas. The difference is referred to infiltration or/evaporation while crossing the plain area.

Hydrogeology

The hydrogeology of Al Batinah is considered as an important factor in the occurrence of groundwater at Al Batinah plain. Through millions of years, the plain is formed by the effect of natural processes as rainfall and weathering. Rainfall on the mountain area has spread sediments from the Jebel to build up the plain. Complex patterns of gravel and clay have been formed in the braided wadi channels (Stanger, 1986). The main aquifer along Al Batinah is the alluvial deposits, which could be classified into threefold unit; 1) upper clean gravel, 2) clayey gravel and 3) lower cemented gravel (Gibb, 1976). These alluvial deposits cover the plain overlaying Tertiary limestone. They all are hydraulically connected and in fact it is hard to differentiate among these 3 units (MRMWR, 2010).

Although grain size, degree of sorting, and cementation with calcium carbonate affect this unit hydraulically, its storage and transmissivity are generally good, with average transmissivity values of 550 m^2/day in the Barka-Seeb area (South Al Batinah) and thickness of 350 meters (MWR, 1993). The transmissivity in the Sohar-Saham area (North Al Batinah) is 3000 m^2/day or even larger (6500 m^2/day), due to either higher proportion of coarser materials caused by the narrowness of the coastal plain or a greater aquifer thickness reaching 600 meters at Sohar area.

The recharge to the coastal aquifer of the northern Al Batinah plain is taking place through two main components. Direct recharge is a more significant source to groundwater system from rainfall. Indirect recharge is the primary source of recharge to the aquifer system by wadi flow infiltration. The total recharge from both estimated by about 329 Mm^3/year (MRMWR, 2010) which is equal to 9 mm/day. On the other hand, at the southern Al Batinah plain the principle source of recharge to the coastal aquifer is considered to be bedrock seepage.

Groundwater Pumping

During the 1970's and 1980's groundwater pumpage from Al Batinah coastal aquifer increased dramatically, which resulted in large water-level declines and associated environmental impacts, including groundwater deterioration and sea water intrusion. Agriculture sector has the lion share on water abstraction, constitutes 84% of the total water use. Currently, the coastal aquifer is under stressed as water consumed increased by 29% to the water available reflecting deficit in water balance by 289 Mm^3 (Table 1). This amount is recovered through pumping of the aquifer storage (154 Mm^3) resulting in lowering of water table below sea level near the coast at some pocket areas and sea water intrusion (135 Mm^3). Table 1 clearly showing that Barka and Al Khabourah areas have the highest irrigation consumption representing 93% and 81% respectively along Al Batinah coast.

Table 1: Water Balance for Al- Batinah (MRMWR, 2006)

Area	Water Avail.	Water Consumed					Deficit	Storage Depletion	Sea water Intrusion
		Agri.	L, stock	Dom	Ind/ Com/ Mun	Total			
Seeb	46	46	0.32	21.1	5.5	73	-27	15	12
Barka	118	173	0.38	8.3	6.1	188	-70	36	35
Al Kha-bourah	94	152	0.35	20.3	15.2	188	-93	48	45.7
Saham	60	91	0.37	6.2	4.7	103	-43	23	19.8
Sohar	52	73	0.34	7.6	5.2	86	-34	21	12
Liwa Shi-na	38	50	0.18	5.3	4.1	60	-22	11	11
Total	407	585	2	69	41	696	-289	154	135

Material and Methods

Field Survey and Data Collection

There are two main methods of determining the salt content of water. Total dissolved Salts (or Solids) and Electrical Conductivity (Helen and David, 1999). Electrical Conductivity (EC) measures how much the water sample transmits the flow between two plates. On the same time (EC) measurements is much quicker and simpler and is very useful for field measurement and can be used to give an estimate of Total Dissolve Salts (TDS). Therefore, the more dissolved salt in water, the stronger the current flow and higher the EC. In general, EC can be effectively converted to TDS by the following relationship: [TDS (mg/L) = EC (μS/cm at 25°C) X 0.6] Table 2 classified the relation between TDS and EC for different groundwater types (Fetter, 2001).

Table 2: Types of Groundwater Based on TDS Content in mg/l and their Corresponding EC in μS/cm

Water Type	TDS (mg/l)	EC (μS/cm)
Fresh water	0-1,000	0-2,000
Brackish water	1,000-10,000	2,000-20,000
Saline water	10,000-100,000	20,000-180,000
Brine	> 100,000	>180,000

(*Modified after Fetter 2001*)

Monitoring of salt-water intrusion beneath Al Batinah coastal plain is carried out through a mass sampling of hundreds of coastal hand dug wells. The Public Authority for Water Resources (PAWR) undertook three extensive surveys, covering the entire Batinah coast over the period 1982 to 1984. The surveys were repeated during 1985, 1986 and 1988 for some parts along the Batinah coast. Since 1989 the surveys undertaken every two years to cover the periods 1989, 1991, 1993, 1995, 1997, 2000 and 2005 (Tariq, *et. al*, 2006).

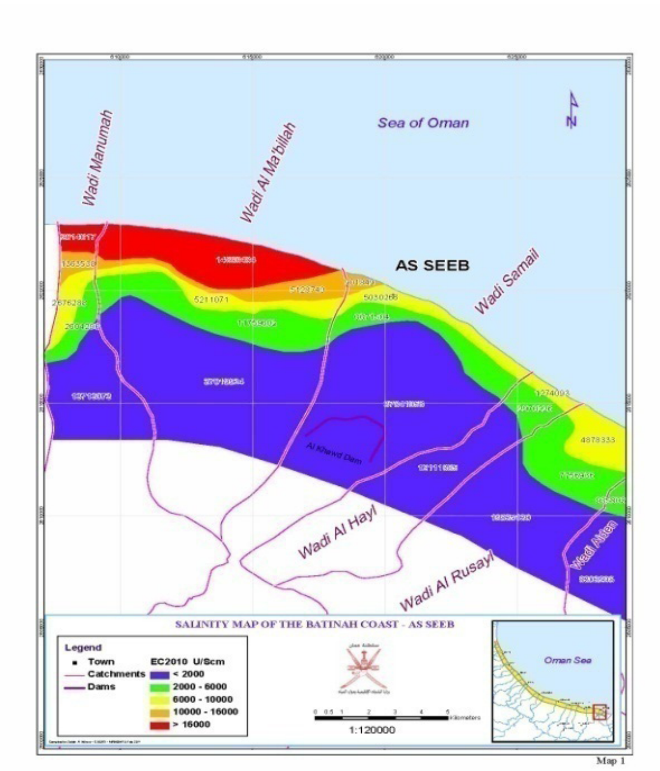
2010, the field survey includes measurements of an 1150 wells with an average spacing of 0.4 km^2 per well, 90% of them are productive wells, located along the study area (3000 km^2) on both sides of the Batinah Coast highway. Water samples were collected from all productive wells and non-pumped wells were pumped using MP1 pump with 2 inch diameter. The wells depths ranging from 20–100 meters taping the upper gravel layer of the Batinah aquifer. Electric Conductivity (EC) was measured using a calibrated EC meter at 25°C. All electrical conductivity measurements were adjusted to a temperature of 25°C so that the variations in conductance will only reflect the variations in the concentration of the dissolved salts. In addition, and for the first time 700 water samples were collected from productive wells and tested on the laboratory for complete physical and chemical analysis.

Explanation of Maps and Figures

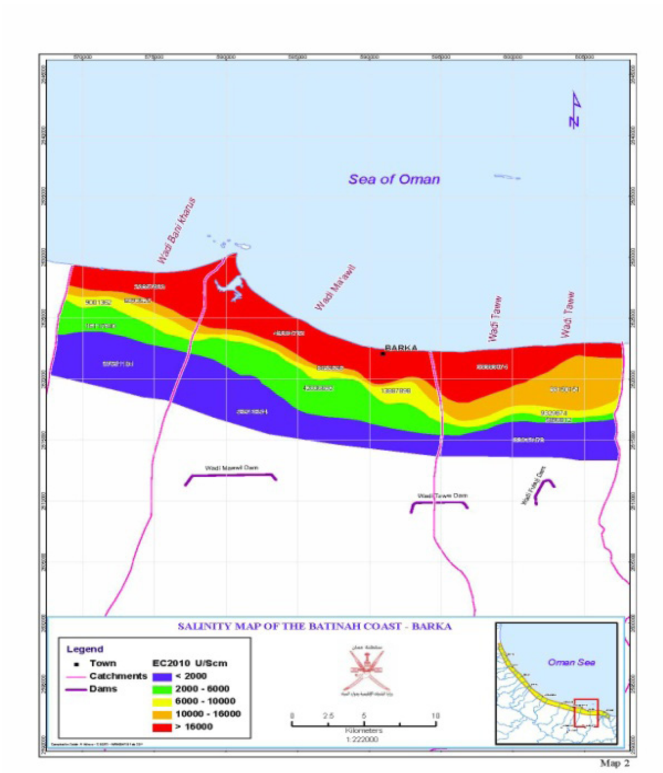
Field data measurements for the year 2010 which includes the wells locations (coordinates) and their field EC were digitized on 6 maps named Seeb, Barka, Suwaiq, Al-Khabourah, Sohar and Shinas. Contour maps are produced using Arc-GIS techniques. Zones of salinity ranges are colored and their areas were computed and compared to the total catchment area of each wadi. Then graphs were drawn using the long-term data back to 1982 for the same area to illustrate the EC changes with time. These surveys were designed to provide an overall picture of coastal salinity conditions beneath the Batinah coast and to demonstrate any long-term groundwater deteriorations existed. Five salinity ranges of Legend applied to Figures and maps is as on the map legend.

Results and Discussion

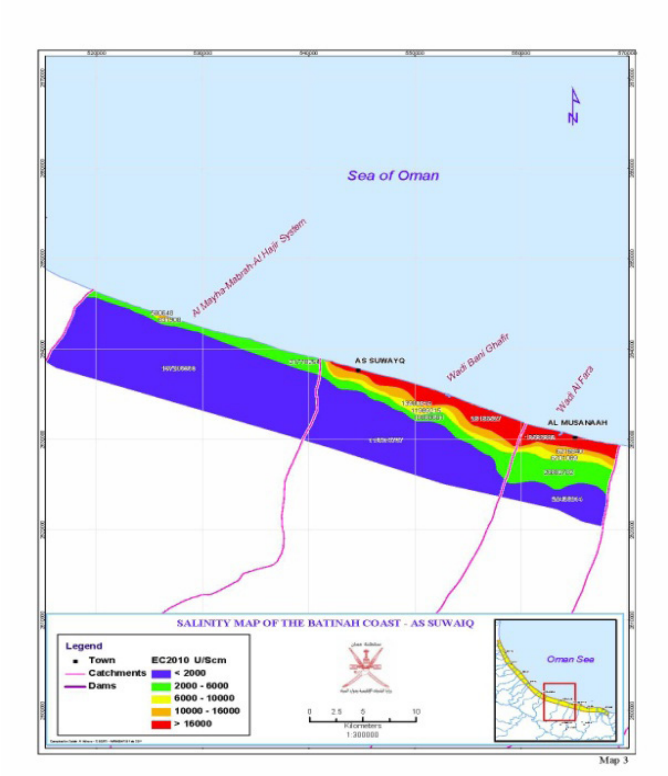
Groundwater quality along Al Batinah coastal aquifer is extremely varying. In the mountains near the recharge sources, water quality is good, with TDS of less than 1500mg/l. In the plain and low land area, water quality decreases as groundwater dissolves many salts on its way to the sea, with higher TDS values in the range 1500 to 6500 mg/l associated with the larger settlements. In the coastal zone fresh water is largely intercepted by high pumpage rate. The salt-water wedge is located several kilometers inland in some places. The saltwater interface is approximately delineated by the red colored zones with EC > 16000 mmhos/cm shown on maps 1 to 6.



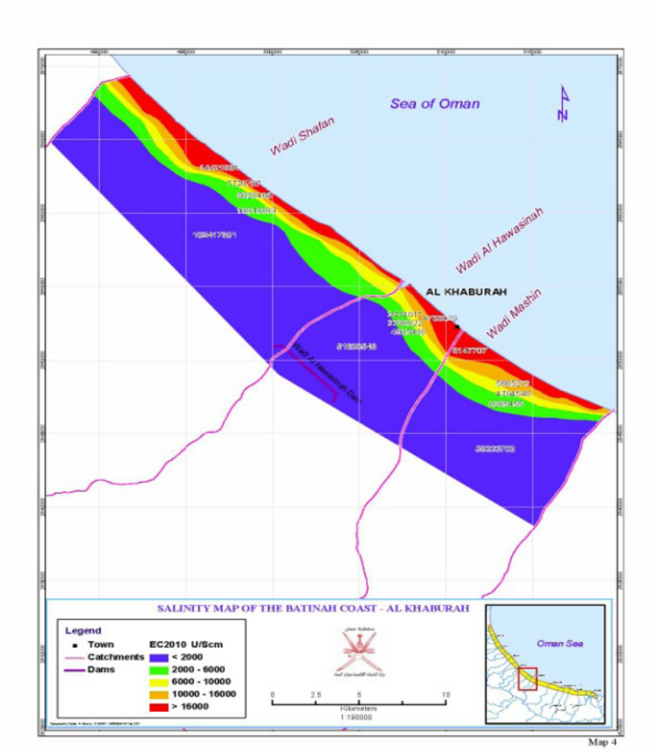
Map 1: Seeb Area



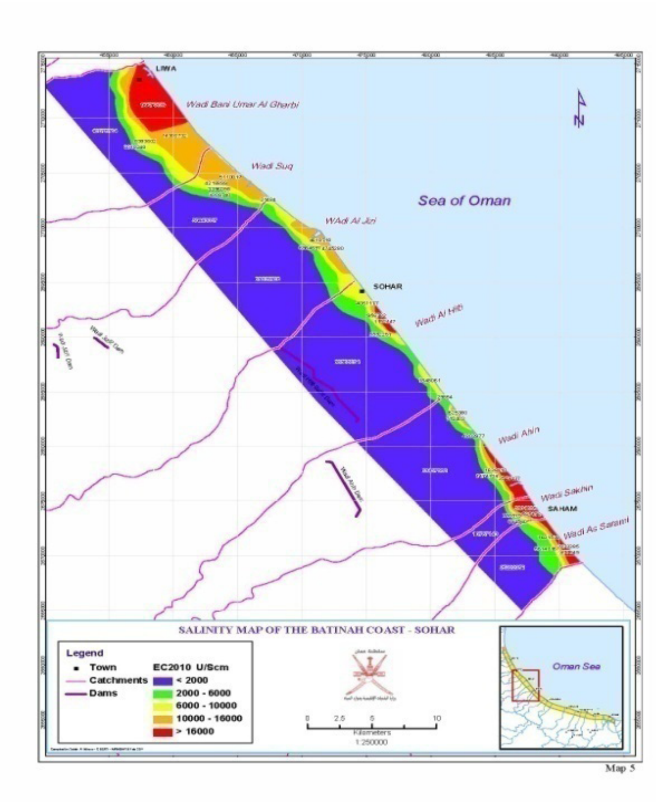
Map 2: Barka Area



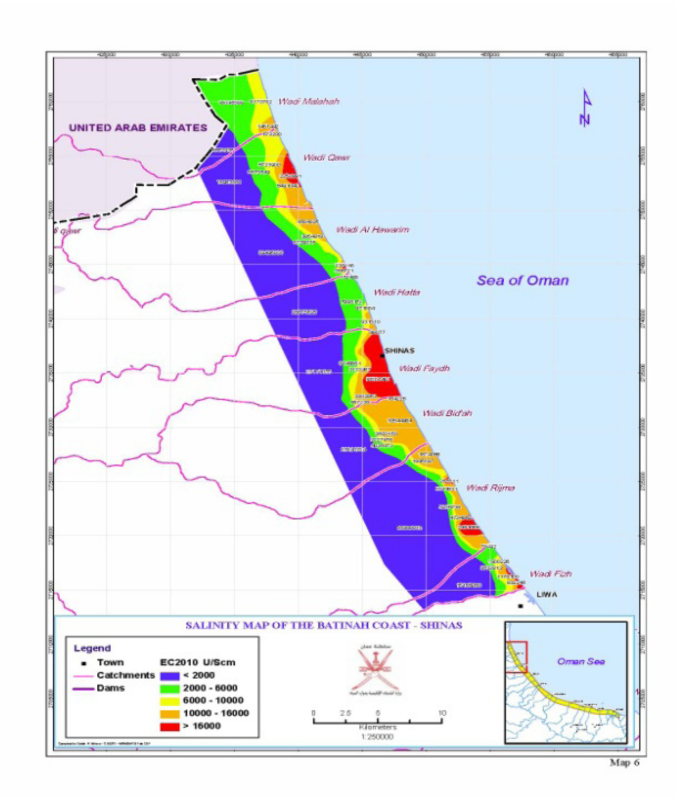
Map 3: Suwaiq Area



Map 4: Al Khabourah area



Map 5: Sohar Area



Map 6: Shinas Area

The 2010 Salinity Survey Results

The total study area covered 3000 km^2, and 1150 wells. This study compares the 2010 survey results with all the available ones since the year 1983. The following are the most important outcomes (figs. 3-8 in appendices):

(a) The results of the chemical analyses of the 700 collected groundwater samples indicated the following sequence of anions and cations:

(i) Seeb area: $cl^- > SO_4^{2-} > HCO_3^-$ $Na^- > Mg^{2+} > Ca^{2+}$

(ii) South Al Batinah area: $cl^- > SO_4^{2-} > HCO_3^-$ $cl^- > HCO_3^- > SO_4^{2-}$
$Na^- > Mg^{2+} > Ca^{2+}$ $Na^- > Ca^{2+} > Mg^{2+}$

(iii) North Al Batinah area: $cl^- > SO_4^{2-} > HCO_3^-$ $cl^- > HCO_3^- > SO_4^{2-}$
$HCO_3^- > cl^- > SO_4^{2-}$ $Mg^{2+} > Na^- > Ca^{2+}$

(b) The groundwater changes from Chloride-SO_4/Na-Magnesium water type in Seeb area to become Chloride-HCO_3/Mg^2-Sodium at North Al Batinah area.
(c) Fresh water area within the 51 % of wells has EC less than 6000 μ/cm.
(d) Only 20% of wells have EC less than 2000 μ/cm.
(e) More than one third 33% has EC more than 10.000 μ/cm.
(f) There is increase in the numbers of abandoned wells from 7% in 2005 to reach 20% in 2010, i.e. from 70 to 299 wells.
(g) On 2010 survey, there is deterioration of cultivated area reaching (9,800 ha) equal to 5% of total area, compared to (13,000 ha) during 2000-2005.
(h) Barka and Sohar areas are the highly affected areas by sea water intrusion.
(i) On the other hand, few areas (catchments) during 2010 survey were showing slight improvement such as Seeb, Al Khabourah and Shinas areas.
(j) Regardless all the above facts, groundwater deterioration and sea water intrusion still exist along major parts of Al Batinah coast.

Groundwater quality improvements at some parts and/or deterioration of others along Al Batinah coast on 2010 survey is controlled by both hydrological and socio-economical conditions prevailing during the last five years. These conditions could be summarized as on the following:

(a) Groundwater deterioration/increasing sea water intrusion is directly related to areas of high agriculture intensity such as Barka and Al Khabourah (see, table 1 & maps 2, 4 & figures 4, 5 and 6).
(b) Recharge from natural resource (exceptional recharge from two cyclones Guno 2007 and Phet 2010 at Wadis Al Khoud, Rusayl and Manumah). These cyclones hit Seeb area as part of Al Batinah coast.
(c) Recharge from retained dams (Al Khoud, Al Jizzi, Al Hawasinah).
(d) Rapid economic development and increase of urbanization rate
(e) Changing land use
(f) Changing source of water supply system from conventional source (groundwater) to non-conventional source (desalination)

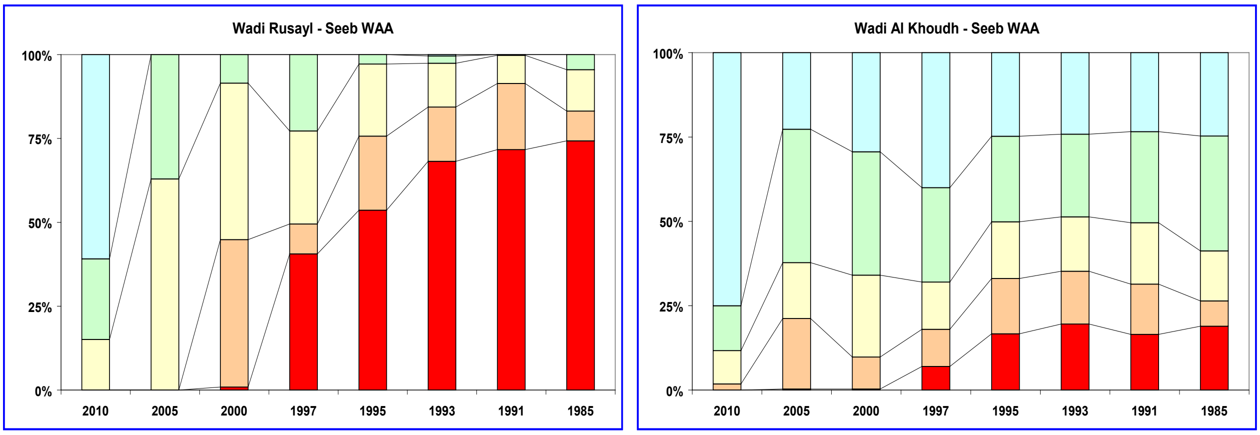


Figure 3: Salinity Changes at Seeb Area 1985-2010

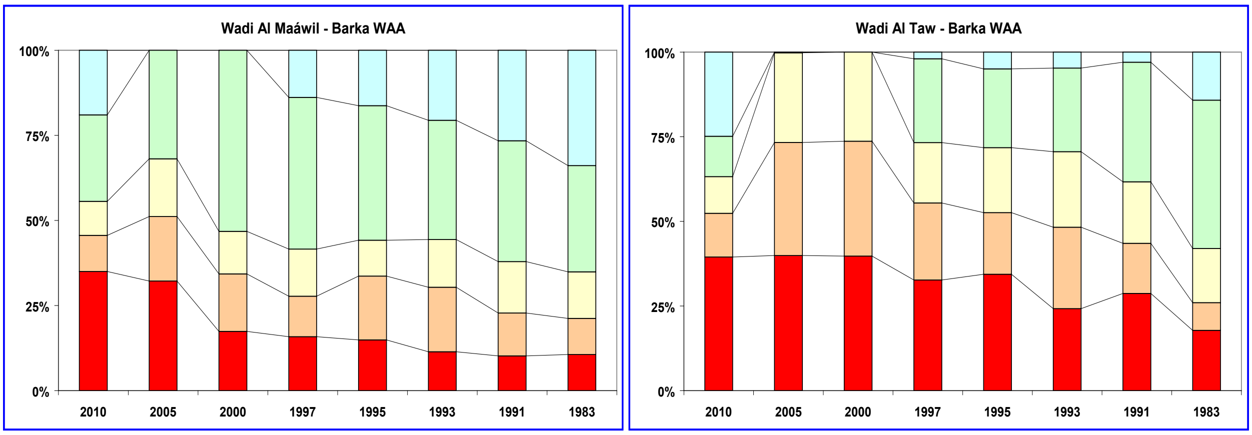


Figure 4: Salinity Changes at Barka Area 1983-2010

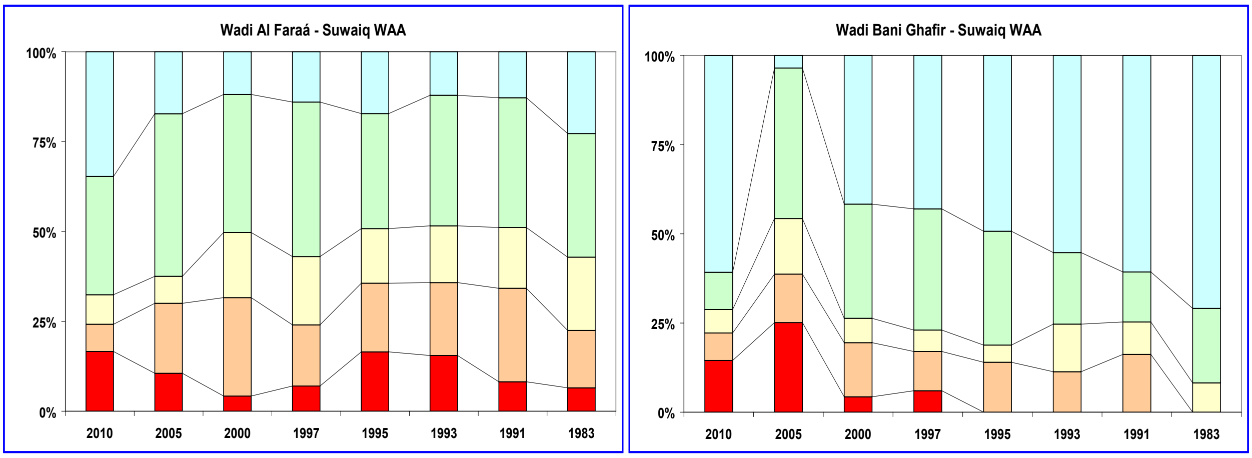


Figure 5: Salinity Changes at Suwaiq Area 1983-2010

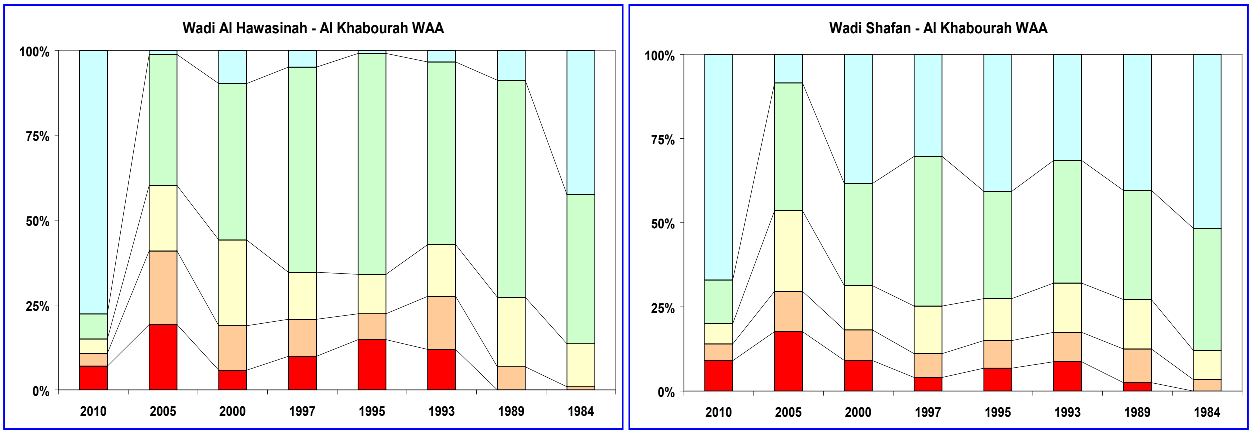


Figure 6: Salinity Changes at Al Khabourah Area 1984-2010

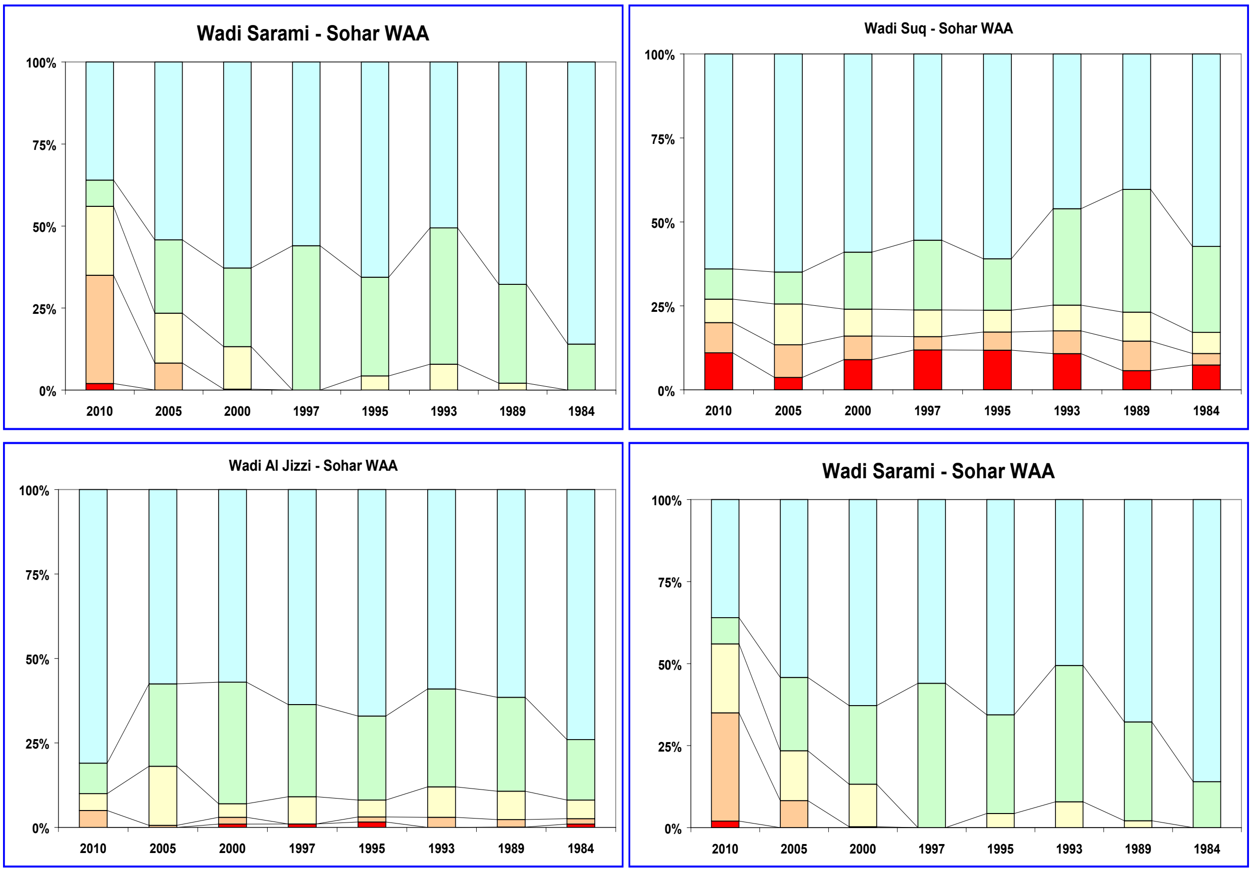


Figure 7: Salinity Changes at Sohar Area 1984-2010

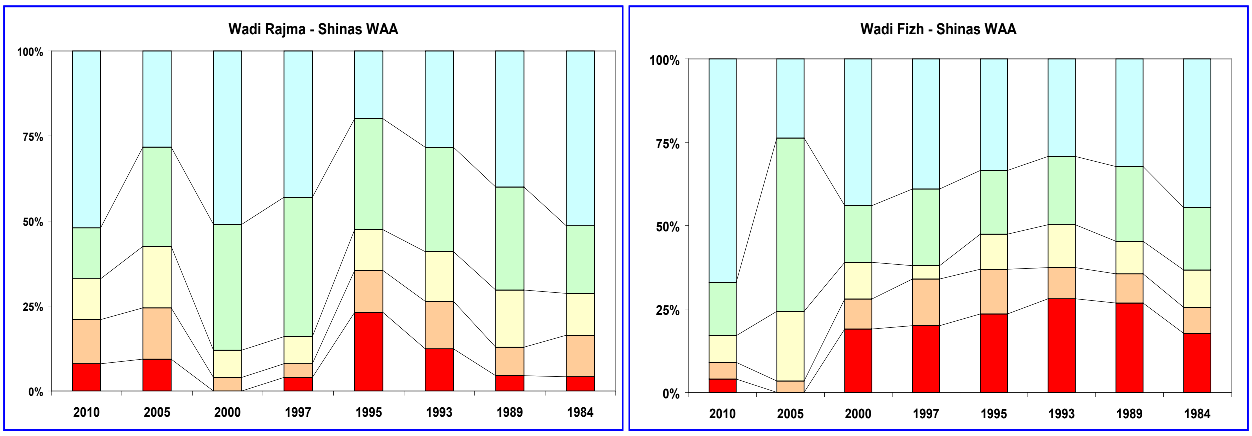


Figure 8: Salinity Changes at Shinas Area1984-2010

Conclusion and Recommendations

Preventing the saline water intrusion along the Batinah coast depend on the following factors; continuous recharge events from rainfall and wadi flows which maintaining high water levels and, controlling the over pumping from wells along the Batinah coast. In order to manage and prevent salinity changes of coastal aquifers (salt water intrusion) a strategic plan should be implemented these actions can be grouped broadly into three general categories: scientific monitoring and assessment, engineering techniques, and regulatory (or legislative) approaches.

(1) Scientific monitoring and assessment approaches

(2) Engineering approaches:

(2.1) Artificial recharging the aquifer to recover water levels within Al Batinah coastal aquifer through construction of recharge dams along Al Batinah main wadis.

(2.2) Cloud seeding to increase the natural recharge to the coastal aquifer.

(3) Regulatory approaches:

(3.1) Abstraction control through installation of water meters on wells to regulate withdrawal which could save approximately 20% (GRC, 2006) and consequently water level will be recovered by about 0.1 m to 1 m during the period 2011-2020.

(3.2) Changing crop types

(3.3) Changing type of irrigation systems to modern ones.

(3.4) Tertiary treated wastewater should be used for aquifer injection.

(3.5) Encourage the creation of local water user associations to engage in self-regulation within every catchment.

(3.6) Continued monitoring of groundwater levels, chloride and salinity within the coastal zone to determine how the hydrologic systems respond to management actions.

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Determining the Sources of Nitrate Pollution of the Liwa Quaternary Aquifer in the United Arab Emirates

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Abstract: Major ions chemistry and nitrate isotopes (^{15}N and ^{18}O) were used to identify the sources of nitrate pollution of the Liwa Quaternary aquifer in the United Arab Emirates (UAE), and to estimate the contribution of each pollution source. Twenty two groundwater samples were collected from the aquifer for chemical and isotope analyses. Ternary diagrams of anions (Cl, NO_3-N, SO_4; and SO_4, Cl, HCO_3) and cations (Ca, Na+K, Mg) indicate that fertilizers are the main source of nitrate in the aquifer. A few samples are consistent with residential sources. The dominance of $CaSO_4$ water type supports the agricultural source of nitrate, while the high NaCl water type is associated with residential land use. The measured $d^{18}O$ isotope varies between 1.9 and 3.8‰ and averages 2.6‰, indicating that nitrate is primarily derived from nitrification of ammonium (NH_4^+) in the soil. The $d^{15}N$ ratio varies between -5.6 and 8.6‰ and averages 1.6‰, confirming that agriculture is the main source of nitrate. However, the influence of residential land use can be seen in the elevated $d^{15}N$ values (5.8, 6.2, 8.4 and 8.6‰) in four wells (wells number 29, 12, 16 and 28, respectively). Plot of $d^{15}N$ versus NO_3-N shows that the sources contributing to nitrate pollution in the Liwa Quaternary aquifer are: animal waste (10%), soil nitrogen (25%) and fertilizers (65%).

Keywords Nitrate pollution, Land use, Major ions chemistry, Nitrogen isotopes, Liwa Quaternary aquifer, United Arab Emirates.

Introduction

The Liwa oasis is located on the northeastern edge of Ar Rub al Khali, or “Empty Quarter”, desert approximately 150 km southwest of the city of Abu Dhabi. The oasis is made up of 120 farm clusters and 50 small towns and villages, locally called “Mahader”, with farms right up against sand dunes which often reach hundreds of meters high. The oasis depends on the Liwa Quaternary aquifer as the main source of water for agricultural and domestic uses. The 200,000 inhabitants living in the oasis depend on agriculture and produce mainly dates. However, the main income comes from tourism. The infrastructure is excellent, with well-maintained farms, green houses with fiber glass matting tunnels and drip irrigation for outdoor crops.

The widespread pollution of groundwater with nitrate is a global concern to both scientists and general public. In groundwater, nitrogen in the form of nitrate is mobile, persistent, and exceeds the upper concentration limit for drinking water more than any other agricultural chemical (Freeze and Cherry 1979). The World Health Organization (WHO 1984) standard for nitrate in drinking water is 45 milligrams per liter (mg/L) as NO_3^- or 10 mg/L nitrate as nitrogen (NO_3^--N). The United States Environmental Protection Agency (EPA 2006) has determined drinking water levels that exceed 10 mg/L NO_3^--N to be unsafe to human. This is especially true for infants where blue baby syndrome, or methemoglobinemia (Fetter 1988), may occur when nitrate (NO_3^-) is converted to nitrite (NO_2^-) which interacts with the hemoglobin in red blood cells reducing its ability to carry oxygen.

The study area lies in the southern part of the Abu Dhabi Emirate between latitudes 22° 45’ and 23° 45’ North, and longitudes 53° 00’ and 54° 30’ East. The area is bounded by Habshan oil field in the north, the UAE-Saudi Arabia border in the south, Asab and Sahil oil fields in the east and Bu Hasa oil field in the west (Figure 1).

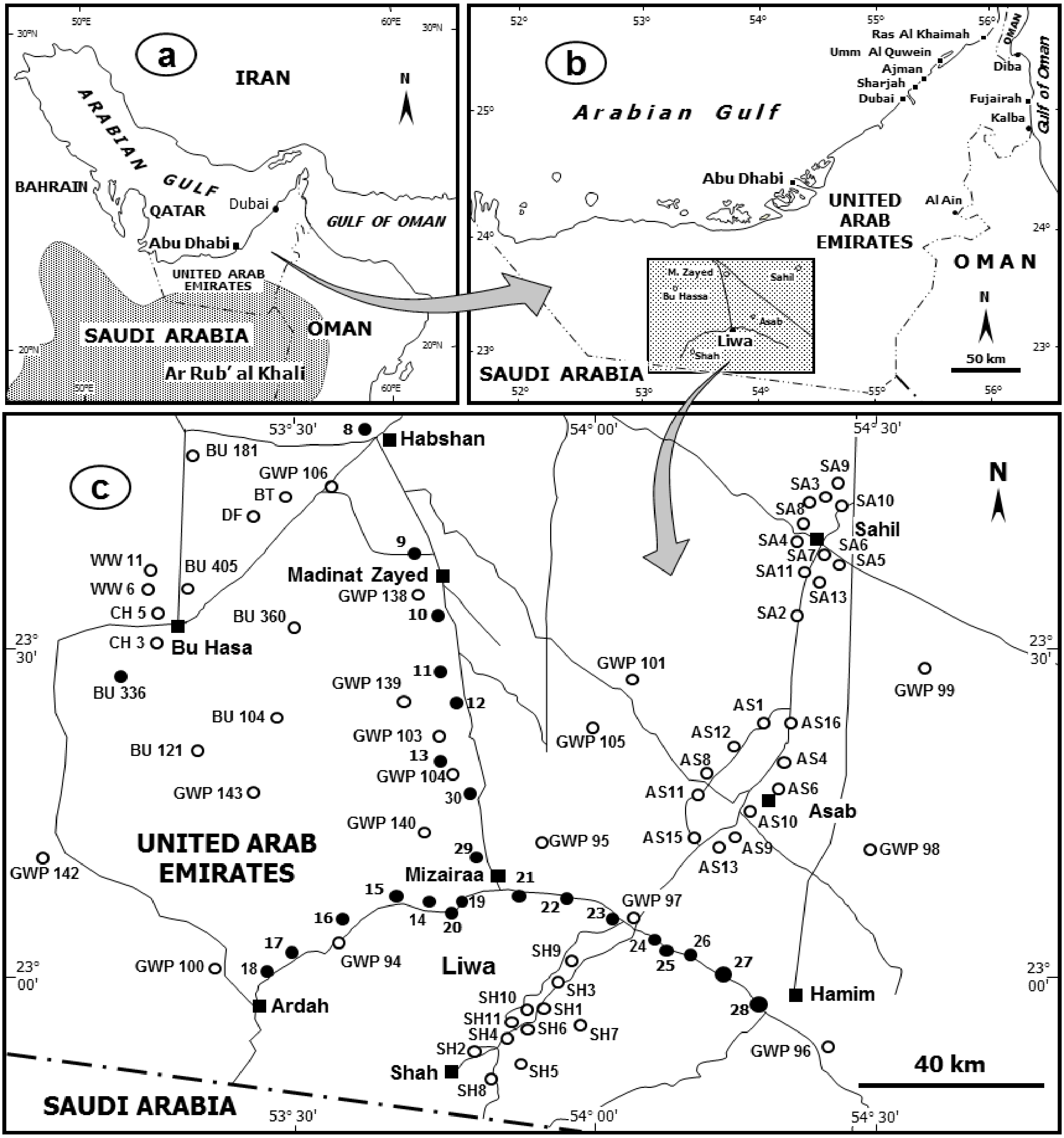
The present annual rainfall in the Liwa area is extremely variable in space and time, but averages 40 millimeters/year (mm/y), while potential pan evaporation exceeds 3,500 mm/y (Alsharhan et al. 2001). Wood and Imes (1995) and Wood and Imes (2003) showed that paleo-rainfall between 32,000 and 26,000 years BP and again between 9,000 and 6,000 years BP was approximately 200 ± 50 mm/y. Rainfall in the intervening hyperarid interval is believed to be approximately 40 mm/y, similar to the present.

Rizk and Alsharhan (2003) pointed out the close relation between high NO_3^- and areas of intensive farming, and suggested that agriculture is the main source of nitrates in shallow groundwater of the UAE (Figure 2).

Previous investigators of the sources of nitrate in groundwater have used ^{15}N isotope to identify the source of nitrate pollution (Bleifuss et al. 2000; Flipse et al. 1984; Kreitler et al. 1978). However, due to overlapping source signatures, nitrogen isotopes alone were not sufficient to characterize the sources of nitrate. More recent studies have shown that major ions that coexist with nitrate in the groundwater may distinguish sources of nitrate with less ambiguity (Bleifuss et al. 2000; Elhatip et al. 2003; Trauth and Xanthopoulos 1997).

Materials and Methods

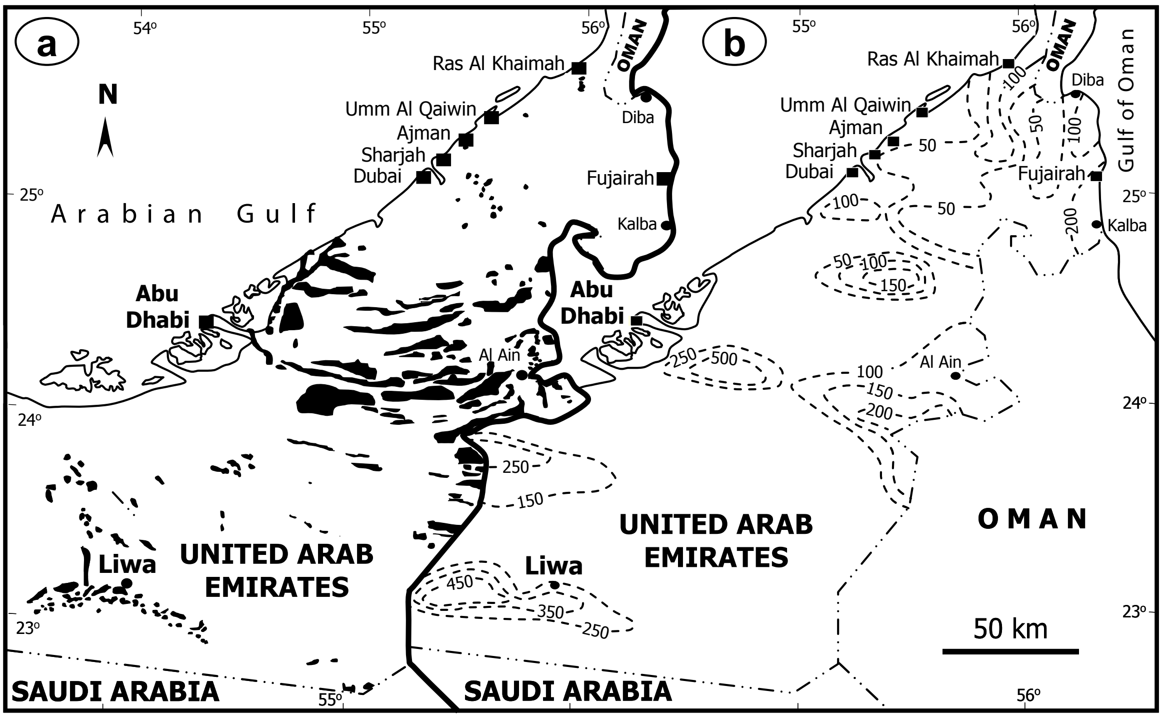
Water temperature (°C), hydrogen ion concentration (pH) and electrical conductivity (EC) in microsiemens per centimeters (mS/cm) were directly measured in the field because they change after sample collection (Hem 1985). All samples were field filtered through 0.45 micron flow-through filters and stored on ice until they could be refrigerated or frozen on return to the lab. Samples for the determination of ^{15}N and ^{18}O were preserved with mercuric chloride.



((a) *United Arab Emirates*; (b) *Liwa area* ; Black circles in (c) *represent water well sampled for this study*)

Figure 1: Location maps of the Arabian Gulf region

Chemical analyses of groundwater samples were conducted in the Food and Environment Control Center of Abu Dhabi Municipality. Standard analytical techniques described in Rainwater and Thatcher (1960), FAO (1970), Wood (1976), APHA (1995) and Skoog et al. (2004) were applied. Chemical analyses of major, minor and trace chemical constituents in groundwater were performed using titration methods (APHA 1995), ion chromatography (Weiss 1986), atomic absorption spectrophotometry (AAS) (Ediger 1973) and inductively coupled plasma-atomic emission spectrometry (ICP-AES) (Wolf and Grosser 1997).



((a) *with areas of nitrate pollution (NO_3^- in mg/L) of sand and gravel aquifer*; (b) *in the United Arab Emirates,* Reference (Modified from Rizk and Alsharhan 2003).
Figure 2: Coincidence of areas of intensive agricultural activities

Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) anions were determined by titration of 50 ml water sample against 0.02 N HCl solution using phenolphthalein and methyl orange as indicators (Skoog et al. 2004). Total hardness was measured by addition of 2 ml of the buffer solution pH-10 and 3-4 drops of Erichrome Black T indicator to 10 ml water sample, and titration with standard 0.01 M EDTA solution. Fluoride (F^-), chloride (Cl^-), nitrates (NO_3^-) and sulphate (SO_4^{2-}) concentrations were determined by ion chromatography. A calibration curve was prepared for each anion using aliquots anion concentrations higher than detection limits. The detection limits of F^-, Cl^-, NO_3^- and SO_4^{2-} were 0.05, 0.03, 0.13 and 0.03 mg/L, respectively. Prior to the determination of total metal concentrations by AAS or ICP-AES, each water sample was acidified with nitric acid (8 ml/L Analar grade), boiled for 4-5 minutes to ensure complete solubility of metal ions (Skoog et al. 2004), and then filtered. Filtrate was used for both AAS and ICP-AES measurements. Atomic absorption spectrophotometry_(AAS) was used for the determination of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{2+}) and potassium (K^+) ions by measuring their absorbance at the maximum wavelengths, against reagent blank (Ediger 1973). Measurements were carried out using the AAS (GBC 906), equipped with autosampler and background corrector. Inductively Coupled Plasma-Atomic Emission Spectrometer (ICP-AES) was used for determination of trace elements strontium (Sr), iron (Fe), boron (B), chromium (Cr) and zinc (Zn). Table 1 lists recommended wavelengths and detection limits of ions and trace elements determined with the use of AAS and ICP-AES. The samples collected for nitrate isotope analysis were filtered through 0.45-mm filter and freezed until shipment to laboratory. The measurements nitrate isotopes ^{15}N and ^{18}O were conducted in the Central Laboratories of the International Atomic Energy Agency (IAEA) in Vienna, Austria. The analytical method is Continuous flow isotope ratio mass spectrometry, and the analytical precisions for $d^{15}N$ and $d^{18}O$ are ±0.7‰ and ±0.5‰, respectively (Casciotti et al. 2002). Unless otherwise specified, acids are concentrated analytical grade. * Potassium detection limit is variable and highly dependent on operating conditions and plasma position (Vela et al. 1993).

Table 1: Wavelengths (mn) and detection limits (mg/L) of ions and trace elements determined in groundwater samples from the Liwa Quaternary aquifer, using AAS and ICP-AES.

Element	Symbol	Analytical Method Atomic Absorption Spectrometry (AAS)		
		Reference Material	Wavelength (nm)	Detection Limit (mg/L)
Calcium	Ca^{2+}	$CaCO_3$	239.9	0.040
Magnesium	Mg^{2+}	MgO	202.6	0.010
Sodium	Na^+	NaCl	330.4	0.020
Potassium*	K^+	KCl	404.4	0.032
Element	Symbol	Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES)		
Strontium	Sr	$SrCO_3$	460.733	0.060
Iron	Fe	Fe_2O_3	258.588	0.007
Boron	B	H_3BO_3	249.772	0.050
Chromium	Cr	CrO_3	267.716	0.007
Zinc	Zn	ZnO	334.502	0.002

Results and Discussion

1. Sources of Nitrate

Nitrogen sources in groundwater include fertilizers, animal waste, domestic and industrial effluent, landfill leachates, stormwater runoff, leakage from sewer lines and cesspools and acid rain (Clark and Fritz 1997; Bleifuss et al. 2000; Mengis et al. 2001; Böhlke 2002). In addition to these anthropogenic sources of nitrate, microorganisms fix atmospheric nitrogen in the soil and convert all forms of nitrogen into ammonium (NH_4^+) or nitrate (NO_3^-). Because NO_3^- is more water soluble than NH_4^+ it becomes more available to plants. But, under most conditions, farmers supply more than twice the nitrogen fertilizer required by a crop to achieve the best yields. Unfortunately, much of the applied nitrogen is mobile in soil and is carried to groundwater, causing aquifer pollution (Barnes et al. 1992). Andersen and Kristiansen (1984) and Spalding and Exner (1991) believe that the principal sources of nitrate in groundwater are associated with agricultural activities and animal and domestic waste.

The Liwa oasis is an isolated agricultural area with several small villages of limited municipal infrastructure. Therefore, the relative contributions of different nitrogen sources to nitrate pollution of the Liwa Quaternary aquifer can be identified. High nitrate concentrations in the aquifer are mainly related to non-point sources such as fertilized cropland or point sources such as sewage disposal systems and livestock facilities.

The maximum background concentration of nitrate representing naturally occurring sources in groundwater under cropland in High Plains in the United States has been estimated to be about 2 to 4 mg/L (Madison and Brunett 1983; Gosselin 1991; Mueller and Helsel 1996; McMahon 2001; McMahon et al. 2006; Becker et al. 2002). Although nitrate is found naturally in groundwater, elevated concentrations generally are caused by human-related sources (Spalding and Kitchen 1988; Bruce et al. 2003; McMahon and Böhlke 2006).

Nitrate is the dominant form of nitrogen in oxygenated water; whereas nitrite, ammonium, and organic nitrogen are more stable when oxygen concentrations are low (DO < 2.0 mg/L). In the Liwa Quaternary aquifer, the DO in 17 groundwater samples ranged from 3 to 5 mg/L and averaged 4.4 mg/L (Rizk and Alsharhan 2003), indicating that nitrate is the dominant nitrogen form.

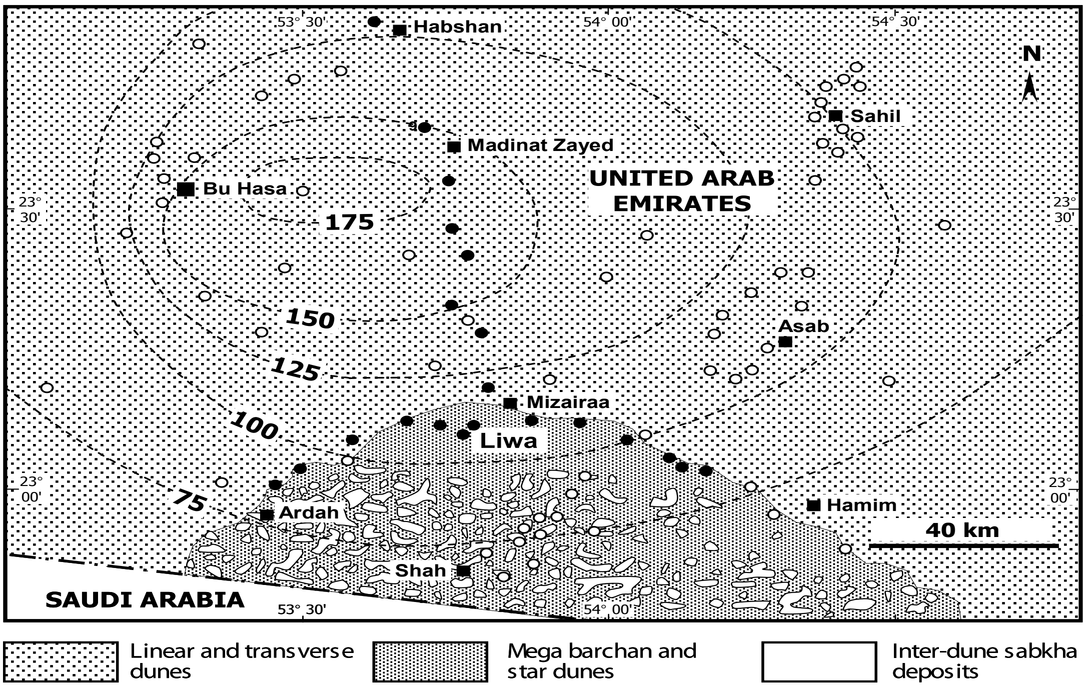
The author believes that the main sources of high nitrate in the Liwa Quaternary aquifer are: 1. fertilizers applied on farm lands, 2. prevailing hydrogeologic conditions, and 3. septic tanks and animal waste. For identification of the relative contribution of different sources to nitrate pollution in the aquifer, the following is a detailed discussion of the hydrogeology, land use, major ions chemistry and nitrate isotopes.

2. Hydrogeology

Absence of confining layers and proximity to the land surface makes the Liwa Quaternary aquifer especially vulnerable to nitrate pollution. The aquifer is unconfined with the entire flowpath oxygenated. Depth to groundwater ranges from a few meters (2.5 m above mean sea level (MSL) in well GWP-96 and 12.5 m above MSL in well GWP-104; Figure 1) to tens of meters (50 m above MSL in well GWP-95 and 60 m above MSL in well GWP-139; Figure 1).

High sand dunes (130 - 150 m above MSL) with relief up to 50 m dominate the topography of the area. Nearly flat (typically less than 1 m of relief) valley floors (interdunal sabkhas) separate the dunes over much of the area south of the Liwa crescent. The surface elevations of these sabkhas are controlled by a dynamic equilibrium between the water table and eolian processes (Wood and Imes 1995). Dunes forming the aquifer are deposited on essentially flat-lying Miocene-age clastics (Alsharhan et al. 2001), the top of which is near (± 10 m) sea level. The top of these clastics forms the base of the active flow system of the aquifer. Below the clastics is a sequence of carbonate and evaporite formations (Rizk and Alsharhan 2008).

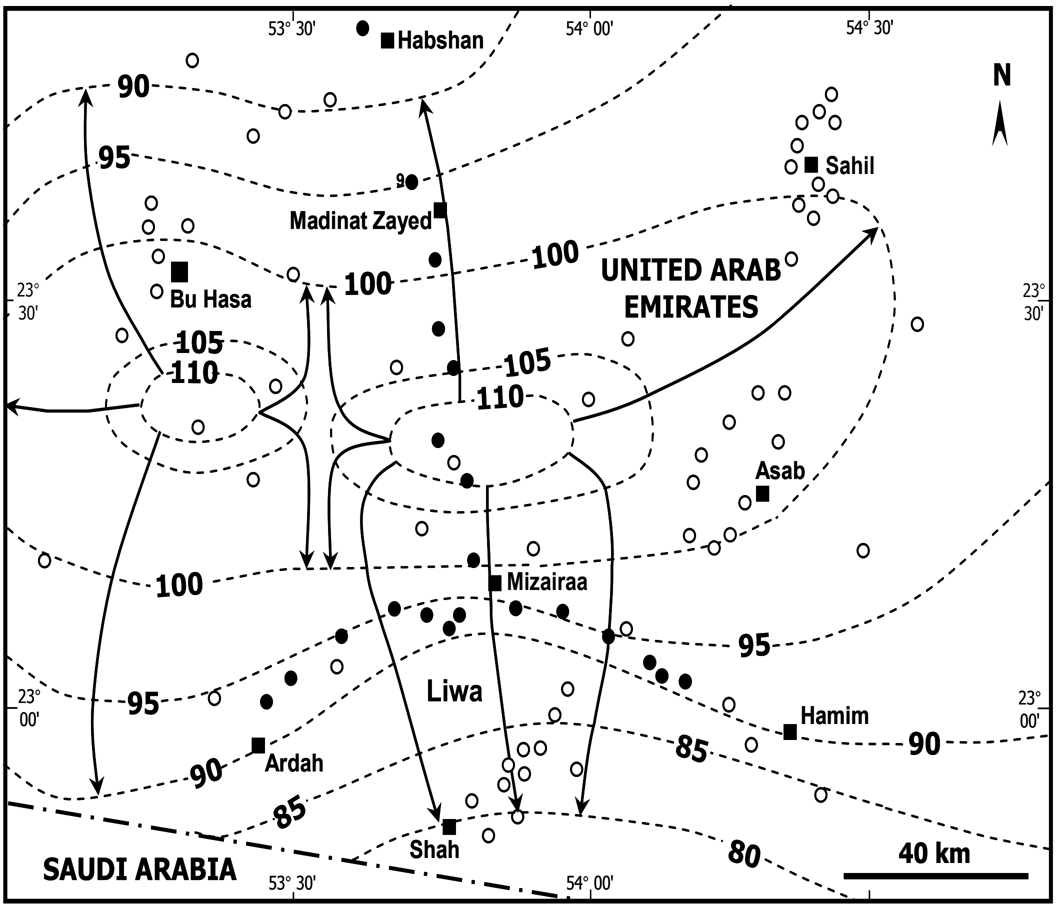
The aquifer is composed largely of quartz, equal amounts calcite and dolomite, and minor amounts of anhydrite, feldspar, and opaque and heavy minerals (Hadley et al. 1998). Porosity of fine eolian sand typically varies between 35 to 40% (Driscoll 1986), and laboratory evaluation of a few samples averaged 38% with little variance (Wood et al. 2003). Specific yield (Sy) of the aquifer is 0.2 (Sanford and Wood 2001), and its average hydraulic conductivity (K) is 1.1 m/d (meters/day) (Wood and Imes 1995). The aquifer has a maximum saturated thickness of 110 m around well no. 13, thinning out to 80 m at Habshan in the north and Shah in the South (Figures 1 and 3).



(*Contour map of saturated thickness of the Liwa Quaternary aquifer, in meters. Open and closed circles represent data points*)

Figure 3: Major landforms in the Liwa area.

The groundwater surface forms two mounds: one approximately 50 km north of the Liwa crescent and one about 30 km south of the Bu Hasa oil field (Figure 4). The water table at the top of both mounds is 110 m above MSL and coincident with the highest elevation of the dune; thus, groundwater flow is away from the mounds in all directions (Figure 4).



(Groundwater flow path indicated with arrow-headed lines)
Figure 4: Contour map of hydraulic head of the Liwa Quaternary aquifer, in meters above mean sea level.

Wood and Imes (2003) showed that much of the water with low dissolved solids was recharged approximately 6,000 years BP. Under pre-development conditions, most groundwater from the aquifer was discharged by evaporation from the top of the capillary fringe in the interdunal sabkhas (Figure 3). Current groundwater recharge to the aquifer is unknown, but believed to be small. The lack of observed water-level rise on continuous water-level recorders after rainfall events and the lack of tritium (^3H) in the center of the groundwater mound beneath the dunes (Wood and Imes 2003) are consistent with the lack of significant groundwater recharge through the dunes. Recharge, however, almost certainly occurs in the area covered by interdunal sabkhas (Sanford and Wood 2001). There is net water loss by evaporation in the sabkhas relative to that gained by recharge. Recharge flux to the aquifer, however, is small because the annual rainfall flux is low, and the interdunal sabkhas cover less than 3% of the surface in the study area.

Land Use

Agricultural practices, especially cultivation and fertilization, are principal causes of nitrate pollution over a regional scale. Septic systems may also locally contribute to nitrate pollution. Groundwater in unsewered residential areas should contain a significant amount of nitrogen contributed by septic systems (Bleifuss *et al.* 2000). Therefore, it should be possible to distinguish nitrates derived from agricultural land use from those derived from residential land use in the Liwa area.

The total area of Abu Dhabi Emirate is 67,340 km^2, representing 86.7% of the total area of UAE, mainly covered by gravel plains, sand dunes and sabkhas. The Emirate has the largest number of farms (24,297 farms in 2005), covering only 3.5% (2,328 km^2) of its total area. The author used satellite images for construction of a detailed land use map for the Liwa area (Figure 5). The utilized land is only 2.5% of the study area (21,624 km^2), which is mainly covered by sand dunes (20,648 km^2), with sabkhas (636.4 km^2) occupying interdune areas south of the Liwa crescent.

Three main land use classes were identified; new farms, old farms and residential areas. The total area of farms (new farms 358.7 km^2 and old farms 80.2 km^2) in the Liwa oasis is 18.8% of the total farming area in the Abu Dhabi Emirate and 82.9% of the total land use in the oasis. The residential areas cover 90.7 km^2, representing 17.1% of the total land use in Liwa (Figure 5). In this area, most wastewater is disposed through domestic cesspools or septic systems.

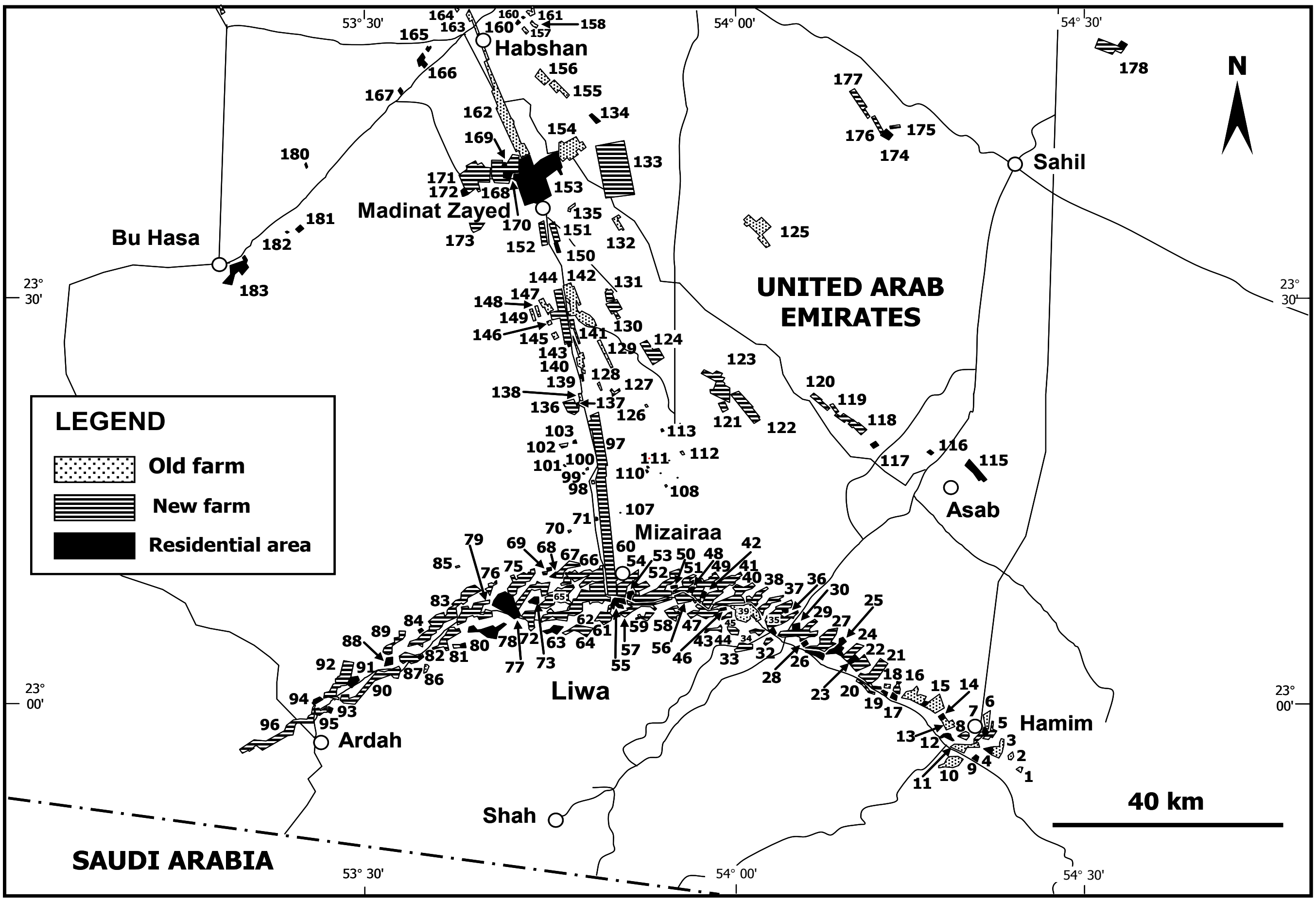
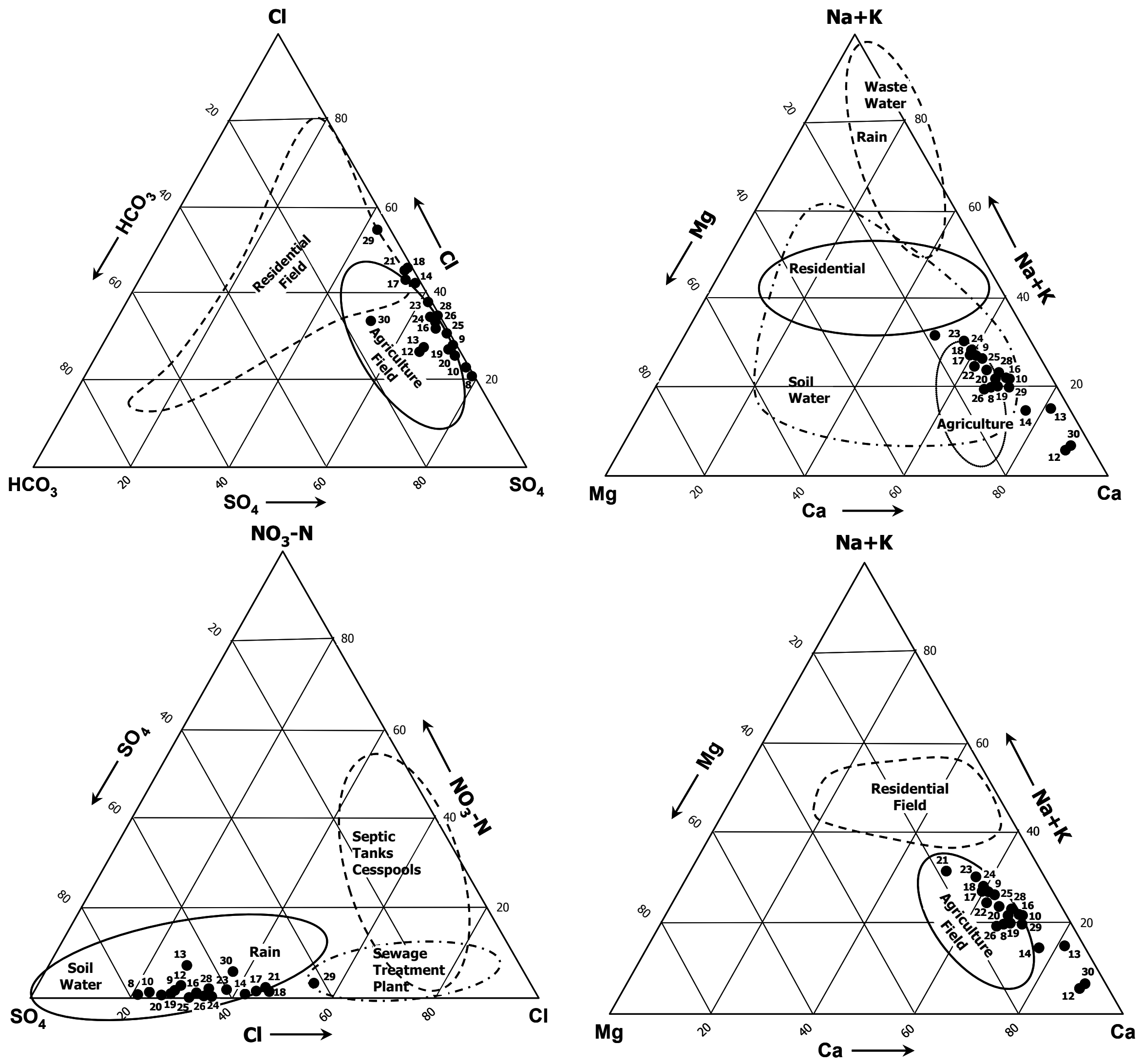


Figure 5: Land use map for the Liwa area, based on data from the Ministry of Environment and Water, satellite images and field study.

Figures 2 and 5 suggest that there is a distinct relationship between land use and source of nitrate pollution in the Liwa Quaternary aquifer. The agricultural land use groundwater samples plot in the rain-soil water field of the anions ternary diagram (Figure 6a) and agriculture-soil water fields of the cations ternary diagram (Figure 6b). Exceptions are sample 29, which plots in the sewage treatment plant field of the anions ternary diagram (Figure 6a), and sample 23, which plots in the soil water field of the cations ternary diagram (Figure 6b). Most groundwater samples plot in the agricultural field on both the anions and cations ternary diagrams (Figures 6c and d). The agricultural field plotted within the soil water field in Figure 6b is consistent with both sources utilizing fertilizers (Bleifuss et al. 2000).



(*a (Cl, N-NO$_3$ and SO$_4$); c (SO$_4$, Cl and HCO$_3$), and cations: b and d (Ca, Na+K and Mg), showing: soil water-rain, sewage treatment plant and septic tanks-cesspools, waste water, residential and agriculture fields*).

Figure 6: Ternary diagram of anions

Major Ions Chemistry

The results of chemical analyses of groundwater samples collected by the author from the Liwa Quaternary aquifer were used to draw ternary diagrams. Groundwater salinity is 1,000 mg/L at the top of Liwa mound and 2,000 mg/L at the top of Bu Hasa mound. Salinity in the aquifer increases in the directions of groundwater flow (Wood et al. 2003).

The major ions chemistry of groundwater varies according to land use. Ternary diagrams of the major anions (Cl, SO_4 and N-NO_3; Cl, SO_4 and HCO_3) and major cations (Na+K, Ca and Mg) show that agricultural and residential water plot in different fields with little overlap (Figures 6a to d). Agricultural land use produces calcium-sulfate ($CaSO_4$) water type due to liming and the application of fertilizers. Residential land use produces water that is more enriched in sodium and either chloride or bicarbonate. The high concentration of sodium and chloride in residential areas is due to the elevated concentrations of these ions in septic system plumes.

Ternary plots (Figures 6c and d) of the major ions indicate that the sampled water wells tapping the Liwa Quaternary aquifer represent areas where nitrate pollution can be clearly linked to intensive agricultural practices. Elevated sodium concentrations are associated with residential land use while high calcium concentrations are associated with agricultural land use. Septic plumes introduce organic carbon into the aquifer which subsequently leads to depletion in dissolved oxygen due to the respiration of organic carbon. In contrast, soil cultivation practices are intended to produce more aerobic conditions within the soil (Bleifuss et al. 2000). The majority of sampled wells is enrichment in calcium and sulfate, characterizing agricultural land use. These wells plot inside agricultural field on the cations ternary diagrams (Figures 6c and d).

The high concentration of nitrate in all sampled wells, despite the relatively low population density, reflects the contribution of agriculture and prevailing hydrogeologic condition to nitrate pollution in the aquifer. Comparison of the depth to groundwater and nitrate concentration in the Liwa Quaternary aquifer shows that nitrate concentrations decreased as the thickness of the unsaturated zone increased. The NO_3^--N concentrations of samples collected from the aquifer ranged from 12 to 94 mg/L, with an average of 54 mg/L. Nitrate concentrations in all samples were greater than 4 mg/L, suggesting that human activities have increased nitrate concentrations in the aquifer. Although the sampled wells are not directly used as a source of drinking water, nitrate concentrations were compared with the WHO drinking water standards (WHO 1984) to relate the quality of groundwater samples at the studied aquifer to internationally recognized drinking water criteria. Nitrate concentrations in all measured groundwater samples were larger than 10 mg/L NO_3-N, the (EPA 2006) standard for drinking water.

Nitrate Isotopes

The natural isotopic composition of nitrates (^{15}N and ^{18}O) has been used successfully in many studies to identify the sources of pollution in unconfined aquifers (Kreitler 1979; Heaton 1986). Nitrogen isotopes are often useful in determining sources of nitrate in groundwater, especially well-drained sandy aquifers, where the ^{15}N of the nitrate has less opportunity to be transformed by biological activity. Nitrate isotopes are also used to evaluate the processes affecting nitrate concentration along the groundwater flow system (Kreitler and Browing 1983; Wassenaar 1995; Böhlke and Denver 1995; Ging et al. 1996).

Nitrogen isotope ratio ($\delta^{15}N$) of nitrate was analyzed to indicate the possible sources of nitrate in groundwater. The $\delta^{15}N$ values represent the ratio of stable-isotopic abundances of $^{15}N/^{14}N$ of nitrate in a sample to those of atmospheric nitrogen. The units of $\delta^{15}N$ are per mil (parts per thousand) and are computed using the formula (Kendall and McDonnell 1998):

$$d^{15}N = ((R\ (sample) / R\ (standard) - 1) \times 1000 \qquad (1)$$

Where R (sample) is the ratio of the heavier stable isotope (^{15}N) to the lighter stable isotope (^{14}N) of nitrate in the groundwater sample, and R (standard) is the ratio of ^{15}N to ^{14}N in atmospheric nitrogen.

The overlap of measured isotopic ratios for the different sources of nitrogen might prevent accurate determination of nitrogen sources (Battaglin et al. 1997). But, the limited possible sources for nitrate pollution in the Liwa Quaternary aquifer enabled the use of $\delta^{15}N$ and $\delta^{18}O$ to distinguish between different sources of nitrate. Figure 7 depicts fields for various nitrate sources based on the work of previous researchers as summarized by Bleifuss et al. (2000).

The $\delta^{15}N$ depends on the nitrogen source but its original signature may be modified by exchange with soil nitrogen (Komor and Anderson 1993), ammonia volatilization (Kreitler 1979) and denitrification (Böttcher et al. 1990). Although ranges for various nitrogen sources can be obtained from the literature (Kreitler 1975; Kreitler and Jones 1975; Porter 1980; Heaton 1986), it was important to determine the isotopic composition of nitrates produced under local conditions in the UAE.

The $\delta^{15}N$ values in fertilizer generally range from 0 to 6‰, varies between 2.7 and 8.8‰ on Long Island (Kreitler et al. 1978) and averages 2.23‰ in High Plains aquifer (Stanton and

Fahliquist 2006). The natural soil nitrogen has δ¹⁵N values in the range of 4 to 8‰. The δ¹⁵N values larger than 10‰ indicate animal waste (Heaton 1986; Clark and Fritz 1997; Mengis et al. 2001; Böhlke 2002; Stanton and Fahliquist 2006). On Long Island, Flipse et al. (1984) reported δ¹⁵N for residential areas (1.1 to 7.7‰). Samples with depleted δ¹⁵N (3.2‰) are derived from the breakdown of organic matter. Kreitler et al. (1978) and Aravena et al. (1993) indicated that disposal of wastewater through septic systems introduces isotopically heavy nitrogen (δ¹⁵N between 7.8 and 9.8‰) to groundwater in residential areas.

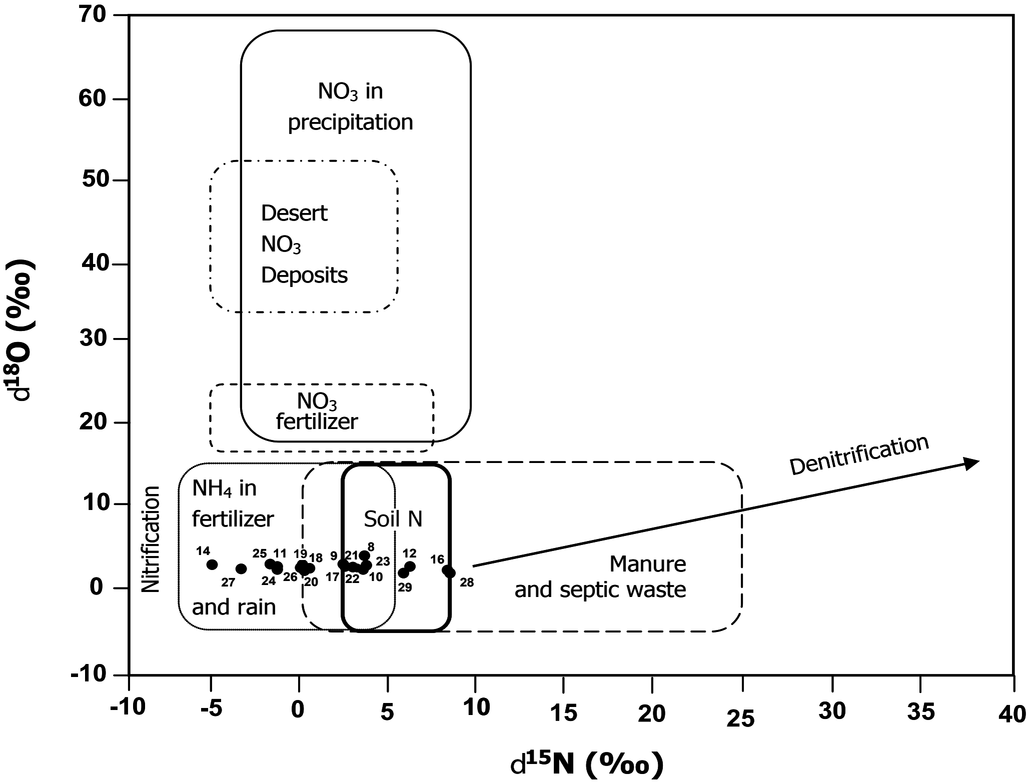


Figure 7: Plot of the nitrates isotopes in the Liwa Quaternary aquifer on a graph illustrating the d¹⁵N and d¹⁸O isotopic composition of nitrate sources (Bleifuss *et al.* 2000).

In Liwa area, the lightest δ¹⁵N values (-3.6, -1.5, and -0.1‰) were measured in the three wells (27, 24, and 26; Figure 1c) with the lowest concentrations of nitrate (NO_3^- = 93, 71, and 84 mg/L, respectively). These wells are close to new farms (Figures 1 and 5). In contrast, groundwater under old farms contains nitrates with heavier isotopic compositions (wells 8 and 11 contain δ¹⁵N of 3.5 and 6.2‰, respectively; Figures 1 and 5). Other wells (18 and 23; Figure 1c), enriched in $CaSO_4$ (25 and 28%), characterize agricultural land use. The δ¹⁵N values in these wells (0.4 and 3.7‰) are in between new and old farms, but still within the range of agricultural source of nitrate.

Some sampled wells show the influence residential activities. These wells are enriched in δ¹⁵N such as wells number 29 (5.8‰), 16 (8.4‰) and 28 (8.6‰). The positive correlation of δ¹⁵N with sodium concentration suggests these nitrates are more likely to come from septic tanks waste. But the negative correlation of δ¹⁵N with sodium concentration indicates an agricultural source of nitrate (Figure 8).

Due to the large oxygen isotopic contrast between nitrates produced in the atmosphere and those produced by microbial processes in the soil (nitrification), the oxygen isotopes in nitrate are particularly useful for the identification of nitrate from fertilizer (Amberger and Schmidt 1987) and atmospheric nitrates (Durka, et al. 1994; Kendall et al. 1997). The δ¹⁸O of nitrates produced by nitrification varies regionally because one oxygen atom in the nitrate is derived from oxygen gas and two oxygen atoms are derived from soil water or groundwater (Anderson and Hooper 1983; Hollocher 1984).

The $\delta^{18}O$ for nitrates produced by nitrification on Long Island in New York ranged from 2.5 to 3.2‰, while the isotopic composition of atmospheric oxygen was 23.5‰ (Amberger and Schmidt 1987). In the Liwa Quaternary aquifer, the $\delta^{18}O$ for nitrates varies between 1.9 and 3.8‰, and averaged 2.6‰, suggesting transformation of NH_3 within a nitrogen fertilizer into NO_3^- and H^+ by the following nitrification process (Ii et al. 1997):

$NH_3 + 2O_2 = NO_3^- + H^+ + H_2O$ (2)

The plot of nitrate isotopes $\delta^{18}O$ versus $\delta^{15}N$ indicates that nitrate in the sampled wells tapping the Liwa Quaternary aquifer is mostly derived from nitrification of ammonium and lies within the nitrification field (Figure 9). Nitrification is a chemical process that produces nitrate (NO_3^-) through the oxidation of ammonium (NH_4^+):

$NH_4^+ + 2O_2 = NO_3^- + 2H^+ + H_2O$ (3)

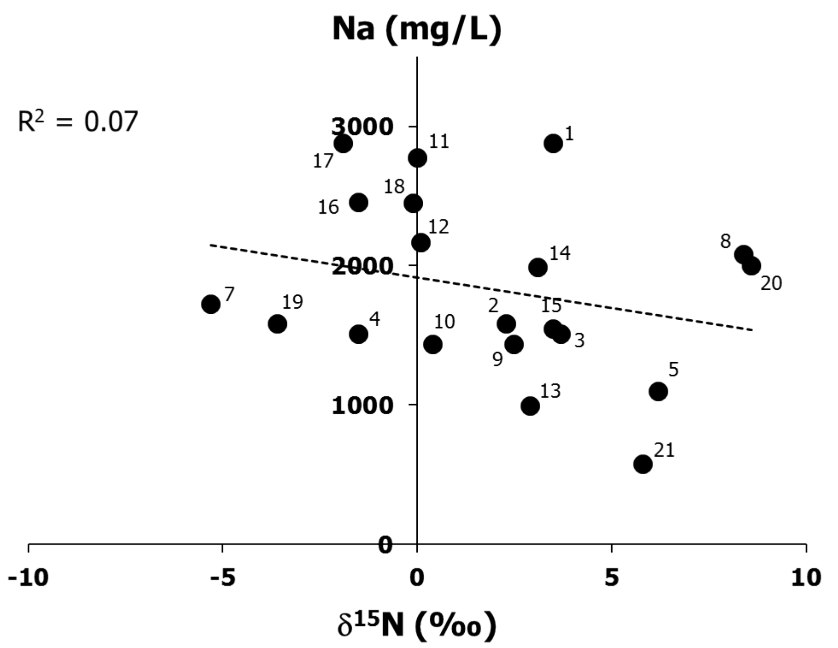


Figure 8: Correlation of nitrogen isotope ratio ($\delta^{15}N$) of nitrate (‰) with sodium ion concentration (mg/L) in groundwater samples collected from the Liwa Quaternary aquifer.

The Liwa Quaternary aquifer is unconfined (Sy = 0.2) and oxygenated (average DO = 4.4 mg/L). Therefore, it is suggested that denitrification (Amberger and Schmidt 1987; Böttcher et al. 1990), which results in enrichment of heavier nitrogen and oxygen isotopes, is not an important process in the aquifer.

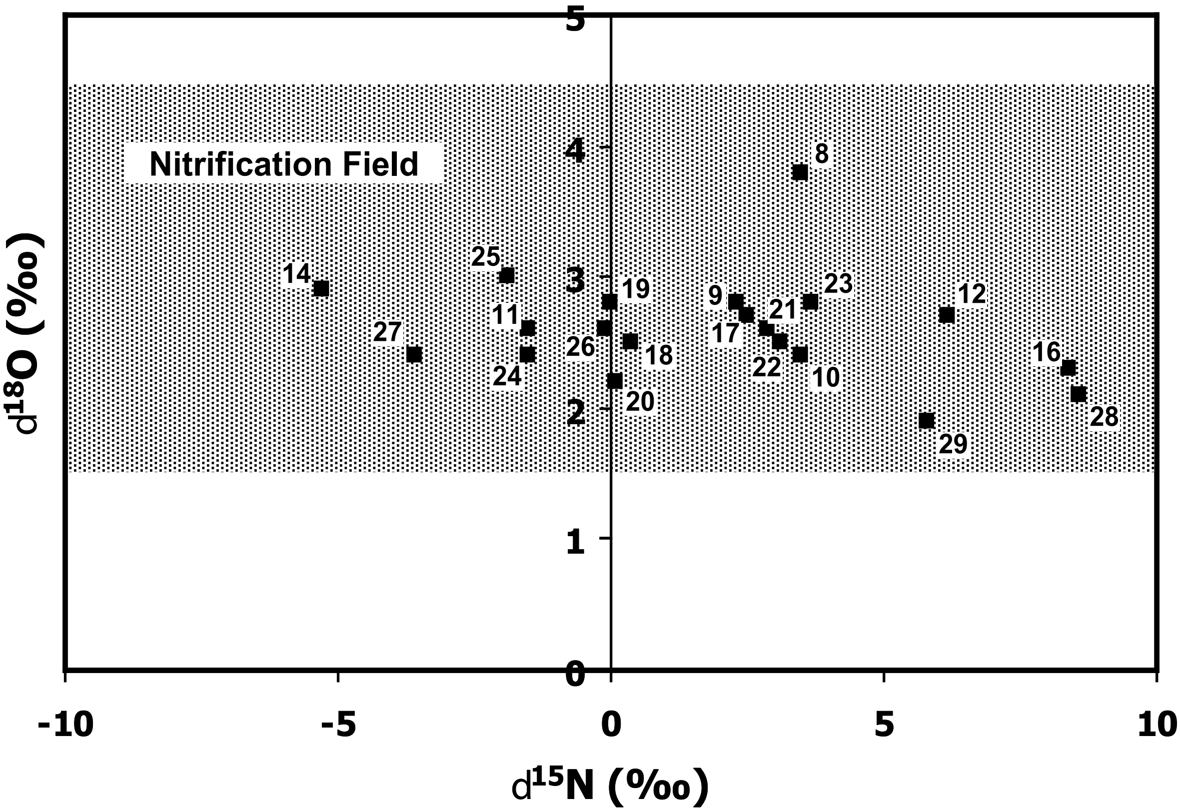


Figure 9: Nitrogen isotope ratio ($\delta^{15}N$) values of nitrate in nitrogen sources and in groundwater samples collected from the Liwa Quaternary aquifer.

The $\delta^{15}N$ and NO_3^--N values in the Liwa Quaternary aquifer ranged from -5.3 to 8.6‰ and 12 to 94 mg/L, respectively (Figure 10). Figure 10 illustrates that the sources contributing to nitrate pollution of the Liwa Quaternary aquifer are animal waste (10%), soil nitrogen (25%) and fertilizers (65%).

Conclusion

Nitrate ion (NO_3^-) is stable and represents the most dominant form of dissolved nitrogen in the Liwa Quaternary aquifer. Groundwater samples from the Liwa Quaternary aquifer plot in the rain-soil water and agricultural fields of anions (Cl, NO_3-N, SO_4; and SO_4, Cl, HCO_3) and cations (Ca, Na+K, Mg) ternary diagrams, indicating that the main source of nitrate is fertilizers applied on farm lands. Plot of sample 29 in the sewage treatment plant field of the anions ternary diagram (Cl, NO_3-N, SO_4) and in the residential field of the anions ternary diagram (SO_4, Cl, HCO_3) is consistent with a septic tank or a cesspool system source. Calculated water-dissolved hypothetical salts in groundwater of the Liwa Quaternary aquifer revealed the dominance of sodium-chloride (NaCl) and calcium-sulfate ($CaSO_4$) water types. The dominance of NaCl water type is related to septic system plumes associated with residential land use, while the high $CaSO_4$ water type reflects agricultural land use due to liming and the application of fertilizers.

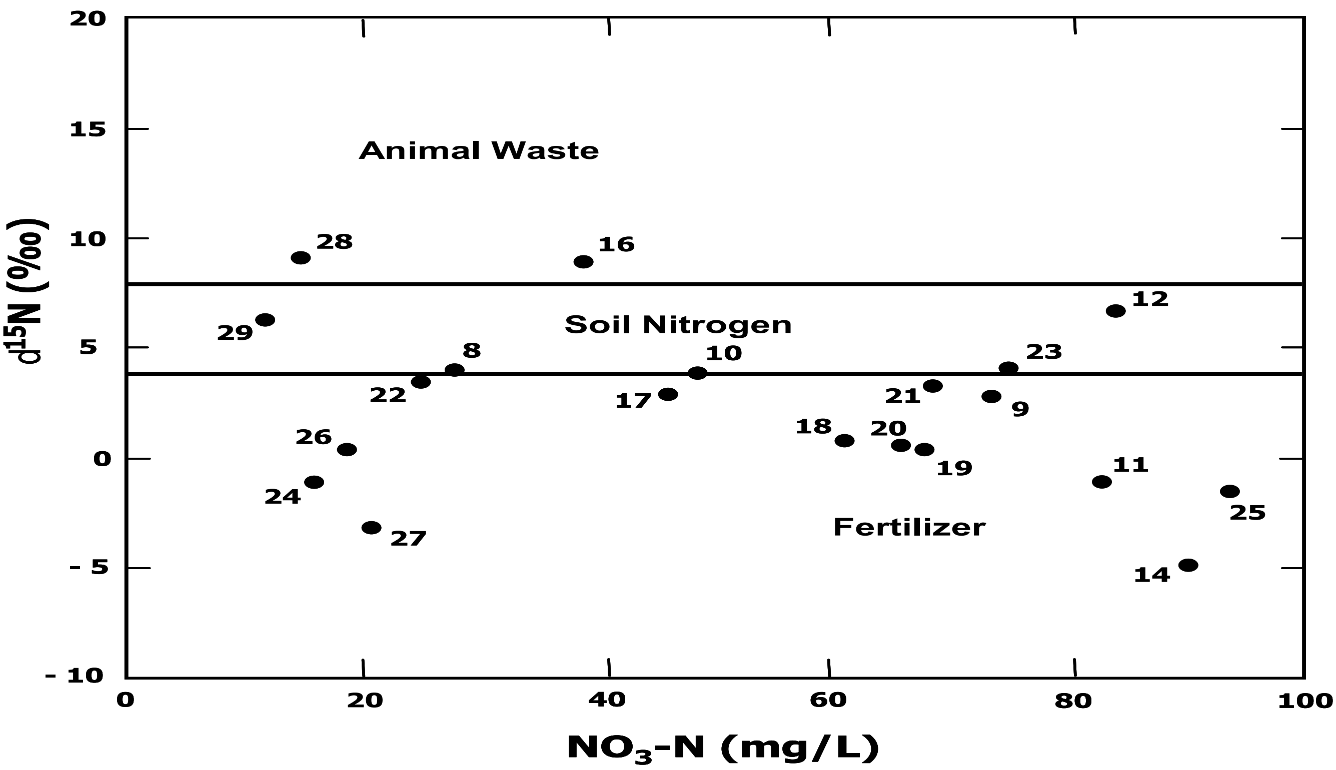


Figure 10: Nitrogen (d^{15}N) and oxygen (d^{18}O) isotopic composition of the Liwa Quaternary aquifer. Nitrification field is the field where nitrate is primarily derived from nitrification of ammonium in the soil.

The limited possible sources of nitrate pollution of the Liwa Quaternary aquifer enabled the use of ^{15}N and ^{18}O to distinguish between different sources of nitrate. The d^{18}O values of the sampled wells varied between 1.9 and 3.8‰ and averaged 2.6‰, indicating that nitrate is primarily derived from nitrification of ammonium in the soil. The d^{15}N values ranged from -5.6 to 8.6‰ and averaged 1.6‰, suggesting dominance of cultivation sources. However, the influence of septic systems waste can be seen in the elevated d^{15}N values (5.8, 6.2, 8.4 and 8.6‰) in a few shallow wells (wells number 29, 12, 16 and 28, respectively). Plot of d^{15}N versus NO_3^--N shows that sources contributing to nitrate pollution in the Liwa Quaternary aquifer are animal waste (10%), soil nitrogen (25%) and fertilizers (65%).

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Biography: *Prof. Zeinelabidin Rizk obtained his BSc. from Egypt and his MSc. and PhD degrees from the United States. Prof. Rizk published over 50 scientific papers and co-authored 2 books on water resources in the Arabian Gulf area and UAE. He participated in research projects with the Technical University of Berlin, Chiba University and the IAEA. For the last 20 years, Prof. Rizk is teaching and conducting research in hydrogeology of arid regions, water resources engineering and management, isotope hydrology and environmental sciences. Prof. Rizk supervised many M. Sc. and Ph. D. theses, and examined several Master and Ph. D. students. He initiated the Master Program on water resources in the UAE University, and founded the Master Program on Groundwater Engineering and Management in Ajman University. Now, Prof. Rizk is the Chief Academic Officer and Dean of the Institute of Environment, Water and Energy at Ajman University in the UAE.*

Possible Effects of Changing Groundwater Level and Chemistry on Building Foundation of Al Shuiaba Residential District Al-Ain City UAE (Case Study)

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United Arab Emirates University, College of Science, Geology Department, Al Ain, UAE

Abstract: Groundwater level and chemistry may significantly affect foundation of buildings due to interaction with building materials, particularly the reinforced concrete sections. This interaction can be intensified when groundwater level enters the foundation zone and concentration of sulfate and chloride increases. Although groundwater level is generally deep in most part of the UAE, the situation has been partly changed in Al Ain city where level of groundwater can be only a few meters below the surface. The shallow groundwater level together with extensive removal of sulfate and chloride during the hot summer times have resulted in a situation involving formation of sulfate and chloride salts along basement foundation in some buildings in the area of Al Shuiaba, located at the southeastern part of Al Ain city. These salts as well as direct groundwater reaction with the concrete can cause corrosion and weaken the structure of foundations, which require constant maintenance to avoid causalities and structural damages that have already happened in some buildings. In the aim of evaluating areas that can be threatened by the groundwater conditions, seventeen wells were selected for sulfate (SO_4^{--}), chloride (Cl^-), Total Dissolved Solid (TDS), and water level measurements. The results indicate large variation (1-20 m below the surface) in groundwater level, but a significant portion of the area is contained within groundwater depth of 1-5 m. Relatively high values of SO_4^{--}(up to 1,000 ppm) and Cl^- (up to 3,000 ppm) and TDS (up to 5,500 ppm) were found in the zone of shallow groundwater. The chemical parameters of the groundwater are within the moderate to severe attack limits on concrete set by the ACI (American Concrete Institute). This means that monitoring of groundwater level is vital for evaluation possible future effects on the foundation buildings in the area.

Keywords: Groundwater, water level, water quality, foundation, environmental hazards.

Introduction

In the last decades, Al Ain City encountered intensive agricultural, industrial, urban and touristic activities. All of these activities required extensive exploitation of water supply that disturbed the groundwater conditions in the area. Because the complex nature of the top subsurface soil zone some risky phenomenon were appeared including rise of water level in the many places in Al Ain city.

The study area represents one of the recent urban areas that may be greatly affected by the groundwater rise, flow direction, and salinity increment (Fig. 1).

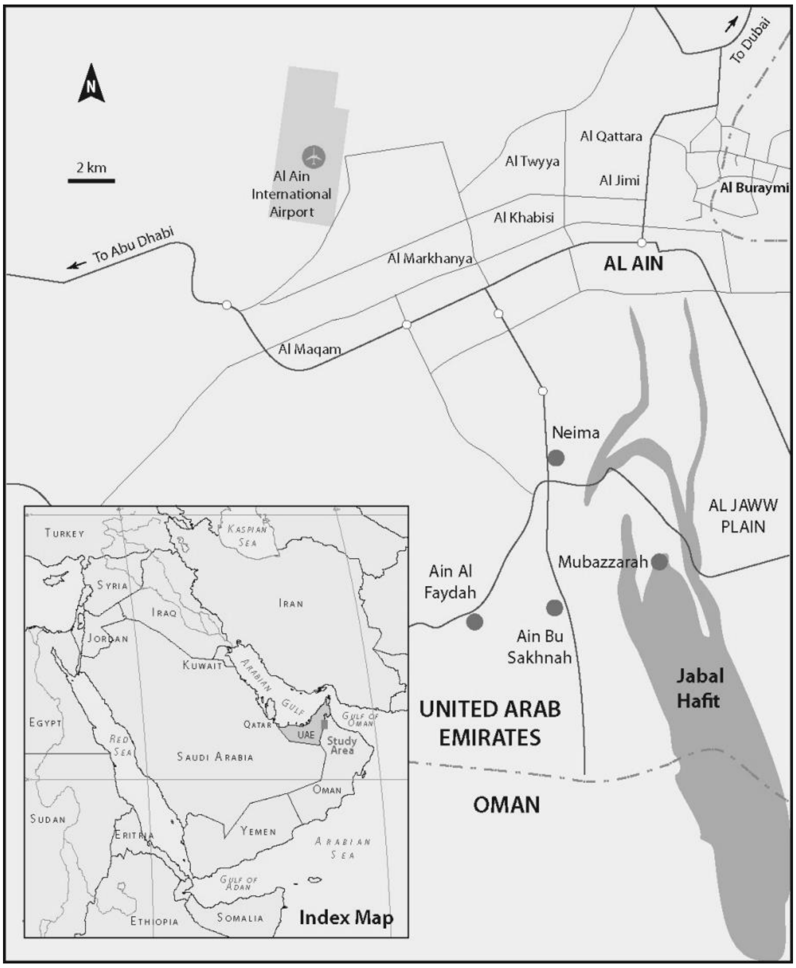

Figure 1: Map showing the location of the study area.

Differential flooding of basements in several houses along Al Shuiaba district shows that in the same area houses just 50-100 meter apart may not be affected by the flooding which is related to sudden rise of groundwater Fig. 2 [1]. This situation was seriously considered in this work in the aim of evaluating other consequences of the rise in the groundwater.

This study intends to construct a depth to water level contour map and showing the direction of groundwater flow, delineate the water level uprising locations and determine the hydraulic parameters of the aquifer such as permeability and transsmissivity. Additionally, location of the highly affected zones and discussion of environmental impact on the present foundations and possible solution to overcome related problems are given.

Hydrogeological Setting

The study area lies within Al-Ain City has arid climate with a very high temperature in summer. According to the available records of the past 17 years, the mean average rainfall is about 64.1

mm/year. The lowest and the highest annual rainfall in Al-Ain were recorded in 1996 and 2001 as 0.9 and162.7 mm, respectively, during the last 17 years. For the same period, the mean average temperature is about 28.8°C and the lowest and the highest annual mean temperature in Al-Ain were 27.6 °C (in 1995), and 29.5 °C (in 1998), giving fluctuation range of about 1.9 °C [2].

The study area lies and strongly affected by watershed and structure of Jabal Hafit Mountain (Fig. 1). The Jabal Hafit is an anticline structure composed of mainly carbonates and argillaceous rocks. Along the low land area neighboring the mountain Quaternary fluvial deposits, sabkhas, and aeolian sand accumulations occur. The study area is located at the northwestern part of Jabal Hafit watershed accumulation of floodwater along troughs and upward seepage in waterlogged zones that are frequently found. Furthermore, wadi channels of variable width also cross cut the study area.

The hydrogeological conditions of the study area are therefore related to geology of Jabal Hafit. The groundwater flow is generally from Jabal Hafit towards the study area, which means that changes in the conditions along this path can affect the groundwater level in the study area (Fig. 3). Among the prominent features in the western foothills of Jabal Hafit are the large pumping stations and springs that serve several facilities (artificial lakes, landscaping, farms and industry) which can alter the hydrogeological conditions both on the surface and in depth.

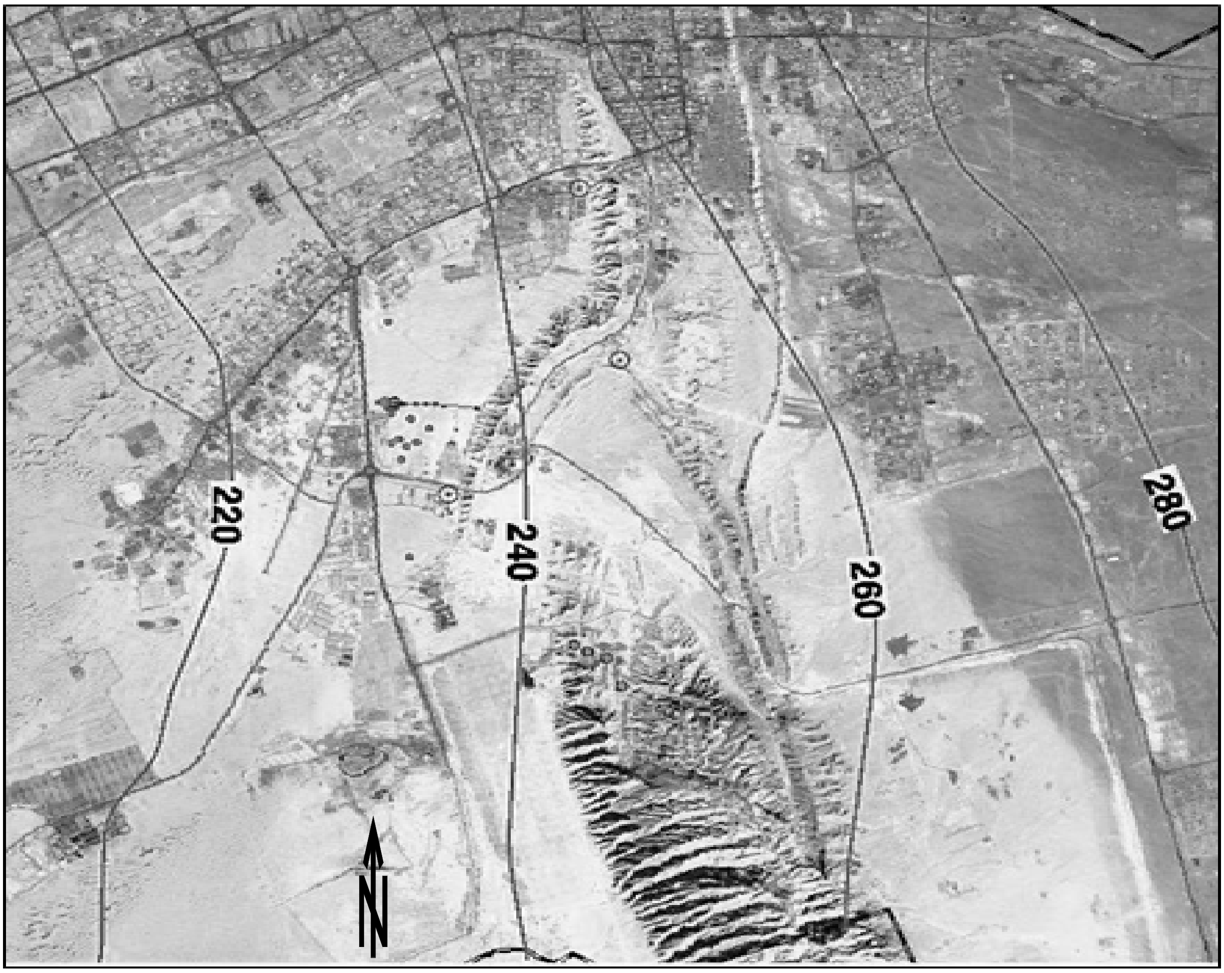

Figure 3: Water table contoursand flow direction map [4].

Study Area and Methods

The study area is composed of predominantly residential part with scattered agricultural plots. The area was primarily a desert landscape that was recently (about 10 years ago) planned to be an urban zone to accommodate the expansion of Al Ain city population. Accordingly, water resource for domestic and farming activities were needed. Consequently, groundwater wells were drilled by the residents and farm owners, which led to divergence of groundwater flow to the area in the aquifers. Additionally, use of large amounts of tape water for gardens and landscaping further disturbed the groundwater natural conditions in the area. These urban activities in addition to poor understanding of the subsurface geological and hydrogeological conditions in the area became vital for the evaluation of the flooding and highly variable groundwater level in the area.

To tackle these problems site visits, field measurements and laboratory analysis were conducted. For estimating groundwater conditions sixteen wells were accessible for measuring groundwater level as well as twelve wells were valid for collecting water samples for chemical analyses as shown in Figure 4 and Table 1.

Figure 4: Location map of the studied wells(from Google map2013).

Table 1. Results of chemical analysis and depth to groundwater level of the studied wells.

Station No	Easting	Northing	Cl^- (mg/L)	SO_4^{--} (mg/L)	TDS (mg/L)	GWL *(m)
1	363095	2672064	984	1145	-	5
2	363614	2673166	466	994	1600	3.3

3	364708	2672448	2893	1316	5440	4
4	364435	2673405	990	1022	2320	3.9
5	364294	2670545	1498	1146	3340	9.8
6	362462	2670747	1762	921	3670	17
7	364197	2674154	1173	471	2063	7.8
8	364144	2671950	2424	655	3792	10.3
9	363886	2671059	2722	888	5046	9.9
10	363187	2670193	1780	1386	4576	18.75
11	361991	2669261	2564	486	4224	29
12	362473	2672000	527	462	1102	-
13	364364	2672772	-	-	-	5.1
14	363009	2672729	-	-	-	5.5
15	362806	2672424	-	-	-	4.9
16	362676	2672412	-	-	-	5.7
17	362580	2671330	-	-	-	5.5

(GWL*= *Depth of water level below ground surface*)

In-situ field measurements of pH (acidity of the water), temperature, electrical conductivity (EC) and TDS were performed using a multiparameter meter instrument HI 9828 with an error of < 5% and an electric sounder was used for measuring water level (Fig. 5). Water samples were collected from each well and all samples were kept in dark and cold conditions (icebox in the field and during transport and refrigerator at 4 °C in the lab) until analyses. The sampling was limited by the availability and accessibility of open wells for direct sampling after one hour continues pumping. The analysis of chloride and sulfate was conducted by titration and Ion chromatography system ICS-90 of AS23 column for oxyhalids and inorganic anions. The suppressor used is Dionex AMMS300 and carbonate anion is used as eluent anion. Standard calibration curve is constructed for every ion with the using of DIONEX seven anions standard solutions. The detection limit for sulfate was 0.01mg/L, with analytical error of <5%.

Results and Discussions

The water level contour map indicate variability from shallow (<10m) in the northern part of the area to deep (> 25 m) in the southern part (Fig. 6). Thus, many houses basement within the northern part were flooded. However, the flooding of the basements was not systematic where neighboring houses at a distance of about 50-100 apart may not be affected by the rising water level. This feature may relate to the observations made by ElSaiy et al. [1], which show that most of the investigated sites are restricted to the sandy gravel and gravelly sand of the wadi channel. In these wadi channels some gravel layers were more permeable than others and houses that were constructed on this gravel paleochannel had their basement flooded compared to those lying outside the channel. The analyses of the pumping test data reveal that the transsmissivity of the carbonate rocks aquifers below the soil package is 100 m^3/d and the hydraulic conductivity is 5 meter/day. These values suggest relatively weak hydraulic properties of the aquifer, thus decline the draining downwards, and consequently enhance retention of groundwater at shallower level [3].

Furthermore, the direction of groundwater flow was recorded to the south west of the study area Fig. 4 [4].The results of TDS, SO_4^{--} and Cl^- were represented in different contour maps as shown in Figures 7, 8 and 9. The variations in concentration are; TDS (1102 up to 5440 ppm), SO_4^{--} (462 to 1386 ppm) and Cl^- (466-2893 ppm) as shown by table 1. Differently from the water level map that show variability between the north and south parts of the area, the TDS, SO_4^{--} and

Cl^- distribution maps indicate relatively high values within the northern central part of the area. The reason for the high values is the shallower groundwater level that has been affected by both extensive evaporation and contact with salt pans with the soils. Additionally, the main sources of the groundwater level rise are extensive irrigation of the farm areas and even the houses gardens and landscaping as well as creation of salt pans in the soils that deteriorate the migration of water from vadose to the saturated zone.

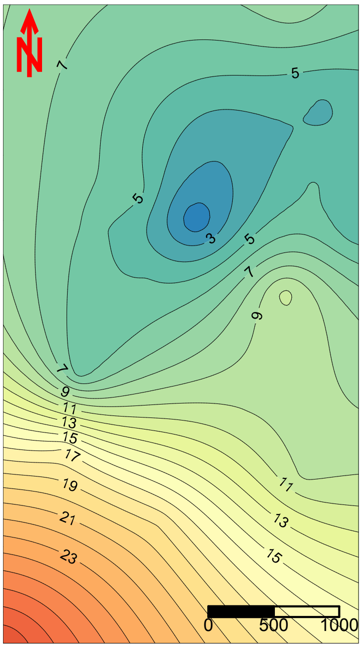

Figure 6. Water level depth contour map.

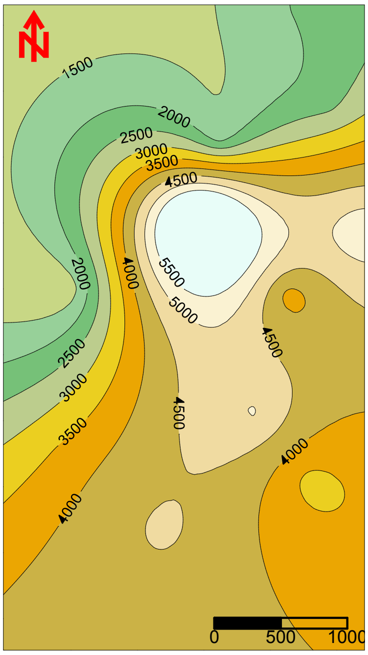

Fig. 7. TDS distribution contour map.

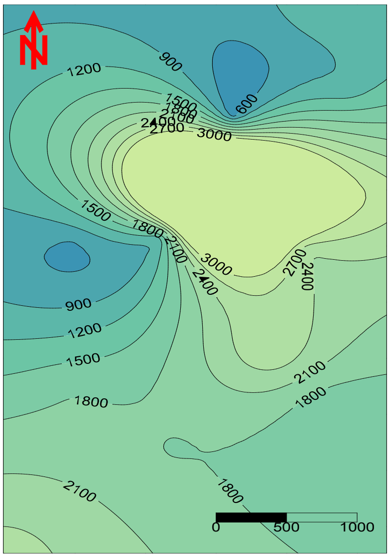

Figure 8. SO_4^{--}distribution contour map.

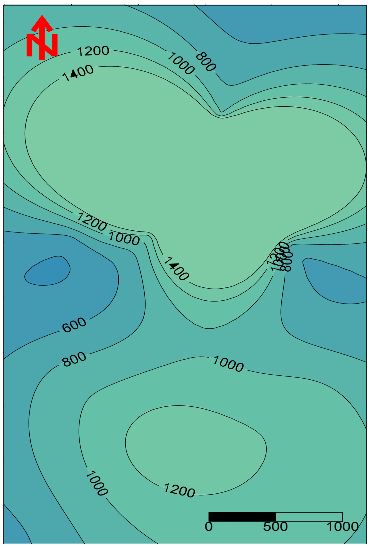

Fig. 9. Cl^- distribution contour map.

Higher concentrations of sulfate in groundwater affect the concrete foundation in the area as shown by Fig 2.,where formation of salt and corrosion of the foundation structures occurred. These effects are rather serious and can deteriorate the building materials and thus actions must be taken to reduce the groundwater level below the foundation depth. According to ACI Building Code 318, the sulfate high concentrations found in the flooded part of the study area that are classified within moderate to severe attack on concrete [5]. These high sulfate concentrations become even more hazardous to the foundation when combined with the high concentration of chlorides that can cause serious corrosion on steel bars in the reinforced concrete.

Conclusion and Recommendation

The results of this investigation indicate that rising groundwater level has been due to extensive irrigation and landscaping activities in the area of Al Shuaiba area. This has led to differential flooding of houses basements in the area that was aided by the specific geological conditions. The rising level of groundwater was also associated with high values of TDS, SO_4^{--} and Cl^- that pose serious problems to the foundation of the buildings within the area. The concentrations of these ions are within the moderate to severe attack limits on concrete set by the ACI. In order to minimize the hazardous impact on the building in the future, periodic monitoring of groundwater level and chemistry is recommended through setting up observation wells. Additionally, detailed investigation of the soil package in the area in terms of mechanical, textural and mineralogical properties are recommended to avoid future damage of building structures in area and even in the other areas that can be affected by similar conditions.

Acknowledgments

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***Biography**:* Dr. Ahmed Murad have a doctorate degree in Hydrogeology from Western Michigan University in USA in 2004. At present, Dr. Murad is Vice Dean – College of Science, UAE University since February 2013 and Associate Professor of Hydrogeology. He has 9 years of academic skills in lecturing and supervising graduate students. Dr. Ahmed Murad have been the chair of Geology Department at UAE University for four years from 2006-2010. The research interest of Dr. Ahmed Murad lies in Hydrogeology, water resources and isotope hydrology. Dr. Murad obtained several research grants since 2005 and still working in different research projects as principal investigator or co-principal investigator. He is serving as member of Advisory board of the International Center for Integrated Water Resources Management (ICIWaRM), Virginia, USA (July 2010 – present) and also was serving as head of Finance Committee of the International Hydrological Programme (IHP), (July 2010 – July 2012). Dr. Murad is Vice President of the Arabian Peninsula Environmental Advisors Network (APEAN) since 2011, member of the Permanent Consultation Mechanism (PCM) of the Groundwater Governance Project (GEF ID No: 3726), member of the Arabic Alliance for Environmental Sciences since 2010 and member of the Board of the Water Science and Technology Association (WASTA), (July 2011-present). He is also serving as member of the National Committee of the IHP in UAE. Dr. Murad is a focal point of the UAE National Committee of IHP. He published over 40 papers in international referred journals and conference proceedings. Also, he participated and presented in more than 50 national and international scientific conferences since 2005. Dr. Ahmed Murad is active in regional and international meetings representing the UAE since joining UAE University.

SESSION 3
MUNICIPAL WATER MANAGEMENT (08:30-10:40)

Keynote

Efficient Management of Municipal Water in the Arab Region

Khaldon Khashman

Secretary General, ACWUA, Jordan

Summary

The Arab region is one with a diverse profile and characteristics; from low income economically challenged underdeveloped countries to middle income low natural resources developing countries, to extremely well off and economically stable countries abundant with natural resources. However, one agreed upon characteristic of almost the whole region is the very scarce conditions it suffers from in terms of the availability of water resources. These challenges are impacting the available water supply as well as demand, which extremely affecting the utilities that are charged with providing water supply and sanitation services in the Arab region.

The functions in a water or wastewater utility are based on the type or nature of services provided, or in other words the value chain linked to this service. In simple terms, a water utility traditionally would be responsible wholly or partly for managing and operating water resources; water supply through the actual production, treatment, transmission, and distribution of water to customers; and water disposal through managing and operation of wastewater collection, treatment and disposal to receiving body.

A well-functioning utility is one that is conducting its business the right way, and providing its services to its constituents successfully, regardless whether it is state owned, or publicly owned, or privately owned. There are certain functional indications that the business is going well in the WSS industry, and those have to do with the type of services provided, and the functions that need to be carried out that are specific to the industry. Those indications include financial viability and good level of service responsive to the needs of the customers; well-maintained assets; technical efficiency and know-how carried out by well trained staff; satisfied customers; and accounting for the sustainability of the resources. This presentation will look at the current challenges facing water and wastewater utilities within day-to-day activities; and what are the approaches recommended to achieve efficient management of municipal water in the Arab region.

__Biography__: Eng. Khaldon Khashman is a senior water utilities management expert, who served the water sector in Jordan for more than 25 years. He started his career at Jordan Drinking Water Corporation in the early eighties, then took over many vital positions at the Water Authority of Jordan in different service areas in Jordan, and finally served as the Secretary General of the Ministry of Water and Irrigation, and in 2009 he was appointed as the Secretary General of the Arab Countries Water Utilities Association (ACWUA). Eng. Khaldon Khashman is a member of board of directors at the Water Authority of Jordan, municipal councils, Jordan Engineers Association and other professional organization, and a former board member in Jordan Water Company (Miyahuna), Northern Governorates Water Administration and Aqaba Water Company. He attended more than 40 local and international professional training programs covering technical, financial, legal and administrative issue in water utilities. He strongly believes in the importance of knowledge and experience transfer between Arab water utilities and promoting ACWUA as regional center of excellence which will partner with water supply and wastewater utilities in Arab countries to provide best practice service delivery to their customers.

Keynote

Gaining Urban Water efficiency in Arid Conditions –Latest Trends

Alexander McPhail

Lead Water & Sanitation Specialist, The World Bank Group

Summary

Exceptional water and wastewater utilities in fast growing arid settings are using modern management approaches to achieve very efficient performance, in spite of increasingly constrained water supplies and variable customer growth patterns. These best practice utilities have adopted an integrated strategy that combines: 1) leveraging emerging technology for the infrastructure; 2) redesigned customer information systems; 3) the extensive use of GIS; and 4) simplified plant operations through reduced size and standardization. Experience from the American Southwest shows how utilities have re-made themselves into efficiency leaders when faced with the combination of droughts, economic boom and then recession, and steadily rising prices. The suite of innovations introduced over the last 5-6 years have already proved themselves through significantly lowering overall demand, presenting the ability to shift demand peaks, much lower energy costs, greatly reduced NRW and bad debts that rarely exceed 3% of sales. These state-of –the-art measures also are yielding large improvements in hydraulic models, in turn leading to lower CAPEX and OPEX (energy) costs, and faster plant construction times. This presentation will highlight examples from Phoenix and Tuscon, Arizona, and Las Vegas, Nevada.

***Biography**: Dr. McPhail has more than 25 years of experience in the water sector in both industrial and developing countries. His expertise includes the operation of large urban water and wastewater utilities, water resource management planning and policy development. He holds a Ph.D. in Environmental Engineering from Johns Hopkins University (USA). Dr. McPhail first came to the World Bank Group 25 years ago. Since then, he has worked on water and sanitation projects and studies in more than 30 counties. During the last five years he has worked exclusively on large and complex operations that combine difficult technical issues with high visibility and significant stakeholder and NGO involvement. For over six years he was on the Board of Directors for DC Water in Washington, DC. Dr. McPhail also served six years on the Public Council for Drinking Water Research and is a member of the International Association for Impact Assessment (IAIA).*

Efficient Management of Municipal Water: Water Crises in the Taiz City in Yemen, A Study of Issues and Options

Abdulla Noaman and Abdelwale Al-Sharjabe

Faculty of Engineering, Sana'a University, PO Box 14469, Sana'a, Yemen

Abstract: The City of Taiz is the third largest city in Yemen located about 250 km south of Sana'a and about 90 km inland from the Red Sea. Taiz is situated on the foothills and slopes of the Jabal Saber Mountain on elevations between 1100 and 1,600 masl. Its population is rapidly increasing and is expected to grow from about 580,000 in 2012 to over 1,000,000 in 2020. Water supply constitutes the most pressing problem in the city of Taiz today due to significant shortage of supply (the average consumption is 23 L/d) caused by the depletion of existing water resources and the lack of a clear direction in dealing with the problem. This forces frequent service interruptions (30-40 days) and the service is rarely extended to new users (only 57% of the population are covered). Sanitation is another daunting problem. The (poorly maintained) sewerage network covers only 44% of the population. In several unsewered areas to the north, east and west of the city, raw sewage is directly disposed in Wadis, which causes a health hazard and threatens to contaminate groundwater resources. The proper computation of demand and supply is based on the various fields. It was performed under this study with a particular model: Water Evaluation and Planning System (WEAP) developed by the Stockholm Environment Institute (SEI). WEAP is supported by a Geographical Information System (GIS). The available and relevant data on poverty and social indicators, water use and sources, surface runoff, surface and groundwater availability, groundwater depletion and management, crop production areas, soil cover, maps, and meteorological information were gathered from a number of sources. There are only two ways to decrease the water deficit: increasing water supply or decreasing water demand. Any adaptation project aims at one of the two. Six projects are proposed, with three in each categories: Project 1: Improvement of irrigation methods, project 2: Improvement of water distribution network in Taiz City, project 3: Water Re-use, project 4: Water Harvesting, project 5: Brackish Water Treatment, and project 6: Desalinization of sea water. Projects 1, 2, and 3 aims at decreasing demand, while projects 4,5 and 6 to increase supply.

Keywords: efficient management, water crises, municipal water, Taiz, WEAP.

Introduction

Yemen is one of the poorest countries in the world and in the Middle East and North Africa (MENA). In the middle of a volatile regional environment, Yemen faces chronic security, political and social instability and all its development indicators are alarming. Taiz is one the main cities of Yemen, located in the interior highlands at altitudes ranging between 1,100m and 1,600m above sea level, at the foothill of Sabir mountain (altitude 3,000m asl). The city is the administrative capital of Taiz governorate, the most populated of Yemen's 20 governorates with close to 16% of the total population. Taiz city's population is estimated today at approximately 665000 inhabitants, out of an estimated 3 million inhabitants in the governorate. There is a concentration of industrial units on the periphery of the city. Agriculture, practiced mostly in the main wadis and in the highlands, is the primary means of livelihood for the rural population [1].

Water supply constitutes the most pressing problem in Taiz today due to significant shortage of supply (the average consumption is 23 L/d) caused by the depletion of existing water resources and the lack of a clear direction in dealing with the problem. This forces frequent service interruptions (30-40 days) and the service is rarely extended to new users (only 57% of the population are covered). Sanitation is another daunting problem. The (poorly maintained) sewerage network covers only 44% of the population. In several unsewered areas to the north, east and west of the city, raw sewage is directly disposed in Wadis, which causes a health hazard and threatens to contaminate groundwater resources [1].

1. Site and Sector Specifics

1.1. Physical Geography of the Study Area

The Upper Wadi Rasyan is a part of Taiz Governorate and it is located in the interior highlands at altitudes ranging between 1,100m and 3,000m above sea level, at the foothill of Sabir mountain (altitude 3,000m asl). Upper wadi rasyan is one of the major Wadis draining the highland and midland regions of the Red Sea Basin. According to [1], the total catchment area of wadi Rasyan "up to the mouth of the river at the sea" is 2,550 km2. However, the area of the upper and middle catchments (*i.e.,* excluding the coastal or Tihama part of the catchment) is only 1,990 km2 [2] The study area (figure 1) comprises the upper catchment of Wadi Rasyan which is defined as the catchment area upstream from the point 378 UTME and 1510 UTMN. This area covers approximately 929 km2.

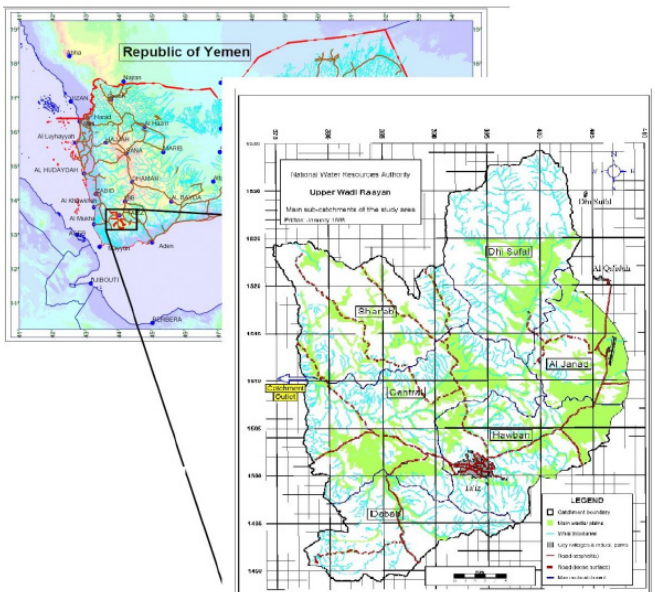


Figure 1: Upper Wadi Rasyan Location

1.2. Human Geography of the Study Area

Based on the 2004 census, the total population of upper Wadi Rasyan was estimated for the year of 2013 as 0.82 million, 0.70 million in the city of Taiz and 0.12 million in the rural area. Projections for 2030 are of 1.25 million inhabitants (almost 90% of them in Taiz). The other parameters of human resources for upper Wadi Rasyan is assumed to be the same as that of the Taiz governorate, which indicate that the gender ratio is 103.2, and the average number of persons per household is 7.8 [3].

1.3. Water supply in the Study Area

Water supply study consists in the quantification of the general systematic representation of the water cycle. It entails the understanding of how much water it is raining and how these would split into river stream flow, groundwater recharge and flow. This eventually leads to knowing the quantity of water available both renewable and non-renewable. These are then used as constraints to see whether the water use is sustainable or not for a given time horizon.

2. Rain and Runoff

The rain pattern in upper Wadi Rasyan follow East-West gradient (figure 2). It is the source of runoff in the Wadi and recharge of ground water in the upper Wadi Rasyan. The site is characterized by convective rainfalls that are localized and having intensive precipitations of short durations. The spatial pattern of annual rainfall varies from year to another. It ranges between 250 mm at the plain areas to more than 300 mm at the south-western mountains.

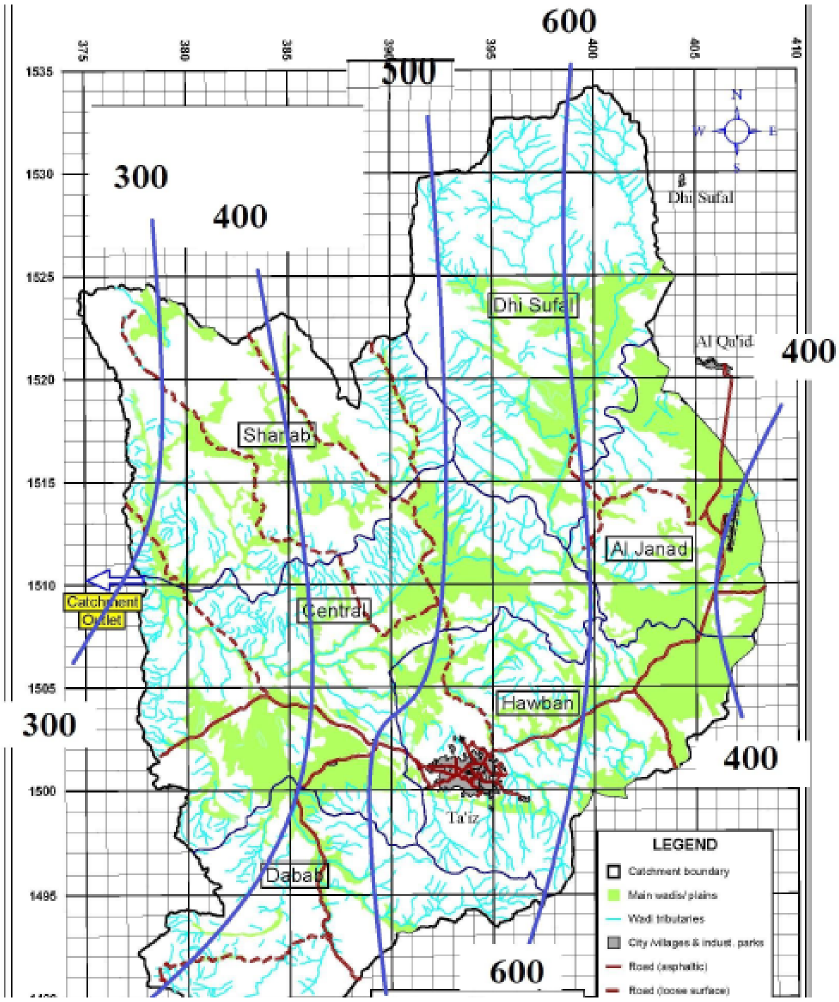


Figure 2: Contour lines for rainfall in Wadi Rasyan [1]

2.1. Groundwater Storage

Groundwater storage in the area may be estimated with varying degrees of difficulties and uncertainties depending on the state of knowledge on each of the three aquifers in the area.

Estimations of the stored volume of groundwater in the alluvial aquifer were based on data on the alluvial area, average alluvial thickness, and average depth to water in the six sub-areas. Assuming a storage coefficient ranging from 8 to 15% with a recommended value of 12%, the total volume of groundwater storage in the alluvium aquifer was estimated to range from 150 to 280 Mm3 , with a best estimate of 220 Mm^3 [1]

2.2. Groundwater Recharge

Groundwater aquifers in the study area are recharged by two types of water (renewable and recycled) and through two types of processes (natural and artificial). In their report of 1977, Montgomery suggested that the total quantity of annual surface flow available for recharging the potential water sources surrounding Ta'iz (defined as the groundwater basins of Hawban, Hawjalah, Hougfa, Dabab, and Haimah; total drainage area of 509 km2) is about 25 Mm3, representing an average of 4.9 Mm3 / 100 km2 [5]

2.3. Water Use in the Study Area

The total abstraction in the Basin estimated by NWRA [1] is shown in the table 1 below, as a summary of annual groundwater abstraction and use for different use in the urban and rural areas. However, it is emphasized that these results should be used as gross estimations only since the water pumped from the majority of wells in the Basin is mixed water that may not represent a particular aquifer type.

Table 1 : Total Annual Groundwater Abstraction in Taiz Basin [2]

	(Sector use (Mcm/yr						
Source	Irrigation		Municipal		Industry		Total
	Urban	Rural	Urban	Rural	Urban	Rural	
Private	0	27	5.1	2.0	4.0	-	
Public (NWSA)	0	0	5.6	-			
Total	0	27	10.7	2.0	4.0	-	43.7

3. Model Description and Application

The Water Evaluation and Planning System (WEAP) model of the upper Wadi Rasyan catchment represents 6 hydrologic sub-basins and six localized aquifer systems identified by [1] explicitly representing the Central, Hawban, Dhabab, Sharab, Janad and Dhi Sufal Southwestern Catchment areas and Groundwater aquifers enabled modelling of regional differences in groundwater storage and availability across the upper Wadi Rasyan catchment to be analyzed. Hydrologic simulation in Water Evaluation and Planning System (WEAP) included partitioning of rainfall between runoff, infiltration, and evapotranspiration in the 6 sub-basins using a semi-distributed, lumped parameter hydrologic model embedded in Water Evaluation and Planning System (WEAP) [4]. Each of these 6 sub-basins was linked to one of the six aquifers for purposes of simulating groundwater recharge. Irrigated, rainfed, and inactive land cover areas obtained from the National Water Resources Authority (NWRA) were included in this parameterization. Crop types delineated included Qat, grains, maize, and sorghum. Domestic demand was simulated using population projections for each of the sub-basins (figure 3).

In the Reference scenario, the climate sequence for future years was developed by repeating historical data for the period 1975 to 2005 and assuming a similar periodicity through 2050.

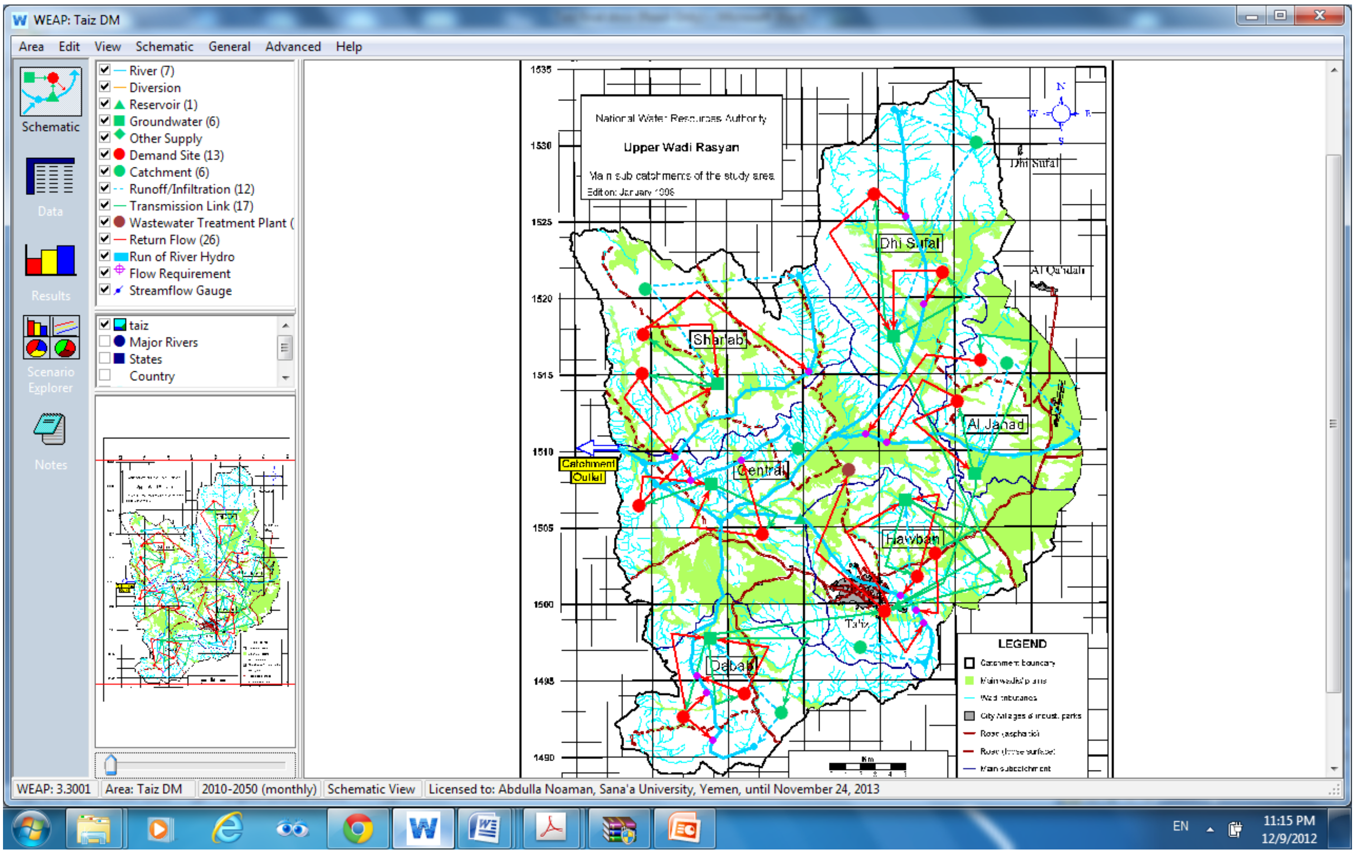


Figure 3: Water Evaluation and Planning System (WEAP)

Schematic View of upper Wadi Rasyan Basin.

3.1. Inputs for Modelling

All the above serves as a basis to inform the Water Evaluation and Planning System (WEAP) model used to compute the water balance throughout time and understand whether the trajectory is sustainable or not. the model input requirement to present the inputs in a concise fashion are: mean monthly Rainfall,_ mean monthly temperature, water demand and use.

3.2. Outputs of Modelling

The results of the climate change impacts on sub basin runoff generated and ground water recharge are shown in the tables 2 and 3, and figures 4 and 5 for two conditions only temperature change and both temperature and rainfall changes.

Table 2 : Temperature Impact on Runoff and Groundwater Recharge in Wadi Rasyan (considering the sole effect of temperature)

Time horizon	2013		2030	
Sub-basin	Runoff gener- (ated (Mm3	Groundwater recharge ((Mm3	Runoff generated ((Mm3	Groundwater recharge ((Mm3
Al Janad	4.07	2.03	3.63	1.82
Central	8.1	3.12	7.4	2.86
Dabab	7.66	2.06	7.1	1.91
Dhi Sufal	11.43	5.70	10.30	5.14
Hawban	7.78	3.39	6.55	3.67
Sharab	9.61	4.23	4.96	2.24
Total	48.7	20.5	40.0	17.6

Table 3: Temperature Impact on Runoff and Groundwater Recharge in Wadi Rasyan (if instead we consider the effects of both temperature and rainfall)

Time horizon	2013		2030	
Sub-basin	Runoff generated (Mm3)	Groundwater recharge (Mm3)	Runoff generated (Mm3)	Groundwater recharge (Mm3)
Al Janad	4.07	2.03	4.42	2.20
Central	8.1	3.12	9.40	3.41
Dabab	7.66	2.06	8.91	2.21
Dhi Sufal	11.43	5.70	12.65	6.24
Hawban	7.78	3.39	7.85	3.37
Sharab	9.61	4.23	5.83	2.59
Total	48.7	20.5	49.1	20.0

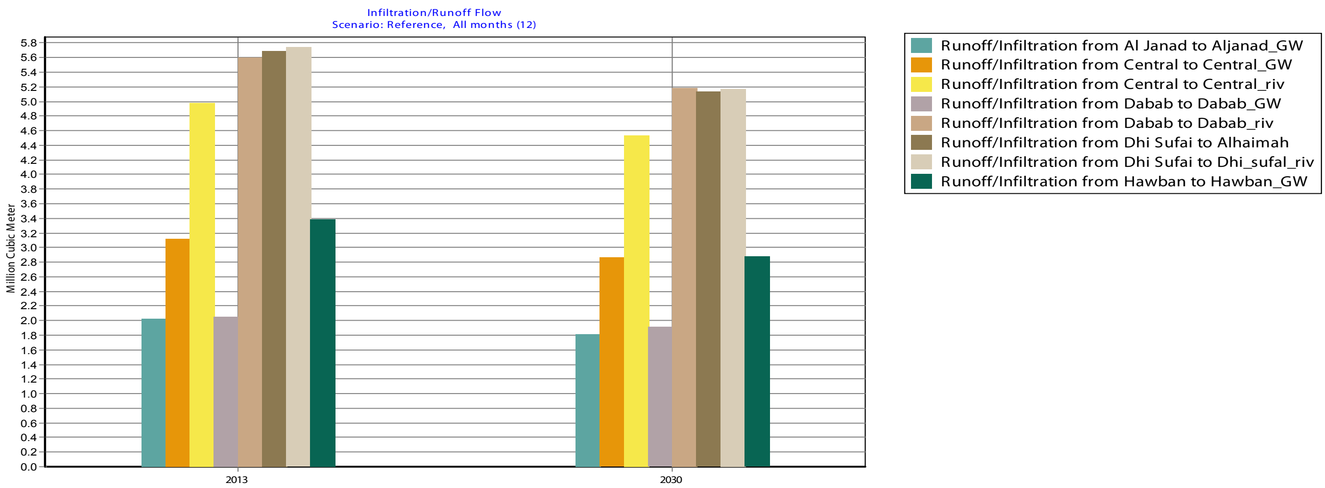


Figure 4 : Comparison in Runoff and Recharge between 2013 and 2030, Wadi Rasyan

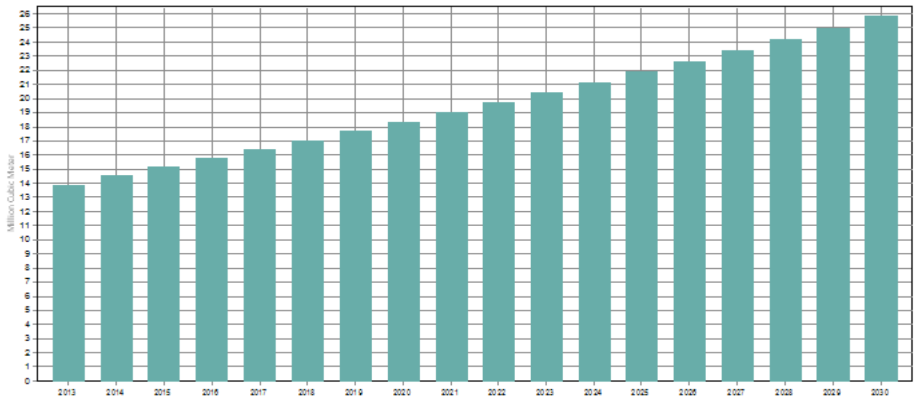


Figure 5 : Unmet Demand in Wadi Rasyan Basin from 2013 to 2030 (M cum)

The above results show that as a result of increased temperature from 2013 to 2030 the total surface runoff in the Upper Wadi Rasyan will decrease from 48.7 to 40.0 Mm3 (18%) and the groundwater recharge from 20.5 to 17.6 Mm3 (14%). As the three figures below show, there is a clear drop in supply and rapid growing demand, which is clearly an unsustainable pattern.

According to the results with both temperature and rainfall changes the overall impact on water resources and groundwater recharge is not significant in the basin because the rainfall change is positive to produce more runoff and groundwater recharge which cancels the negative impact as a result of temperature increases.

4. Adaptation Measure

4.1. Reduce the Water Balance Deficit

There are only two kinds of options to reduce the water balance deficit: reduce the demand or increase the supply.

i. Reducing Demand: Project 1: Improvement of irrigation methods, project 2: Improvement of water distribution network in Taiz City, and project 3: Water Re-use.

ii. Increasing Supply: Project 4: Water Harvesting, project 5: Brackish Water Treatment, and project 6: Desalinization of sea water.

4.2. Modelling of the Adaptation Measures

The same Water Evaluation and Planning System (WEAP) model is used with the following new assumptions derived from the above project proposals:

i. Irrigation Improvement: The irrigation improvement will increase the irrigation efficiency. The irrigation efficiency is assumed to improve from 40% to 80% by the introduction of the drip system under a sound water management policy.

ii. Water Distribution System Improvement: It entails reduction in losses in the municipal water distribution system and introduction of water saving domestic features; it is here modelled by a drop in the annual water use rate in Taiz by 0.5% per year starting in 2014 and a drop of losses in the distribution system from 30% to 10%.

iii. Water Re-use: This additional water will be modelled by linking to one of the irrigation sites instead of discharging it the Wadi.

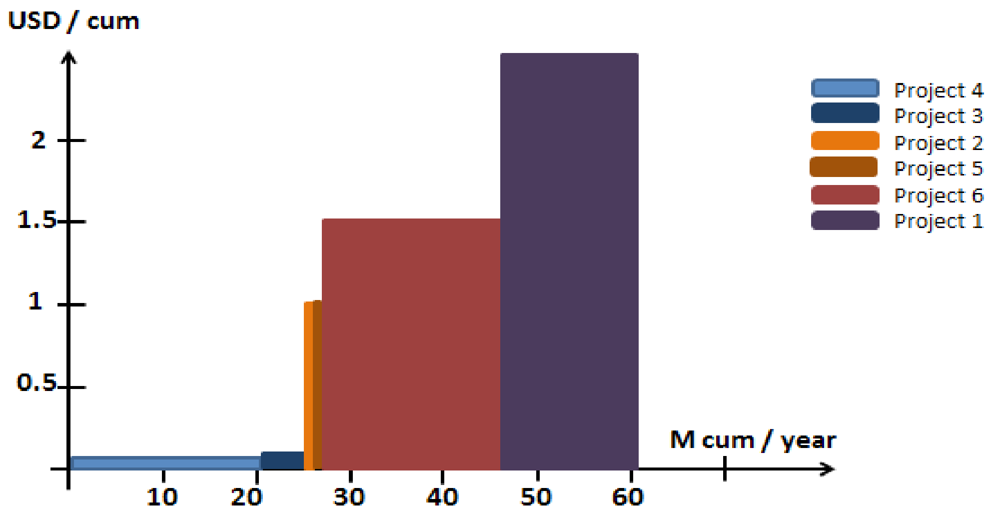
iv. Water Harvesting**:** This will bring an additional water resource of about 21.7 MCM for Taiz City.

v. Brakish Water Treatment: This brings an additional water of 4,000 cum per day for Taiz city.

vi. Desalinization of Sea Water: This brings an additional water of 50,000 cum per day to the city.

5. Economic overview

Figure 6 ranks measures by efficiency and potential of water each one could unlock.



(*The projects scenarios are the following*: Project 1: *Improvement of irrigation methods – MUSD 24*/ project 2: *Improvement of water distribution network in Taiz City- MUSD 20*/ project 3: *Water Re-use- MUSD 3.1*/ project 4: *Water Harvesting- MUSD 22*/ project 5: *Brackish Water Treatment- MUSD 20*/ and project 6: *Desalinization of sea water- MUSD 300*)

Figure 6: Summary Figure of Adaptation Measures in Wadi Rasyan

This figure was made for comparison purposes and with the idea of getting a feel of the relative efficiency and extent each measure could potentially offer. There is however uncertainty of each value, and the above is in no way to replace adequate in-depth economic study of each one, with its own terms. The perhaps most important example in this regard relates to irrigation improvement measures, project 1which provides water for as expensive as about 2.5USD/cum (this is a median, cf. above for the proper probability distribution). But this evaluation alone does not capture the fact that some value is also produced with this water, as part of an agricultural production process. If the latter is profitable, the cost overall, including of water, could appear much lower or even negative. Also, as far as irrigation is concerned, it is not sure at all that better technology means water savings. Indeed, better use of water is likely to increase profitability, and hence make a formidable incentive to expand quantitatively the crops. If that is not prevented either by natural limitation (land), capital or market demand, then only legal barriers effectively enforced can guarantee that some water is indeed saved.

Nonetheless and with all the attention that should be given in comparison purposes, the figure is instructive. It clearly puts forwards projects 3 and 4, altogether tallying in the range of 25 M cum a year. This should be the priority. Projects 2 and 5, for as decently profitable as they are compared to others, brings only a rather marginal input in quantity terms. And finally, as one may have expected, desalination in Makah is very expensive, but has a huge potential capacity to buffer the water gap (almost 20 M cum a year).

Finally, it is also worth noticing that project 1, 3 and 4 can be implemented very progressively; this is also true, to a lesser extent with project 2. In contrast, projects 5 and 6 do require to be financed in one fell swoop.

Conclusion

The main purpose in the upper Wadi Rasyan was to investigate on the water balance in the widi, *i.e*. the difference between present and projected consumption (demand) and the supply. There is high confidence about the steady increase of water demand. The greatest uncertainties are looming on the supply side, *i.e*. the quantity of water available, notably underground.

The limited renewable resources make it inevitable under the current circumstances to continue to tap in the non-renewable stock of water. This unsustainable approach will lead to a tragedy as the non-renewable resources have been fully exploited, and perhaps before because of increasing costs and efforts to get the diminishing water resources.

The impact of climate change *per se* in this unsustainable scheme remains in the realm of speculation, though the most consensual interpretations of climate projections suggest that on the long run (coming decades), the situation will be worsened.

In a risk management perspective, it is not recommended to consider that the most likely, or the average or median scenario will not come up, and instead it is very fair to be willing to hedge for more pessimistic futures, even without a thorough capacity to describe it in all details. In any of such perspective, the situation in upper Wadi Rasyan is very worrying as far as water resources are concerned, and not being proactive would in fact jeopardize the capacity to handle a potentially tragic situation that calls for a complete set of measures.

There are only two ways to decrease the water deficit: increasing water supply or decreasing water demand. Any adaptation project aims at one of the two. Six projects are proposed, with three in each categories (1,2,3 in decreasing demand and 4,5 and 6 to increase supply).Project 3 and 4 seem particularly opportune for they provide large quantities of water at cheap cost. 5 and 6 would make the water expensive, but they can bring substantial quantities. Projects 2 and 5, for as decently profitable as they are compared to others, brings only a rather marginal input in quantity terms. Project 1 is a bit special: it brings water at high costs, but it is part of a productive process, so depending on the crop value chain and marketing conditions, it may be very worthy too.

Acknowledgements

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Biography

Dr. Noaman holds a PhD Degree in Hydrology and Water Management from Technical University of Braunschweig, Germany in 2001. Currently he is an associate professor at the faculty of engineering and at the Water and Environmental Center (WEC) at Sana'a university. He has more than 20 Years experiences in the field of hydrological studies and modeling, dam design, water supply, climate change and sanitations projects in Yemen.

Dr. Noaman has been involved in many national and international studies and consultancies in fields of water management, modeling, climate change adaptation and mitigation

Dr. Noaman has more than 30 publications and articles in national and international scientific Journals in the field water management, modeling, climate change adaptation and mitigation

Improvement of Environmental Performance by Activities Related to Water Supply Systems

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Abstract: A tremendous amount of energy is used to provide potable water in Oman. Urban demand for water is growing dramatically in Sultanate so that more energy is necessary for moving water through water systems, making water potable. By the year 2020, expected demand for treated water in Muscat City alone is estimated at 345,796 m^3/day, which will require 140,950 kWh of electricity to transmit water to reservoirs in east and west of Muscat. The projected power consumption for water to Muscat and suburbs will increase by three times equivalent to present requirement. Electricity consumption in a water scheme will increase than its actual requirement owing to several factors hence that will lead to increase of waste of energy. Water losses in the distribution and transmission pipes, consumer's behavioral pattern of water usage, water system inefficiencies are some of contributing factors for the waste of energy. Use of water and energy excessively would result not only in wasting thousand of liters of water wasted by reverse osmosis systems, overexploitation of surface water, ground water but also bring impact to the environment. By understanding the situation many countries have been studying in every possible aspect of how effectively use of energy and water in pumping systems and thereby the ways of protecting the environment. The paper will present the process of identifying , understanding and determining the energy losses due to system inefficiencies and the procedures of reducing the energy losses and the expected amount of emission level of CO_2 to the environment due activities related to water supply systems. The water supply to the Muscat has been selected as the study area.

Keywords: energy, environment, emission, power consumption, Oman.

1. Introduction

The Public Authority for Water and Electricity of Oman (PAEW) currently serve 1.5 million people around the sultanate except Sohar City and Dhofar Governorate by providing 650,000 m3 of drinking water per day. Total production in 2012 was 161.2 millions of m^3 [4] on which the desalination plants significantly contributed in producing 85% of its total production where as ground water had contributed to fill the rest of 15%.

The water demand in the Sultanate of Oman has been steadily increasing over recent years by around 15% per year as the result of the economic growth and the rapid developments taking place around the sultanate, so that with increase of the demand for the potable water, PAEW plans in continuing rely on large desalination plants as the main source of water.

Public Authority for Water and Electricity of Oman (PAEW) at present, take water from large desalination plants located in Ghubra, Baraka, Sohar and Sur. All these plants are contributed to produce nearly 631,000 m^3/day to serve the areas in Muscat, Batinah South and North, Ash Sharqiyah governorate. In addition small desalination plants located in Al Wasta, Musandam, Ash Sharqiyah South are used to serve areas which also capable of producing 3300 m^3 per day.

Construction of a new desalination plant and a pumping station in Gubrah are underway and expected their services and operation of both plant beginning of year 2015 as the existing desalination plant and the pumping station in Muscat not capable to meet the increased demand.

2. Planning and Implementing Unaccounted for Water in Oman

Unaccounted for water (UFW) percentage in Sultanate is comparatively high and it records more than 30% in year 2012 [4]. The highest Unaccounted for water (UFW) percentage is recorded in Muscat but slight reduction about 4% has shown compared to year 2011. Reservoir overflows, illegal connections, meter errors, construction failures, lack of communications, are some of contributing factors are found to be for the high rate for Unaccounted for water (UFW).

The International Water Association (IWA) has developed a detailed methodology to assess the various components of unaccounted for water Unaccounted for water (UFW). A methodology is followed in Public Authority for Water and Electricity of Oman (PAEW) which is similar to (IWA) to assess the percentage of (UFW) in all governorate .

Water losses in potable water can be divided into two major parts namely real and apparent losses as to the methodology. Real losses mean the leakages on transmission and distribution mains, leakages and overflows at storage tanks, and leakages on service connections up to point of customer meter.

Unauthorized consumption and customer meter accuracies are described under apparent losses. These two key elements are considered as performance indicators which could and should be used to measure and compare various components of unaccounted for water (UFW).

Non revenue water (NRW) means that the water is lost before it reaches to the customers. If the NRW level of a water scheme is high, the scheme is not financially viable and also deteriorates of water quality. (UFW) is typically measured as volume of water lost as a share of water produced. This is measured as a percentage.

In all water utilities water loss strategy has become one of the major operational tasks of the distribution network. The diagnostic approach followed by practical implementation of solutions which are practicable and achievable can be applied to any water utility anywhere in the world to develop a strategy for (UFW) management. Available tools and mechanisms can be used to suggest appropriate solutions for formulating the strategy.

Develop of an action plan for each activity to reduce percentage of (UFW) is necessary and also responsibilities and accountability is to be defined to maintain the strategy and sustain the achievements gained. Various methods are followed in many countries to reduce (NRW) percentage. Recent developments in instrumentation and data acquisition system are used to make continuous monitoring of water losses in pipe network.

3. Conservation of Water

Public Authority for Water and Electricity of Oman (PAEW) has taken tremendous effort in implementing several strategies [4] not only to provide better service to the customers but also to save energy, save water and the same time to protect the environment. Some of strategies that they have taken are: (a) Accurate meter reading procedure developed to measure the water incoming from desalination plant and at the same time replacing all the non functional meters in the well field. (b) Development in instrumentation of all transmission network in Muscat and other governorate (ex. Pressure monitoring etc.) and integrating with Supervisory Control and Data Acquisition (SCADA) to monitor the behavior of flow in the transmission and delivery lines. (c) Establishing all District Meter Area (DMA) concepts throughout the service area. (d) Metering and Accounting improvement mechanism to measure correctly the quantity of water fill to water tankers. (e) Community awareness and educational programs on water savings and promoting water saving methods. (f) Different communication methods are used to communicate the consumer on water conservation. (g) Speedy arrangement to repair the leaky pipes and replacing old equipment and pipes and improving the water systems.

By addressing for areas mentioned above with the support of media the importance of water conservation and encouraging the consumers about conservation, the Public Authority for Water and Electricity of Oman (PAEW) is expecting to receive favorable responds from the consumers and accordingly to achieve the desired objectives.

4. Energy Conservation Options in Water Sector

In water sector, conveying water through the pipes consumes energy [1]. Water pumps and other related equipment using for the treatment and piping are the major components to be considered as a system in a water scheme. The overall design of the system is one of the most critical features in a water utility in terms of efficiency.

System designers intentionally oversize equipment to ensure the equipment meets maximum system requirements. The excess margins leads to problematic situations as a results the power consumption eventually goes up. Upgrading to newer, higher efficiency equipment will likely improve system performance if correctly sized and integrated into the entire system.

Control by pump speed regulation is most advantageous in view of energy saving, however equipment costs are rather high and professional maintenance services are sometimes necessary. Variable Speed Drive (VSD) is suitable for the case with a rising system head curve such as for a long distribution pipeline or pipe line network in which demand fluctuates considerably. Speed can be controlled in a number of ways with the most popular type of variable drive (VSD) being the Variable Frequency Drive (VFD).

There is a relationship between impeller peripheral velocity and generated head [2]. Peripheral velocity is directly related to shaft rotational speed for a fixed impeller diameter. Varying the rotational speed therefore has a direct effect on the pump's performance.

5. Environmental Impacts Due to Water Related Activities

Energy is predominantly produced by burning of fossil such as coal, oil, and natural gas or hydro power. When fossil fuel is used for power generation considerable amount unwanted gases like Sulfur dioxide (SO_2), Nitrogen oxides (NO_x), Carbon monoxide (CO), particulates, mercury and other dangerous pollutants. In addition, CO_2 is the primary gas [5] is responsible for global climate change; it is believed and found that it is adversely bringing impact on extreme whether events, such as droughts, heat waves, floods and storms.

Over harvesting of water is also environmentally risky [1]. Removing too much water from ground, lakes and reservoirs can devastate local ecosystem and lead to soil salinisation and even desertification. Water sector authorities must need to recognize the environmental risks from energy use and over harvesting of water resources

6. Case Study: Environmental Effects Due to Water and Energy Use

The Water from the current Gubbrah desalination plant is transmitted to Qurum, Wattaya , Ruwi, Muscat reservoir, Mumtaz overhead tanks and Al Amerath in line pumping station in the Eastern region and to Bowsher and airport reservoir in Western region via forwarding pumps at Gubbrah pumping station. Following table shows the operational data of the forwarding pumps.

Table 1: Operational Data of the Forwarding Pumps

Pump station	NPS 1	NPS 2
Pump operation and type	6 duty KSB spilt case	6 duty KSB spilt case
Year of installation	1982	1991
Pump duty point	1000 m^3/hr at 105 meters	1000 m^3/hr at 105 meters
Total capacity m^3/hr	4000 m^3/hr	4000 m^3/hr

Centrifugal split casing pumps (12Nos) are arranged in two pumping stations named NPS1 & NPS2 and operate parallels to receive the maximum flows during high demands periods. All pumps have been using more than 15 years and overall efficiency of each unit has not been estimated and however it is found that significant increase of flows does not show as the characteristics curves of pumps are flat in shape therefore it increased the hydraulic losses rather increasing the flow. As a result of this, the operating point is shifted to left of the curve and therefore will not provide significantly increase to the total flow capacity of the overall pumping system.

All operational data of pumps in NPS1 & NPS 2 are being maintained and recorded in every month. Records of three months in year 2012 were considered for this study and based on the behavioral pattern of energy consumption of pumps and flow its discharge being studied to examine the impact on the entire system and to identify the opportunities for improvement. The results were linked to estimate the estimated total impact could be cause annually to the environment due to operation of pumps.

7. Calculation of Power for the Existing System

The present situation of existing pumping system was analyzed based on site records, which shows a combination of pumps in NPS 1 or NPS 2 are arranged in a such a way to discharge a total capacity of approximately 4000 m^3per hour.

The power consumed for the production were used to calculate the specific energy consumption (kWh/m^3).The specific energy consumption (kWh/m^3) *i.e.* the required power consumption to produce one meter cubic of water is a good tool to investigate the pump performance. Accordingly, monthly operational records from December 2013 to February 2014 are taken for the study and the specific energy consumption for the pump combination used in NPS1 & NPS 2 in each day in the relevant month and results are depicted in figures 1, 2, and 3.

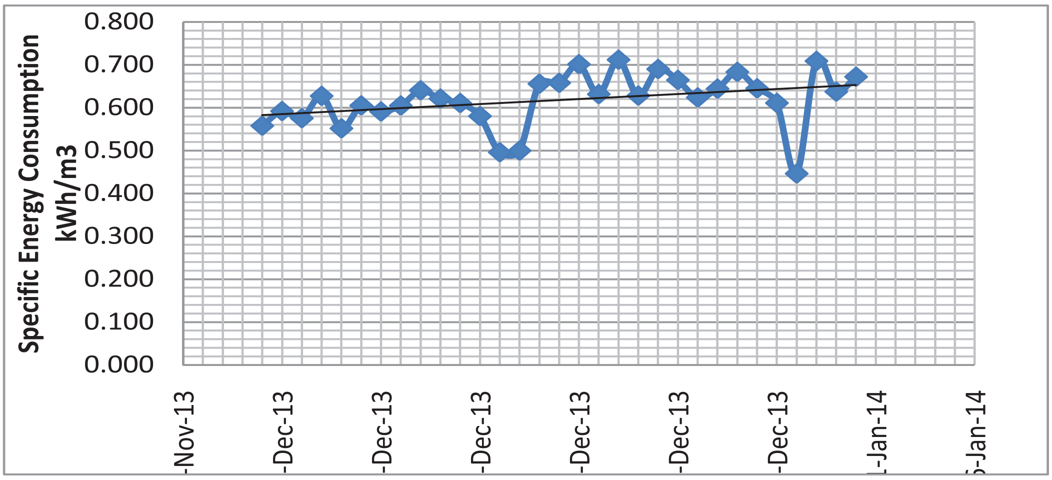

Figure 1: Specific Energy Consumption in December 2013

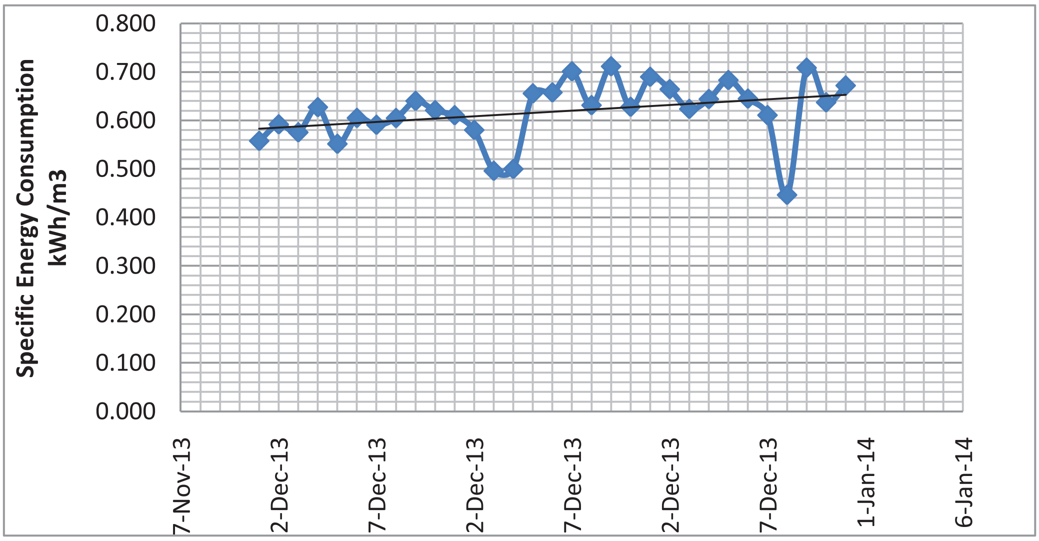

Figure 2: Specific Energy Consumption in January 2014

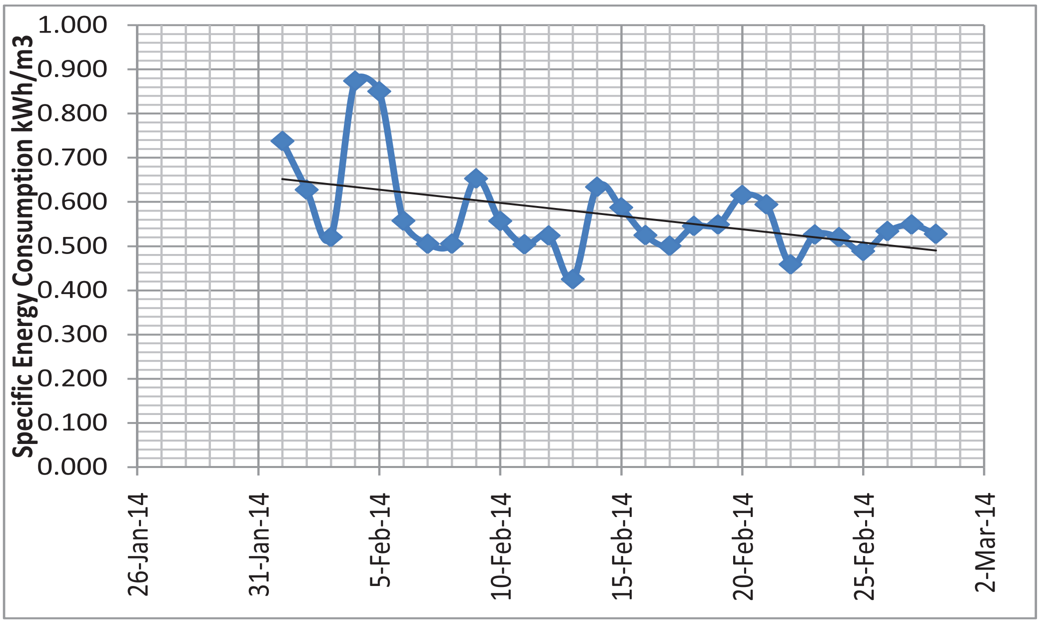

Figure 3: Specific Energy Consumption in February 2014

In December 2013 as to the monthly operational records, Pumps in NPS 1 & NPS 2 were capable of forwarding 4,026,682 m^3 of water to reservoirs. Total power consumed to produce the quantity during the month was 2475.1 MWH.

It is clear from figure1 (see, figure 1) that the specific energy consumption in each day is slightly varying but it has a rising trend towards the end of the month. The energy consumption in 28th December has recorded the lowest where as the highest consumption recorded in 19th of December. From this figures (see, figure1), it is revealed that more energy is consumed than it requires to produce the daily requirement of water. This may be due to several reasons like loss of pump efficiency in some pumps or the increase of flow resistivity due to partially closer of valves ,pipe ageing etc that require more energy to move the water through pipes. However the combination of pumps which were arranged in NPS 1 & NPS 2 to operate on 13th and 28th of December need to be studied further since the lowest energy consumption were recorded on respective days.

Compared to specific energy consumption in December, the specific power consumption to produce one m^3 of water is relatively low. In January 2014, total power consumption in the month was 2425.1MWH to produce 3,927,648 $m^3$of water (see, figure2). The lowest power consumption was recorded on 13th January where as the highest was recorded on 20th January 2014. Further studies are required to check the setting the combination of pumps put into operation in 13th January were the same pump set used in the day that the power consumption showed lowest in December2013.

Slight reduction in specific energy consumption was shown as to the figure 3.in the month of February2014. The lowest energy consumption was shown in 13th of February where the specific energy consumption is 0.425 kWh/m^3 which was the lowest figure compared to the previous months. As to the above figure, it is evident that 22 days in February, the specific power consumption was more than 0.500 kWh/m^3.

It is obvious that the required quantity of water as to the daily requirement was supplied using all pumps. All six pumps were arranged to work simultaneously, therefore the required quantity can be achieved but in failure of one pump a remarkable drop in flow is noticeable since the respective pump curve is not steeper enough. Receiving water from reservoir to pumps also a contributed factor to increase or decrease the total head of pumps. In either situation, the energy wastages could be evaluated but need further studies in each pump.

In table 2 the average specific energy consumption in February shows a drop compared to previous months. As to the operational records there is no any system operational improvement were taken place during February so that the drop in energy consumption could be due to operational arrangement of pumps.

Table 2: Production Details in Each Month

Month	Dec., 2013	Jan., 2014	Feb., 2014
Monthly water production (m^3)	4026.682	3927.648	3451.317
Monthly power consumption Power (MWH)	2475.1	2451.1	1943.7
Specific energy consumption (kWh/m^3)	0.617	0.615	0.563

8. Calculation of Non Revenue Water in Studied Area

The non revenue water percentage in the Sultanate in 2012 was considerably high and it is recorded 30% [4]. This means that the revenue in which to be collected is lost due to many reasons like overflow in reservoirs, meter errors, leaks in pipes, an increase of pressure etc. has resulted to increase of non revenue water percentage. In certain areas pipe born water is not accessible therefore water is supplied to many customers using water tankers. Most of water tanker filling stations are metered but few filling stations are still exist without metered therefore this also contributed in increasing of Unaccounted for water (UFW).

Non revenue water cannot totally eliminate. However Public Authority for Water and Electricity (PAEW) has taken several strategies in maintaining consistently to keep at a lower percentage. A developing network of District Meter Areas (DMA) throughout of its service area is one of strategy is in process to conserve water and energy.

Replacing with new pipes in the distribution network and attending to repair leaky pipes within shortest possible time are some of strategies are in progress with in Public Authority for Water and Electricity (PAEW).

Results and Discussion

From the table3, average input powers to pumps are changing from 0.617 kWh to 0.563 kWh to produce one meter cube of water. It is apparent by changing control system of operation in each bank *i.e.* NPS 1 & NPS 2 if arranged in such a way, a remarkable energy could be saved and pumps could have operate in a lower energy consumption.

Table 3: Specific Energy Consumption

Month	Dec., 2013	Jan., 2014	Feb., 2014
Monthly water production (m^3)	4. 026. 682	3.927.648	3.451.317
Monthly power consumption power (MWH)	2475.1	2451.1	1943.7
Specific energy consumption (kWh/m^3)	0.617	0.615	0.563
Lowest specific energy consumption recorded	0.446	0.481	0.425
Monthly power consumption if pumps operated at lowest SEC	1711.34	1669.25	1466.80

Environmental Effects Due to Operation of Water Systems

Oman generate electricity by using primarily on natural gas although there is some diesel generation. Therefore electricity sector in Oman relies on the domestic gas resources. In 2013 natural gas accounted for more than 80% of the country's electricity generation [6]. Oman generating capacity doubled between 2005 and 2010 from 8.6 billion kilowatt-hours to approximately 18.6 billion kilowatt-hours. Electricity consumption over the same period grew at a similar rate, rising by roughly 2.6 billion kilowatt-hours.

As to above, natural gas is an important fuel in the Oman. Therefore saving the domestic resources becoming an important aspect and every possible option on minimizing any waste of power in the industry has to be looked.

Maximize in utilizing the generated power and minimizing the power wastages could result not only saving the natural gas reserves but also reduction in emitting harmful green house gases as well.(CO_2 ,CH_4, Nitrous oxide and fluorinated gases) .

Global warming is a result of accumulating these green house gases in more quantities in the atmosphere which contribute to disrupt the eco system in the environment. It is reported that Oman alone in year 2013 has contributed to release a remarkable amount of 52.75 million metric tons of CO_2 which is the main green house gas to the environment. Tables 4 and 5 shows the emission amount of CO_2 and other gases during natural gas combined cycle power generation system.

Table 4: Emmisson Amount

Green House gases	Emission amount g/kWh
Total CO_2 emission	439.7
Total CH_4 emission	59.2
Total N_2O emission	0.00073

Table 5: CO_2 Emission Due to Waste of Power

Month	Dec., 2013	Jan., 2014	Feb., 2014
Monthly power consumption power (MWH)	2475.1	2451.1	1943.7
Specific energy consumption (kWh/m^3)	0.617	0.615	0.563
Specific energy consumption assumed can operate to kWh/m^3	0.525	0.525	0.525
Power consumption if pumps operated at assumed value MWH	2114.0	2062.0	1812.0
Monthly Power saving MWH	361.1	389.1	131.7
Total amount of CO_2 emission due to waste of power (Tons)	158.5	170.8	57.9

In considering above, the amount of power wastages and the amount of un necessarily release of CO_2 due to operation of pumps can be estimated [5] and accordingly how the water sector is contributing to disrupt the environment is discussed in the latter stages in this paper.

Based on the results, it is found that the control system change of pumps in NPS1 and NPS2 to deliver water to reservoirs has resulted a significant change of power consumption which might lead to increase of power wastages. It is clear that if the system is assumed to be operated in value of 0.525kWh/m^3 in each month then remarkable amount of power can be saved and also approximately 125 tons of CO_2 could be avoided monthly releasing to the environment due the water supply activities**.**

Also the water losses in the distribution that is the non revenue water percentage (NRW) in Muscat area if arrangement are taken to reduce from 30 % to 25%, the saving of power and the amount of emission of green house gases can be avoided to release to the environment is given in table 6.

Table 6: CO_2 Emission Due to Non Revenue Water

Demand side losses	Saving of power (KWh) due to the reduction leaks in network (Monthly)	Total CO_2 generation that can be avoided (Tons Monthly)
Reducing distribution network losses (NRW) from the prevailing rate 30% to 25%	102375	45

Non revenue losses are high and as a result remarkable amount of input power to pumps are wasted amounting 70 MWH if calculated to prevailing NRW rate. Also 30 tons of CO_2 and other harmful green house gases due to power generation could be avoided emitting to the environment.

Non revenue water cannot be totally eliminated but can be minimized with monitoring and corrective actions timely if taken. Let's assume as to the table that the prevailing NRW is reduced from 35% to 25% that is 5% reduction. It is evident that from the system , reducing distribution network losses and reducing end users losses through awareness program on water saving a remarkable amount of energy using for water production can be saved and simultaneously 45 Tons of CO_2 monthly being generated due to these activities can be reduced .

It is clear from the study that due to in efficiencies in the water system consumes remarkable amount of energy and could be corrected and reduced the energy consumption if suitable measures are applied. These measures can be identified as short and long term measures but investments will require for correcting them.

Results obtained from above shall not indicate the accurate values to ascertain or to make a concrete conclusion about the environmental risk from energy use and from the water waste. But it can get an idea about the quantum of CO_2 release from water related activities that are taken place in the country. However accurate readings and properly analyzing would bring the clear picture about the environmental risk.

Results from table 5, it can say that considerable amount of CO_2 that can be avoided releasing to environment if inefficiencies are reduced at least to small percentage. To identify the inefficiencies in water systems, detailed studies to be carried out in order to obtain correct results.

Reduction of water loss was higher in year 2012[4]. Due to the loss of water not only squandered but energy was lost. If the non revenue water percentage could be brought or maintain at least to 20%, a remarkable amount of CO_2 that could have avoided releasing to environment.

Conclusions

Correct design of a water system is important since it could maximize the benefit of energy using and the use of water resources. It also can minimize their negative environmental impacts. It is becoming necessary of having condition monitoring facility linked to pump unit and correctly system controlling of pumps when pumps arrange for parallel operation. The power input changes to pumps, the specific energy consumption, and other important parameters are required to monitor in order to diagnosis any faults in pumps operation in advance which enables to take precautionary action before it fails.

Reducing leaks and losses is a critical part of any water system. A well developed methodology and system approach would not only reduce the water losses but will improve the overall efficiency of the system. In addition, lowering the power consumption by reducing energy wastages and environmental risk by overusing water can be minimized if the systems are carefully studied and monitored.

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Biography

Eng. Padmasiri Dissanayake, has a Bachelor of Technology (Engineering) from the Open university of Sri lanka in 1994. Also he holds the Master of Science (Engineering) in Environmental Pollution Control from University of Peradeniya Sri lanka earned in 2009 He is having 20 years of experience as a Mechanical engineer. He possesses wide professional experience and specialization in design, construction, engineering, procurement, supervision and commissioning of clean and sewage water pumping stations. He has been working with Public Authority for Electricity and Water-Oman since 2012 as a Mechanical Engineering Advisor and currently involves in technical Support team in the Project Division. He is a chartered engineer and the corporate member in the Institution of Engineers –Sri Lanka and also holds the membership in the Oman Water Society.

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Non-Revenue Water Management in Oman Water Distribution Networks

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Abstract: The water supply utilities (systems) should fulfill the water requirement with quantitatively and qualitatively. Drinking water systems are exposed to both natural (hurricanes and flood) and manmade hazards (risks) that are common in Oman. Among manmade risks is the water loss or Non-Revenue Water (NRW) which remains a major concern in Oman. Levels are estimated at approximately 40 to 50 percent, which is in high levels as per the international standards. In this research work, an attempt is made to study the performance of water distribution systems in terms of NRW in Sultanate of Oman taking Nizwa city water distribution network as a case study. The main objective of the present research is to estimate and audit the water losses in the water distribution network of Nizwa and obtained more information on current water loss prevention and management practices. The basic information has been collected from Public Authority for Electricity and Water (PAEW) archive, and one questionnaire has been design and prepared by the researcher in order to collect the necessary data for water auditing and assess the views of stakeholder in PAEW (staff) on the current status of water losses and NRW in Nizwa water distribution system. The analysis of water losses was carried out using water loss and auditing software developed by American Water Works Association (AWWA) version 3.0. The results reveal that the estimated present values of water losses and non revenue water in the Nizwa city are high and reach more than 30%. The main factors that contribute to water losses are the inaccuracies in billing volumes and the method of estimating consumptions through faulty meters. Policy for water losses reduction is available in Oman. But, it is clear that the number of qualified staffs available to carry out the activities related to leak detection is low, and there is lack of appropriate technologies for water loss reduction, and maintenance system, which should be improved for better performance of the network by decrease water losses.

Keywords: Non-Revenue Water, Water Loss, Water Auditing, Real Loss, Apparent Loss, Leak Detection, Water Meters.

Introduction

Efficient distribution of water is a key element for any water authority or company both in terms of cost and maximizing availability of water for customers. This is particularly true in countries like Sultanate of Oman where scarcity of water resources forces the extensive use of desalination to produce potable water. High levels of Non Revenue Water (NRW) reflect huge volumes of water being lost through leaks, not invoicing to customers, or both. It seriously affects the financial viability of water utilities through lost revenues and increased operational costs. A high NRW level is normally a surrogate for a poorly run water utility that lacks the governance, the autonomy, the accountability, and the technical and managerial skills necessary to provide reliable service to their population (Kingdom *et al*, 2006, p. V). The waste of resources resulting from high NRW levels in Oman is considerable.

There is an increasing awareness around the world that water is becoming the critical issue of the twenty-first century (McKenzie, 2005). Water loss, which is the major component of non-revenue water, has been one of the major challenges in managing water utilities all over the world and it is even more challenging and serious in Oman. This is aggravated by the fact that there is a lack of technological expertise and equipment to deal with water loss in most water utilities. Therefore, taking all these challenges in to account, better management of the water resources in the country is extremely important and research is required by studying and understanding these losses and the proper management of distribution systems (Adu Yeboah, 2008).

The literature and studies about Non-Revenue Water in Oman and on ongoing efforts to assess the water systems and needs to repair and reconstruct damaged systems are lacking. The available data (PAEW, 2010) indicate that the level of water loss is above 40%, but the strategy for metering improvements and Non Revenue Water (NRW) reduction is not clear nor has this topic been deeply studied before. The emergency response to water leakage should be to acceptable level. The philosophy of Public Authority of Electricity and Water current emergency response practice shows it is focused principally on resolving the cause of the problem as quickly as possible. The other important elements of providing public information, alternative water supplies and examining the contingency options for further reconfiguring the network and speeding up the repair during long duration events are not given the same level of focus.

According to the literature provided by Interior Water Department of PAEW, the water systems in the study area (Interior Governorate of Oman) faces a number of problems, among which are; low coverage, low service levels, some problems with hydraulic designs, high non-revenue water, frequent pipeline bursts, problems with billing and collection of revenue, and stopped or faulty water meters. The purpose of the present study is to identify the problem of NRW that affect the operating of water systems in Oman and to suggest how these problem may be reduced through effective mitigation measures. The study investigates the state of public water system in Interior Governorate to first determine current water loss accounting practices and resulting loss estimates, gain more information on current water loss prevention and management practices, and then to make recommendations for more consistent water use accounting and water loss management. Nizwa city water system is taken as a case study for water losses investigation.

Review of Water Losses Figures and Management

The present PAEW strategy focuses mainly on Unaccounted for Water (UFW) with the addition of extending infrastructure to permit a reduction in the amount of water supplied free of charge. The previous data and early calculations indicate that the level of average water loss in Oman Governorates is above 40%. The old data show that the values of water losses or UFW (PAEW, 2010) are varied from one Governorate to another as presented in table (1).

Table 1: Regional Network Assessment in Terms of UFW (2010)

Governorate	Total Production (Mm^3)	Total Consumption (Mm^3)	UFW (%)	Trans. Length (km)	Dist. Length (km)	Trans. Loss (%)	Dist. Loss (%)
Muscat	106.373	63.170	40.6	230	2116	2	98
Dhakhliyah	14.24	7.337	48.5	230	378	10	90
Sharqiyah	15.156	7.832	48.3	324	302	14	86
Dhahirah	6.23	4.587	26.4	389	454	74	26
Wusta	1.095	1.189	-8.6	28	11	-	-
Batinah	17.172	1.189	43.6	668	985	28	72
Buraimi	8.267	5.723	30.8	160	270	20	80
Musandam	3.923	2.446	37.7	33	154	7	93
Total	172.456	101.962	40.9	2062	4368	9	91

The main reasons for a high level of loss are being: unmetered connections, leakage, metering errors, operational use, and inaccuracies in billing volumes. The split in the volume of water lost is in the ratio of 9% transmission and 91% distribution (real and apparent) The average loss (both apparent and real losses at that stage) per km of distribution pipe per day is around 40 m^3.

It is worth noting that meter reading, billing and collection is subcontracted to two companies, OIFC (Oman Investment & Finance Company) for the Muscat area, and ONEIC (Oman National Engineer & Investment Company) for the regions. They are not carried out meter readings on a frequent basis. At the same time, the majority of consumer meters are exposed and not installed within meter boxes. This exposes the meters to the full climatic conditions, especially the sun.

Apart from its other responsibilities (water quality, etc.), Water Operation department is in charge of the various NRW-related tasks in the field, such as: monitoring the volume of water produced by the different sources throughout the country; operating and maintaining the water infrastructures and supervising leaks repairs; performing leak detection and District Meter Area (DMA) monitoring;

replacing customers' meters and supporting for technical customers complaints; and producing monthly and annual reports.

The leak detection teams fall under the control of operation department. The primary function of these teams is to continuously monitor the performance of the networks, and identify the causes of the decrease in the network efficiency levels. They are provided with the equipments necessary for leak detection. At the current time leak detection is actively carried out based upon the results of the minimum night flow assessment.

Methodology

1. Collection of Data

The basic data and information such as the characteristics of the distributed pipes including pipe diameters, lengths and materials along with some maps were collected from PAEW archive. For the purpose of the present study and in order to estimate and audit the water losses in the water distribution network of the study area (Nizwa City), data sheet presented in table (2) were prepared in order to collect from the engineers in charge of water leakage detection program the data and information necessary for water auditing using American Water Works Association (AWWA) free Water Audit Software.

Table 2: Data Sheet for Water Loss Information

A- Basic Information					
Name of City or Utility:		Country:			
Reporting Year:	Start Date (MM/YYYY):	Start Date (MM/YYYY):			
Name of Contact Person:	E-mail:				
Telephone:	Fax:	Mobile:			
Reporting Units for Water Volume:					
B- Reporting Work Sheet	2008	2009	2010	2011	2012
1. Water Supplies					
1.1 Volume from Own Sources					
1.2 Master Meter Error Adjustment					
1.3 Water Imported					
1.4 Water Exported					
2. Authorized Consumption					
2.1 Billed Metered					
2.2 Billed Unmetered					
2.3 Unbilled Metered					
2.4 Unbilled Unmetered					
3. Apparent Losses					
3.1 Unauthorized Consumption					
3.2 Customer Metering Inaccuracies					
3.3 Systematic Data Handling Errors					
4. System Data					
4.1 Length of Mains					
4.2 Number of Active and Inactive Service Connections					
4.3 Average Length of Costumer Service Line					
4.4 Average Operating Pressure					
5. Cost Data					
5.1 Total Annual Cost of Operating Water System					
5.2 Costumer Retail Unit Cost (Applied to Apparent Losses)					
5.3 Variable Production Cost (Applied to Real Losses					

Within the framework of the present research work and in order to achieve the main objective of this study, the researcher has prepared a questionnaire for PAEW staff. The aim of this questionnaire is to assess the views of stakeholder in PAEW (staff) on the current status of water losses in Oman from technical and strategic aspects. It seeks to discover from PAEW staff who are concerned with water losses, what their perceptions are about the stated NRW figure, their understanding of the impact and main causes of water loss, and their opinions on PAEW's procedures and policy related to water loss reduction.

The questionnaire was developed based on the objectives of the study and by looking to similar questionnaires given in the literature. The researcher pilot tests it before final use. Thirty staff form head offices in Muscat and other Governorate offices of PAEW was interviewed face to face and filled the questionnaires. The staffs are mainly from engineers whom they are concerned with water losses and some managers.

The questionnaire consists of primary and secondary questions and sub-divided into two main sections. The first section addresses the basic information, and the second one deals with water losses in Nizwa water network. The questionnaire is given in table (3). The data analysis was performed by first tabulated the collected data after taking the percentage value for each answer, and then discuss the results. For some questions, the researcher calculated the average values and the standard deviations for the data to check the consensus between the answers.

Table 3: Questionnaire for PAEW Staff

A- Basic Information			
Name of Contact Person:			
Position:		Department:	
Job Related to Water Loss			
Telephone:		Fax:	Mobile:
E-mail:			
Water Loss in Nizwa Network			
1.	General Information		
1.1	What is your estimated percentage for the water losses (UFW) in Nizwa Network?		
	o 10-20%	o 20-30%	o 30-40%
	o 40-50%	o More than 50%	o Don’t know
1.2	What do you think the main factors that contribute to water losses? Please prioritize the factors according to their contribution (1 = very high, 6 = very low)		
	o Meter Inaccuracies	o Losses during repair	o Age of pipes
	o Illegal Connection	o Service reservoir overflow	o Water pressure
	Your opinion based on your experience:		
1.3	What do you consider to be the best solution to the reduce water losses in Nizwa water system? Please prioritize the measures according to their efficiency (1 = very high, 6 = very low)		
	o Improve pipe maintenance	o Clampdown on illegal connection	o Pipe replacement
	o Active leak detection	o Increase public Awareness	o Improve metering
	Your opinion based on your experience:		

	In which method of PAEW strategy focuses of deriving water loss figure:		
1.4	o Leakage Level (%)	o Leakage level (%) and UFW	o UFW
	o Non-Revenue Water	o UFW and NRW	o Don't know
	What do you think the possible impacts to high water losses figures? Please prioritize the impacts according to their effect (1 = very high, 6 = very low)		
1.5	o Reduction in pressure	o Increase expenditure on development	o Water contamination
	o High cost of O&M	o Short lifespan of existing resources	o Property damage

2.	Procedures and Policy	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
2.1	A National Water Policy exists which aims at reducing water losses.					
2.2	A Water loss reduction program is implemented.					
2.3	Pressure management is used to reduce water losses.					
2.6	A Network Maintenance/ Rehabilitation Program is Implemented.					
2.7	Measures to fight illegal connections are applied					

3.	Obstacles for Fighting Water Losses	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
3.1	Institutional situation					
3.2	Lack of financial means from PAEW					
3.3	Lack of appropriate technologies for water loss reduction.					
3.4	Maintenance system					
3.5	Personnel capacities(technicians)					
3.6	Personnel awareness					
3.7	Public acceptance / awareness					

Staff Opinion: Please state your opinion on the issue of water losses in Oman

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2. AWWA Water Audit Software

The level of water losses can be determined by conducting a Water Audit with the results shown in a Water Balance consistent with the international terminology. A Water Balance is based on measurements or estimations of water produced, imported, exported, used and lost. American Water Works Association (AWWA) developed Water Audit Software based on the standard water balance.

The software has capable of analyzing losses in it is different categories and calculating the revenue and non revenue water and other parameters. The program runs under excel Microsoft office with number of working sheet. Once data entries are accomplished, the program calculates losses, revenue and non revenue water and the detail water balance. The analysis of water losses was carried out using water loss and auditing software developed by AWWA version 3.0.

Analysis and Discusion of Results

1. Water Losses in Nizwa Water Supply System

The data of water supplies, authorized consumption and system data for the last five years (2008-2012) for Nizwa water distribution network were collected and the predicted values of water losses and non revenue water were obtained using AWWA version 3.0 as a first time for Nizwa city. The percentage values of apparent losses, real losses and total water losses predicted from software analysis, along with non revenue water for Nizwa city are presented in table (4).

Table 4: The Values of Water Losses and NRW as Percent of Water Supplied

Year	Water Losses			Non-Revenue Water (%)
	Apparent (%)	Real (%)	Total (%)	
2008	18.9	38.4	57.3	58.6
2009	18.0	30.9	48.9	50.1
2010	18.6	28.5	47.1	48.4
2011	18.9	12.4	31.3	32.6
2012	19.1	10.8	29.9	31.2

The apparent losses includes all types of inaccuracies associated with customer metering as well as data handling errors (meter reading and billing), plus unauthorized consumption (theft or illegal use). The results indicate that the values of apparent losses are very high (around 19%). The high values are attributed to the following reasons:

i. The performance of Billing Company and their delay in issuing water consumption bills.
ii. Non-registration of the monthly readings of meters.
iii. Trading and transfer of the data are inaccurate and disorganized.
iv. High water pressure in some parts of the network.
v. The inaccuracy of the water meters. The meters are not change periodically, and many of them are 15 years old. The most common meters encountered in Oman are volumetric meters.

The values of real losses are comparatively high; but the data show that the value of real losses is decreased from about 38.4% in year 2008 to about 10.8% in year 2012, that may be because in the past Nizwa was depended on ground water wells as the main source of water, and PAEW used large water tankers to feed the reservoirs and storage tanks with water. But after the arrival of water from the desalination plants in 2010, the condition is improved, and percentage of real water losses becomes less. The management of water network is also improved, and there are intensification in maintenance work and speed in repair the faults and breaks in the pipes.

The values of NRW are very high especially in year 2008 where the values are more than 58%. The value now is around 31%, and still it is high because the problem of high values of apparent losses as explained above. The values of unbilled authorized consumption are low (less than 2%).

The values obtained for financial indicator of water losses and NRW are given in table (5). The results reveal that the total annual cost of NRW, apparent and real losses is very high. The cost of total losses for year 2012 is more than 1.5 million USD due to high of water losses and NRW.

Table 5: The Financial Indicator of Water Losses and NRW for Nizwa City

Year	Annual Cost of Water Losses		Non-Revenue Water as Percent of Cost (%)
	Apparent (USD)	Real (USD)	
2008	553,088	1,523,134	110.4
2009	630,559	1,470,871	96.0
2010	775,781	1,616,392	109.5
2011	751,302	667,313	49.5
2012	906,626	694,669	51.7

The Infrastructure Leakage Index (ILI) is the ratio of the current annual real losses (real losses) to the Unavoidable Annual Real Losses (UARL), where UARL is a theoretical reference value representing the technical low limit of the leakage that could be achieved if all of today's best technology could be successfully applied. The ILI is a highly effective performance indicator for comparing (benchmarking) the performance of the utilities in operational management of real losses. The results of apparent and real losses per service connection per day (liter/ connection/ day) and ILI are illustrated in table (6).

Table 6: The Operational Indicator of Water Losses and NRW for Nizwa City

Year	Losses per Service Connection per Day (liter/connection/ day)		Infrastructure Leakage Index (ILI) (real losses/UARL)
	Apparent losses	Real losses	
2008	166.6	337.5	6.33
2009	174.2	298.9	4.87
2010	191.6	293.6	3.66
2011	167.1	109.2	1.57
2012	183.8	103.6	1.52

The values of apparent losses per service connection per day are very close because the figure of apparent losses for the last five years is almost same (around 19%), where the value of real losses per service connection per day is decreased from 337.5 in year 2008 to 103.6 in the last year due to decreased in real losses per unit volume of water. The value of ILI is also decreased to 1.52 in year 2012 because of low real water losses, and this value is more or less acceptable in terms of water losses where benchmark is 1.0.

2. System Water Balance

The water balance for the years of study for Nizwa water network were obtained from the results of the software. Table (7) summarizes the software water balance results for year 2012 based on the data reported for the same year from the reporting sheet of the software. The percentage values are given in final output Table.

The water balance for Nizwa city indicates clearly that more than half of the water supplied in years 2008 is without revenue and considered as losses, but the condition is improved in the last two years when the water from the desalination plants become the main source of water supply and the revenue water now is about 68.8%. At the same time the data of water balance show that the billed unmetered water consumption and unbilled metered water consumption is zero for all the years, which means the authorized water consumption includes all billed metered and unbilled unmetered water consumption.

Table 7: Nizwa Water Balance for Year 2012

AWWA Water Audit Software: Water Balance				Report For: Nizwa	Report Year: 2012
Own Sources (Adjusted for known errors) (100%)	Water Exported (0%)	Billed Water Exported (0%)			
	Water Supplied (100%)	Authorized Consumption (70.1%)	Billed Authorized Consumption (68.8%)	Billed Metered Consumption (68.8%)	**Revenue Water (68.8%)**
				Billed Unmetered Consumption (0%)	
			Unbilled Authorized Consumption (1.3%)	Unbilled Metered Consumption (0%)	
				Unbilled Unmetered Consumption (1.3%)	
		Water Losses (29.9%)	Apparent Losses (19.1%)	Unauthorized Consumption (0.2%)	**Non-Revenue Water (NRW) (31.2%)**
				Customer Metering Inaccuracies (1.4%)	
				Systematic Data Handling Errors (17.5%)	
Water Imported (0%)			Real Losses (10.8%)	Leakage on Transmission and/or Distribution mains Not broken down	
				Leakage and Overflow at Utility's Storage Tank Not broken down	
				Leakage on Service Connections Not broken down	

The water balance for Nizwa city indicates clearly that more than half of the water supplied in years 2008 is without revenue and considered as losses, but the condition is improved in the last two years when the water from the desalination plants become the main source of water supply and the revenue water now is about 68.8%. At the same time the data of water balance show that the billed unmetered water consumption and unbilled metered water consumption is zero for all the years, which means the authorized water consumption includes all billed metered and unbilled unmetered water consumption.

The value of apparent losses is almost constant in the last five years (around 20%). The results reveal that apparent losses is mainly because of data handling errors (17.5%) related to the performance of billing and collection company. The customer metering inaccuracies and illegal connections in Nizwa city area is low (less than 2%).

Unbilled authorized consumption may include items such as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. The results of water auditing show that the percentage value of this authorized consumption is within 2.0% only.

3. Existing Situation and Management Strategy

The aim of the first questions in the questionnaire is to review the causes of water losses, impacts and suggested solutions from standpoint of PAEW staff. The answers of the question (What do you think the main factors that contribute to water losses?) is listed in table (8).

Table 8: The Main Factors that Contribute to Water Losses

Answers		Prioritize According to Contribution(1 = very high, 6 = very low)					
1		2	3	4	5	6	
Meter Inaccuracies	Percentage Values (%)	70	20	10	0	0	0
Losses during repair		0	10	10	50	20	10
Age of pipes		10	30	20	30	10	0
Illegal Connection		0	0	0	10	20	70
Service reservoir overflow		0	10	20	0	50	20
Water pressure		20	30	40	10	0	0

The data show that the main factors that contribute to water losses in Nizwa city is the inaccuracies in billing volumes and the method of estimating consumptions through faulty meters, that call for improve meter accuracy and identify meters that require maintenance. The other factor that contributes to water losses is water pressure in the network and with less degree the age of the pipes. The pressure in the network is increased in some areas where the pipes are also old causing water leakage problem, and where it is necessary, pressure management should be implemented. It seems that the illegal connection is very less.

The answers to the question (What do you think the possible impacts to high water losses figures?) are presented in table (9). The results emphasize that high water loss figures results in high cost of Operation and Maintenance (O&M), short lifespan of existing resources and increase expenditure on development. The high water losses did not cause damage to water properties.

Table 9: The Possible Impacts to High Water Losses Figures

Answers		Prioritize According to Contribution(1 = very high, 6 = very low)					
		1	2	3	4	5	6
Reduction in pressure	Percentage Values (%)	10	10	20	50	0	10
Increase expenditure on development		30	20	20	20	10	0
Water contamination		0	10	10	0	30	50
High cost of O&M		50	30	10	0	10	0
Short lifespan of existing resources		30	20	30	10	10	0
Property damage		0	0	0	0	30	70

Table (10) summary of the best solutions that could be utilized to reduce water losses in Nizwa water system according to answers of PAEW staff to the question (What do you consider to be the best solution to the reduce water losses in Nizwa water system?). 60% of the staff thinks that the first priority is active leak detection and 40% think that improving metering is the first priority. The answers of the other staff show that improvement of pipe maintenance and replacement of old pipes is important. But, there is no need to clamp down on illegal connection.

Table 10: The Best Solution to the Reduce Water Losses in Nizwa Water System

Answers		Prioritize According to Contribution(1 = very high, 6 = very low)					
		1	2	3	4	5	6
Improve pipe maintenance	Percentage Values (%)	0	30	30	20	20	0
Clampdown on illegal connection		0	0	10	0	10	80
Pipe replacement		0	40	10	30	10	10
Active leak detection		60	30	10	0	0	0
Increase public Awareness		0	0	30	10	50	10
Improve metering		40	0	20	40	0	0

The second part of the questions to staff is related to current procedures and policy. Five option are given for each policy (strongly agree, agree, neutral, disagree, and strongly disagree). The summary of the answers are presented in table (11).

Table 11: Procedures and Policy for Water Losses

Procedures and Policy	Strongly agree	Agree	Neutral	Dis-agree	Strongly disagree
	Percentage Value (%)				
A National Water Policy exists which aims at reducing water losses.	10	70	10	10	0
A Water loss reduction program is implemented.	70	0	20	10	0
Pressure management is used to reduce water losses.	30	50	20	0	0
A Network Maintenance/ Rehabilitation Program is Implemented.	0	80	20	0	0
Measures to fight illegal connections are applied	50	10	10	30	0

(*Grades: Strongly agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly disagree =* 1)

Most of the staff agree that there is a national water policy exists which aims at reducing water losses and water loss reduction program is implemented. The government is try to apply this policy for different areas through water loss reduction program. In the Nizwa city pressure management and control is almost used to reduce water losses and network maintenance and rehabilitation program is implemented, because of this the values of water losses and NRW are decreased in the last two years.

The last set of questions to the staff is related to the obstacles for fighting water losses, and in the same way five options are given for each question (strongly agree, agree, neutral, disagree, and strongly disagree). The answers of the PAEW staff are given in Table (12).

Table 12: Obstacles for Fighting Water Losses

Obstacles	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
	Percentage Value (%)				
Institutional situation	0	0	20	50	30
Lack of financial means from PAEW	0	10	20	70	0
Lack of appropriate technologies for water loss reduction.	30	70	0	0	0
Maintenance system	10	50	0	20	10
Personnel capacities(technicians)	60	40	0	0	0
Personnel awareness	20	30	10	0	40
Public acceptance / awareness	10	30	0	20	40

(*Grades: Strongly agree = 5, Agree = 4, Neutral = 3, Disagree = 2, Strongly disagree = 1*)

It is clear that the main obstacle is with the leak detection staff. It seems there are insufficient qualified staffs available to carry out the activities related to leak detection. However there are no formal or refresher training programmes in the use of the leakage equipments, it is clear that training is given a very low priority. The other important factor is the lack of appropriate technologies for water loss reduction. It seems classic techniques are used, and there is necessary to move to new technology.

The situation of the PAEW is strong and no lack of financial means from PAEW that prevent the implementation of any strong program for fighting water losses. 60% of the staff agrees that there is problem in maintenance system, which should be improved for better performance of the network by decrease water losses. The other factors such as personnel awareness and public acceptance/awareness have not big obstacles for fighting water losses.

4. Strategy for Reducing Water Losses

According to field survey, analysis of results, and comments and opinion of interviewed staff, the strategy for reducing water losses should includes the following:

4.1. A proper organization: including the recruitment of field supervisors for Customer Services in order to reduce frauds and update customer database, and the recruitment of leak detection teams throughout the whole country.

4.2. Adequate and tailored training: One example has been given with the organization of tailored leak detection program in small groups of 3 to 5 employees, providing the attendees the right tools and methodology to raise leak detection practices in Oman to the best international standards, while taking into account the specificities of PAEW assets and the Omani water operational context.

4.3. The purchase of appropriate equipment and technologies: including leak detection equipment (acoustic correlator, leak detection through gas techniques, etc.), tanker filling stations monitoring equipment, etc.

4.4. Meter accuracy: improve meter reading accuracy and identify meters that require maintenance. The PAEW reports show that currently 24,000 meters in Muscat and over 2,000 in the regions require replacement. Water Operations have already implemented a programme of work to verify the number of meters requiring replacement. At the same time, the standards and specification contains a metering specification designed to improve the accuracy of meters and prolong their working life.

4.5. Pressure management: Reinstate existing pressure management schemes and identify scope for extension of pressure management throughout PAEW.

4.6. Leakage teams: It is essential that sufficient leakage teams are created and that they are provided with the necessary equipment to enable them to carry out their allotted tasks efficiently.

4.7. Contractual tools: The development of appropriate contractual tools to closely manage our contractors (penalties, framework contracts, *etc.*

Conclusion

The results indicate that the level of average water loss in Oman Governorates is above 40%. The main factors that contribute to water losses are the inaccuracies in billing volumes and the method of estimating consumptions through faulty meters.

The results indicate that the values of apparent losses are very high (around 19%). The high values are attributed mainly to the performance of Billing and Collection Company and their delay in issuing water consumption bills, non-registration of the monthly readings of meters, and the inaccuracy of the water meters.

The values of real losses are decreased in the last two years when PAEW began transferring the water to water distribution networks from the desalination plants in 2010. At the same time, PAEW rehabilitated and upgrading many of the pipelines in the network, and replaced many of main and service water meter. The management of water network is also improved.

The results of field survey emphasize that high water loss figures results in high cost of operation and maintenance, short lifespan of existing resources and increase expenditure on development. The best solutions that could be utilized to reduce water losses as PAEW staff stated are applying active leak detection program, improving metering, and improvement of pipe maintenance and replacement of old pipes.

Policy for water losses reduction is available in Oman and the government is trying to apply this policy through water loss reduction program. But, it is clear that the main obstacle for fighting water losses is with the leak detection staff. It seems there are insufficient qualified staffs available to carry out the activities related to leak detection.

According to field survey, analysis of results, and comments and opinion of interviewed staff, the strategy for reducing water losses should includes: a proper organization; adequate and tailored training; purchase of appropriate equipment and technologies; meter accuracy; pressure management; leakage teams and contractual tools.

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Assessment of Drinking Water Quality: A Case Study of Qatar's Drinking Water

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Abstract: Drinking water quality directly affects human health. Such impacts reflect the level of contamination of whole drinking water supply system. The primary goals of environmental especially drinking water management are to provide safe drinking water supply in international and national scale independently of their stage of development and their social and economic conditions. To properly assess and monitor the drinking water quality parameters throughout the distribution system, KAHRAMAA (KM) developed and approved a comprehensive and long-term monitoring plan that would help to identify required actions and overall challenges to improve monitoring over the coming decade. The plan considers numerous drivers as main/crucial inputs including (but not limited to): International standards and guidelines, efficient control over production facilities, strict and comprehensive coverage for the entire distribution system, laboratory competency profile, etc. For easier and effective traceability for the drinking water quality parameters, the plan considers new concepts for monitoring the network sampling points distribution (for instance: fixed/variable concept, etc). On annual bases, the plan is adapted considering all possible improvements and suggestions (either internal or external). The present study is devoted to assessment of drinking water quality in the network distribution system within the state of Qatar for the last couple of years using mathematical statistical processing of composition data (physiochemical & biological). As KM has numerous concerns on both WHO guidelines and GSO 149:2009 standard for un-bottled drinking water (either absence of some important parameters or non correct specs were the main concerns), KM had developed, approved and implemented its own requirements which is emanated from both WHO and GSO. The water quality compliance was based on KM internal requirements. In order to assess the drinking water quality in Qatar, the water samples were analyzed for different physicochemical and biological properties. Among other parameters, the following had been analyzed: pH, Electrical Conductivity (EC), Total Hardness (TH), total alkalinity (TA), Disinfectant By Products (DBP's: Bromate, Chlorite, Chlorate and THM's), Total Coliform and E-coli. Also, sort of correlation matrix was also calculated for different parameters of drinking water. All the physiochemical and biological parameters were found to be in the prescribed permissible limit. Moreover, the parameters had been categorized as Physical, Chemical and Biological categories for overall compliance assessments. As an overall conclusion, the water quality in the state of Qatar is excellent and protected with a virtual absence of threat or impairment where water conditions are very close to natural or pristine levels. Different water quality indices for chemical, physical and biological variable show quite high drinking water quality. Moreover, it's clearly observed that at least for 4 successive years; Qatar's drinking water quality exceeds the international guidance for biological compliance declared by WHO. Numerous factors influence such high level of compliance such as: proper quality management system, new infrastructure and network replacements, and proper selection of the used disinfectant, etc. On the other hand, the water quality assessment process is quite robust utilizing the internationally competent sampling and monitoring plan developed by KM/WQL team.

Keywords: drinking water quality, annual sampling and monitoring plan, chemical composition, mathematical statistics, drinking water quality indices and Qatar.

Introduction

Water is most essential but scarce resource within the GCC countries. Geometric increase in population coupled with rapid urbanization & industrialization and agricultural development has resulted in high impact on quality and quantity of water in our country. Water quality is changed and affected by both natural processes and human activities. A variety of human activities (for instance: agricultural activities, urban and industrial development, mining and recreation) potentially significantly alter the quality of natural waters and may be water quality. The key to sustainable water resources is; therefore; to ensure that the quality of water resources are suitable for their intended uses while at the same allowing them to be used and developed to a certain extent. The situation warrants immediate redressal through radically improved water resource and effective water quality management strategies.

The primary goals of environmental especially drinking water management are to provide safe drinking water supply in international and national scale independently of their stage of development and their social and economic conditions. Unfortunately, recent statistics on water and sanitation do not provide specific evidence about the quality of water being provided to communities, households and institutions, and the safety of the drinking-water supply can only be inferred. There is, therefore, an urgent need to obtain independently verifiable water-quality data, to support national governments in their efforts to provide safe water to households. Such data would provide useful information about current conditions and the likely public-health burden related to an inadequate and unsafe water supply. The data would also reveal the extent of major water quality problems and inform future investment priorities.

Normally, the following 6 steps are to be followed while assessing the water quality compliance/parameters:

i. Develop objectives for the testing program (Is it for assessing water source safety, gather more information about known contamination or to test the effectiveness of a treatment technology).

ii. Decision to be taken on what to test for (considering limitations on time, funding and access to analytical services).

iii. Decision on testing methods and techniques.

iv. Plan for sampling, monitoring and testing program.

v. Conduct testing (sterilization, sample collection, sample analysis, ..etc).

vi. Data interpretation and link all possible improvements (corrective action, preventive action and opportunities for improvements) to such interpretations.

The present work was carried out to assess the distributed drinking water quality within the state of Qatar for the last couple of years against KAHRAMAA (KM) as internal requirements which is more restricted than WHO international guidelines. KM developed and approved a comprehensive and long-term monitoring plans helped to identify required actions and overall challenges to improve monitoring over the coming decade. This internationally competent sampling & monitoring plan would be utilized for proper assessment of the drinking water quality parameters throughout the distribution system.

Materials and Methods

KM Water Quality Requirements (Reasons and Implementations)

KM does have numerous observations on not only the latest WHO guidelines but also the GSO 149 standard. Examples of those observations are highlighted below. To negate such observations, KM developed and implemented its own internal standards/requirements for water quality parameters. These requirements are emanated from international and GCC standards with more restriction in numerous parameters.

1. Concerns on WHO Guidelines and Desalinated Water

The latest WHO Guidelines (4th edition) are not fully covering some important factors/parameters that can be encountered for desalinated water distribution system (from water intakes to distribution system including production facilities). Moreover, more guidance would be required particularly when evaluating the impact of desalination process on water quality for some other areas. For instance: neither chlorine dioxide nor some aesthetic parameters and system stability indicators were declared in the WHO guidelines. On the other hand, no quality management guidance for the disinfectants levels for blending Water Scenarios (water with different disinfectants for instance).

2, Concerns on Un-bottled Drinking Water GCC Standard (GSO 149:2009)

Numerous concerns on the current GSO 149:2009 standard for the un-bottled drinking water is currently raised. Those concerns categorized either as absence of some important parameters (for instance: chlorine dioxide, many aesthetic parameters and system stability indicators) or non-correct specs (for instance: THM specs). Pn the other hand, only one standard is declared for un-bottled drinking water while at least two standards should be developed and implemented; one for production facilities and another one for the distribution system. Moreover, it might be an added value if one standard is developed for Reverse Osmosis production facilities.

3. Developing KM Internal Standards/Requirements

Due to the aforementioned concerns for both WHO as well as GSO 149:2009, KM developed and approved three different water quality internal standards/requirements that cover desalinated water, distributed water within the distribution system and a third one for R.O. plants. Each standards/requirements has its own water quality specs based on numerous factors (for instance: technology, operational requirements, best practices, bench marking,...etc) and all of them are emanated from WHO guidelines and GSO 149. Moreover, KM developed a fourth internal standard/requirement particularly for water quality requirements while commissioning new pipe lines.

Annual Water Quality Sampling ad Monitoring Program

KM developed a comprehensive water quality sampling and monitoring plan that compete internationally. The plan considers some drivers as main/crucial inputs. Those numerous drivers include (but not limited to): International standards and guidelines, efficient control over production facilities, strict and comprehensive coverage for the entire distribution system, laboratory competency profile,…etc.

The plan covers the entire distribution system (from production plants to the customer points along with the KM reservoirs. Moreover, the plan introduces some new concepts for monitoring the network sampling points distribution (for instance: fixed/variable concept, …*etc*) that allows an easier and effective traceability for the drinking water quality parameters. On annual bases, the plan is adapted considering all possible improvements and suggestions (either internal or external).

Hence, the water quality compliance was based on KM internal requirement. In order to assess the drinking water quality in Qatar, the water samples were analyzed for different physico-chemical and biological properties.

Drinking Water Quality Index (WQI)

WQI is a dimensionless number that combines multiple water-quality factors into a single number by normalizing values to subjective rating curves. Factors to be included in WQI model could vary depending upon the designated water uses and local preferences. Actually, the Drinking Water Quality Index (WQI) is simplified but powerful tool intended to provide an easy to understand “ranking of water quality”. The Index is determined by comparing commonly monitored physio-chemical constituents along with bacteriological parameters within the network distribution system to KM's Drinking Water Quality requirements and Objectives. The water quality analysis data used to calculate the Index is based on KM's actual water quality analysis within the last couple of years. The evaluation produces a number between 0 and 100 and in turn the numerical value is ranked as poor, marginal, fair, good, or excellent.

Within the study, KM utilized the Baseline Comparative model for WQI calculations. The results of testing the following parameters/indicators found in drinking water are used to calculate the index: pH, Electrical Conductivity (EC), Total Hardness (TH), total alkalinity (TA), Disinfectant By Products (DBP's: Bromate, Chlorite, Chlorate and THM's), Total coliform and E-coli. Those parameters represent the most and commonly interested parameters for the entire GCC countries. Those parameters might be the base for WQI benchmarking within GCC.

1. The Drinking Water Quality Index (WQI) Calculations based on Baseline Comparative Model

Essentially, the WQI model consists of three main elements/measures of variance from selected water quality objectives (Scope; Frequency; Amplitude). The "Scope (F1)" represents the extent of water quality guideline non-compliance over the time period of interest (i.e: number of variables not meeting water quality objectives). The "Frequency (F2)" represents the percentage of individual tests that do not meet objectives (i.e: the number of times these objectives are not met). The "Amplitude (F3)" represents the amount by which failed tests do not meet their objectives (i.e: amount by which the objectives are not met). These three factors combine to produce a value between 0 and 100 that represents the overall water quality. The formulation of the WQI as follows:

(3.1.1)The measure for scope is F1.

This represents the extent of water quality guideline non-compliance over the time period of interest.

$$\boldsymbol{F1} = \frac{\textbf{Number of Failed Variables (parameters)}}{\textbf{Total Number of variables (parameters)}} \boldsymbol{x100} \ldots\ldots (1)$$

(3.1.2)The measure for frequency is F2.

This represents the percentage of individual tests that do not meet objectives ("failed tests").

$$\boldsymbol{F2} = \frac{\textbf{Number of Failed Tests}}{\textbf{Total Number of Tests}} \boldsymbol{x100} \ldots\ldots (2)$$

(3.1.3)The measure for amplitude is F3.

This represents the amount by which failed test values do not meet their objectives. This is calculated in three steps:

(a) Calculation of Excursion:

Excursion is the number of times by which an individual concentration is greater than (or less than, when the objective is a minimum) the objective.

(i) When the test value must not exceed the objective:

$$\boldsymbol{excursion} = \frac{\textbf{Failed Test Value}}{\textbf{Objective}} - \boldsymbol{1} \ldots (3)$$

(ii) When the test value must not fall below the objective:

$$\boldsymbol{excursion} = \frac{\textbf{Objective}}{\textbf{Failed Test Vlue}} - \boldsymbol{1} \ldots\ldots (4)$$

(b) Calculation of Normalized Sum of Excursions:

The normalized sum of excursions, nse, is the collective amount by which individual tests are out of compliance. This is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives).

$$\boldsymbol{nse} = \frac{\sum_{k=1}^{n} \text{Excrusion}}{\textbf{Number of Tests}} \ldots\ldots (5)$$

(c) Calculation of F3:

F3 is calculated by an asymptotic function that scales the normalized sum of the excursions from objectives to yield a range from 0 to 100.

$$\boldsymbol{F3} = \frac{\text{nse}}{\mathbf{0.01nse+0.01}} \text{....... (6)}$$

(3.1.4)Then, WQI is calculated based on the following equation:

$$WQI = 100 - \frac{\sqrt{F1^2 - F2^2 + F3^2}}{1.732} \text{...... (7)}$$

Where: WQI: Water Quality Index; F1: represents Scope (Equation 1); F2: represents Frequency (Equation 2); F3: represents Amplitude (Equation 6).

2. The Drinking Water Quality Index (WQI) is Ranked as Follows

Excellent: WQI Value 95-100/ Very Good: WQI Value 89-94/ Good: WQI Value 80-88/ Fair: WQI Value 65-79/ Marginal: WQI Value 45-64/ Poor: WQI Value 0-44.
The Drinking Water Quality Index is not an absolute indicator of the overall safety of the water delivered to the consumers tap. It is one factor that a consumer may choose to consider in evaluating drinking water quality.

Results and Discussions

The results of testing the following parameters/indicators found in drinking water are used to calculate the index: pH, Electrical Conductivity (EC), Total Hardness (TH), total alkalinity (TA), Disinfectant By Products (DBP's: Bromate, Chlorite, Chlorate and THM's), Total coliform and E-coli. Those parameters represent the most and commonly interested parameters for the entire GCC countries. Those parameters might be the base for WQI benchmarking within GCC. Moreover, KM internal requirements were the base for compliance verifications.
The results will be split into two main sections; parameter compliance along with the WQI calculations.

1. Parameter's Compliance:

1.1. pH

Table (1) shows pH compliance for all Qatar areas along with the overall pH compliance based on the total number of samples and Off-specs samples. The pH compliance ranged from 95% to 100%. Figure (1) shows average pH values for all areas in comparison to KM internal requirements. All areas along with the overall water falls within the compliance range.

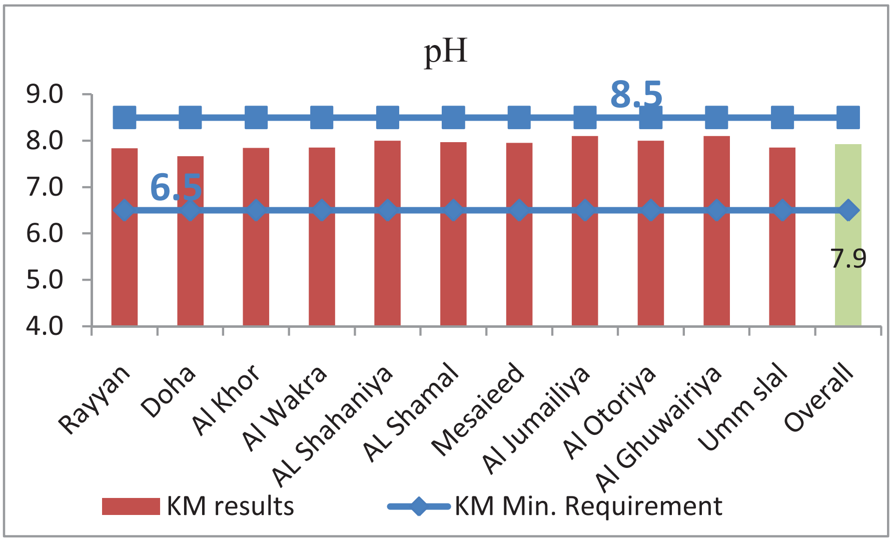

Figure 1: pH Average Values for All Areas in Comparison to KM Internal Requirements

2. Turbidity

Table (2) shows Turbidity compliance for all Qatar areas along with the overall Turbidity compliance based on the total number of samples and Off-specs samples. The Turbidity compliance ranged from 87% to 100%. All areas along with the overall water falls within the compliance range except for Al Otoriya area where compliance % reaches 87%. The main reason behind such decrease is the water stagnation due to very low consumption rate within the network. After comprehensive study and monitoring process, proper and frequent flushing solved the turbidity issue that causes such decrease. Figure (2) shows average Turbidity values in NTU for all areas in comparison to KM internal requirements where all areas along with the overall water turbidity lie within the compliance range.

Table 2: Turbidity Compliance for all Qatar Areas along with the Overall Turbidity Compliance

Area	No of samples	No of off specs samples	Comliance (%)
Rayyan	3851	237	094%
Doha	3408	067	098%
Al Khor	0718	023	097%
Al Wakra	0540	013	098%
AL Shahaniya	0151	007	095%
AL Shamal	0133	005	096%
Mesaieed	0121	003	098%
Al Jumailiya	0037	002	095%
Al Otoriya	0023	003	087%
Al Ghuwairiya	0019	000	100%
Umm slal	0005	000	100%
Overall Turbidity compliance (%) in the State of Qatar	9006	360	96%

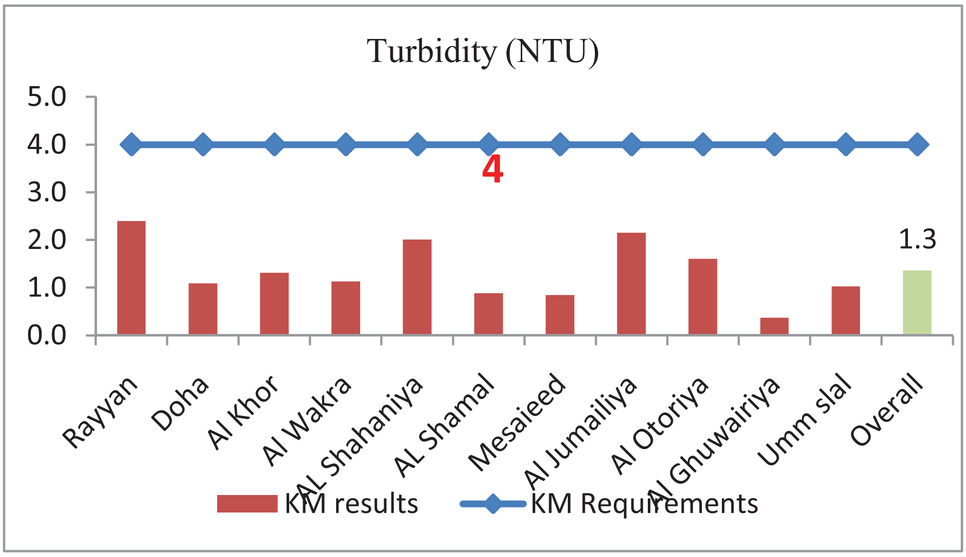

Figure 2: Turbidity (NTU) Average Values for all Areas in Comparison to KM Internal Requirements.

3. Total Hardness (mg/l as $CaCO_3$)

Table (3) shows Total Hardness (mg/l as $CaCO_3$) compliance for all Qatar areas along with the overall Total Hardness compliance based on the total number of samples and Off-specs samples. All samples were compliant to KM requirements. Figure (3) shows Total Hardness average values (mg/l as $CaCO_3$) for all areas in comparison to KM internal requirements where all areas along with the overall water Total Hardness lie within the compliance range.

Table 3: Total Hardness (mg/l as $CaCO_3$) Compliance for all Qatar Areas along with the Overall Total Hardness Compliance

Area	No of samples	No of off specs samples	Comliance (%)
Rayyan	168	00	100%
Doha	144	00	100%
Al Khor	050	00	100%
Al Wakra	045	00	100%
AL Shahaniya	045	00	100%
AL Shamal	032	00	100%
Mesaieed	030	00	100%
Al Jumailiya	025	00	100%
Al Otoriya	025	00	100%
Al Ghuwairiya	020	00	100%
Umm slal	020	00	100%
Overall total Hardness compliance (%) in the State of Qatar	604	00	100%

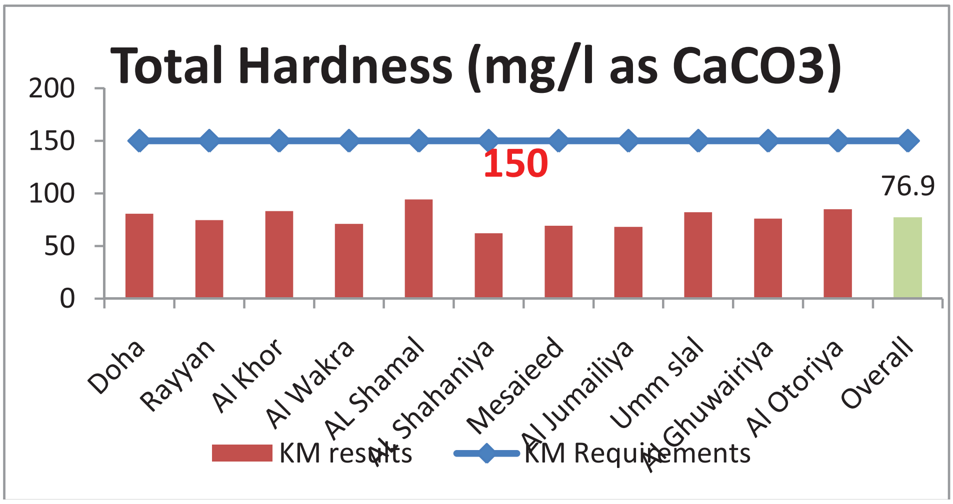

Figure 3: Total Hardness (mg/l as $CaCO_3$) Average Values for all Areas in Comparison to KM Internal Requirements

4. Alkalinity (mg/l as $CaCO_3$)

Table (4) shows Alkalinity (mg/l as $CaCO_3$) compliance for all Qatar areas along with the overall Alkalinity compliance based on the total number of samples and Off-specs samples. All samples were compliant to KM requirements. Figure (4) shows Alkalinity (mg/l as $CaCO_3$) average values for all areas in comparison to KM internal requirements where all areas along with the overall water alkalinity lie within the compliance range.

Table 4: Alkalinity (mg/l as $CaCO_3$) Compliance for all Qatar Areas along with the Overall Alkalinity Compliance

Area	No of samples	No of off specs samples	Comliance (%)
Rayyan	204	00	100%
Doha	176	00	100%
Al Khor	050	00	100%
Al Wakra	045	00	100%
AL Shahaniya	045	00	100%
AL Shamal	032	00	100%
Mesaieed	030	00	100%
Al Jumailiya	025	00	100%
Al Otoriya	025	00	100%
Al Ghuwairiya	020	00	100%
Umm slal	020	00	100%
Overall total Alkalinity compliance (%) in the State of Qatar	672	00	100%

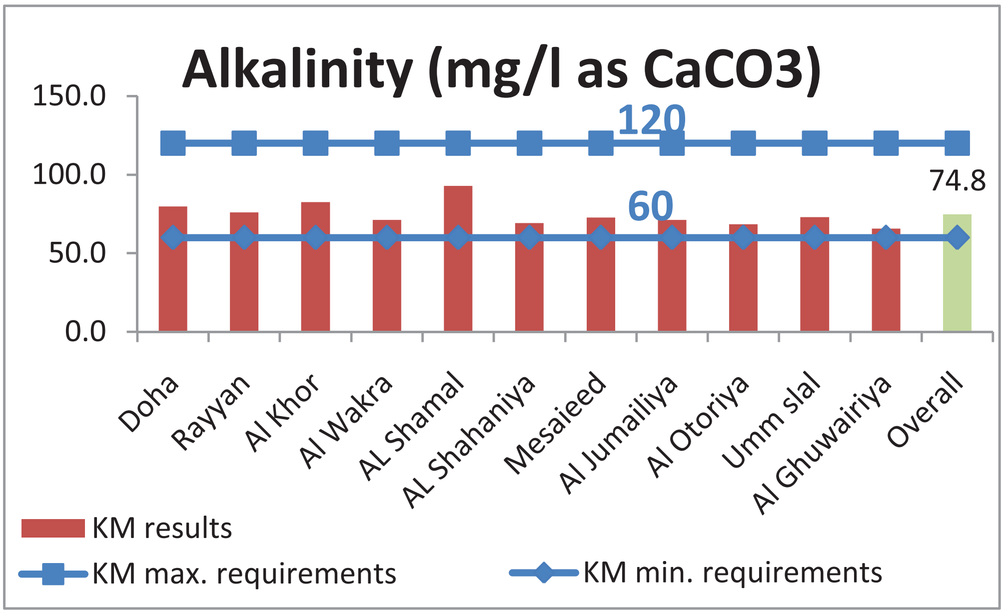

Figure 4: Alkalinity (mg/l as $CaCO_3$) Average Values for all Areas in Comparison to KM Internal Requirements

5. Chlorite (μg/l)

Table (5) shows Chlorite (μg/l) compliance for all Qatar areas along with the overall chlorite compliance based on the total number of samples and Off-specs samples. All samples were compliant to KM requirements. Figure (5) shows Chlorite (μg/l) average values for all areas in comparison to KM internal requirements where all areas along with the overall water Chlorite levels lie within the compliance range.

Table 5: Chlorite Levels (μg/l) Compliance for all Qatar Areas along with the Overall Chlorite Compliance

Area	No of samples	No of off specs samples	Comliance (%)
Rayyan	288	00	100%
Doha	264	00	100%
Al Khor	074	00	100%
Al Wakra	053	00	100%
AL Shahaniya	025	00	100%
AL Shamal	020	00	100%
Mesaieed	012	00	100%
Al Jumailiya	012	00	100%
Al Otoriya	010	00	100%
Al Ghuwairiya	008	00	100%
Umm slal	008	00	100%
Overall Chlorite compliance (%) in the State of Qatar	774	00	100%

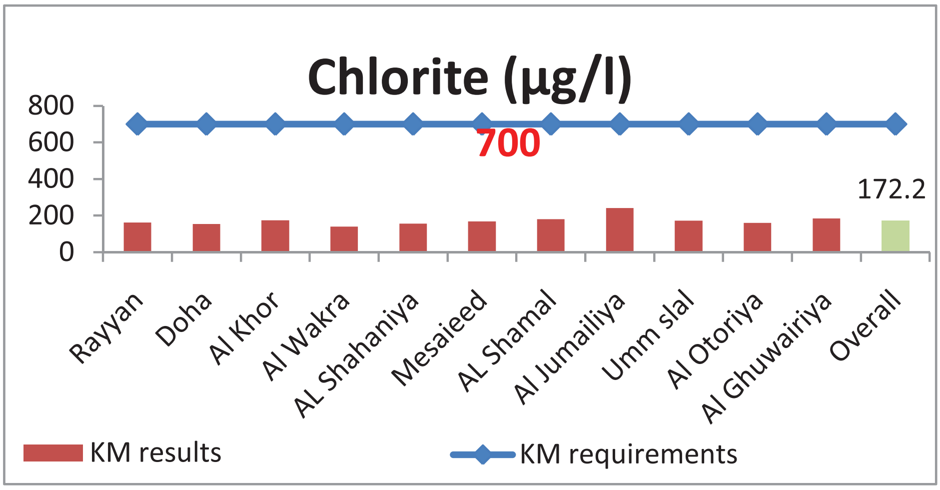

Figure 5: Chlorite (μg/l) Average Values for all Areas in Comparison to KM Internal Requirements

6. Chlorate (µg/l)

Table (6) shows Chlorate (µg/l) compliance for all Qatar areas along with the overall chlorate compliance based on the total number of samples and Off-specs samples. All samples were compliant to KM requirements. Figure (6) shows Chlorate (µg/l) average values for all areas in comparison to KM internal requirements where all Areas along with the overall water Chlorate levels lie within the compliance range.

Table 6: Chlorate Levels (µg/l) Compliance for all Qatar Areas along with the Overall Chlorate Compliance

Area	No of samples	No of off specs samples	Comliance (%)
Rayyan	288	00	100%
Doha	264	00	100%
Al Khor	074	00	100%
Al Wakra	053	00	100%
AL Shahaniya	025	00	100%
AL Shamal	020	00	100%
Mesaieed	012	00	100%
Al Jumailiya	012	00	100%
Al Otoriya	010	00	100%
Al Ghuwairiya	008	00	100%
Umm slal	008	00	100%
Overall Chlorate compliance (%) in the State of Qatar	774	00	100%

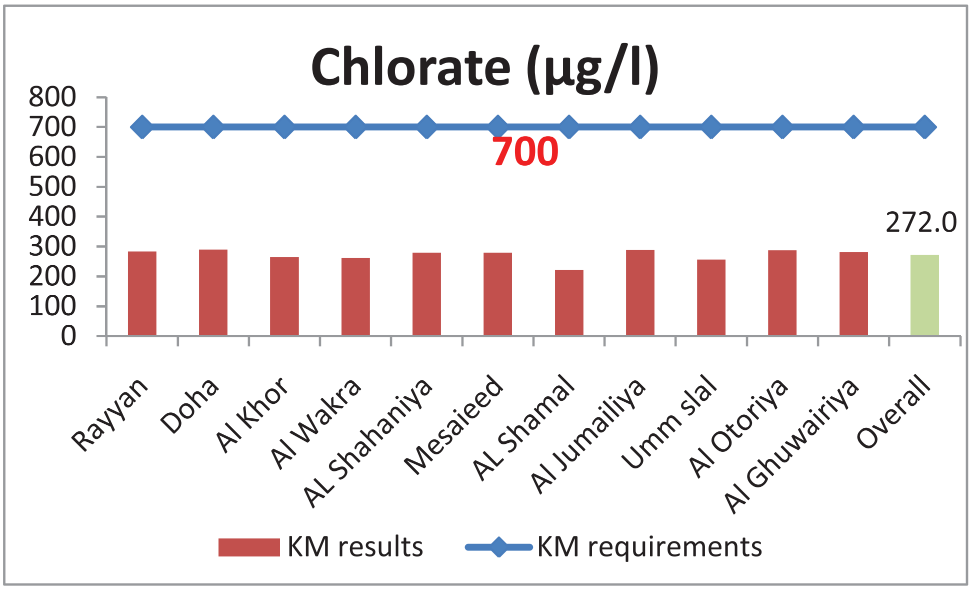

Figure 6: Chlorate (µg/l) Average Values for all Areas in Comparison to KM Internal Requirements.

7. Bromate (μg/l)

The Bromate analysis was split in two set of dat. The first set represents data while using chlorine as disinfectant (before using chlorine dioxide) while the other set represents data after using chlorine dioxide as disinfectant in all desalination plants. Tables (7 and 8) show Bromate (μg/l) compliance for all Qatar areas along with the overall bromate compliance based on the total number of samples and Off-specs samples before and after chlorine dioxide usage respectively. It's obviously clear that KM was having issues with bromate before chlorine dioxide usage while after using chlorine dioxide, bromate levels are all in N.D. levels. Figure (7) shows Bromate (μg/l) average values for all areas in comparison to KM internal requirements before and after chlorine dioxide usage.

Table 7: Bromate Levels (μg/l) Compliance for all Qatar Areas along with the overall Bromate Compliance using Chlorine as Disinfectant (before Chlorine Dioxide Disinfection)

Area	No of samples	No of off specs samples	Comliance (%)
Rayyan	222	24	089%
Doha	218	27	088%
Al Khor	051	17	067%
Al Wakra	042	03	093%
AL Shahaniya	015	00	100%
AL Shamal	012	00	100%
Mesaieed	009	01	089%
Al Jumailiya	008	00	100%
Al Otoriya	008	00	100%
Al Ghuwairiya	006	00	100%
Umm slal	006	00	100%
Overall Bromate compliance (%) in the State of Qatar	597	72	088%

Table 8: Bromate levels (μg/l) Compliance for all Qatar Areas alongwith the overall Bromate Compliance after Chlorine Dioxide disinfection

Area	No of samples	No of off specs samples	Comliance (%)
Rayyan	075	00	100%
Doha	058	00	100%
Al Khor	049	00	100%
Al Wakra	040	00	100%
AL Shahaniya	031	00	100%
AL Shamal	019	00	100%
Mesaieed	019	00	100%
Al Jumailiya	016	00	100%
Al Otoriya	013	00	100%
Al Ghuwairiya	013	00	100%
Umm slal	011	00	100%
Overall Bromate compliance (%) in the State of Qatar	344	00	100%

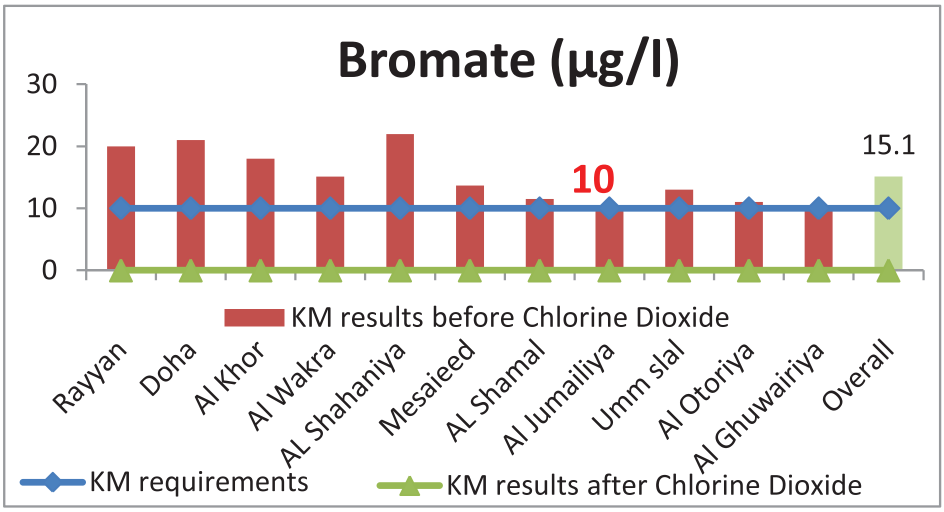

Figure 7: Bromate (*µ*g/l) Average Values for all Areas in Comparison to KM Internal Requirements before and after using Chlorine Dioxide as Primary Disinfectant

8, THM

Table (10) shows THM compliance for all Qatar areas along with the overall THM compliance based on the total number of samples and Off-specs samples. All samples were compliant to KM requirements. Figure (8) shows THM average values for all areas in comparison to KM internal requirements where all areas along with the overall water THM levels lie within the compliance range.

Table 10: THM Levels Compliance for all Qatar Areas along with the Overall THM Compliance

Area	No of samples	No of off specs samples	Comliance (%)
Rayyan	167	09	095%
Doha	159	06	096%
Al Khor	038	01	097%
Al Wakra	029	00	100%
AL Shahaniya	018	00	100%
AL Shamal	015	00	100%
Mesaieed	012	01	092%
Al Jumailiya	010	01	090%
Al Otoriya	008	00	100%
Al Ghuwairiya	007	00	100%
Umm slal	008	00	100%
Overall THM compliance (%) in the State of Qatar	471	18	96%

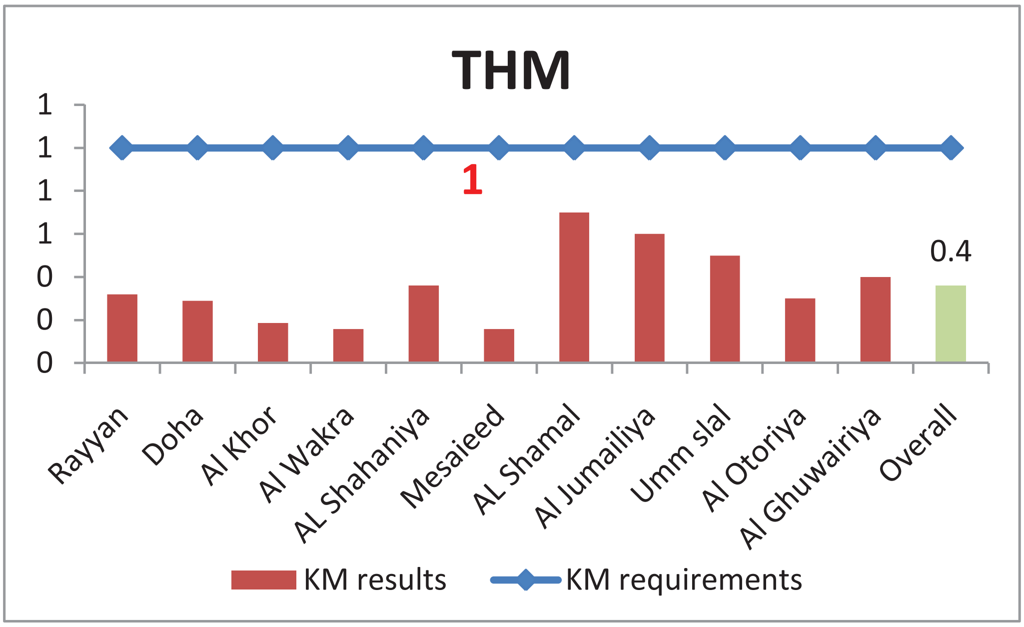

Figure 8: THM Average Values for all Areas in Comparison to KM Internal Requirements

Water Quality Index (WQI)

Table (11) shows the area's individual WQI along with the overall water quality index within the state of Qatar utilizing the Baseline Comparative model for WQI calculations. The WQI ranged between 95.3% & 98.6% with an overall WQI of 97.1% for all areas. Therefore, Qatar's distributed drinking water is excellent as individual areas along with the overall water considering the analyzed parameters.

Table 11: Calculated WQI for Individual Areas along with the Overall Water Quality Index within the State of Qatar.

Area	Water Quality Index % (WQI	WQI Ranking
Al Doha	98.6	Excellent
Al Rayyan	98.3	Excellent
Al Khor	98.1	Excellent
Al Wakra	97.4	Excellent
AL Shamal	97.6	Excellent
AL Shahaniya	96.8	Excellent
Mesaieed	96.3	Excellent
Al Jumailiya	96.0	Excellent
Al Otoriya	95.3	Excellent
Umm slal	96.4	Excellent
Al Ghuwairiya	97.2	Excellent
Overall WQI in the state of Qatar	97.1	Excellent
Min. WQI	95.3	Excellent
Max. WQI	98.6	Excellent

Numerous factors influence such high level of compliance such as: proper quality management system, new infrastructure & network replacements, proper selection of the used disinfectant, unique disinfectant injection, …*etc.* Although WQI for all areas is excellent with an average of 97.1%, Al Otoriya area shows on the boarder value for WQI (95.3%) which is slightly lower than the other areas. The main reason behind such slight decrease is the water stagnation due to very low consumption rate within the network. After comprehensive study and monitoring process, proper and frequent flushing solved the turbidity issue that causes such decrease.

Conclusions and Recommendations

1. For the last couple of years, Qatar's distributed drinking water is excellent as individual areas along with the overall water considering the analyzed parameters. The WQI ranged between 95.3% & 98.6 % with an overall WQI of 97.1% for all areas. Moreover, Qatar's water quality compliance exceeds the international guidelines for drinking water.

2. Numerous factors influence such high level of compliance such as: proper quality management system, new infrastructure & network replacements, proper selection of the used disinfectant, unique disinfectant injection, …etc. On the other hand, the water quality assessment process is quite robust utilizing the internationally competent sampling & monitoring plan developed by KM/WQL team.

3. Although WQI for all areas is excellent with an average of 97.1%, Al Otoriya area shows on the boarder value for WQI (95.3%) which is slightly lower than the other areas. The main reason behind such slight decrease is the water stagnation due to very low consumption rate within the network. After comprehensive study and monitoring process, proper and frequent flushing solved the turbidity issue that causes such decrease.

4. To calculate the WQI, KM/WQL selected those parameters that would be commonly interested by all GCC countries. Qatar's would strongly recommend all GCC countries to emanate KM concept and benchmark WQI based on commonly agreed water quality parameters.

5. Water quality management in the State of Qatar is quite matured and is competent locally & internationally. Therefore, it could be considered as a successful/base example for all GCC countries in order to develop common drinking water quality management aspects including the drinking water security and sustainability strategies.

6. KM (KM) developed, approved and implemented its own robust standards/requirements (4 different standards/requirements) that helped in managing drinking water quality related issues within the state of Qatar; as a result of some observations in both WHO guidelines and GSO 149:2009 standard. Those four different KM internal standards/requirements are emanated from WHO and GSO 149 with more restriction in numerous parameters and covers desalination plants, R.O. plants, distribution system and new pipeline commissioning.

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Reviving Ancient Wisdom: Using Mobile Technology to Re-build Social Norms for Water Conservation in Oman

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Abstract: Domestic water consumption has changed dramatically in the Sultanate of Oman over the past 40 years. New urban development has allowed for a much higher level of water consumption, and traditional ethics of water conservation have lost some of their influence over consumer behaviour. As the capital city of Muscat grapples with increasing water scarcity, it is necessary for Oman to employ Water Demand Management strategies to reduce domestic consumption. One option available is using electronic or mobile governance platforms to strengthen social norms for water conservation. The East Bay Municipal Utilities District in California has implemented such a technological solution and has seen significant decreases in consumer demand. This paper examines the theoretical possibility of reapplying this type of technology to promote behaviour change in Oman and the potential that this strategy has for reviving traditional Omani ethics surrounding water conservation.

Keywords: Water Demand Management, m-governance, e-governance, behaviour change, social norms, Oman.

Introduction

Within the discourse on water and development, considerable analysis has been given to the challenges that water insecurity will pose for the aspirations of the global poor. However, relatively little attention has been paid to the challenges of water security for the newmiddle class and *nouveau riche*—those people living in rapidly developing environments whose new standards of living rely on young economies, institutions and public services. The growing coastal cities of the Sultanate of Oman present one such situation, a case where future water governance under conditions of great scarcity may play a key role in maintaining recently acquired lifestyles.

Looking to the future, Oman is anticipating increasing water scarcity as a product of climate change and rising demand due to rapid population growth (MRMWR, 2005). With groundwater resources being rapidly depleted, the urban areas rely almost entirely on desalination to serve domestic and industrial water needs (MRMWR, 2005).The costs of this process are artificially low at present due to the availability of cheap energy, however as the national oil reserves decrease, we can assume that the production costs of desalinated water will rise dramatically (McLoughlin, 2011). Simply producing more water to meet growing demand may not be feasible in the not-too-distant future, making demand reductiona critical element of Oman's future water security strategy.

Water Demand Management (WDM)has been hailed by many as the key to achieving urban water security in many contexts (Kayaga and Smout, 2011). There are three main policy options for reducing domestic water consumption: regulation to curb water use (hosepipe bans etc.), economic incentives, and behaviour change programs. (Of these options, economic incentives are the most common around the world, however due to the inelasticity of water, increasing already low water prices alone has little effect (Gaudin, 2006). Introducing regulation is a highly politicized issue, and for a country facing future changes in its governmental structure, directly restricting citizen's water use may not be politically feasible.) While typically implementing a suite of different options simultaneously is most beneficial (Kayaga and Smout, 2011; OFWAT, 2011),this analysis focuses on the latter option, behaviour change. Numerous cases around the world point to behaviour change and domestic conservation as a valuable and relatively inexpensive route to water savings (OFWAT, 2011).

Traditional programsto encourage people to voluntarily conserve water typically rely on education and public awareness campaigns, both of which are slow to realize any effect. One potential solution to this program design challenge is to consider alternative streams of communication and interaction with the public. Changes in information and communication technology (ICT) have already spurred new systems of electronic and mobile governance (e/m-governance) which can be applied to water management around the world. Mobile technology in particular has been dubbed an increasingly valuable tool, asthe technology allows initiatives to reach increasingly high proportions of the public(Hope et al., 2012). This then leads to a core question in need of analysis: Does mobile technology provide an appropriate and effective avenue for increasing water conservation in the Sultanate of Oman?

This paper has several tasks in order to answer this question. First the background section will seek to contextualize this research by providing a social explanation for why domestic water use has increased in the past few decades. Following this, the theoretical framework will discuss a case study and literature on e-governance in order to set up criteria for successful application of m-governance in WDM. The body of the analysis will then examine the specifics of the Muscat case against the proposed criteria, leading to conclusions on the potential suitability of implementing mobile WDMstrategies in this city.

Background

Over the past 40 years, the Sultanate of Oman has undergone dramatic changes in development; its main cities transforming from traditional settlements to modern metropolises in the course of one generation (Wilkinson, 2006; Wilkinson, 1977). Known fondly by locals as the Omani "Renaissance," this period of economic growth has brought major improvements in education, infrastructure and public services that have increased the quality of life of average citizens (Owtram, 2004). The capital city of Muscat experienced the bulk of this development. Rapid urbanisation has significantly altered modern Omani culture, including perceptions of water use.

Water consumption in Muscat today differs considerably from traditional norms of water conservation. For thousands of years, Oman had highly formalised community-based institutions for water governance (MRMWR, 2005). These institutions largely regulated abstractions from the communal *qanat* system called the *aflaj*, and relied heavily on interpersonal monitoring and a strong religious moral framework to conserve water resources (Al-Ghafri, Inoue and Nagasawa, 2007;Foltz, Denny and Azizan Haji Baharuddin., 2003).Within the arid environment of Oman, water-saving behaviour developed out of necessity and the socially enforced rules and practices around conservation became embedded in culture. These social norms and customs are still observed in rural Oman today, however they have largely been ignored in the context of urban water use (Boone, 2013).

Interview evidence shows that people living in Muscat have varied perceptions on the need for conservation, altering their behaviour significantly between urban and rural contexts(Boone, 2013). According to this research, one of the most significant elements influencing increased urban consumption is the removal of traditional social pressures to conserve water. Because of this, reviving traditional social norms and reducing urban water demand may provide a partial solution to Muscat's impending water scarcity.

Theoretical Framework

Before analysing the potential for mobile-WDM in Oman, it is necessary to define some theoretical criteria against which to assess its suitability and potential for success. For comparison, this section first examines the emerging success story inEast Bay, California, a region that has recently used ICT interventions to significantly reduce demand. The criteria for successfully implementing such a strategy elsewhereare then derived by analysing this case through the theoretical lenses of technology acceptance models.

1. e-WDM: The Case of Water Smart in East Bay, California

East Bay Municipal Utility District (EBMUD), the water service provider for the metropolitan areas nestled between the major cities of San Francisco and Sacramento, has struggled with water scarcity. Droughts are becoming more frequent in this part of the US and climate and weather predictions forecast increasing scarcity. Continuing the recent trend, 2013 was reported as the driest year on record (Sacramento City Council, January 2014). However, natural water scarcity is also exacerbated in this region by human activity. This area is known for its profligate water use, with average per capita consumption exceeding 165US gallons(625 litres) per day(Willis, 08/02/14). This rate of consumption is not only unsustainable for this semi-arid environment but may also pose serious consequences for the local economy. As many cities in California are suffering similar water shortages, the state government is now requiring all utilities to reduce demand by 20% by 2020(Sacramento City Council, January 2014).

To meet this goal, utilities have turned to 'behavioural water efficiency' strategies, in addition to traditional demand management options (Boxall, 03/03/14). East Bay's experience in consumer behaviour change is particularly significant, due to the ICT component of their current WDM strategy. In 2009,WaterSmart Software Inc. began to develop a suite of online and mobile applications (apps) designed to use social pressure to encourage water conservation. East Bay was early to adopt the new web and phone app, its pilot programs showing a 5% average decrease in consumption over the first six months (Boxall, 03/03/14). While a recent working paper analysing this case has shown significant heterogeneity in the results (Brent, Cook and Olsen, 2013), the initial water savings from these pilots are impressive nonetheless.

The success of these apps is attributed to the way they apply social comparisons in the display of an individual household's water use. The Water Smart mobile app provides a number of new services for the water customer, including a more accurate, detailed and frequent description of their water consumption and tailored recommendations on how to conserve(Boxall, 03/03/14). Through the phone app, customers in East Bay can also receive updates and 'push notifications' on the current water security situation in their city and alerts on new regulations, such as summer-time hosepipe bans. But the most important element of this new electronic and mobile service is the way it presents individual data against the user's previous trends in consumption and against the average for similar households in the user's area. These comparisons create a gentle social pressure through codifying an acceptable norm and then analysing a particular household's behaviour against this standard.

The Water Smart app is a classic application of behavioural economics and psychology. Social norms, a common concept in these fields of research, are the types and patterns of behaviour considered acceptable by a defined group of people (Brennan, 2013). Research into the effect of social norms on pro-environmental behaviour show that they are strongly influenced by communally held values and beliefs (Steg and Vlek, 2009: 311). Figure 2 Water Smart Software's new smart phone app for viewing domestic consumption reports (watersmartsoftware.com).

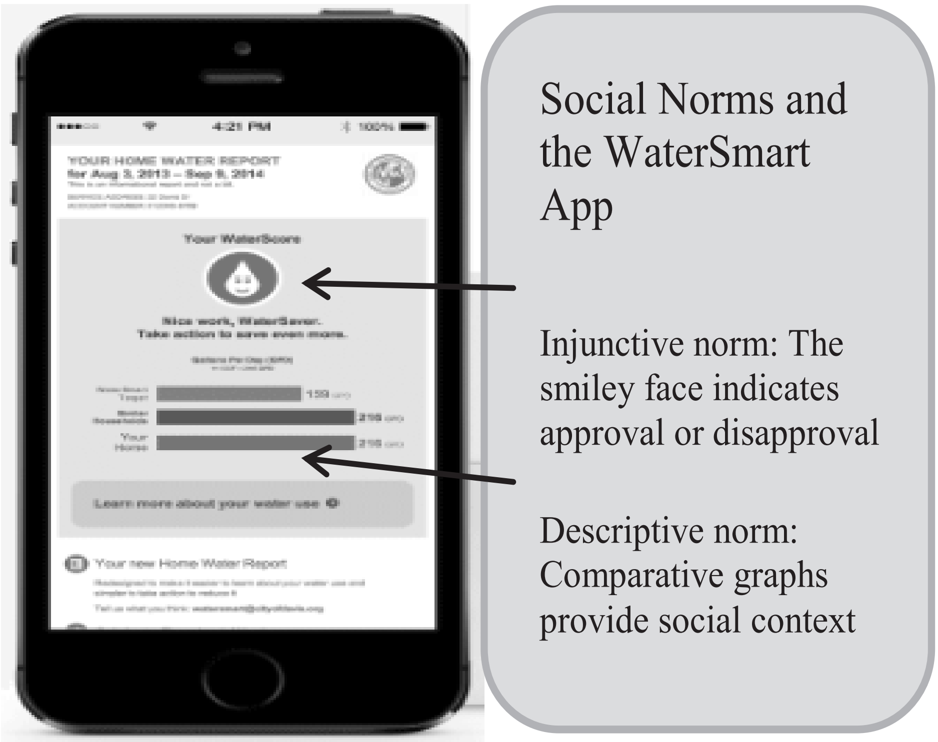

Figure 3: Water Smart Software's new smart phone app for viewing domestic consumption reports

Using web and mobile platforms as the primary method of distributing this information to customers has also been important to the success of East Bay's WDM program. While other cities around the world have tried to implement similar normative campaigns (OFWAT, 2011; SPU2011), traditional communications mediums (mailings, public advertisements etc.) are much slower, more expensive and cannot provide enough detailed information for individual users. For this reason, WaterSmart's app may have had increased effect due to its incorporation of mobile technology.

2. Criteria for Successful Implementation of Mobile WDM

Examples like that of East Bay give us insight into the way that ubiquitous mobile computingcan provide new avenues for e-governance in the water sector. Mobiles and smartphones are increasingly important in the way that people in the Global North conduct their lives(Donner, 2008: 146). But while this technological intervention has proved useful in Northern California, this avenue for WDM may not be appropriate in many other parts of the worlddue to varying needs and conditions (Van Der Meer and Van Winden, 2003).

To judge where similar programs might be effectiverequires a basic understanding of relevant theory.The Technology Acceptance Model (TAM) is very useful in evaluating the potential uptake of mobile water governance. TAM evolved out of the Theory of Reasoned Action and the Theory of Planned Behaviour (Fishbein and Ajzen, 1975;Ajzen, 1991) and contends that the main factors effecting technology acceptance are 'perceived usefulness and ease of use' (Venkatesh and Davis, 2000). In the case of East Bay California, the WaterSmart application met both of these criteria as the need for saving water wasclear and well understood bythe population and the technology utilised--web and mobile applications--werefamiliar and easily accessible for residents in this community.

TAM can describe the reasons that technology might be adopted, but this tells us little about weather an app driven by social norms would be effective. In essence, there is also an issue of social acceptability that must be considered. A newer model, the Unified Theory of Acceptance and Use of Technology (UTAUT) seeks to improve upon TAM by including measures of social acceptance(Alkhunaizan and Love, 2013;Venkatesh *et al.*, 2003). This theory focuses on trust placed in technology and other social and demographic variables.

From these theoretical works, three major criteria emerge for the successful implementation of m-governance for water demand management: Conservation potential, technological feasibility and social acceptability.

3. Conservation Potential

To meet this criterion, a city's residents must be able to reduce their water consumption without forfeiting their human right to water and without significantly reducing their quality of life. This criteria builds upon the 'perceived usefulness' aspect of TAM by validating the need to reduce consumer demand. Needless to say, it would be ridiculous to invest in behaviour change trategies in developing contexts where consumption is already so low that conservation would reduce welfare.

4. Technological Feasibility

In respect to technology, the appropriate government or utility institution must be able to provide, manage and maintain all aspects of the m-governance system. This requires both hardware and software capabilities and investments, such as having metering systems in place to provide the required data, or having trained personnel on staff who can edit the app content for various mobile platforms (Zefferer, Kreuzhuber and Teufl, 2013). On the side of the consumer, technological feasibility also implies 'ease of use' and will only be met if internet or mobile connectivity is high among the target populations.

5. Social Acceptability

Finally, the m-governance system must be appropriate for the user demographics, it must be trusted, and it must present culturally relevant solutions. As seen in the East Bay example, the effect of the mobile and internet apps wasmuch greater among populations whose political and environmental ideologies already pre-disposed them toward conservation (Brent, Cook and Olsen, 2013). Thus, the norms being promoted should build upon existing, positively perceived ideologies or ethical frameworks.

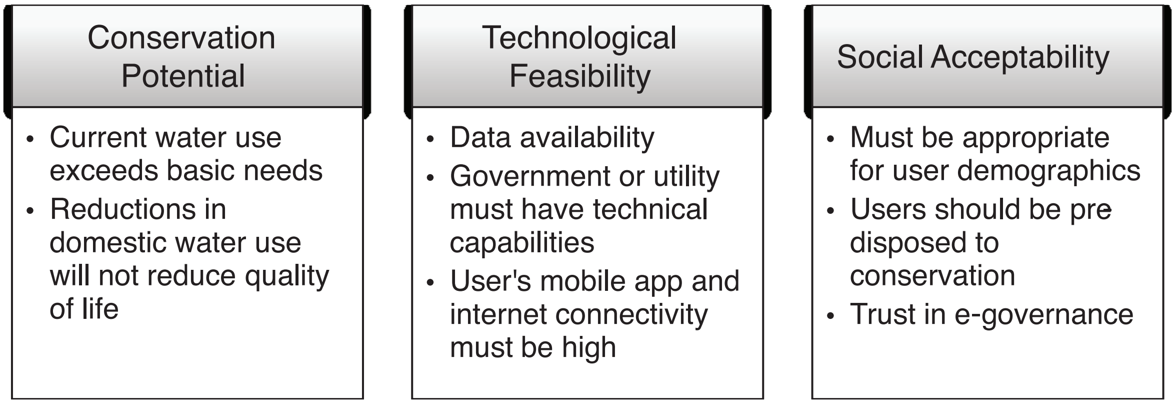

Figure 4: Criteria for considering mobile-WDM

These criteria are intended to be broad enough in scope to indicate a basic level of suitability of mobile behaviour change strategies in many different contexts, however they do not wholly account for the unique challenges and requirements of any individual city. The following sections explore each of these criteria within the case study of Muscat. The data presented is a synthesis of existing research, statistical archive data and perspectives from recent qualitative interviews (The interviews constitute the primary source of evidence for a recent study on water ethics in Oman (Boone, 2013), however the transcripts of Muscat residents have been re-analyzed for this paper. For interviewee demographics, see table 1.

Table 1: Interviewee Demographics

Interview #	Gender	Age Group
1	Male	30-39
2	Male	18-29
3	Female	30-39
4	Female	18-29
5	Female	18-29
6	Female	18-29
7	Female	18-29

6. Conservation Potential

Judging Muscat resident's potential to conserve water is not straightforward. It is difficult to determine whether people are actually using water in excess of their needs or if scarcity is simply a product of population growth. The quality of statistical data on domestic consumption per capita in Oman is highly variable, making it hard to know how this has changed over time. Until recently, records for Muscat showed only total production and consumption of water (Ministry of National Economy, 2013). A simple calculation with this data shows per-capita consumption doubling between 1995 and 2010 (Ministry of National Economy, 2013;Ministry of Information, 1972;1983;2004;2012). While Figure3 shows the expected upward trend in consumption, it aggregates industrial and governmental uses of water with domestic consumption. Without being able to isolate domestic consumption, we cannot show empirically how the domestic average per capita has increased. More recent data from the Public Authority for Electricity and Water (PAEW) might be able to distinguish these trends better, however at present this data is not available to the public.

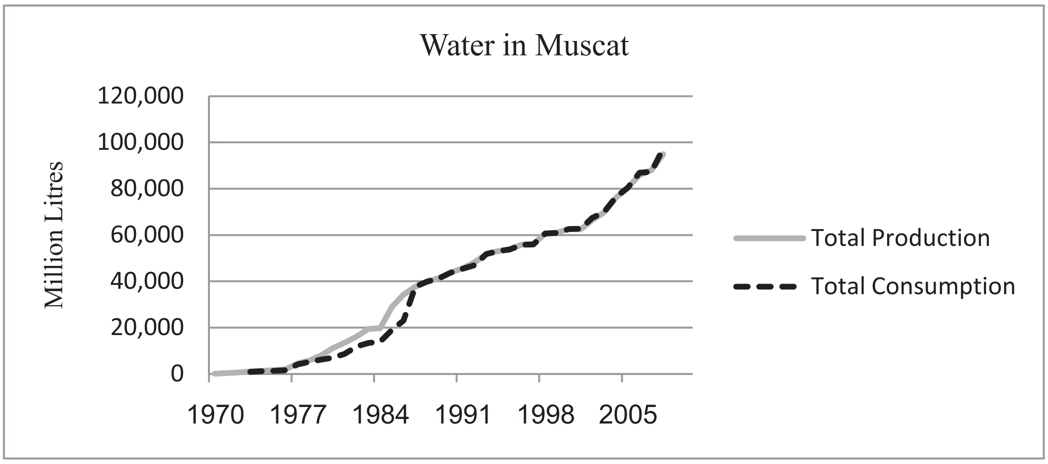

Figure 5: Total water production and consumption in Muscat (Data: Ministry of Info., Stat. Yearbooks 1972-2012)

Instead, qualitative evidence from interviews with Muscat residents may offer some insight into how residents perceive their ability to conserve. Seven residents between the ages of 18 and 39 were interviewed about their water use habits. In general the interviewees freely admitted to using more water than they needed (interview #s 2,3,4,5). To justify their use, they commonly described how desalination could produce an unlimited supply of water (#3,6). For young professionals, they also cited their independence from family and removal of parental pressure as a significant reason for their increased consumption (#1, 4, and 7).

While they described using water without much care in the city, the same participants also described their interest not to waste water. While they knew they were probably using more than they needed, they could not recall how much water they personally consumed, or how much they could conceivably save. However they did seem to believe that they would be able to conserve water if it was necessary (all except #1).

While the data is not strong, it seems that significant savings from behaviour change might be possible without reducing the quality of life in Muscat. Before considering any WDM policy, a more thorough study would be highly valuable to fully understand the potential scope of reasonable water savings.

Technological Feasibility

1. Data Availability

The first consideration when assessing the technological feasibility of implementing a strategy similar to that in East Bay is whether or not there is adequate data on individual household's water use available to the waterutility. Providing personalized data to each household was vital to the success of the WaterSmart app. The key requirement for such a system, then, is reliable metering data that can provide accurate comparisons between households. Thankfully, this condition is largely met by the current water distribution system in Oman, as both piped and tanker-distributed water is now charged at a metered rate in Muscat (PAEW, 2014).Due to this we can assume Muscat meets this criterion.

2. Institutional Capabilities

A second technical consideration is whether or not the Public Administration for Electricity and Water has the institutional capability to support an e-government system and mobile application. At present the answer is unclear. In 2013, the PAEW made significant investments into upgrading their website in order to provide more services, such as viewing water bills online and calculating potential water costs. While the organisation might not have capacity to manage a mobile program at present, it is expected that PAEW could quickly acquire sufficient skill to handle these programs. The Royal Oman Police have also recently deployed a new smartphone app providing services to pay traffic fines, making institutional learning and sharing of best practices a possibility.

3. Mobile/Smartphone Penetration

The final technical criterion that must be met is the suitability of mobile phones as a platform for e-governance. In the California case study, water customers had no problems accessing the mobile and web-based accounts due to the ubiquitous nature of these technologies within American households. Naturally, the program would not have been as successful if access to the system had been a concern.

In this regard, Oman presents a nearly ideal opportunity for mobile governance. Since the turn of the millennium, subscriptions for mobile phones have dramatically surpassed all other forms of ICT, with penetration nearing 180 percent (Refworld, 2012). The two mobile service providers, Omantel and Nawrus, provide data plans that have placed mobile communication within the financial realm of possibility for nearly all Omanis.

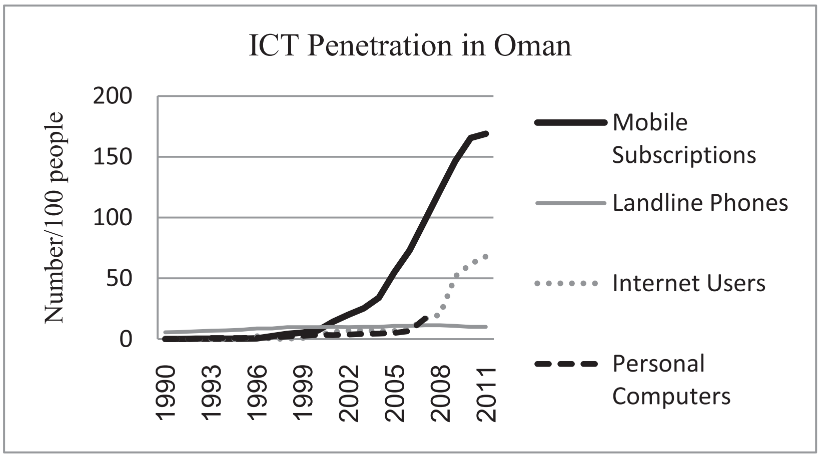

Figure 7: ICT penetration per 100 people.
(Data: UNSD MDG 2012, DevInfo.)

In addition to the rapid increase in mobile communication, the rise of internet use has also been strong in the past decade. Omantel and Nawrus recognized the importance of mobile internet access early on and started including data plans even before internet access on personal computers was widespread. As a result, statistics on personal computer ownership have trailed behind internet access, with many more Omanis surfing the web solely from their mobile phone (Refworld, 2012).

Omanis have been quick to adopt smartphone technology, and the younger generations have been especially keen in their uptake of the newest handsets from popular brands(Belwal and Belwal, 2009). A survey conducted by Freedom House showed that 92% of respondents in Oman owned a smartphone, of which the newest versions of the Apple iPhone, Samsung and Blackberry handsets were the most popular (Refworld, 2012).

Social Acceptability

1. Demographic Considerations

As described in UTAUT, if mobile interventions for WDM are to be successful, they must also be appropriate within the social and cultural atmosphere of Muscat. The demographics of greatest concern in respect to setting future conservation norms are the young urban professionals. Based on Muscat residents' anecdotal evidence and perceptions, the young professional demographics are responsible for much of the inefficient water usage (Boone, 2013).To revive traditional ethics of water conservation, the potential mobile app would need to be accessible to these populations who are just solidifying their urban habits and are at the ideal stage of their lives to make long-lasting changes to their behaviour.Given the high level of mobile and smartphone use among this-target demographic(Belwal and Belwal, 2009), mobile-WDM might be a well-suited intervention.

2. Trust in M-governance

The trust Omanis place in m-governance systems is also an important cultural issue to consider. While no studies have yet analysed trust in m-governance, data on the trust placed in m-commerce (or the buying and selling of goods and services via mobile phones) may provide a useful proxy-indicator. A 2006 survey on m-commerce in Muscat, showed that 25% of respondents had used their phone to make online purchases and 67% indicated that they would hypothetically be comfortable making purchases if the security of the payment system were ensured (Manochehri and AlHinai, 2006).While this study has not been repeated, we can reasonably assume that these figures have grown in the interim. Comparable studies conducted in Saudi Arabia show that trust of m-commerce and e-governance is generally increasing (Al-Sobhi, Weerakkody and El-Haddadeh, 2011). This indicates that citizens in similar cultural contexts to those in Oman are fairly neutral in their willingness to trust e-governance services and that there are no significant cultural barriers to the adoption of this technology.

Conclusion

Oman is at a watershed point for m-governance and considering the implications for water demand management is vital. Enthusiasm for this new method of service provision has been building rapidly within various government ministries. As of this writing, the Omani government has just held its first conference on e-governance and has started to build it into its institutional development goals for the next few years (Times of Oman, 2014).

Based on the criteria outlined here, Muscat's urban environment seems to have reached a level of technical development in which implementing m-governance for WDM could be successful. While the amount of water savings that could be reasonably expected from such an intervention is still highly unknown, the city seems to meet the technical and social criteria well. Due to the high level of mobile phone use, such a program would probably be more successful that traditional behaviour change campaigns. The choice of implementing a norm-driven behaviour change strategy would also be valuable as it could draw upon the existing traditions of conservation as a way to legitimize its message and increase its impact.

Limitations and Avenues for Future Research

The first limitation of this analysis is theoretical. Defining criteria from the East Bay experience may be premature as the program has only been in place for a few years and long term effects are still unknown. A second limitation is the quality of the interview data examined. The interview responses analysed here are the product of a pilot study with a small number of participants, and due to the snowball sampling method, there is some chance of selection bias. These points to the need for future research to produce more robust evidence.

In general, there is a research gap surrounding the emerging role of ICT in water governance. Based on the research conducted here, there are several main topics in urgent need of exploration. As these technological interventions are quite new, their effectiveness in the long-term is not well understood and future studies into the durability of behaviour change strategies would be very valuable. There is also a significant opportunity to explore the implications that ITC may have for modelling behaviour change. At present, computer models such as DAWN have attempted to describe the way social interactions between neighbours influence domestic water use and conservation (Kayaga and Smout, 2011). However no work has yet shown how virtual social pressure via mobile phone apps may alter these models.

Finally, this paper has examined the potential for using m-governance in the Sultanate of

Oman, but the concept of using mobile apps to revitalize traditional ethics and norms of conservation may be applicable in many other cities around the world. At a minimum, future research should explore similar cases in the Middle East where rapid urbanisation has stressed water resources. In such cases, updating and preserving traditional ethics may provide a valuable tool for maintaining water security in these rapidly changing societies.

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SESSION 4
DESALINATION MANAGEMENT

Nanotechnology-based Pretreatment and Desalination for Effective Salt Removal from Brackish Water

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Summary

Environmental pollution and industrialization on a global scale have drawn attention to the vital need for developing new hygienically friendly purification technologies. Cost-effective treatment of pollutants requires the transformation of hazardous substances into benign forms and the subsequent development of effective risk management strategies from harmful effects of pollutants that are highly toxic, persistent, and difficult to treat. Prefiltration using nanotechnology based filters utilizing photocatalytic processes that activate the antimicrobial properties under sunlight and Capacitive Deionization techniques promise as an interesting alternative for effective removal of dissolved ions from saline water. Heterogeneous photocatalytic systems using zinc oxide nanorod coated surfaces capable to operate effectively and efficiently for treatment of water are discussed. With these technologies, remote locations could be served as the processes require low or no electrical power to run. Development of these techniques would make it possible to install delocalized systems with very little capital investment and operation & maintenance costs.

Introduction

Most of the estimated water reserve on earth (326 million trillion gallons of water) is brackish or in the oceans (98%). Ground water is only 0.36 % while about 0.036 % water are in lakes and rivers as a majority of water are locked in polar icecaps and glaciers, while the rest is in transition in the atmosphere as water vapor [1]. Nearly 50% the World's population depends on groundwater as the source of drinking water. It is estimated that by 2050, 19% increase worldwide in the demand in water for agricultural purposes will be necessary to support the growing population. In many places groundwater is brackish and not suitable for human consumption, livestock watering, or crop irrigation, and it is only increasing due to extensive ground water extraction.

Furthermore due to ground water pollution and due to industrialization and urbanization, it needs to be purified from unwanted chemicals, biohazardous microorganisms, solid wastes and dissolved gases to be suitable for drinking. In order to address these challenges, a sustainable use of water needs to be developed to balance demands with available resources. Today around 1% of the world's population depends on desalinated water to meet their daily needs, but it is expected to increase drastically as 14% of the world's population are poised to encounter water scarcity by 2025. The Arabian Peninsula has very limited water resources, with less than 10 mm/year of rainfall on average, and is in a situation of very severe water scarcity, with available water between 200 and 700 m^3/inhabitant/year [2].

In order to address the future water scarcity, a combination of approaches including water conservation, recycling, and treatment of impaired water from nontraditional resources to "create" new water need to be developed. One of the areas that no longer can be overlooked for increasing water supplies is the application of desalination technologies to treat brackish surface and ground water resources.

Desalination is an integral and often critical part of water management strategies. Globally it is the source for some, or all, the daily water needs of an estimated 300 million people around the world. Over 16,000 desalination plants worldwide produce more than 20 billion gallons of drinkable water per day (in perspective, current global water consumption is estimated to be about 1,200 billion gallons). This is expected to reach more than 30 billion gallons per day by 2020, with one third of that capacity in the Middle East [3].

Desalination has been practiced throughout human civilization with possibly the first recorded mention of seawater distillation in 320 B.C. was by Aristotle [4]. Through the mid-1900s, the most commonly used techniques to desalt water involved evaporation and distillation. Rapid development of desalination technologies took place during World War II, due to the requirement to supply fresh water to the troops positioned in arid areas. Commercial desalting units, mostly thermal distillation units, producing up to 8,000 m^3/d were installed in various parts of the world by late 1960's. In the early 1970s, commercial membrane processes, such as reverse osmosis (RO) and electrodialysis (ED), were introduced. Since ED could desalt brackish water more economically than distillation, more interest was focused on using ED as a way to provide water for municipalities with limited fresh water supplies but with easy availability of brackish water sources. By 1990s the use of desalination technologies for municipal water supplies was a commonplace. Today, the major desalination plants employ membrane and thermal technologies with roughly 63 percent of installed capacity using membrane desalination technologies and the rest using thermal processes. RO involves pretreatment of the feed water via mechanical and chemical means to remove suspended solids followed by membrane separation of the dissolved salts rejected by RO membranes. Energy requirements, exclusive of energy required for pre-treatment, brine disposal and water transport, are estimated to be 4.7-5.7 kWh/m^3 for RO and between 23-27 kWh/m^3 for multistage flash distillation (MSF). In order to be more energy efficient, many desalination facilities, particularly in the Middle East and North Africa region, have been constructed as co-generation facilities to simultaneously produce both electrical power and desalinated water within the same complex. Most of the thermal distillation processes are normally designed to take advantage of a co-generation situation.

One of the principal concerns in any water system is eliminating microbial risks. Conventional drinking water treatment of surface water consist of coagulation, flocculation, sedimentation, sand filtration and disinfection by a form of chlorine. Trace chemical removal is also highly desirable and practiced, but there is a consensus that risks, if any, of consumption of parts per billion and parts per trillion of a few residual organics is not significant. Typical TOC levels of conventional finished water are at the several mg/l levels. Conventional treatment is not designed to effectively remove many industrial chemicals and disinfection byproducts upon chlorination. Further removal of microbes require very effective filtration or disinfection modifications because chlorine is not totally effective for microbes like protozoa, especially cryptosporidium. Mostly, multiple treatments of impaired water through granular carbon, sequences of membrane treatments including microfiltration, ultrafiltration or nanofiltration followed by salt removal and disinfection by chlorine, ozone, chlorine dioxide and ultraviolet light are practised.

Advanced oxidation (AO) technologies can be used to remove trace organic chemicals like residual pharmaceuticals or recalcitrant chemicals like 1,4-dioxane, but the processes are not generally practiced since they are very expensive. Advanced oxidation produce hydroxyl radicals, which have a free electron that are very reactive, from hydrogen peroxide or ozonation using ultraviolet light. This requires a lot of electrical energy thus increasing the operating cost for the treatment. However, AO processes can destroy practically all organic chemicals converting them to carbon dioxide and water if a sufficiently high dosage is used. Energy, in absolute terms, is not in short supply in the world. The world's total annual use of commercial energy is on the order of 400 quadrillion BTUs (Quads), and the sun pours about 6 million Quads of radiant energy into the earth's atmosphere each year. Thus if the solar energy can be used for assisting the disinfection process, then the advanced oxidation processes can be a commercially viable technology.

Nanotechnology is the breakthrough development in innovative materials and components by control at the atomic, molecular, or macromolecular level. The dimensions of such materials can be in the range of approximately 1-100 nanometers (nm) – 1 billionth of a meter. Applications in Nanotechnology are wide ranging and are constantly evolving as its development includes control at the nano scale and integration of nanoscale structures into larger material components, systems, and architectures [5, 6]. Nanomaterials typically have large specific surface area and size dependent properties that make them suitable for applications in water treatment processes [7]. Visible light photocatalysis is such a promising water treatment technique/tool introduced by nanotechnology for the removal of microbes from either the source water or treated water [8].

Existing water treatment technologies (including waste water treatments) demand high capital investment and operation and maintenance cost, and large area. Cost-effective treatment of pollutants requires the transformation of hazardous substances into benign forms and the subsequent development of effective risk management strategies from harmful effects of pollutants that are highly toxic, persistent, and difficult to treat. Heterogeneous photocatalytic systems via metal oxide semiconductors like titanium dioxide (TiO_2) and zinc oxide (ZnO) nanomaterials are capable to operate effectively and efficiently for sanitization of water. We discuss about the use of supported ZnO nanorods for sanitization of water.

For brackish water desalination, capacitive deionization (CDI) is one of the most promising technologies for removing dissolved ions. CDI with lower installation costs and lower energy requirements is an alternative for desalting low salinity water [9, 10]. CDI technology utilizes nano electrodes for separating the ions using a novel, environmentally friendly and less energy consuming processes. We report about a prototype desalination system using activated carbon cloth (ACC) material for effective salt removal.

Photocatalytic water treatment

Photocatalysis is a promising technique for water treatment that uses a light active nanostructured catalysts to degrade various pollutants in water [11]. Nanostructured wide band gap semiconductors are used in photocatalysis which upon absorption of a light of energy higher than its bandgap energy generates electron-hole (e-h) pair. The photo-generated e-h pair then produces highly reactive oxidizing and/or reducing radicals, such as super oxides (O_2^-), hydroxyl ions ($OH^{\square}$) or other radicals, in water. These radicals oxidize pollutant molecules present in the contaminated water through secondary reactions. The degradation of the water contaminants can also occur through direct transfer of the photo-generated electrons or holes from the catalyst surface to the contaminant molecules (Fig. 1). Nanostructured metal oxide materials are better suited for photocatalysis compared to their bulk counter parts, since most of the photo-generation of electrons and holes occur at the surface and hence the high surface to volume ratio of nanomaterials leads to a better efficiency of degradation per gram of material used. Wide bandgap semiconductors normally absorb light in the UV region of the solar spectrum. However, the use of high energy UV light sources to excite the catalysts is not a cost effective solution in most of the cases.

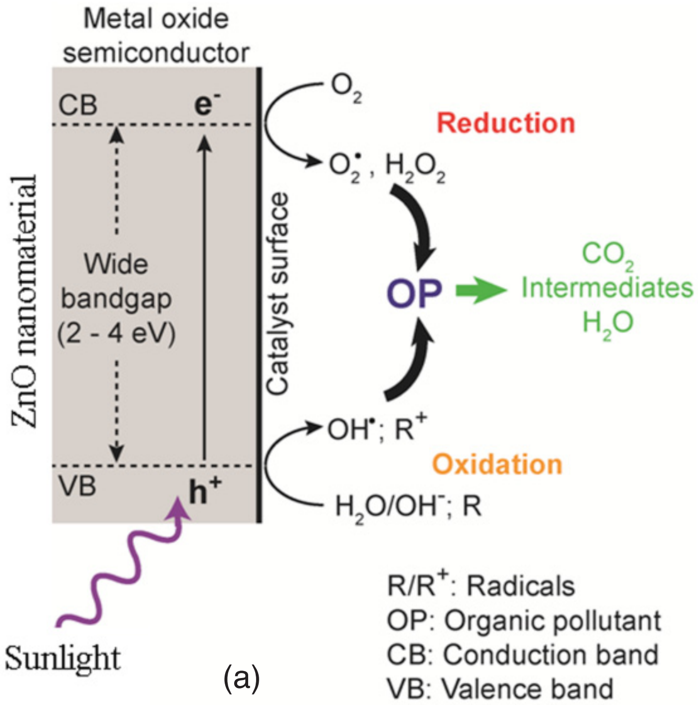


Figure 1 Schematic representation of a typical photocatalysis process on the surface of a nanostructured wide band gap metal oxide semiconductor photocatalyst (zinc oxide).

Solar spectra roughly consist of roughly 46% visible light, 47% infrared radiation and only 7% ultra-violet (UV) light. Thus it is necessary to engineer nanomaterials to render them effective for visible light absorption. Several attempts have been reported in the literature for the modification of the wide bandgap semiconductor catalysts to harvest the visible light region of the solar spectrum and their visible light photocatalytic activities. Doping of the semiconductor catalysts [12, 13], coupling with narrow bandgap semiconductors [14], sensitization by visible light active organic dyes [15], and application of metal nanoparticles for surface plasmon induced visible light photocatalysis [16, 17] are some of the approaches that has been taken. Alcohols, carboxylic acids, phenolic derivatives and chlorinated aromatic contaminants have been successfully degraded through photocatalysis [18]. Metal oxides, such as TiO_2, ZnO etc. have also shown great potential to photocatalytically degrade dyes and natural organic matters or humic substances from water [19].

Waterborne bacteria *Escherichia coli* (*E. coli*), *Bacillus subtilis* (*B. subtilis*) and *Staphylococcus aureus* (*S. aureus*) has been shown to be inactivated by ZnO nanorods under visible light irradiation. Zinc oxide nanorods can be grown by a simple low temperature (less than 100 °C) hydrothermal process. The hydrothermal growth of ZnO nanorods require sources of zinc ions (Zn^{2+}) and hydroxyl ions (OH^-) [20]. A very commonly used method of growing ZnO nanowires is the use of an equimolar solution of zinc nitrate hexahydrate and hexamethylenetetramine (HMT) maintained at temperatures in the range of 65 °C to 95 °C. The inactivation of pathogenic bacterial densities by the ZnO nanorods in the presence of visible light effecting photocatalytic reactions shows the potential application of these types of nanostructured coatings for the pretreatment of water using sunlight. Microbial cell membrane damage occurs due to the highly reactive oxidation/reduction radicals and evidence of possible DNA damage was also reported [21].

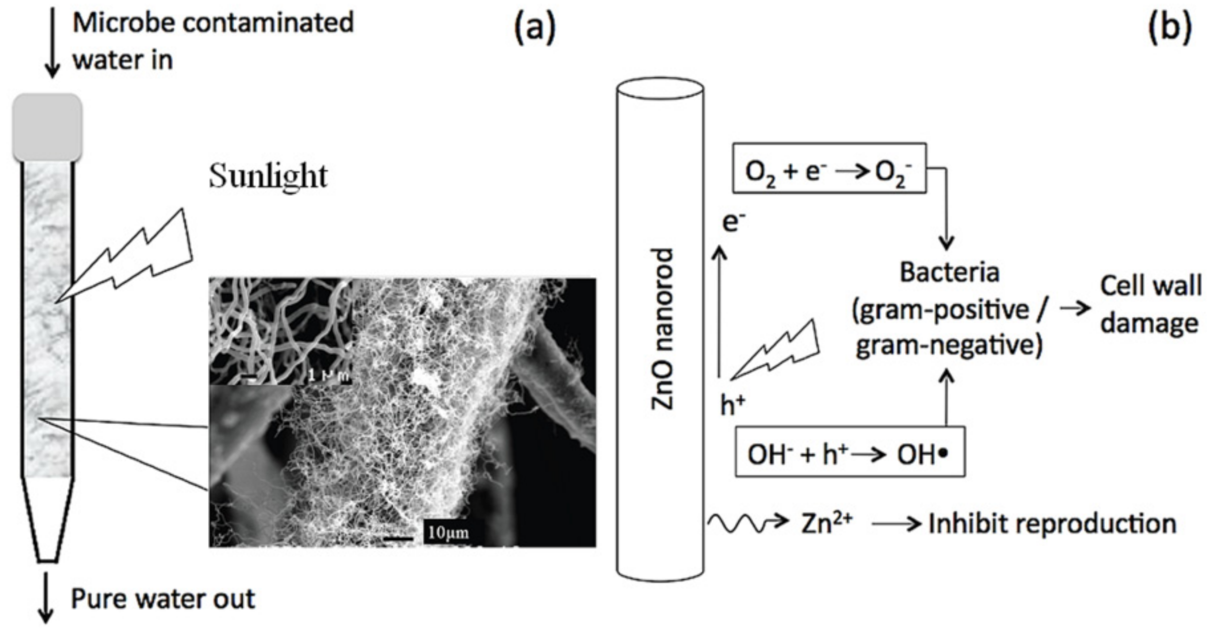


Figure 2 Schematic representations of (a) water purifier comprising of ZnO nanorods on polyethylene fibers enclosed in a glass tube (b) mechanism of bacterial immobilization by ZnO nanorods. Free electrons interact with oxygen forming superoxides while the holes convert hydroxyl ions into highly reactive hydroxyl radicals.

An innovative water purifier consisting of membranes precoated with ZnO nanorods grown on polyethylene fibers is shown in **Fig. 2a** [22]. Up to 99% of *E. coli* and *S. aureus* in spiked water containing about 10^{10} colony forming units (CFU) of bacterial cells could be immobilized under sunlight within a few minutes of exposure. In other experiments, ZnO nanorod coatings in the presence of sunlight, was found to reduce densities of marine bacterium *Acinetobacter* sp. AZ4C and the marine alga *Tetraselmis* sp., prevented biofilm formation and decreased settlement of the bryozoan larvae *B. neritina* under laboratory conditions [23]. Antifouling effect of the ZnO nanorod coatings were attributed to the reactive oxygen species (ROS) produced by photocatalysis process (**Fig. 2b**). ZnO nanorod coatings thus can effectively prevent micro- and macro-fouling in both marine and sweet water conditions. It could be useful for pretreatment of impaired water to prevent membrane fouling during subsequent water treatment processes including desalination processes.

Capacitive desalination (CDI) of brackish water

Capacitive deionization (CDI) is environmentally friendly technology with no secondary contaminants produced during the desalination process. Moreover, low energy is consumed for desalting water as the devices operate at low DC potential ranging from 1.0 to 2.0 V, in order to avoid electrochemical reactions on electrode surfaces, making it a suitable technique for remote applications. Specific surface area, pore size distribution (micro/meso or macro pores), functional groups on the electrode surfaces and adsorption or desorption characteristics of ions determine the ultimate efficiency of CDI electrodes. A typical CDI cell consists of two symmetrical parallel electrodes electrically isolated from each other. A typical desalination cycle consists of accumulation of anions/cations in the electrical double layer (EDL) produced upon the application of an electrical potential across the electrodes. The resulting force from electric field acting from the positive electrode to the negative electrode (circuit ground) is expressed as the force experienced by a unit positive charge (cation) placed in the electric field (eg. Na^+ ion). The cations are removed through a combination of both attraction by the negative electrode and repulsion by the positive electrodes. Anions (eg. Cl^- ions) would collect in the opposite electrode during the desalination step. A linear adsorption and desorption of ions are generally observed during the desalination and the regeneration cycles.

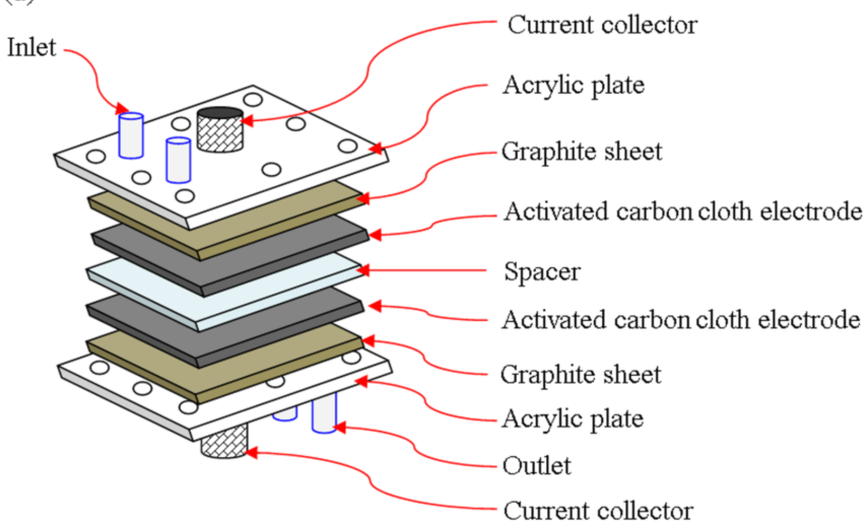
$$Salt\ removal\ efficiency = \frac{C_0 - C_f}{C_0} \times 100\ \%$$

The desalination or regeneration efficiency are estimated as follows:

where C_0 and C_f are initial and final conductivity of saline water.

In a prototype that we have developed, CDI cell electrodes with activated carbon cloth (ACC) of specific surface area ~ 1200 m^2/g, interspersed between two graphite sheets acting as current collectors and to achieve uniform field distribution over the complete ACC surfaces are separated by an insulating spacer. The electrodes are 9.5 cm x 9.5 cm yielding a total surface area of ~ 90 cm^2. A schematic representation of CDI cell and experimental set up are shown in **Fig. 3a-b**. Online conductivity probe is installed at the outlet of CDI cell in order to monitor the conductivity changes during desalination and regeneration processes.

(a)



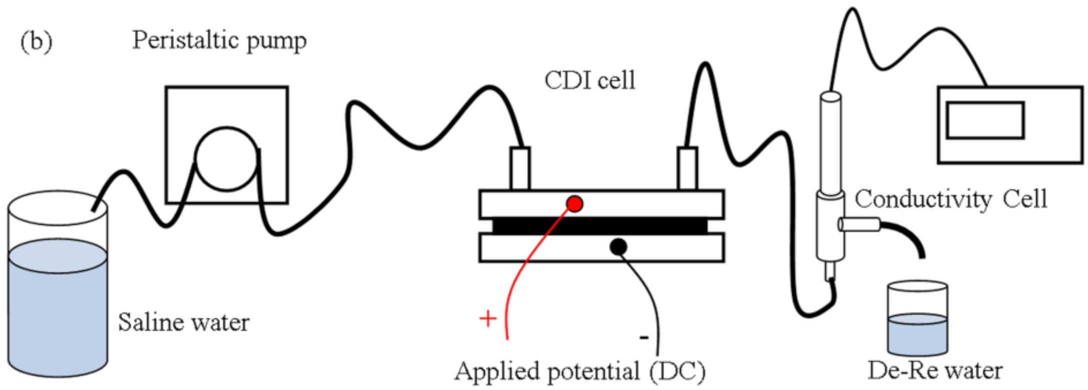


Figure 3 Schematic representation of (a) single CDI cell arrangement (b) experimental set up for measuring desalting performance of fabricated CDI electrode.

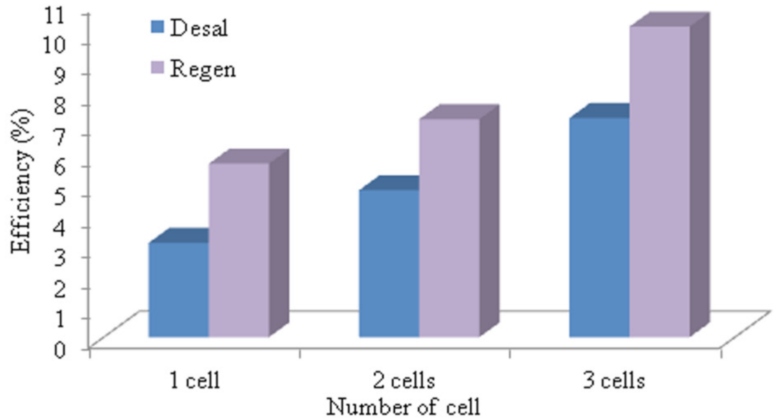


Figure 4: (a) Desalination and regeneration efficiencies of three different cells arrangement under applied potential of 1.6 V (DC) using 10000 ppm NaCl solution with the flow rate of 5 ml/min (b) Schematic diagram of conceptual design for higher throughput for brackish water desalination.

figure. 4a shows the desalination and regeneration (De-Re) efficiency of single and multiple cell arrangements. De-Re efficiency is directly proportional to the number of cells used in the process whereby 10% efficiency of salt removal for 10,000 ppm sodium chloride solution could be achieved. The efficiency of removal of low salinity water is much higher approaching 50% for 1000 ppm Nacl chloride concentrations. A conceptual prototype design for effective desalination using CDI is proposed in figure. 4b.

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Scale Control in Multi Stage Flash (MSF) Desalination Plants – Lessons Learnt

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Abstract: Most of the large desalination plants in the GCC region are employing the MSF desalination process. One of the main factors which contributed to the massive application of MSF desalination process is the adoption of successful methods for scale control. Formation of scale on heat transfer surfaces is a major operating problem in MSF desalination processes. It impedes the rate of heat conducted form the vapor condensing outside the tubes to the brine flowing inside the tubes, which will consequently reduce the distiller performance and increase specific energy consumption. The main scale forming constituents of sea water are calcium, magnesium, bicarbonate and sulfate. The calcium and magnesium ions together with the bicarbonate will be responsible for the formation of calcium carbonate and magnesium hydroxide salts which are normally known as alkaline scale. The calcium and sulfate ions will be responsible for the formation of calcium sulfate salts which is normally termed as “hard Scale”. Alkaline scale is controlled by either lowering the pH through bicarbonate depletion by acid dosing or by chemical additives treatment methods combined with the use of on-lone ball cleaning. In this paper, the evolution of alkaline scale control in MSF desalination plants during the last four decades will be described and reviewed. The unique experience gained by the Saline Water Conversion Corporation (SWCC) of Saudi Arabia in controlling alkaline scale formation, will be presented. The extensive optimization tests, which have been carried out by SWCC and materialized in significant reduction of anti-scalant dose rates, are thoroughly reviewed. Procedures employed for on-line sponge ball cleaning are discussed. The various corrective measures that are normally adopted to mitigate the consequences of malfunctions of anti-scalant dosing or the on-line ball cleaning systems, are presented. Most of the MSF desalination plants are currently operating with the alkaline scale boundaries and top brine temperatures (TBT) are not exceeded 115^{o}C.The prospects of controlling non-alkaline scale and operating MSF desalination plants at high TBT using nano-filtration pretreatment will be discussed. Increase of TBT shall result in the increase of water production and reduction of specific energy consumption.

Keywords: MSF, Scale control, Alkaline scale, Ball cleaning, Nanofiltration pretreatment.

Introduction

Control of scale formation on heat transfer surfaces is one of the basic problems in the distillation processes. Formation of scale on heat transfer surfaces impedes the rate of heat conducted and increase energy consumption. The main scale forming constituents of sea water are calcium bicarbonate, magnesium salts and calcium sulfate. On heating, bicarbonate yields carbonate which can precipitate with calcium if the saturation limit is exceeded. As a result, magnesium hydroxide isalso formed. Calcium carbonate and magnesium hydroxide are generally referred to as "alkaline scales". This is for identification since they form under alkaline conditions, i.e., at pH values above 8. On the other hand, calcium sulfate is known as "non-alkaline scale" merely for distinguishing it from alkaline salts.Formation of alkaline scale is controlled by either lowering the pH through bicarbonate depletion or by threshold additive chelation. Conversely, $CaSO_4$ formation is primarily controlled, so far in commercial plants, by operating at top brine temperatures that are lower than its appreciable precipitation limits, i.e., TBT < 120 ^{o}C in view of the raised salt concentration in MSF brine streams. Alkaline scale formation in condenser tubes is a major problem encountered in the operation of MSF distillers. Prevention of scale deposition can be controlled by depletion of carbonate through pH adjustment by acid addition or by controlling scale precipitation through the addition of much less than stochiometric quantities of threshold agents which are mainly inorganic or organic polymer compounds. The commonly used antiscalants are derived from three families:condensed polyphosphates, organophosphonateand polyelectrolytes. Polyelectrolytes are mostly Polycarboxylates which include polyacrylicacid,polymethaerylic acid and polymaleic acid.The mechanism of threshold agents has not yet been fully established. It might be due to adsorption of threshold agents on the scale crystal nuclei which leads to crystal distortion and subsequent growth inhibition [1].

Mixtures of sodium tripolyphosphate dispersing agent have been used to inhibit alkaline scale deposition in sea water evaporators since the 1950s [2]. The major problem with polyphosphate based inhibitors was found to be the thermal degradation of polyphosphate at temperatures above 90^{o}C and the subsequent loss of threshold effect of the product. This restriction in top brine temperature to 90^{o}C (by hydrolysis) limited the thermal efficiency of evaporator designed for threshold treatment [2,3].

Acid dosing was introduced in the 1960s as a means of overcoming the temperature limitations and the poor performance of polyphosphate [1]. Acid dosing, by removing the bicarbonate from the feed water, allowed evaporators to operate at increased top temperatures, close to the calcium sulfate solubility limits. It was found to have certain drawbacks such as the mandatory careful control and monitoring of the dose level which was quite essential to minimize the risks of plants' corrosion or scale formation and to ensure a reasonable plant life.

As problems associated with acid operation became dominant, the opportunity for high temperature scale control additives to replace acid while giving commensurable performance was noted from the mid of 1970 onwards [1,2]. Low molecular weight polymeric/carboxylic acid and phosphorous base alkaline were developed as high temperature additives. Phosphonatebased polymers do not hydrolyze as easily as the polyphosphate group due to the greater stability of the c-p bond in phosphonates as compared with the p-o bond in phosphates.The dosing rate of scale control additives is one of the most important operating parameters. Under- dosing leads to scale formation, while overdosing is believed to enhance sludge formation [3]. It is thus essential to establish an optimum dose rate.

Although, a number of methods have been developed to minimize or prevent the formation of alkaline scales, no commonly accepted method for avoiding the formation of scales due to calcium sulfate salts at high temperatures and brine concentrations in large commercial MSF plants is available. The only commercialized approach so far, i.e., currently used to prevent the formation of calcium sulfate; is to operate the plant below the solubility limits of calcium sulfate.

In this paper, the evolution of alkaline scale control in MSF desalination plants and lessons learnt during the last four decades are described and reviewed. Thepotential of controlling non-alkaline scale and operating MSF desalination plants at high TBT usingnanofiltration pretreatment arealso be discussed.

SWCC's Experiences On Scale Control

Saline Water Conversion Corporation (SWCC) of Saudi Arabia has been actively involved in the inhibition of scale formation in order to improve the performance of its distillers. A number of optimization tests have been carried out resulting in successful operation of MSF distillers at low antiscalant dosing rates [3-17]. This can be attributed to several factors such as plant operators' awareness to reduce chemical dosing while maintaining effective plant performance, adoption of on-line sponge ball cleaning and competition amongst various additive suppliers to provide the most cost effective dose levels to meet the needs of SWCC.

A direct comparison on the performance characteristics and economics of three additives tested on the MSF distillers of Al-Jubail phase-I, has been reported [4]. The tested additives include polyphosphate, polyphosphonate and polycarboxylates. The performance testing revealed that the best scale control method was operation at low temperature (90.6°C) and low additive dosing. The three tested antiscalants proved to be successful during the 30 days test period. Individual dose rates varied between 3 and 5 ppm. The sponge rubber ball on-line cleaning system was found to be effective with polyphosphate additive. However, the slight soft scale accumulation with the polycaboxylate and polyphosphonate additives did not warrant extensive use of the ball cleaning system. The design heat transfer fouling resistance is more than required by either type of chemical additive. If a lower design fouling factor is used, smaller heat transfer area will be required which will then have a significant decrease in total evaporator installed equipment cost.

Another study was reported on the evaluation of various additives at Al-Jubail phase-I during reliability tests [5]. Performance ratio calculations were used to predict the time span between acid cleaning for three additives. Assuming a linear relationship between performance ratio and time, the test results showed that the predicted time spans in days before acid cleaning is required were 310, 590 and 1466 for three additives tested. It has been stated that it would be of great interest if chemical instruments would be fixed on the MSF distillers to measure in situ both alkalinity and pH under operating conditions. Such measurements will give a direct estimate of the quantity of scale deposited.

Optimization of scale control additive dose levels at different top brine temperatures in Al-Khobar II and Al-Jubail II desalination plants has been reported [6]. Both plants were originally designed to operate at low or high temperature using polyphosphates or liquid polymers. Suggested dose rates by design were from 3-5 ppm for low temperature additives (LTA) and 7-12 ppm for high temperature additives (HTA). Antiscalant dose rates were reduced in a stepwise procedure. Dose levels were reduced to as low as 2.2 and 0.8 ppm for effective and safe operation at high and low temperature, respectively.

Gained operational experiences on Al Khobar Phase II plant during the period 1982-1992 was reported [7]. The water production, top brine temperature, antiscalant type and dose rate and performance ratio of three distillers were reported. The distillers were initially dosed with polyphosphate antiscalant for a period of one year (1984) and with a TBT of 85°C and a dose rate of 3 ppm. Polyphosphate was then replaced by polymaleic acid during the year 1985 with a dose rate of 2 ppm and TBT of 90°C. From 1986 up to 1992 polyphosphonate liquid with a reasonably low dose rate of around 1 ppm and TBT ranging between 85 to 100°C was used. Up to 1990, the gain out ratio (GOR) was ranging between 6.6 to 7.0 which was near or better than the design value. From 1990 onwards the GOR dropped to as low as 6.3 which was attributed mainly to postponed acid cleaning. It has been concluded that reasonably low antiscalant dose rate (1-2 ppm of make-up sea water) was adequate, ideal TBT for operation with proven capabilities of polymeric acid was 105°C and no safe operation could be endorsed without good sponge ball cleaning. Close monitoring of the MSF distiller would mandate acid cleaning of heat transfer tubes once or as a maximum twice per decade.

Trial tests on the performance of polymaleic acid (PMA) and polyphosphonate (PPN) antiscalants at Al-Jubail phase II desalination plant was reported [8]. The results revealed thatpolymaleic acid was performing better compared to phosphonate based polymer. Also visual inspection for selected units after a predetermined time span revealed that polymaleic acid had a better performance. However, the ball cleaning operation had more tangible effect on the phosphonate group over the polymaleic group.

Evaluation test was carried out in one of Al-Jubail Phase II distillers to investigate the effectiveness of phosphonic acid-based antiscalant when employed at a TBT of 90.6°C and a dose rate of 0.8 PPM [13, 14]. Thermal and chemical parameter monitoring of the distiller which included flash range, performance ratio, overall heat transfer coefficient, fouling factor, loss of total alkalinity as well as distillate production and conductivity during a test period of 337 days, showed that the operation was smooth and steady. Also post-test visual inspection of the unit revealed that the heat transfer tubes of the brine heater were clean and demister pads were also found relatively in a clean condition and with no detrimental scale build up. It has thus been concluded that the antiscalant was quite effective and successful in controlling scale formation at a TBT of 90.6°C and a dose rate of 0.8 PPM.

A trial test was conducted in Unit 6 of Al-Jubail Plant-Phase II at a top brine temperature (TBT) of 98°C and a dose rate of 0.8 ppm of polymaleic acid-based antiscalant for a period of 394 days [17]. Thermal performance and chemical assessment of the unit showed that the operation during the test period was smooth and steady. The fouling factors of both brine heater and heat recovery section were found well below the corresponding design values. Monitoring of loss of total alkalinity (LTA) indicated no scale deposition. Post-test visual inspection of the distiller revealed that the brine heater, flash chamber and water boxes were in good condition and there was no adverse effect due to the low dose rate of antiscalant. It has thus been concluded that the polymaleic acid-based antiscalant was quite effective and successful in controlling scale formation at a TBT of 98°C and a dose rate of 0.8 ppm during a test period of 394 days.

A comprehensive study was carried out [16] for the direct comparison of the performances and effectiveness of three of the most widely used antiscalants by SWCC, which included a maleic acid based copolymer antiscalant (1), a maleic acid based copolymer antiscalant (2) and phosphonate based antiscalant (3). The comparative study was performed in anMSF pilot plant under very harsh operating conditions. For each of the three antiscalants, the MSF pilot plant was operated at a TBT of 119°C, dose rate of 1 ppm and brine recycle concentration factor of 1.9 for a one month period. A base-line test was performed under the same TBT and concentration factor and without the use of any antiscalant. The rate of increase of brine heater fouling factor with time was observed and quantified using regression analysis. The test results revealed that the three examined antiscalants were quite effective in suppressing scale formation under the very harsh selected operating conditions. However, antiscalant a maleic acid based copolymer antiscalant (2) was the best performing material followed by a maleic acid based copolymer antiscalant (1) and phosphonate based antiscalant (3)), respectively. Because of the excellent scale control effectiveness of the three examined chemical additives under the MSF pilot plant harsh operating conditions, it is recommended to reconsider the current scale control operating conditions of commercial MSF plants especially with regard to the optimization of antiscalant dose rate as well as brine concentration factor.

As shown in figure 1, the optimization tests, which were carried out by SWCC, resulted in reduction of antiscalant dose rates from 3.0 ppm as recommended by the plant manufacturers in 1983 to 0.8 ppm at TBT of 90°C and from 9 to 2.0 ppm at TBT of 110°C.

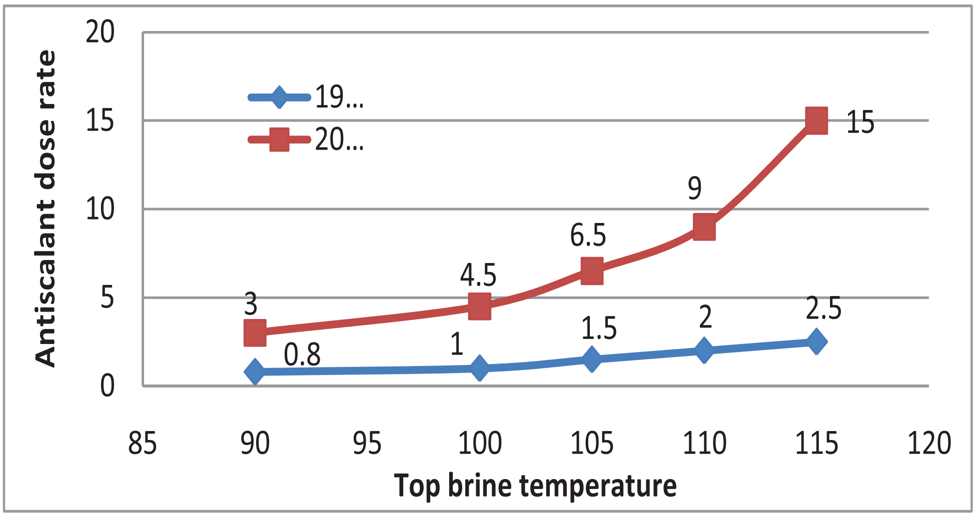

Figure 1: Achievements of SWCC in controlling alkaline scale formation

Scale Control and On-load Sponge Ball Cleaning

Although, the formation of scale is combated and controlled by threshold treatment with the use of antiscalant, its complete prevention is impracticable. Sludge or distorted scale is also formed as a result of threshold treatment deposited on tube metallic surfaces and induce resistance to heat transfer. The combined use of chemical additives and on-line tube cleaning has been proved to be the most cost effective means to combat scale formation and to avoid acid cleaning [20-22].

All SWCC MSF plants are employing on-load sponge ball cleaning. The chemical treatment, ball to tube ratio and frequency of cleaning in different MSF plants are shown in Table 1. The ball to tube ratio for plants using chemical additive treatment varies from as low as 0.22 in Al-Shuqaiq up to about 0.45 in Al Jubail Phase I and Al-Khobar plants with average frequency of three ball cleaning operations per day for all plants. The ball to tube ratio in SWCC MSF plants, thus in most cases, lie within the reported accepted range [20, 21]. Larger number of ball to tube ratio may cause problems by several balls passing one tube simultaneously and getting stuck while smaller ratio is notcapable to reach all tubes [22]. The wide variation of ball to tube ratio reveals that ball cleaning operation is not yet well established. This can be attributed to its dependence on many interacting operating and design factors such as brine chemistry, type of inhibitor and control regime, ball type and MSF design parameters such as temperatures, number of stages and tube length, flow pattern and arrangement of ball injection points.

Table 1: On-load sponge ball cleaning

S. No.	Plant	Chemical Treatment	Ball/ Tube Ratio		Frequency of Ball Cleaning Operation	No. of cycles per operation
			BH	HRC		
1	Al-Jubail Ph. I	Antiscalant	0.450	0.427	3 Oper. / Day	8 Cycles / Oper.
2	Al-Jubail Ph. II					
	C2 & C3	Antiscalant	0.342	0.324	3 Oper. / Day	8 Cycles / Oper.
	C4	Antiscalant	0.270	0.257	3 Oper. / Day	8 Cycles / Oper.
	C5	Antiscalant	0.300	0.302	3 Oper. / Day	8 Cycles / Oper.
3	Jeddah Ph II	Acid	0.296	0.236	One/week	3 cycle/oper
4	Jeddah Ph III	Antiscalant	0.29	0.665	3 Oper. / Day	4 Cycles / Oper.
5	Jeddah Ph IV	Antiscalant	0.251	0.370	2 Oper./ Week	10 Cycles / Oper.

6	Al-Khobar II	Antiscalant	0.453	0.458	3 Oper. / Day	9 Cycles / Oper.
7	Yanbu I	Antiscalant	0.243	0.249	3 Oper. / Day	12 Cycles / Oper.
		Acid	0.243	0.249	One Oper./ week	12 Cycles / Oper.
8	Al-Shuqaiq	Antiscalant	0.22	0.22	3 Oper/ Day	8 Cycles / Oper. (16 for high TBT)
9	Al-Shoaiba I	Antiscalant	0.251	0.253	3 Oper/ Day	3 Cycles / Oper.
10	Al-Khafji	Antiscalant	0.351	0.351	One Oper/ Day	9 Cycles / Oper.

Interruption of Antiscalant Dosing or Circulation of Cleaning Balls

Commercial MSF desalination plants sometimes experience interruption of antiscalant dosing or circulation of cleaning balls. Either the interruption may be due to sudden system failure or the system is needed to be isolated for maintenance works. In such circumstances, commercial plants normally adopt certain operating procedures to counter the consequences of mal-operation of antiscalant dosing or cleaning balls systems.

The corrective measures that are normally adopted by SWCC MSF plants to mitigate the consequences of malfunctions of the antiscalant dose or the on-line ball cleaning systems are varying [18, 19]. Generally, there are three different approaches normally followed by SWCC MSF plants to counter the interruption and failure of antiscalant dosing system. Al-Khafji, Shoaiba and Yanbu plants generally resort to shut down the distiller immediately or employ cold circulation mode. The second group of plants, which include Al-Jubail, Al-Khobar and Shuqaiq, utilize continuous circulation of cleaning balls and reduce the top brine temperature to less than 90°C. Jeddah plants, which represent the third approach, normally use the standby acid dosing system when the antiscalant dosing system is malfunctioned.

An evaluation study was carried out to determine the impact of interruption of antiscalant dosing at Al-Khobar Phase-II plant. The evaluation test revealed that it is quite safe to operate the MSF distiller without antiscalant dosing for a maximum period of 3 hours [18].

The remedial actions, which are normally followed by SWCC MSF plant when the ball cleaning system is inoperative, are also quite different. Al-Jubail plant prefers to solely increase the antiscalant dose rate by 50 per cent. Other plants favor the increase of antiscalant dose rate coupled either with the increase of the make-up flow such as Al-Khobar or Al-Khafji plants or with the reduction of the distiller production load as normally practiced in Yanbu plant. Jeddah plants can tolerate operation without ball cleaning for a maximum period of one month when using phosphonate based antiscalant and six months with the use of polycarboxylate based antiscalant.

Economic Impact of Effective and Optimized MSF Scale Control

The extensive series of optimization tests which were carried out in various SWCC plants resulted in a substantial decrease in the antiscalant dosing rates, which, in turn, reduced the operational costs of the desalination plants. The tests resulted in reduction of antiscalant dosing rates from 1.0 to 0.8 ppm at TBT of 90 °C and from 2.5 to 1.8 ppm at TBT of 110 °C.For example, the annual savings due to the reduction of antiscalant dose rate to 0.8 ppm at top brine temperatures of 90 and 98°C in Al-Jubail Phase-I & II MSF desalination plants are around 4.5 million Saudi Riyals (SR). For Jeddah distillers, which operate at TBT of around 110°C, a reduction in the dose rate to 1.8 ppm at the Jeddah IV plant and 2.5 ppm at the Jeddah III plant resulted in annual savings of more than 1.5 million SR. The total annual savings due to the reduction of antiscalant dose rates in SWCC MSF plants amount to more than 12 million SR.

As a result of limited operational experience and lack of confidence,it has been observed that high design fouling factors were initially selected for MSF plants which were built two or three decades back. The design fouling factors (FF) of the brine heaters and heat recovery sections for additive plants range between 0.176 and 0.325 m^2K/kW. However, due to the good performance of antiscalants in conjunction with the effective use of sponge ball cleaning, these FF values are very conservative (larger than required). Selection of large fouling factors results in the design of heat exchangers containing more surface area than required. Low values of design fouling factors such as 0.15 m^2K/kW, or even lower can be safely employed in new additive MSF designs [15].

However, selection of high design fouling factors for the existing MSF plants resulted in over-sizing of the heat transfer surfaces. This will allow these plants to operate at a top brine temperature equal to or even higher than maximum design values. The result is an increase in water production.

Potential of Development of Non-alkaline Scale Control

$CaSO_4$ formation is primarily controlled, so far in commercial plants, by operating at top brine temperatures (TBT) lower than its appreciable precipitation limits, i.e., TBT <120°C in view of the raised salt concentration in MSF brine recycle stream.The Saline Water Desalination Research Institute (SWDRI) of Saline Water Conversion Corporation (SWCC) of Saudi Arabia recently introduced a promising approach for pretreatment of seawater using nanofiltration membrane [23-33]. Chemical analysis of the NF membrane permeate showed that the total hardness as $CaCO_3$ in seawater is reduced from 7857 ppm to 510 ppm, sulphate ions from 3400 to less than 1ppm and the bicarbonate ions which were initially reduced by acid addition from 158 to 123 ppm to protect the NF membranes, were reduced further by NF membrane to 35 ppm.The pretreated seawater can thus be used as make-up to MSF and will subsequently offer a viable alternative to escape from the top brine temperature limitation. Removing calcium, magnesium, bicarbonate and sulphate ions from the raw seawater by nanofiltration opens the possibility to safely increase TBT of MSF distiller above 120°C. Increase of top brine temperature of MSF plants will result in the decrease of specific thermal and electrical energy consumption as well reduce the required specific heat transfer area and will subsequently reduce unit water production cost [27,30,31].

Extensive experimental tests were carried out on a pilot plant scale to explore the potential of using nanofiltration pretreatment to the MSF process.[32,33]. The MSF was first operated within the context of the dihybrid NF/MSF configuration at TBT up to130°C, which is the design TBT limit of the MSF pilot plant [32]. The thermal performance of the unit during an operational period of 50 days was smooth and the fouling factor (FF) of the brine heater was steady and well below the design FF. The product recovery of the MSF unit was increased up to 73 percent as compared to only 40 percent at TBT of 90°C when the make-up feed consisted of seawater without NF pretreatment [32]. Post-test visual inspection revealed that the brine heater was in a very clean condition and there was no sign of scale or sludge deposition on the heat exchanger surfaces. Chemical analysis revealed that the concentration of sulfate and calcium ions in the brine recycle were well below the solubility limit of calcium sulfate salt. It has been concluded that the MSF pilot plant can be operated safely and without any scaling problems up to a top brine temperature of 130°C with a make-up which is formed from nanofiltration product.

Extensive experimental studies were also conducted when the MSF pilot plant was operated within the context of the tri-hybrid NF/RO/MSF configurations shown in Fig. 2 [33]. The system was configured in such a way that the NF unit received seawater feed from the heat rejection of the MSF pilot plant and was able to operate at a fairly constant temperature of about 33°C which produced NF permeate (NFP) at a recovery ratio of about 64 percent. The SWRO unit which received the NFP as a feed yielded a permeate recovery of about 47 percent. Average chemical analysis of the RO reject (ROR) revealed that the sulphate and calcium concentrations were only 124 and 281 ppm, respectively, and was subsequently used as a make-up to the MSF pilot plant. The very low concentration of the sulphate and calcium ions in the brine recycle which were below the saturation limits enabled to operate the MSF unit safely up to a top brine temperature of 130°C (unit temperature design limit) and water recovery ratio of about 69%.

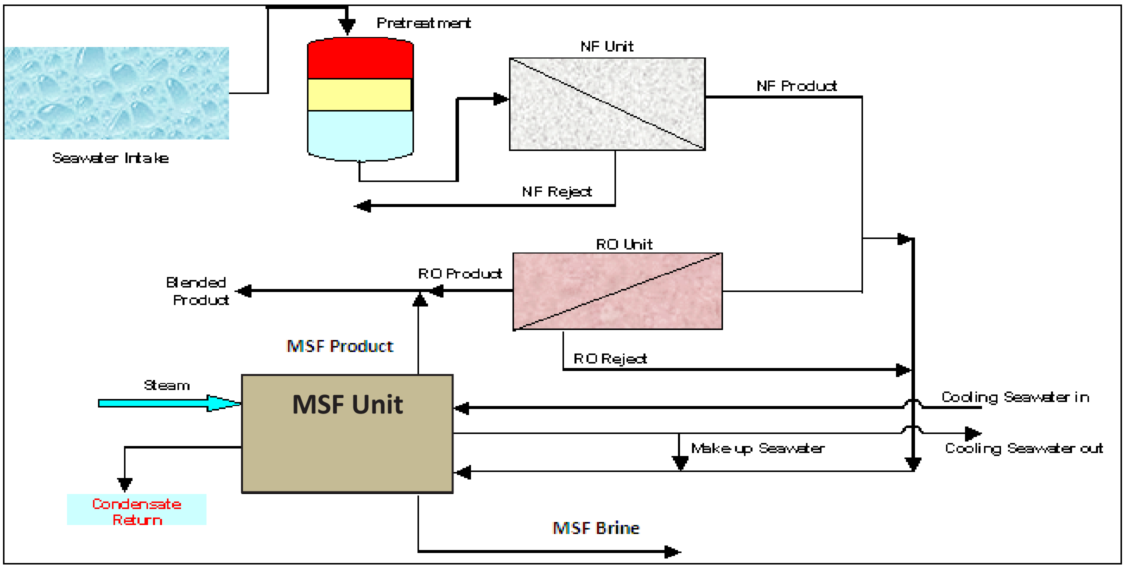

Figure 2: Schematic diagram of the tri-hybrid NF/RO/MSF desalination system

Based on the pilot plant experimental results, the economic viability of operating at the MSF unit at elevated TBT reaching 130ºC within the context of dihybrid NF/MSF or trihybrid NF/RO/MSF configuration, was examined.Figure 3 shows the impact of energy cost in $/bbl oil equivalent on the water production cost for three different cases:

Case-1: MSF plant operating at TBT of 110ºC with conventional scale control additives.

Case-2: MSF unit operating at TBT of 130ºC within the context of dihybrid NF/MSF configuration.

Case-3: MSF unit operating at TBT of 130ºC within the context of trihybrid NF/RO/MSF configuration.

Figure 3 shows the trihybrid NF/RO/MSF configuration is consistently yielding low water production cost compared to dihybrid NF/MSF and conventional MSF process. The percentage reduction in water production cost of the trihybrid NF/RO/MSF system compared to single MSF unit ranges from 24 to 63% as the energy cost is varied from $12/bbl to $100/bbl. Meanwhile, the percentage reduction of water production cost of the dihybrid NF/MSF system ranges between 12 to 30% for the same range of energy cost.

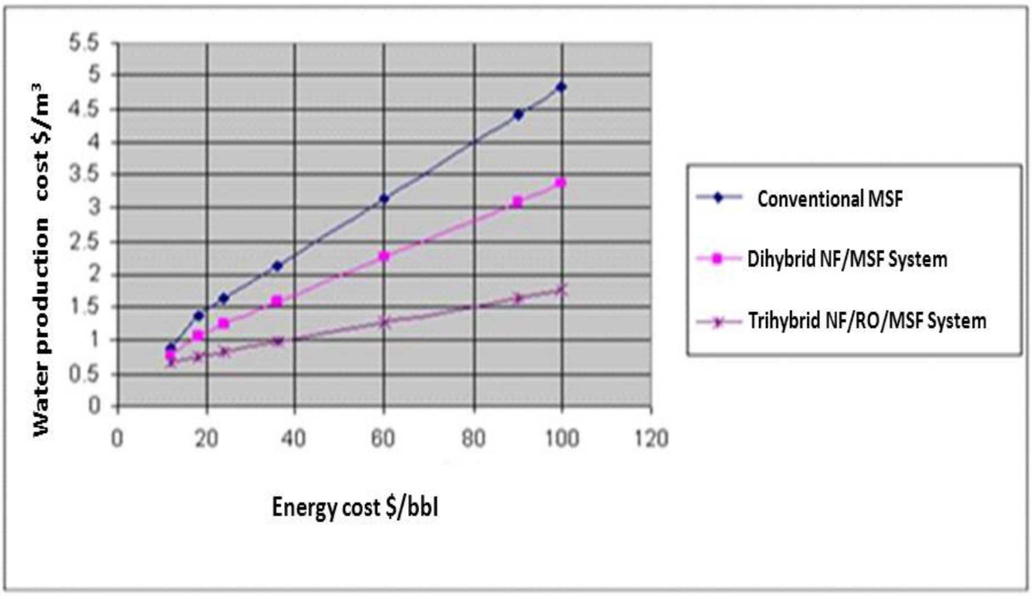

Figure 3: The impact of energy cost on water production cost

Concluding Remarks

1. MSF desalination plants are currently employing high temperature inorganic or organic polymers compounds rather than acid treatment to control the formation of alkaline scale.Antiscalant dose rates are reduced to as low as 2.0 and 0.8 ppm for top brine temperature of 110 and 90°C, respectively.

2. **In combination with chemical additives, MSF plants are employing on-load ball tube cleaning with a ball to tube ratio in the range of 0.22 to 0.45 to combat scale formation.**

3. As a result of effective additive scale control, design fouling factors less than 0.15 m^2K/kW can be safely employed in new additive MSF designs.

4. The various corrective measures that are normally adopted by MSF plants to mitigate the consequences of malfunctions of the antiscalant dose or the on-line ball cleaning systems are reviewed

5. Nano-filtration pretreatment is a promising approach to control non-alkaline scale control in MSF desalination process and enhance its techno economic viability.

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Modified Date Palm Leaflets for the Treatment of Brackish Water

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Abstract: Recently, the ground water of the coastal wilayat of Al-Batinah North and South governorates showed considerable levels of salinity in the range between brackish and saline water affecting, adversely, the agricultural farm areas in those coastal regions. The analysis of ground water from selected wells in the eight coastal Wilayat in Al-Batinah North and South governorates showed elevated levels of Mg, Ca and Na, however with low levels of K, Cr, Zn and Fe. The selected farm well from Al-Khabora showed the highest level of total dissolved solids (TDS) exceeding 15,000 mg/L, however, the selected farm well from Sohar showed the lowest TDS level. Omani date palm leaflets as an agricultural waste were converted to dehydrated carbon (DC) at 200 ^{o}C using sulfuric acid treatment. Produced DC was further sulfonated at 70 ^{o}C producing sulfonated dehydrated carbon (SDC). Carbons prepared were characterized for surface area, surface functional group, cation exchange capacity and pHzpc. The carbons were tested for the removal of the metals from the brackish water. Equilibrium was obtained within almost two hours. The results showed that SDC showed better performance for metal removal from brackish water, particularly for Na than DC. The extent of sulfonic groups acts as a strong cationic exchanger for the immobilization of Na. The carbons were recycled for four times without losing its metal removal capability. Column studies were also carried out. Dehydrated sulfonated carbons showed promising results and can be introduced as a cheap, sustainable and recyclable ion exchanger for removal of metals from brackish water.

Keywords: Sulfonated , dehydrated, carbon, brackish, water, desalination.

Introduction

Irrigation water is classified according to its salinity to seawater with TDS more than 15000 mg/L, brackish water with TDS ranging between 1000-15000 mg/L and fresh water with TDS less than 500 mg/L (El-Manharawy and Hafez 2001). According to the guideline of irrigation water provided by Food and Agriculture Organization (FAO, 2014), the usual ranges of sodium, calcium and magnesium in irrigation water are 0-920 mg/L ,0-400 mg/L and 0-60 mg/L, respectively. In the Sultanate of Oman, there are a total of 167,000 wells and 3,045 aflaj used for irrigation distributed in different places (Omezzine *et al.*, 1998). However, these water sources are limited due to the extensive usage of water for both agriculture and industry. Over-pumping of groundwater has led to seawater intrusion which was noticed since 1970s (Walter *et al.*, 2012) and, therefore, the groundwater are becoming saline. The degradation of ground water quality is an expected problem in the coastal aquifers as a result of different natural processes including saline water intrusion, wind driven sea spray and marine aerosols deposited on the topsoil (Rajmohan and Al-Futaisi, 2009). The groundwater over-pumping is a global problem especially in the arid or semi-arid regions like Oman. The coastal areas of Oman are the most affected area from that extensive pumping which leads to seawater intrusion and degradation of water sources (Zekri, 2009). It affects the quality of the groundwater by making it more saline and therefore not suitable for drinking and, even for agriculture, in severe conditions.

Salinity of soil is considered to be a major threat to crop production. It affects vegetation on vegetation at all stages of growth including germination, seeding, vegetative and mature stages as a result of osmotic effects (dehydration), ion toxicity and nutrition imbalance (Dong, 2012). High concentrations of salts in soil decrease the infiltration and percolation rates leading to water deficiency and limiting the growth of plants (Leone *et al.*, 2007). There are different types of salts that accumulate in the saline soil, however Na salts are the most dominant which cause osmotic stress to most plants species. The presence of Na at elevated concentrations interferes with K metabolism which is an essential element to plants growth and restricts its intake by the plants through the outer surface of the roots (plasma membrane) (Kopittke, 2012). The presence of burnt leaf and dead tissue in the plant is an indication of the presence of Na toxicity. In addition, both Mg and Ca salts in the soil cause adverse effects in the plants and may induce specific salts toxicity if they accumulate in the soil to toxic levels. High concentration of Mg blocks the K channels in the chloroplast leading to deactivation of enzymes which is important in carbon fixation process. This in turn, leads to formation of free radicals that cause oxidation damage (Kopittke, 2012). Oman is one of the countries that are extremely affected by soil salinity. This problem began in the 1990_s as a result of the extensive water withdrawn from the aquifers to an extent of causing seawater intrusion (Naifer *et al.*, 2011). The survey data of the agricultural lands in Oman showed that the total affected areas form the salinity are about 44.18 %, in which 11.2 % are cultivated lands while 88.8 % are lands that are not suitable for agriculture. The cost of the crops loss was estimated to be about 49.04 m$ out of which loss was 4.46 m$ from the losses of the date palm orchards (Hussain *et al.*, 2006). The decline in the crops production is a matter of great concern as it, negatively, affects the agriculture sector and matters on the job creation and the income of the country. In addition, it has social impacts since families gather in the farms during harvesting period especially in the harvesting of date palms.

Methods of removal of metals from saline water include basically thermal and membrane technology methods. Thermal desalination methods are costive as they are energy consuming (Khawajia *et al.*, 2008). Membrane technology methods that include reverse osmosis and electrodialysis are widely used for desalination, however, in addition of being energy consuming, they produce large amount of metal concentrated water. In addition, membrane fouling is a great challenge due to the presence of suspended organic matter and organic substances in brackish or saline water in addition to mineral scale formation (Greenlee *et al.*, 2009).

Date palm (*Phoenix dactylifera* L.) is the most important crop in Oman and the Arabian Peninsula. Date palm trees occupy ~ 49 % of cultivated area and 82 % of all fruit crops grown in the country (Handoo & Livingston, 2005). There are roughly eight million date palm trees in the Sultanate of Oman (Al-Yahyai & Al-Khanjari, 2008). ~180,000 and ~ 3 million tons of palm leaflets, as agricultural waste, are produced annually in Oman and the Gulf States, respectively (El-Shafey *et al.*, 2012). Burning in the field is a common practice that poses environmental air pollution. In this paper, dehydrated carbon (DC) was prepared from date palm leaflets via sulfuric acid oxidative dehydration. DC was transformed to sulfonated dehydrated carbon (SDC). Both carbons were investigated for the removal of metals from brackish water from Al-Batina North and South Governorates.

Methods

1. Brackish Water Sample Collection and Analysis

Brackish water samples were collected from different farm wells in the coastal areas of Al- Batinah North and South governorates (Table 1) in March 2013. 10 litres vessels were washed several times with the farm well water before it was filled completely and then closed well and transferred to the laboratory for water analysis. TDS was determined using a YSI Professional Plus (USA) and the water pH was analysed using a calibrated pH meter. Atomic absorption spectrometer (Varian/SpectraAA/220FS, Australia) was used for the analysis of Mg concentrations at a wavelength (λ) of 202.6 nm and slit width 1.0 nm using acetylene as fuel and oxygen as oxidant under oxidizing flame conditions. Na and Ca concentrations were analysed using flame photometer (Gallenhamp, USA). Samples collected for metal analysis were acidified using nitric acid. Brackish water from Sohar and Al Khabora farm wells were selected for the removal study of Mg, Ca and Na cations using DC and SDC. The brackish water used in the removal study was used as received without acidification.

Table 1 : Water quality parameters in brackish water from different wells in Al Batinah North and South

Water Source	Well Location	Conductivity (μS/cm)	TDS (mg /L)		Metal concentration (mg/L)		
				pH	Mg	Ca	Na
Barka	23.935 °N, 58.619 °E	11455	7767.5	7.27	1687	966	1302
Al Musanah	23.788 °N, 57.515 °E	1878	1254	7.46	379	88.4	393
Al Suwaiq	23.504 °N, 57.250 °E	12007	8183.5	7.78	1626	525	2334
Al Khabora	23.991 °N, 57.090 °E	28739	19506	7.83	1852	1546	7863
Saham	24.136 °N, 56.884 °E	2139	1449.5	7.51	588	27.6	614
Sohar	24.278 °N, 56.799 °E	1195	819	8.29	350	27.0	270
Liwa	24.559 °N, 56.565 °E	22866	15535	7.33	1859	1104	3323
Shinas	24.806 °N, 56.426 °E	1478	1001	8.14	464	27.6	295

2. Carbon Preparation

Date palm leaflets were collected from a local farm in Muscat. The leaflets were washed several times with distilled water to remove dust and surface impurities. The leaflets were put in trays and left to dry in open air at room temperature. ~ 20 g of clean air-dried palm leaflets were mixed with 180 mL of 2.2 M sulfuric acid. The mixture was heated to 200 °C till dryness. The black product was allowed to cool at room temperature, and then filtered using a Buchner funnel under vacuum. The carbonized material was washed several times with distilled water to remove residual acid until the wash water did not show a change in methyl orange indicator colour. The acid free dehydrated carbon (DC) was allowed to dry at 120 ^{o}C for 4 hours in an oven, transferred to a desiccator to cool, stored in a dry, clean and well closed polyethylene jar. 12 g of DC was mixed with 300 mL of 0.4 M sodium sulfite and the mixture was adjusted to pH 3 using 1 M HNO_3. The mixture were stirred and kept at 70 ^{o}C in the oven for 24 hours. The mixture was then filtered under vacuum using Buchner funnel and washed several times with 2 M HCl, to release adsorbed sodium cations, followed by washing with distilled water to remove residual acid. The acid-free sulfonated dehydrated carbon (SDC) was allowed to dry at 120 ^{o}C for 4 hours.

3. Carbon Characterization

The surface area of carbons was determined by nitrogen adsorption at 77K using Autosorb-1, Quantachrome Instruments (Quantachrome Instruments, USA). CEC was analysed using a standard method (Thorpe, 1973). pH_{zpc} was determined following the method of Moreno-Castilla *et al.* (2000). Sulfur and oxygen contents were analysed using Joel/O JSM 5600 energy dispersive spectrometer, EDS, (Joel, Japan). Infrared spectra were obtained using FT-IR spectrometer (Spectrun BX, Berkin Elmer, Germany). The carbon samples were dried in an oven at 120 ^{o}C overnight to remove any moisture retained from the atmosphere which could interfere with observation of hydroxyl groups on the surface. Pellets made of a mixture of 1.0 mg of activated carbon and 10 mg of KBr were pressed at high pressure. The pellet was scanned in transition mode using FT-IR spectrometer (spectrum BX, Berkin Elmer, Germany) through a wavelength range from 4000 to 400 cm^{-1} with background subtraction.

4. Removal of Mg, Ca and Na from Brackish Water

For the kinetic study, 1.2g of DC or SDC was mixed with 25 mL of brackish water from Sohar farm well at room temperature (22^{o}C) under continuous shaking (100 rpm/hr). At different periods of time, aliquots of supernatants were withdrawn and metals were analysed.

For the equilibrium study, the removal efficiency of metals was investigated via varying the amount of carbons (0.07 – 2 g) added to 25 mL of brackish water from sohar and Al Khabora farm wells. The mixtures were left under continuous shaking (100 rpm/hr) until the equilibrium was reached. Aliquots of supernatants were withdrawn and analysed for metal contents.

For carbon desorption and reuse, ~0.9 g of each carbon sorbents was transferred into polyethylene bottles containing 25 mL of brackish water collected from both of Sohar and Al Khabora farm wells. The samples were shaken continuously for 2 hours until the equilibrium was reached. Aliquots of supernatant were separated for analysis. The metal loaded carbons were filtered off using Watman filter paper and then washed with 0.1 M HNO_3 to remove loaded metals. The carbon was washed several times with pure water until residual acid is removed. The acid free carbon was transferred carefully into another polyethylene bottle containing 25 mL of the brackish water. This procedure of sorption desorption cycle was repeated four times. All experiments and analysis was carried out at least twice.

Results and Discussion

1. Farm Well Analysis

It is evident that Al Khabora farm well shows the highest concentration of Na, Ca, Mg and TDS, however, on the other hand, Sohar farm well, showed the lowest concentrations of metals and TDS (see table 1). Conductivity measurement supported these results with Al Khabora farm well analysis showing the highest conductivity value however Sohar farm well showed the least conductivity among selected wells. The metal analysis showed a variation in the metal concentration from one farm well to another, Table 1. Na was the highest in concentration in Al Musanah, Al Khabora, Al Suwaiq, Sahm and Liwa. However, Mg was found to be the highest in Barka, Sohar and Shinas. K metal was found to be in the range of 9.1-20.3 mg/L and oth; Fe (<0.45 mg L^{-1}), Zn (< 0.4 mg/L) and Cr (< 0.32 mg/L). The pH value was found to be slightly alkaline ranging between (7.27 – 8.29). Such variation in metal concentration is related to the different rate of ground water pumping from one place to another in addition to different hydrogeological reasons (Duribe *et al.*, 2007). Due to their presence in high concentrations in brackish water, Na, Ca and Mg were selected for the removal studies using DC and SDC from Date palm leaflets.

2. Carbon Characterization

pH_{zpc} and CEC were found to be 3.35 and 129 meq/100 g for DC and 2.54 and 200 meq/100 g for SDC, respectively, indicating that SDC surface is more acidic than DC surface. EDS analysis showed that the percentages of oxygen and sulfur were 34.2 and 1.32 for DC and 35.9 and 3.91 for SDC. The increase in oxygen and sulfur contents on SDC is related to the presence of sulfonic groups on its surface.

Surface area of DC and SDC were measured using nitrogen at 77 *K* and were found to be 3.6 and 1.7 m^2/g, respectively. Monolayer capacity and the BET-*C* constant were found to be 0.83 cm^3/g and 51 for DC and 0.39 and 89 for SDC, respectively. Similar low surface areas were reported earlier for dehydrated carbons prepared via sulfuric acid treatment from flax shive (19 m^2/g) (Cox *et al.*, 1999) and date palm leaflets (24 m^2/g) (El-Shafey *et al.*, 2012). Dehydrated carbons possess low surface areas due to the presence of high load of polar functional groups on its surface. The presence of carbon–oxygen species results in a decrease in the surface area as they occupy a large fraction of the adsorbent surface by oxidation (El-Shafey 2010). It is clear that surface area has decreased further after surface sulfonation due to the addition of sulfonic groups that occupy more space on the surface of the carbon.

FTIR spectra for DC and SDC are shown in Figure 1. The broad band at 3400 cm^{-1} for DC and SDC, respectively, are connected with (O-H) stretching vibrations. The shoulder around 2922 cm^{-1} for DC and SDC refers to stretching C-H vibrations in CH_2 groups. The small band at 1708 cm^{-1} in both carbons suggests the presence of stretching C=O vibrations arising from groups such as lactone and carboxylic acids. The intense band around 1612 cm^{-1} for both carbons may be due to the asymmetric and symmetric stretching COO^- vibrations or to skeletal C=C aromatic vibrations. The small band at 1382 cm^{-1} for SDC is related to the SO_2 asymmetric stretching vibration (Singare *et al.*, 2011) and_ENREF_103 such band is not available in DC spectrum. The various bands and shoulders from 1300 to 900 cm^{-1} for both carbons are variously ascribable to stretching C-O vibrations in hydroxyl groups and ether type structures.

The process of carbonization can be explained as follows. By mixing date palm leaflets with ~2 M sulfuric acid and heating at 200 °C an extent of hydrolysis to hemicelluloses takes place with swelling of the precursor material. As the water evaporates, the acid concentrates carbonizing the plant material via the removal of water from the cellulose and hemicellulose and causing partial oxidation to the carbonized material (El-Shafey *et al.*, 2014). DC produced is loaded with carbon-oxygen functional groups. DC produced, in this study; include lignin material within the dehydrated cellulosic network. Sulfonation at pH 3 has led to an extent of carbon sulfonation as shown from FTIR study.

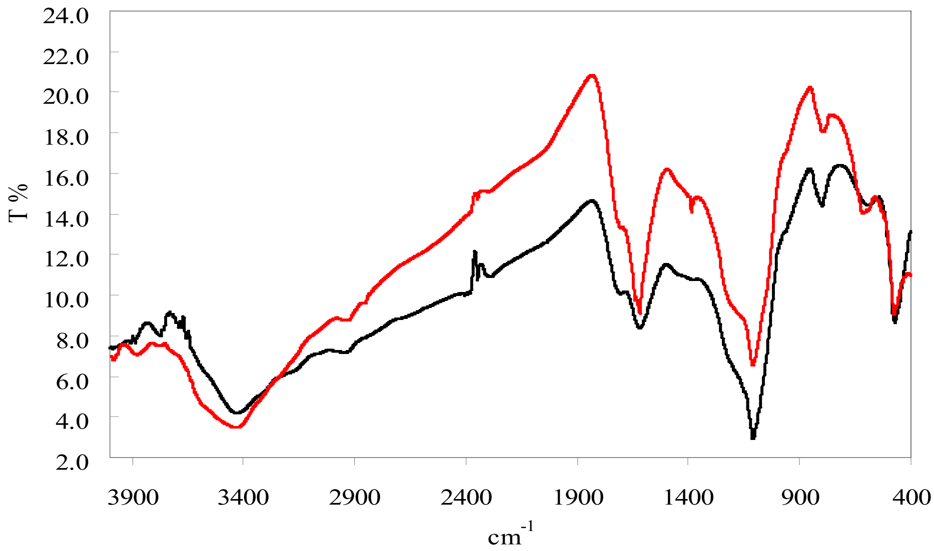


Figure 1: FTIR Spectra of DC and SDC

3. Kinetics of metal sorption from brackish water

Brackish water from Sohar farm well was selected for investigating the kinetics of removal of Na, Ca and Mg using both DC and SDC at room temperature (22 ^{o}C). Brackish water from Sohar farm well contains Na 270, Ca 27 and Mg 350 mg/L with initial pH of about 8.2. As Ca cations is very low in the brackish water, its removal was complete after a short period of time on both carbons (Figures 2). Mg shows the highest initial concentration and, thus, its removal percentage was less than that of Ca. Na cation sorption desorption behavior was also clear using the brackish water (Figure 2). Mg and Ca possess higher charge density than Na and, in addition, Mg is available in high concentration. Thus, Mg is expected to replace an extent of Na.

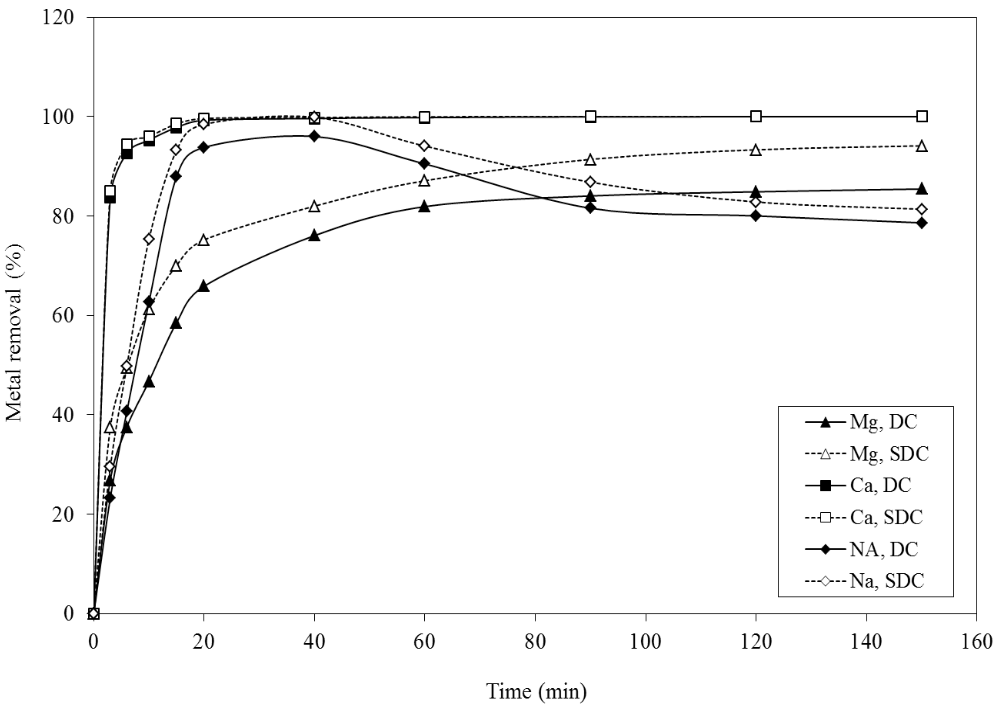


Figure 2. Removal of Na, Mg and Ca from Sohar brackish water at25^{o}C. (Initial Concentrations: Na: 270, Ca: 27 and Mg 350 mg/L)

Metal uptake was found to vary almost linearly with the half power of time, $t^{0.5}$, in the initial stages of sorption (equation 1). Similar results were found for different adsorbates applying equation 1 (Weber *et al*., 1963; El-Shafey & Al Hashmi, 2013).

$$q = k_d t^{0.5} \qquad (1)$$

where q indicates the metal sorbed (mg/g) and k_d is the rate constant of pore diffusion. Such behavior is predicted when a large initial fraction of the reaction is controlled by intra-particle diffusion (Weber *et al*., 1963). Values for k_d are presented in table 2.

Table 2. Pore diffusion and rate constants of pseudo second order models for the kinetics of metal sorption from brackish water (Sohar farm well).

Metal	Carbon	Pore diffusion constant k_d mg/g/ $min^{-0.5}$	Pseudo second order model			
			rate const k, g/mg/min	Initial adsorption rate, h, mg/g/min	capacity, q_e, mg/g	R^2
Na	DC	1.34	-	-	-	-
	SDC	1.57	-	-	-	-
Mg	DC	1.068	0.0210	0.854	6.382	0.9997
	SDC	1.191	0.0249	1.20	6.93	0.9998
Ca	DC	0.0691	4.458	1.393	0.559	1
	SDC	0.0717	5.829	1.829	0.560	1

The kinetic sorption data of the sorption of Mg and Ca were tested for the pseudo second order kinetic model (Ho, 2006), Equation 2, with high R^2 values. Na sorption data did not fit the model due to the sorption desorption behaviour.

$$t/q_t = 1/kq_e^2 + t/q_e \qquad (2)$$

Where k is the rate constant for the pseudo first order model and q_t (mg/g) is the sorbed amount of metal at time t. The initial sorption rate, $h = k_2 q_e^2$.

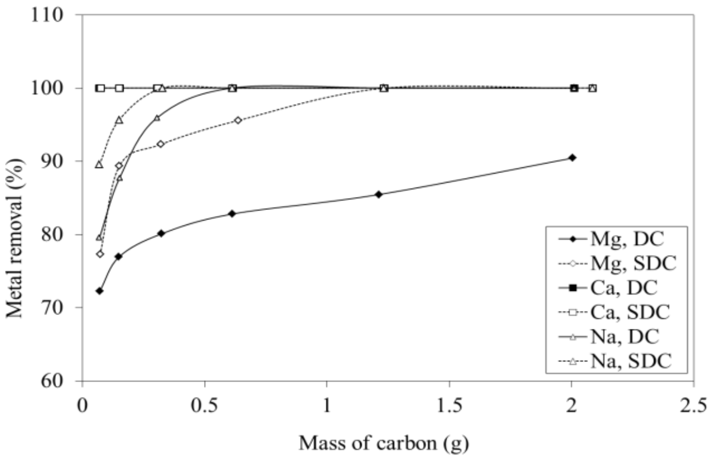
Values of k_d, k and h for the sorption of the different metal cations depends mostly on the type of carbon, metal cation and their concentrations. SDC shows higher values of k_d, k, h and q_e than DC (see, table 2). Higher initial concentration acts as a driving force for more sorption on the carbon surface illustrated by the higher q_e for Mg than that for Ca. The variation of k_d, k and h among these metals is mostly related to their hydrated sizes, charge densities and their different initial concentrations. Preliminary studies showed the presence of Cl^- and SO_4^{2-} as major anions in the brackish water. Mg or Ca cations could exist as ion pairs or as complexes with other ligand moieties in the brackish water (Rijck & Schrevens 1999). It is clear that the removal efficiency is about 100 % for Ca, 80-90 % for Mg and about 70-75 % for Na. The complete removal of Ca is because of its low concentration in the brackish water.

4. Effect of Sorbent Mass on the Removal of Mg, Ca and Na from Brackish Water

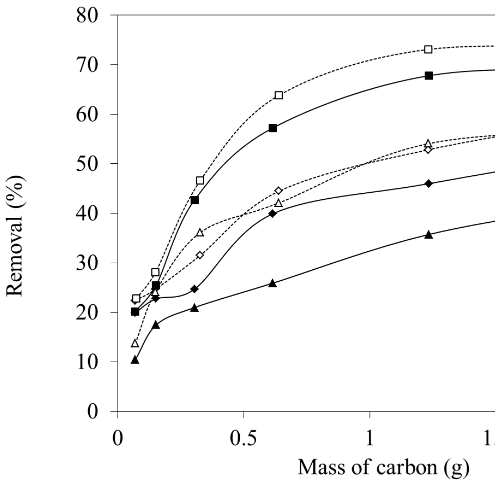
Brackish water from sohar and Al Khabora farm wells were selected to study the removal of metals. The effect of varying the carbon amount was studied and shown in figure 3(A & B). Metal removal percentage was calculated from equations 3.

$$\text{Removal (\%)} = (C_o - C_e) \times 100/C_o \qquad (3)$$

C_o and C_e are initial and equilibrium concentration of metals (mg/L), respectively. q_e is metal amount sorbed per gram of carbon (mg/g), V is volume of sorption solution (L) and m is the mass of carbon (g).



(A)



(B)

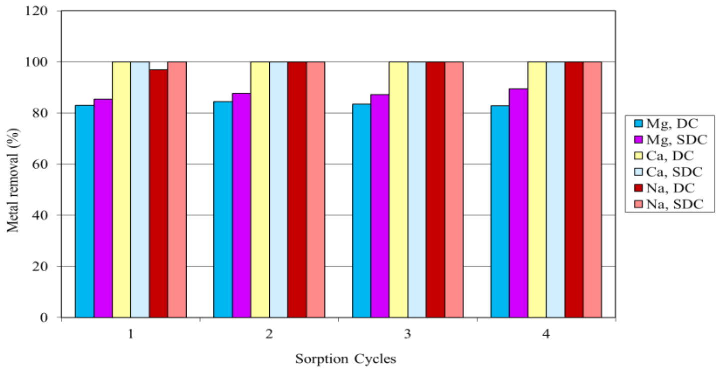
Figure 3: Effect of carbon mass on the removal of Na, Mg and Ca from (A) sohar and (B) Al Khabora brackish water.

Sohar and Al Khabora farm wells were selected for this study through varying the amount of carbons used. As shown in figure 3 (A & B), as the sorbent weight increases, the percentage of metal removal increases. Increasing the amount of sorbent has resulted in a more efficient removal of Na, Ca and Mg from aqueous solution. Similar behavior was found also to the brackish water from Al Khabora farm well, however, with less efficiency of metal removal than Sohar farm well because of the lower metal concentration in Sohar brackish water. Similar results were found for Cd^{2+} and Zn^{2+} sorption using different weights of activated carbon_ENREF_142 (Marzal *et al.*, 1996).

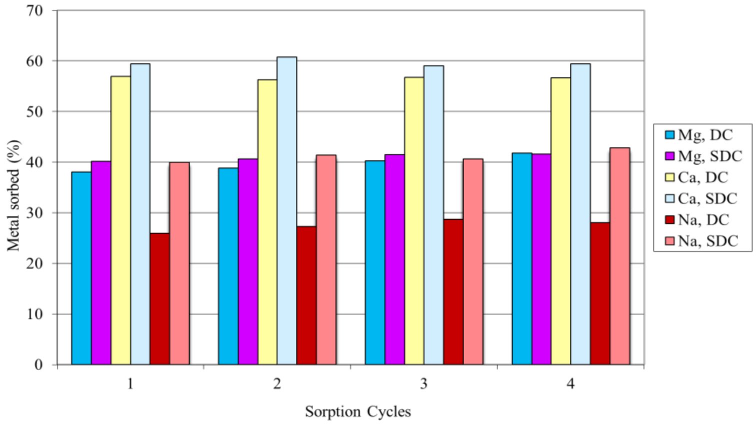
SDC shows better performance for the removal of Mg, Ca and Na than DC. The presence of the strong sulfonic group, $-SO_3H$, is more advantageous for Na removal. Eventhough the hydrated radius of Mg, Ca and Na is 47, 42 and 30 nm respectively, and charge densities of metal ions follow the order Mg> Ca > Na, the initial concentration acts as dominating factor. High initial concentration acts as a driving force for adsorbate towards the carbon surface.

Desorption and Recycle

Metal loaded carbons using brackish water from Sohar and Al Khabora farm wells were stripped using 0.1M nitric acid followed by deniozed water to remove the acidity and then reused in a new cycle of metal sorption. The process was repeated 4 cycles. Sorption of metals almost maintains its efficiency in both brackish water samples for the different metals. SDC showed higher removal efficiency for Na, Ca and Mg than DC. Removal efficiency reached about 100 % for Sohar brackish water because the metal content is much lower than that of Al-Khabora as shown in Figure 4 (A & B).



(A)



(B)

Figure 4: Sorption recycles of Na, Ca and Mg from(A) Sohar and (B) Al Khabora brackish water.

Conclusion

Brackish water showed high levels of Na, Ca, Mg in all samples. DC and SDC possess low surface area of 3.6 and 1.7 m^2 g, respectively, however, with high content of surface functional groups. SDC possess larger content of functional groups than DC as a result of sulfonation. The kinetic study showed that equilibrium was obtained within 2 hours showing that an extent of Na desorption was found as time proceeds because of exchange with Mg and Ca. SDC shows better performance for metal removal than DC specially for Na removal. The study showed that DC and SDC are promising alternatives for metal removal from brackish water as they are efficient, cheap, recyclable and sustainable in Oman.

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Development of Activated Carbon from Oil Fly Ash for Water and Wastewater Treatment Systems

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Abstract: Oil fly ash (OFA) is a by-product generated by the combustion of heavy fuel oil and crude oil. About 3-4 kg of OFA is produced by burning 1,000 liters of oil. Because power and desalination plants in the Gulf Countries use various types of fuels, including heavy fuel oil and crude oil, a significant amount of OFA is generated on a daily basis. The current OFA management practice is its disposal into landfills. A chemical analysis of OFA shows that it has a very high percentage of unburned carbon (80-90% by weight), with organic impurities and heavy metals such as vanadium, nickel, cadmium, zinc, magnesium, and iron. Therefore, its disposal without proper treatment may cause serious problems in the air during its transport to the disposal sites and the potential contamination of the soil and groundwater due to leaching from these landfills. In order to explore the benefits of OFA, our research team at Memorial University has been conducting research on it since 2007. We have analyzed several OFA samples from the Rabigh and Shoaibah power plants in the Kingdom of Saudi Arabia. These two plants generate more than 70 tons of OFA daily. This paper summarizes the physical and chemical characterization of OFA and the environmental issues that result from its current disposal into landfills. This paper also highlights economical methods of extracting carbon from OFA and the subsequent activation of the carbon to make a low-cost adsorbent to treat water and wastewater in order to remove polycyclic aromatic hydrocarbons (PAHs), total organic carbon, color and turbidity, naphthalene, chromium, and disinfection by-products. The research findings on treating wastewater and case studies on the development of a cost-effective and affordable filtration technology to supply safe drinking water in small communities are also presented.

Keywords: Activated carbon, Disinfection by-products, Drinking water, Filtration technology, Oil fly ash, Wastewater treatment.

Background Information

The burning of heavy fuel oil and crude oil yields about 3 kg of ash per kiloliter of fuel (Tsai and Tsai, 1997); most of the ash (approximately 90%), known as oil fly ash(OFA), passes through the flue gas steam, which is collected by electrostatic precipitators or cyclones (Hsieh and Tsai, 2003). A chemical analysis shows that OFA is composed mainly of unburned carbon, which accounts for about 70 to 80% by weight, depending on the fuel type and burning efficiency. OFA also contains a significant amount of heavy metals such as cadmium (Cd), copper (Cu), vanadium (V), nickel (Ni), iron (Fe), and magnesium (Mg) (Tsai and Tsai, 1997; Kwon *et al.,* 2005; Mofarrah, 2014). The bulk density of OFA varies from 0.24 to 1.50 g cm^{-3} and its true density and porosity are reported as 2.15 g cm^{-3} and 10.31% respectively (Kwon *et al.,* 2005; Mofarrah, 2014; Mofarrah and Husain, 2013).

Due to a growing trend in the use of heavy fuel oil and crude oil in power plants to meet growing energy demands, millions of tons of OFA are generated worldwide. It is anticipated that, due to limited fuel alternatives, OFA generation will continue to increase. Therefore, energy utility industries are concerned about the disposal of its produced OFA. The current practice is mainly disposal into landfills. Due to its low density (0.24-0.4 g cm^{-3}) and fine particle size, ranging from 5 micrometer (μm) to above 400 μm, it easily disperses into the air and is inhaled by the exposed population. Since this airborne dust is attached to metals and organic impurities, long-term exposure to high levels of airborne OFA can cause many types of illnesses and respiratory diseases.

The typical chemical composition of the OFA from the Rabigh and Shoaibah sites is listed in table 1 (Al-Malack *et al.,* 2013; Mofarrah, 2014). The nickel concentration in the Rabigh power plant OFA varies from 182 to 4,334 mg/kg and vanadium from 517 to 15,619 mg/kg. The nickel concentration in the Shoaibah desalination plant OFA is higher: it varies from 1,772 to 22,730 mg/kg and vanadium from 3,167 to 40,879 mg/kg. The values for nickel and vanadium in the OFA are comparable to those in the ores in mining industries. The Rabigh and Shoaibah OFA contains above 85% carbon by weight, which, if extracted, will significantly reduce the amount of OFA disposal in the landfill; this will not only reduce the cost of the disposal but it will also make the management of OFA economically feasible and environmentally safe and sustainable.

Table 1: *Metals in OFA from the Rabigh and Shoaibah Plants*

	Other Studies (mg/kg) (Al-Malack *et al.,* 2013)						Memorial Study (mg/kg) (Mofarrah, 2014)	
Elements	Rabigh Power Plant			Shoaibah Desalination Plant			Rabigh	Shoaibah
	mean	min	max	mean	min	max	mean	mean
Cr	37	12	64	113	64	169	5	11
Fe	72	277	20,225	8,771	3,527	17,909	862	2,282
Mg	6,971	2,584	12,622	94,608	42 ,159	175,353	403	4,355
Ni	2,382	741	4,334	13,633	6,760	22,730	182	1,772
Va	9,072	3,103	15,619	31,044	22,954	40,879	517	3,167
Zn	22	13	34	118	28	202	12	35

Current Disposal Practice and Environmental Concerns

The current practice for OFA disposal is mainly dumping it into a landfill. Very little OFA is being processed for the extraction of nickel and vanadium. Since OFA is composed of low-density fine particles which can travel long distances before settling on the land, it may contaminate the soil, water, and air. The inhalation of OFA particles may pose potential health risk, since they contain a high level of heavy metals. The current disposal of OFA into landfills has triggered in the rise of many environmental issues, including:

i. Air pollution: High particulate matter emission during transportation and dumping;
ii. Soil and water pollution: Effluent discharge from ash ponds or pollutants leaching from fly ash dumping sites; and
iii. Land use: Disposal of a large quantity of fly ash occupies thousands of hectares of valuable land.

Metal-borne particles can cause coughing, decreased lung function, bronchial irritation. gastrointestinal diseases, and skin and eye diseases. Particles of less than 10 μm can cause cardiovascular diseases (Comba *et al.,* 2006).

Cleaning of OFA and Activated Carbon Process

Activated carbon (AC) is a carbonaceous material which has a high porosity, suitable pore distribution, high mechanical strength, and a large internal surface area. The internal surface areas of commercial AC range from 500 to 1,500 m^2/g. The conventional method by which AC is manufactured is the pyrolysis of wood chips, bamboo fibers, coconut shells, petroleum coke, and bituminous coal at high temperatures, followed by controlled oxidation. The unit market price of AC depends on the availability and cost of these raw materials. As a result, the price of the AC in the marketplace varies widely. Both physical and chemical activation are used in the production of AC. Physical activation consists of pyrolysis of the carbonaceous matrix under an inert atmosphere, followed by the gasification of the resulting char in the presence of gases such as CO_2 or steam. The temperatures needed to achieve pyrolysis are normally in the range of 600 to 900°C. Chemical activation consists of pyrolysis of the precursor in the presence of chemical agents that are normally alkali and some acids. Figure 1 shows the steps in obtaining clean carbon from OFA, and its activation process. A detailed description of recovering clean carbon and its activation using both physical and chemical methods are discussed in Mofarrah (2014) and Mofarrah, Husain, and Danish (2012), Mofarrah, Husain, and Chen (2013), and Mofarrah, Husain, and Bottaro (2014).

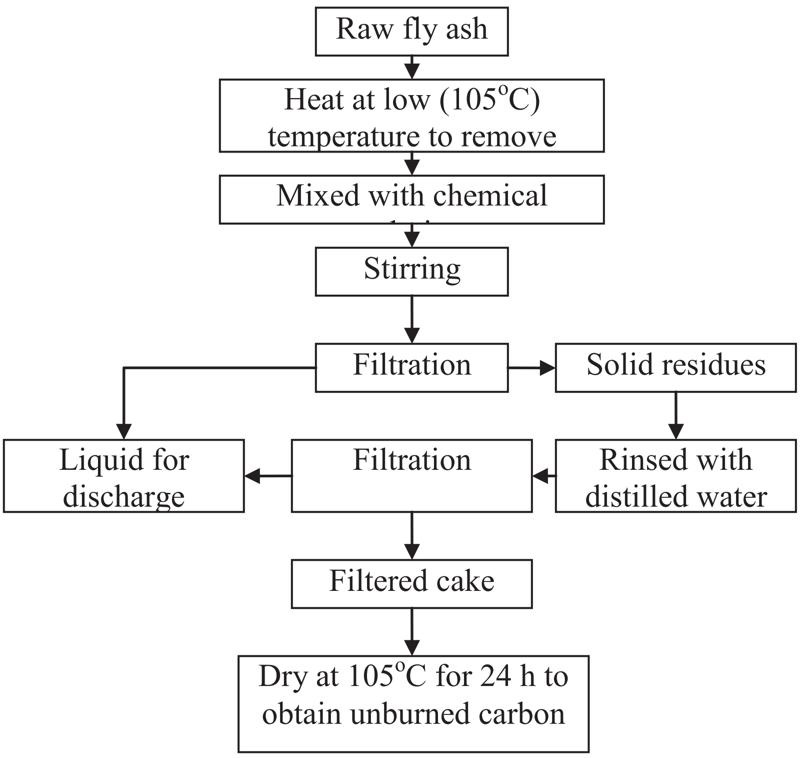
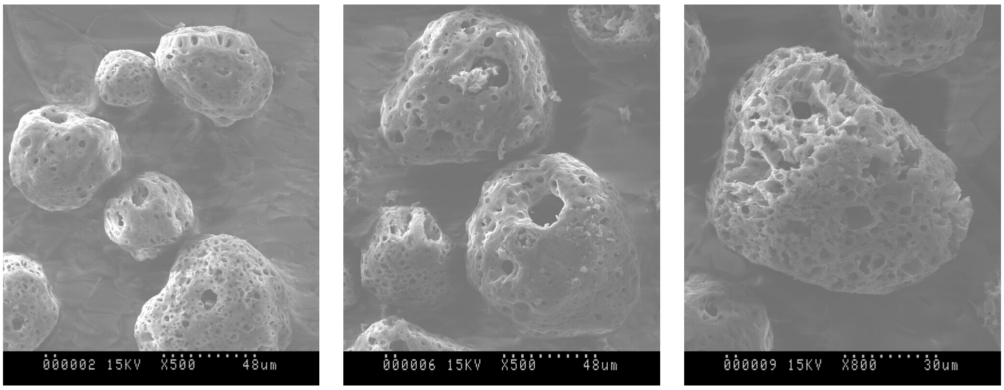


Figure 1: The Process of Recovering Unburned Carbon

A scanning electron microscope (SEM) micrograph (figure 2) shows the surface features of the particles at a high magnification: the spherical particles of the fly ash samples range in size from a few to several μm and are mostly porous in nature.



(a) (b) (c)

((a) *raw HOFA,* (b) *after washing,* (c) *after heating at 900°C*))

Figure 2: SEM analysis of dry samples

The pores were individually situated and randomly located on the particle surface. The washing and heating process increases the porous structures on the particles' surface. This is due to the removal of mineral matter from the carbon structures. A laser scattering particle size analyzer confirmed that the mean aerodynamic diameter of the collected fly ash sample is 53.5 μm with a standard deviation of 32.9 μm. Particle size is especially important in designing an adsorption technology. Smaller particles have more surface area and consequently are a better adsorbent. The particle size distribution of the fly ash is shown in figure 3.

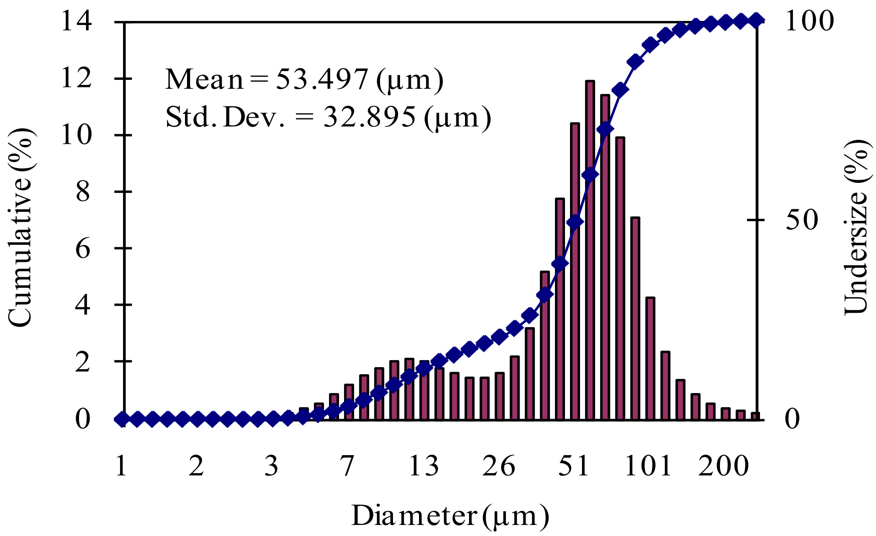


Figure 3: Particle Size Distribution of Fly Ash

The developed fly ash activated carbon was characterized, with respect to surface areas, using the procedure developed by Brunauer, Emmett, and Teller (BET, 1940). The Dubinin-Radushkevich (DR) method (Dubinin *et al.,* 1947) was used to calculate the micropore volume of the produced AC. The surface areas and micropore volumes were compared with those of other commercially available AC, as shown in table 2 (Mofarrah, 2014). Based on a comparative analysis, it can be concluded that OFA has the potential to be used as a raw material for AC. The study revealed that Saudi Arabian OFA can be used as an effective and inexpensive (since the OFA is very cheap at generation points) raw material for AC production, which has the potential to be used in various industrial applications, especially in the adsorption process for the removal of pollutants with large molecules, where a mesopore volume is required.

Table 2: Characteristics of Activated Carbon from Various Sources

Raw Material	Activation agent	BET (m2/g)	Total pore volume (cm3/g)	References
Plum kernels	NaOH	113	0.083	Tseng, 2007
Anthracite	NaOH	334	0.140	Lillo-Rodenas *et al.,* 2004
HOFA	NaOH	97.612	0.065	This study (Mofarrah, 2014)
HOFA	KOH	116.41	0.191	This study (Mofarrah, 2014)
HOFA	H3PO4	143.46	0.439	This study (Mofarrah, 2014)
HOFA	Physical activation	14.03	0.0221	This study (Mofarrah, 2014)
Lignite	KOH	1594	0.71	Lillo-Rodenas *et al.,* 2007
Coconut shells	KOH	1740	0.74	Lillo-Rodenas *et al.,* 2007

Application of AC in Wastewater Treatment Systems

Mofarrah (2014) investigated the possible utilization of AC developed from OFA as an adsorbent for the removal of methylene blue dye, chromium (Cr) V!, and naphthalene from wastewater systems and several studies were conducted. The results show that the removal efficiency of the dye is influenced by the adsorbent dose and the initial dye concentration. An adsorption equilibrium was reached at 120 minutes. Under the experimental conditions the maximum dye removed was about 21.28 mg/g.

Mofarrah and Husain (2012) studied the removal of Cr (VI) on the AC produced from OFA. Batch adsorption experiments were conducted to evaluate the effects of such parameters as initial Cr (VI) concentration, pH, and AC dose on the removal of Cr (VI) from an aqueous solution. A total of 17 adsorption experimental runs were carried out. The results indicate that developed AC has the potential to remove Cr (VI) from wastewater. Under test conditions, a maximum of 91.51% Cr (VI) removal efficiency was achieved.

In another study, Mofarrah and Husain (2014) investigated the adsorption of naphthalene from an aqueous solution on the AC prepared from OFA. The study showed that the removal efficiency of naphthalene increased with an increase of the adsorbent dose and initial concentration. The maximum naphthalene uptake on AC was greater than 85% (i.e., 20.2 mg/g) and 76% (i.e., 19.0 mg/g) respectively for FAC prepared with KOH and with NaOH. The present study showed that the FAC derived from OFA can be used as a low cost adsorbent for the removal of naphthalene from wastewater.

The Application of AC in Drinking-Water Systems

Chlorine is used as a disinfectant to eradicate pathogenic organisms in water but in the presence of natural organic matter (NOM) it forms disinfection by-products (DBPs). Long-term exposure to DBPs at a level above the regulatory limits is harmful to human health; and some DBPs are possible carcinogens or cause adverse reproductive or developmental effects in animals (Clifford *et al.,* 1999; Fearing *et al.,* 2004; WHO, 2004). Although approximately 500 DBPs have been reported in the literature (Richardson, 2003), the recent focus has been on two DBP groups, trihalomethanes (THMs) and haloacetic acids (HAAs), as these have been identified as the largest classes of DBPs detected on a weight basis in chlorinated drinking water. The maximum concentration level (MCL) as specified by Health Canada for total THMs (TTHMs) and five compounds within HAAs is 100 and 80 μg/l respectively (Health Canada, 2012). According to the United States Environmental Protection Agency (US EPA), the MCL for THM_4 and HAA_5 are 80 and 60 μg/l respectively (US EPA, 1998).

Most Canadian drinking-water systems use chlorine to ensure the destruction of potentially harmful pathogens in the water and to maintain a residual level between 0.4 mg/l and 2.0 mg/l in these distribution systems to prevent bacterial re-growth (Health Canada, 2012). In the Canadian province of Newfoundland and Labrador, 459 out of the 536 public water-supply systems use chlorine. The province, which began monitoring THMs and HAAs in 1998, found that 124 water systems have high levels of THMs and 184 have high levels of HAAs above the specified Canadian guidelines (Dept. Env. Cons., 2009).

To develop an affordable technology that will reduce DBPs in drinking-water systems, an AC filter was used as an adsorbent in the communities of Torbay, with 6,000 people, and Pouch Cove, with 1,800 people. Both of these communities are located near St. John's, as shown in Figure 4 (Ahmad, 2013).

Figure 4: Location of Pouch Cove and Torbay Communities

These communities use water from ponds which are chlorinated to eradicate pathogens before being supplied to the distribution systems. However, due to the presence of dissolved organic matter in the water, high levels of THMs and HAAs were found in the drinking water of these communities. An analysis of the drinking water by our research team found that in Torbay THMs were present in the range of 15 to 297 μg/l and in Pouch Cove 72 to 388 μg/l; Health Canada's MCL level is 100 μg/l. Similarly, the total HAAs in the Pouch Cove drinking water ranged from 235 to

451 μg/l and in Torbay 165 to 314 μg/l, while Health Canada's MCL level is 80 μg/l. An AC filter made from Rabigh OFA was very effective in removing these DBPs; the efficiency of removal ranged from 50 to 80%.

Since the provincial government's mandate is to supply safe drinking water in all communities, the preferred option for the regulatory agency is to remove the precursors before chlorination rather than providing filtering devices to each household. Keeping this in mind, column tests were conducted to remove the total organic carbon (TOC) from the intake water since the DBP formation is due mainly to the presence of NOM, usually measured as TOC. The best available technologies to reduce NOM as identified by US EPA (2003) are enhanced coagulation and AC. AC, due to its high ability to remove organic matter even at low concentrations, has been used in many water treatment plants, but due to its high cost, small communities cannot afford the conventional AC available in the marketplace.

For both Newfoundland communities water samples from the intake were analysed for pH, total organic carbon, turbidity, and UV (254 nm), and column tests were performed to determine the removal efficiency of TOC and dissolved matter. As shown in tables 3 and 4, extracted carbon from OFA shows promising results in reducing TOCs and other related parameters causing DBP formation (Ahmad, 2013). In the Pouch Cove system, a TOC level of 13.64 mg/l was reduced more than 70% by AC (Table 3).

Table 3: Intake Water Quality and TOC Reduction in Pouch Cove before and after Filtration

(Time (min	pH	(UV254 (nm	(Turbidity (NTU	(TOC (mg/l	.TOC Red %	C_o/C_i
Raw water quality	6.61	0.13	1.45	13.64	0	1
Filtered water 240	6.14	0.007	0.35	1.16	92	0.08
540	6.7	0.01	0.34	1.04	93	0.076
900	6.63	0.03	0.34	2.10	85	0.15
1620	6.43	0.01	0.36	5.7	58	0.41
2940	6.4	0.005	0.4	6.73	53	0.49
3720	6.51	0.01	0.38	4.90	64	0.35
4020	6.71	0.05	0.34	5.49	60	0.40
4440	6.72	0.005	0.33	5.64	50	0.41
5100	6.65	0.001	0.36	5.45	52	0.40
6000	6.72	0.001	0.35	6.84	39	0.50
7500	6.74	0.001	0.37	5.56	50	0.40

The TOC level in the Torbay water, as listed in table 4, was 5.4 mg/l; this was reduced to less than 3 mg/l by filtering the water with AC from the Rabigh OFA for several hours (Ahmad, 2013). There is also a considerable improvement in the turbidity reduction in the filtered water. UV254, a measure of UV absorption due to the presence of dissolved organic carbon, was reduced from 0.13 to 0.007; this indicates that the filter barrier can remove most of the organic carbon from the water. Once the filtered water was chlorinated, there was a significant reduction in the formation of THMs and HAAs in the drinking water (table 5) and much reduced DBP levels (Ahmad, 2013).

Table 4: Intake Water Quality and TOC Reduction in Torbay Water before and after Filtration

Time (min)	pH	UV254 (nm)	Turbidity (NTU)	TOC (mg/l)	% TOC Reduction	C_0/C_i
Raw water quality	6.23	0.02	0.59	5.41	0	1.00
After filtration 240	5.64	0.04	0.31	1.31	76	0.24
540	5.79	0.002	0.35	1.86	66	0.34
900	5.8	0.003	0.42	1.70	69	0.31
1560	5.76	0.04	0.43	1.83	66	0.18
2880	5.99	0.06	0.39	3.37	38	0.62
3600	6.01	0.042	0.33	2.37	56	0.43
3960	6.43	0.02	0.42	2.08	40	0.38
4200	6.51	0.009	0.35	2.57	55	0.47
4740	6.75	0.007	0.36	2.74	52	0.50
5700	6.74	0.13	0.37	2.87	49	0.53
7200	6.82	0.003	0.34	3.31	41	0.61

Table 5: THM and HAA Formation in Raw and Filtered Water with Various Contact Times after Chlorination

Contact time after chlorination in hours	Total THM in μg/l (MCL Health Canada = 100 μg/l)				Total HAA in μg/l (MCL Health Canada = 80 μg/l)			
	Torbay Intake		Pouch Cove Intake		Torbay Intake		Pouch Cove Intake	
	Raw Water	Filtered Water	Raw Water	Filtered Water	Raw Water	Filtered Water	Raw Water	Filtered Water
4	188	113	258	115	127	12	192	11
12	750	128	270	114			226	34
18	602	383	298	149				
24	744	434	281	158			232	40

Conclusions

The following conclusions are drawn from this study:

1. Carbon in the Saudi Arabian OFA can be used as an effective and inexpensive raw material for the removal of Cr, naphthalene, methylene blue, and organic compounds from industrial or municipal wastewater systems. It also has considerable potential to remove total and dissolved organic carbons, colour, and precursors forming DBPs in drinking-water systems.
2. Chemical activation and partial oxidation at a high temperature improves carbon qualities with high surface and pore volumes.

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Risk Assessment of Tropical Cyclone on Water Supply Systems

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Abstract: Drinking water utilities are exposed to both natural and manmade hazards that are common in Oman. Oman is subjected to tropical cyclone zone that can cause major damage to structures and infrastructure such as water utilities. In June, 2007, a severe category four cyclone, 'Gonu', hit the coastal area of Oman, with 213-232 km/h winds and heavy rainfall and surface run-off causing extensive flooding and substantial damage to critical infrastructure. Particularly severe damage was caused to the water systems. The hurricane left thousands without water service or low water pressure for almost a month. Risk assessment plays an important role in disaster mitigation as it provides the essential information for adopting optimum disaster prevention measures, and for developing effective warning system as well as evacuation and emergency plans. The main objective of the present research is to analysis and assesses the risks caused by tropical cyclone to water supply systems in Oman. The work focuses on the hazard (risk) assessment of Gonu cyclone to drinking water facilities and the emergency responses to repair and reconstruct damaged systems. The data analysis show that the burst of the mains, pump failure, and loss of supply from desalination plants causes a significant risks that will certainly need mitigation measures. The downstream storage and standby pumps are an important control measure. At the same time repairs should be completed to target times. The values of risks show that even after control measures the risks values remain the same, which means some potential solution has to be find and adopted to mitigate the effect of bursts in the pipelines or failures at pump stations and at the desalination plants. The following solutions can help to mitigate the effect of tropical cyclone maintain a basic supply to the population affected: maintain stocks of bottled water and the means to distribute them to affected areas; have reserve plans for tankering water to affected areas; interconnect large regional systems and provide necessary valves and bypass pipe work to allow water to be conveyed in the opposite direction to that it would travel under normal operations; and maintain well fields for emergency use.

Keywords: Risk Assessment, Tropical Cyclone, Gonu, Mitigation Measures, Hazard.

Introduction

Drinking water services are essential in ensuring the health and well-being of populations and as such fulfill an important role in the development process. Drinking water utilities are exposed to both natural and manmade hazards that are common in Oman. Hurricanes, floods, and drought are part of the wide variety of events that cause death, injury, and significant economic losses for the countries affected. The impact of these disasters on the water supply and sewerage systems has been considerable.

The Sultanate of Oman is situated on the northern Indian Ocean and the Arabian Sea, in a tropical cyclone zone. In June 5th 2007, Oman braces for one of the worst cyclonic storms ever to hit the country for many decades. Guno super-cyclone, packing wind speeds of around 220 kilometer per hour was bearing down on Oman's eastern seaboard causing landfall. The approaching storm had an unleashing heavy rainfall (more than 1000 mm in four days), gusting winds and tidal waves. 10-metre-high storm surge Masirah Island as well as Sharqiyah and Wusta coast causing immense damages. An impact of Guno cyclone on infrastructure particularly water facilities was severe. Drinking water was unavailable in some areas in Muscat for days due to interruption of desalination plants and broken water pipes which served the city. The hurricane left thousands without water service or lower water pressure for almost a month.

The Public Authority for Electricity and Water (PAEW) in cooperation with the Ministry of Defense (MOD) and the Royal Oman Police made their best efforts to restore water supply to the needy areas affected by the cyclone. New wells were dug in order to provide fresh water to the most remote isolated areas. Private Wells were made available to the public, while water tankers toured residential areas distributing water to the affected people. The ministry made the follow-up of the people ensuring the transport of water and taking harsh measures against those who exploited the circumstances.

In emergency or disaster situations water services are imperative for the rapid return to normalcy. The impact of a natural disaster can cause contamination of water, breaks in pipelines, damage to structures, water shortages, and collapse of the entire system. Depending on the level of preparedness that the water system authorities have adopted, repair of the system can take days, weeks, and even months. The risk of damage to water systems in disaster situations dramatically increases with factors such as uncontrolled growth in urban areas, deficiencies in infrastructure, and, above all, the location of system components in areas that are vulnerable to natural hazards.

A holistic risk assessment and risk management approach, including the entire drinking water system, from source to tap, is the most effective way to ensure a safe drinking water supply (WHO, 2008). Risk assessment plays an important role in disaster mitigation as it provides the essential information for adopting optimum disaster prevention measures, and for developing effective warning system as well as evacuation and emergency plans. Risk assessment involves the separate assessment of hazard and vulnerability (Tam, 1998). This paper focuses on the hazard (risk) assessment of tropical cyclone to drinking water facilities. The aim of the study is to analysis and assesses the risk factors caused by cyclone Gonu to water supply systems in Oman.

1. Gonu Tropical Cyclone

The most severe and disastrous of tropical cyclone that effected Oman coast was the recent cyclone "Gonu" on June 05 of 2007, it was the most intense in the history of TC in Oman, and it was the first ever experienced in the country natural disaster phenomena like Gonu. It start on first of June as a low pressure/depression on the northern Indian Ocean ~ 650 Km southwest of Bombay, as it moved with a speed of 8-10 km/h toward northwest to the southeast coast of Oman and it developed to tropical storm first on third June and then to TC on 04th of June with a surface wind speed of (213-232 km/h) in the middle of Arabian Sea (Al Hattaly & Al-Kindy, 2008).

On 5th of June it hit the southeast coast on Ras Al Had and Sur with a wind speed of (213-250 km/h) that classified the storm to its highest severity "Category 4" according to the criteria of storm severity. Figure (1) shows a satellite image on 4th of June 2007 to the Guno cyclone with Category 4 maximum wind 211-250 km/h approaching the southeast cost of Oman. The cyclone then moved toward northeast along Gulf of Oman coast destroying and flooding the area of Muscat-Quriyat before it start to decrease its storm intensity to low pressure/depression and moved towards northeast to the Coast of Iran on 07th of June 2007(Al Hattaly & Al-Kindy, 2008).

Figure 1: Satellite Image for Gonu Cyclone on 4/ 6/ 2007

The rainfall associated with Guno TC on the 05th-06th of June was the extreme in history of records in Oman. Cumulative rainfall in Jabal Asfar- a mountainous station in Quriyat reached to 1032 mm, which is 8 times higher than annual average and a return period of 150- 200 years. Dams were filled to their highest capacity and water overflow over the top of dam structures. The biggest of Sultanate Oman dams is Al khoud Dam at Muscat region that can hold a maximum capacity of 12 million cubic meters (mcm), and it was filled and water overflow. The total water flood that was hold by the dams on the 05th to 06th June is approximately 71 mcm, in which 41 mcm of water hold in Al khoud Dam (Al Khatry & Helmi, 2011).

The Government of Oman announced state of alert on 04th of June, and the National Committee on Civil Defense (NCCD) start to implement several procedures to manage the expected disaster. TC Gonu caused havoc to the infrastructures, building and to other properties and several lives in the areas of Muscat, Sur and Quriyat near the coast. The economic loss was to be in the range of 1.5billion Omani Riyal and a claim the lives of more than 50 people. The Photos on 06th of June, 2007 that presented in Figure (2) shows infrastructure destruction, flooded roads, and human responses on the affected areas.

The Height of Water in Al Qurm Area of Muscat

Flooded Roads in Muscat

Road Destruction in Muscat

Human Responses

Figure 2): Destruction Caused by Gonu Cyclone

2. Method of Risk Analysis and Assessment

Risk assessments can be carried out with a range of methods that can be broadly classified into quantitative and qualitative approach. Due to lack of adequate information and the numerical data and resources necessary for a statistically significant quantitative approach, qualitative analysis is conducted. The most common form of qualitative risk assessment is a “risk matrix”, which assesses individual incidents in terms of categories, e.g. low, medium and high, according to their expected consequence and likelihood. Risk and Vulnerability Analysis (RVA) method is used to analyze the risk of tropical cyclone to the water utility systems in Oman.

This methodology of RVA has been developed by the Danish Emergency Management Agency (DEMA). RVA is a method used to identify and assessing threats, risks and vulnerabilities in a specific system. It is an extended version of or resembles a Preliminary Hazard Analysis (PHA) and can be applied to any complex system (Ericsson 2005). RVA model is primarily based on the use of qualitative rather than quantitative data. All assessments are conducted using the index method, in which a level for probability, consequences and vulnerabilities is stated on a scale from 1 to 5, where 1 is best and 5 is worst (Giannopoulos, *et. al.,* 2012).

Disasters brought by tropical cyclones in coastal areas are mainly caused by high winds, waves, storm tides and floods associated with heavy rain. The absolute risk due to a tropical cyclone is a complex, multiplicative function of the hazard level and the vulnerability of a community or system. Vulnerability is defined as a property associated with component, a subsystem, or the overall water system to represent the possibility of being influenced by hazards/treats with given likelihoods and severities. Risks measure thus represents the cumulative effects of frequency and

severity of a hazard/threat. Normally, this measure is represented as:
Risk = Likelihood x Severity (1)

It is obvious that the above definition of risk only consider the influences of threats or hazards. Vulnerabilities of assets are also playing important roles in introducing risks into the water utility. Therefore, a modified of risk is formed as:
Risk = (likelihood x Severity) x Vulnerability (2)

Where, likelihood and severity represent the characteristics of a hazard or threat; while vulnerability represents the property of an asset that is influenced by the hazard or threat. In this definition, both hazard/threats and assets are explicitly considered ((Karamouz et al., 2010). The final form of the equation is expressed as:
Risk = Hazard x Vulnerability (3)

If we are able to rate objectively the hazard and vulnerability on scales of 1 to 5, for the same hazard level of 5, a system with high vulnerability level of 5 would be more times at risk (risk level = 25) than a system with low vulnerability of 1 (risk level = 5) (Tam,1998).

While the hazard level of a coastal region -like Oman- is relatively steady and difficult to change, the vulnerability level can be lowered significantly through the adoption of adequate disaster measures. Some of mitigation measures identified for high risks include monitoring for early warnings, design to appropriate engineering standards, sediment and erosion control, emergency response plan, and trained staff to respond during emergencies.

A tropical cyclone risk assessment matrix is usually developed as part of risk analysis and response plan. The tropical cyclone risk assessment matrix will assist in predicting and assessing cyclone impacts. As an example of cyclone risk assessment matrix is provided in the tables (1).

Table 1: Risk Matrix Key (EMNI, 2012)

Likelihood	Consequences					
	Score	Negligible (1)	Minor (2)	Moderate (3)	Major (4)	Severe (5)
Rare	(1)	Low	Low	Medium	High	High
Unlikely	(2)	Low	Low	Medium	High	Extreme
Possible	(3)	Low	Medium	High	Extreme	Extreme
Likely	(4)	Medium	High	High	Extreme	Extreme
Almost Certain	(5)	High	High	Extreme	Extreme	Extreme

(Low Risk “green scores”: *Maintain preventive measures*/ Medium risk “Yellow scores”: *consider actions*/ High Risk “Anber score”: *Actions are necessary*/ Extreme risk “Red score”: *Immediate action required*

Analysis of Risks

Introduction

The risks to the water infrastructure systems are broadly similar for all cases and may be summarized as follows: Loss of supply from the treatment plants; failures in the transmission mains; failures of pumps; loss of power at pumping stations; andfailure of the control System.

The material in this section describes the variety of hazard, damage and losses caused by the Guno tropical cyclone to water utilities in Oman, and estimate the risks using Risk and Vulnerability Analysis (RVA) and risk matrix concept.

Water Infrastructure Facilities Effected by Gonu

The Guno cyclone caused substantial damage to some of the critical infrastructure components. The worst damages were made to the water desalination plants, drinking water distribution lines, and well fields. Drinking water was unavailable in some areas in Muscat governorate for days due to interruption of desalination plants and broken water pipes which served the city. It left thousands of residents without water service or lower water pressure for almost a month. To summarize, the main impact of Gonu at many water infrastructure facilities are:

(i) Total disruption of Barka desalination plant due to interruption of electric power necessary to run the pumps for pumping water to the districts reservoirs.
(ii) Total disruption of Al-Ghubra desalination plant due to interruption of gas pipe lines necessary to run the plant.
(iii) Collapse and total loss of the Wadi Adai wells due to settling of soil around the well, resulting severe damage.
(iv) Loss of water transmission lines from the well field.
(v) Damage in voltage lines for Al-Khoudh well field due to erosion at the base of the poles causing damage to lines, switchboards, and substations.
(vi) Damage in transmission pipes between the main reservoirs in desalination plants and districts reservoirs resulting in a loss of water.
(vii) Ruptures in pipelines in exposed crossings streams (wadi) as a result of strong currents.
(viii) Breaks and uncoupling of pipes in mountainous topography as a result of landslides and water currents.
(ix) Damage to pipelines appurtenances (such as different types of chambers and valves)
(x) Damage to pumping equipments and electrical installations in some of the pump stations due to the flood.

Risk Estimation

The main aim of this section is to provide a qualitative risk assessment of hazards that may potentially be generated by tropical cyclone upon the water facilities including desalination plants, transmission pipelines, pumping stations, storage tanks, and water distribution networks. The risks were estimated using Risk and Vulnerability Analysis (RVA).

By using RVA model, the level of hazard probability and vulnerabilities is stated on a scale from 1 to 5, where 1 is best and 5 is worst. At the same time PAEW developed a procedure for risk assessment and hazard identification (PAEW, 2012) in which the scores of hazard, vulnerabilities and consequence risk have been developed taken into account the types of event that have occurred. The scorings used for risk analysis and assessments for tropical cyclone to water facilities in Oman are presented in the below tables.

Hazard probability is a threatening event or the probability of occurrence of a potentially damaging phenomenon within given time period and different circumstances. When considering the probability of a potentially harmful event or condition happening, a frequency or time period should be defined. A score for the probability of the hazard event is assigned from the estimated probability of its occurrence within a percentage of frequency as presented in table (2).

Table 2: The Criteria Regarding the Hazard Probability for Risk Matrix

Hazard	Description	Score
Rare	The event may occur only in exceptional circumstances, frequency: <10%	1
Unlikely	The event could occur at sometime, frequency: 10- 30%	2
Possible	The event should occur at sometime, frequency: > 30 -70%	3
Almost Certain	The event will probably occur in most circumstances, frequency	4
Almost Certain	The event expected to occur in most circumstances, frequency: > 90%	5

Vulnerability is the degree of loss resulting from the potentially damaging phenomenon such as tropical cyclone. This combined vulnerability is a function of hazard, exposure and sensitivity. The system vulnerability is defined as its inadequate ability to work and maintain its purpose when it has been affected by a hazardous event. The vulnerability of the hazard event is assessed using individual table for cyclone as illustrated in table (3).

Table 3: Vulnerability of Water Utility for Tropical Cyclone Risk

Vulnerability	Description	Score
Negligible	Minimal disruption to water utility	1
Minor	Minor failure to water utility	2
Moderate	Failure of the water utility	3
Major	Substantial failure of the water utility	4
Severe	Total failure of the water utility	5

The scoring system used in the risk tables to highlight the magnitude of individual risks of tropical cyclones to the security of the water supply is based on the simple Table (4) below. The scores of hazard probability and vulnerability are estimated and the two scores are then multiplied to provide the risk score.

Table 4: Vulnerability and Hazard Categories to Generate Risk Scores

Hazard	Vulnerability					
	Score	Negligible (1)	Minor (2)	Moderate (3)	Major (4)	Severe (5)
Rare	(1)	1	2	3	4	5
Unlikely	(2)	2	4	6	8	10
Possible	(3)	3	6	9	12	15
Likely	(4)	4	8	12	16	20
Almost Certain	5)	5	10	15	20	25

(The risk scores have been assigned a color code to easily represent relative risks as: Green scores, *represent low risks that may not need any mitigation measures*/ Yellow score, *represent medium risk that may need mitigation measures*/ Amber scores, *represent high risks need mitigation measures*/ Red scores, *represent extreme risks that will almost certainly need immediate action*)

The damages to water utilities caused by tropical cyclone are depend on cyclone force (category) and strong wind, heavy rain and storm surge associated with the tropical cyclone. The hazard risks generated by tropical cyclone to the water facilities and consequently to water supply due to failures of transmission systems, desalination plants, wells, storage tanks and reservoirs, station pumps, water networks, *etc.* have been analyzed and assessed initially without any controls and then allowing for existing mitigating measures.

Some of mitigation measures identified for high risks include development of an efficient tropical cyclone warning system and adequate emergency plans design the water utilities to appropriate engineering standards, sediment and erosion control measures, construction of coastal defense structures and stronger tanks and buildings, and trained staff to respond during emergencies.

For each part of water utility, the risks are assessed and given values for hazard probability and impact (vulnerability) in accordance with the Risk Matrices. The risks to water supply systems are summarized in table (5).

Table 5: Risk of Tropical Cyclone to Water Supply Systems (Utilities)

Risks to Water Systems		Before Mitigation Measures			After Mitigation Measures		
Hazard	Vulnerability	P	V	Risk	P	V	Risk
Transmission and Distribution Pipelines							
Complete Damage in transmission pipes	Failure of the water utility	2	3	6	2	3	6
Burst in main transmission lines	Failure of the water utility	4	3	12	4	3	12
Failures in the distribution pipes	Substantial Failure of the water utility	4	4	16	4	3	12
Break in distribution pipelines	Total failure of the water utility	5	5	25	5	4	20
Ruptures in pipelines	Total failure of the water utility	5	5	25	5	4	20
Damage to pipelines appurtenances such as chambers valves and fittings	Total failure of the water utility	4	5	20	4	2	8
Pumping Stations							
Breakdowns of pumps and motors	Substantial Failure of the water utility	4	4	16	2	4	8
Loss of incoming power supply	Total failure of the water utility	5	5	25	2	5	10
Failures of control systems	Total failure of the water utility	4	5	20	2	5	10
Failure of individual pump sets	Total failure of the water utility	5	4	20	2	4	8
Desalination Plant							
Failure of sea intake structures	Failure of the water utility	3	3	9	2	3	6
Excessive suspended solids at the sea intakes	Total failure of the water utility	5	5	25	5	5	25
Failure at desalination Plant	Substantial Failure of the water utility	4	4	16	3	4	12
Major Failure at Desalination Plant	Substantial Failure of the water utility	3	4	12	2	4	8
Mechanical or electrical failure within the desalination plant	Total failure of the water utility	5	5	25	4	5	20
Interruption of gas pipe lines	Total failure of the water utility	5	5	25	3	5	15
Well field and Service Reservoir							
Pollution of water in the reservoir	Total failure of the water utility	3	5	15	1	5	5
Structural failures of the reservoir	Substantial Failure of the water utility	2	4	8	1	4	4
Cracks in the reservoir	Substantial Failure of the water utility	5	4	20	2	4	8
Collapse and total loss of the well field	Total failure of the water utility	2	5	10	1	5	5
Damage in voltage lines for well field	Total failure of the water utility	5	5	25	4	5	20

Table 5 summarized the possible risks of tropical cyclone before and after mitigation measures mentioned above. In fact several of the failure mechanisms to water systems may be due to tropical cyclone (adverse weather). Also, in extreme weather conditions, it is likely that many failures will occur at a single time and they may be spread over a wide area. Furthermore communications may be disrupted, creating difficulties in ascertaining where failures have occurred and reaching sites to undertake repairs.

It is not also possible to guard against all the potential impacts of extreme weather events including tropical cyclone as the extent and severity of the damage could vary widely depending on the nature of the event, the path of the storm, etc. several of the failures and hazards in the water supply system caused by tropical cyclone along with detailed risk analysis can be carried out as further study.

Conclusions

Guno was severe tropical storm that Sultanate of Oman has ever experienced so far. The impact of the cyclone on Muscat's water system was particularly severe. The Public Authority of Electricity and Water (PAEW) worked around the clock to quickly respond and repair damages to minimize system down time and ensure safe adequate potable water supplies to meet system demands.

(i) The most valuable lesson learned from Guno was that; all water systems are required to develop emergency response plans based on vulnerability assessments conducted for their individual systems.

(ii) Aftermath of the cyclone, developing an effective emergency response plan for drinking water has become a top priority for the Public Authority of Electricity and Water (PAEW) after the Guno cyclone. Even though the plan does not guarantee the Public Authority of Electricity and Water (PAEW) supplying of water to the customers during the disaster but it helps to respond quickly.

(iii) The Public Authority of Electricity and Water (PAEW)is planning ahead to provide alternate safe water during an emergency ahead of time to ensure the water is safe and the supply is available for it customers.

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Operational Experience of an Integrated UF-RO System with Arabian Gulf Seawater

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Abstract: Dow Water & Process Solutions agreed a joint development agreement with the Saline Water Desalination Research Institute (SWDRI) in Saudi Arabia in 2013 to test the performance of Ultrafiltration (UF) and Reverse Osmosis (RO) technology using Arabian Gulf seawater. This report details the performance in 2 complete phases. Phase 1 gives an account of the cleaning research conducted on the UF system and the set of optimized conditions achieved in stage 5 of Phase 1. Phase 2 details the performance of the UF and RO integrated system for 6 months. The piloting concludes that membrane based technology is able to demonstrate sustainable and reliable operation with high temperature, high saline seawater despite its biofouling and scaling nature. The UF was able to operate at a recovery of 91% whereas the SWRO demonstrated stable operation at 50% recovery and >15LMH flux. The study conducted will serve as a significant experience on how an integrated UF and RO integrated system performs in challenging waters of the Middle East. The data generated will be used as a key reference when tested integrated UF and RO systems in other remote locations in Saudi Arabia such as the Red Sea.

Keywords: performance testing, UF, RO, seawater, temperature, saline, Arabian Gulf.

Introduction

The water in the Arabian Gulf is known to be challenging for reverse osmosis (RO) seawater desalination. The water is relatively shallow and the temperatures are high. Many small islands off the coast reduce the water exchange with the open sea. This results in seawater with high salinity, high organic content and microbiological activity posing a very high fouling risk for the RO membranes. Carefully designed pretreatment is absolutely essential to ensure economical and sustainable plant operation.

Traditionally, the Kingdom of Saudi Arabia has used Multi Stage Flash Distillation (MSF) technology to desalinate sea water. Membrane technology is seldom used in the Middle East and in particular in Saudi Arabia. For the very few membrane based desalination installations in Saudi Arabia, pre-treatment has consisted typically of dual media filters or sand filters followed reverse osmosis systems. There is significant experience in desalination plants in how the varying sea water quality variations prevent the conventional pretreatment process from producing consistent good quality feed water to the reverse osmosis system. The opportunity to use Dow™ UF as an alternative pre-treatment technology could potentially address the seawater quality of the Middle East and provide consistent reliable good quality feed water to the downstream RO system.

The joint research agreement between Dow and SWDRI is designed to develop a membrane-based desalination process specifically for the Arabian Gulf water which does not suffer from shortcomings in efficiency and reliability and which also offers lower capital and energy costs than thermal (MSF, MED) or hollow fine fiber reverse osmosis membrane processes.

The scope of the project was divided into two main phases. Phase I was designed to optimize the performance of the UF pretreatment technology. Following that, phase II was designed to incorporate findings from phase I and commence the evaluation of UF-RO integrated operation.

Materials and Methods

1. Piloting Site

The research site is located in Jubail, Saudi Arabia. Jubail city is located about 100 kilometers north of Dammam on the shores of the Arabian Gulf. The Dow pilot plant was placed in the main research facility of the Sea Water Conversion Corporation (SWCC), known as the Seawater Desalination Research Institute (SWDRI). The plant is fully contained within two parallel containers each with dimensions of 4m x 10.5m x 2.9m. SWDRI's intake line is located at a depth of around 5 meters within an enclosed bay.

2. Feed Water Characterization

Understanding the feed water characterization is crucial for the pretreatment optimization as well as the RO process. As an example, the fluctuation in feed turbidity can potentially have a significant impact on the operating flux chosen for the UF. Table 2 shows the typical Arabian Gulf sea water conditions provided to Dow by SWDRI. These conditions were used as the basis for defining the UF operating protocol.

Table 1: Typical Gulf Water Characteristics.

Parameter	Units	Value
Sodium	mg/l	11400
Magnesium	mg/l	1380
Calcium	mg/l	480
Bicarbonate	mg/l	130
Chloride	mg/l	24000

Sulphate	mg/l	4700
Boron	mg/l	4.8
TSS	mg/l	5
TDS	mg/l	45,000
Turbidity	NTU	5
TOC	mg/l	5
Oil & Grease	mg/l	Nil

3. Plant Design and Process

3.1.Ultrafiltration (UF)

The pilot plant comprises of two trains, each train offers a complete desalination solution comprising of an integrated UF-RO system. A single train utilizes its own pumps, piping, valves and instrumentation, hence making it completely independent from the other.

The pilot is provided with a chlorinated intake and the seawater to the Dow pilot plant has an approximate concentration of 0.5 ppm Chlorine. Initially, the water is screened by three 130-micron self-cleaning filters (strainers) operating in parallel. This process is shown schematically in **Error! Reference source not found.** starting with the feed tank and ending with the UF tanks. The trains are labeled UF1 and UF2 for the first and second train respectively.

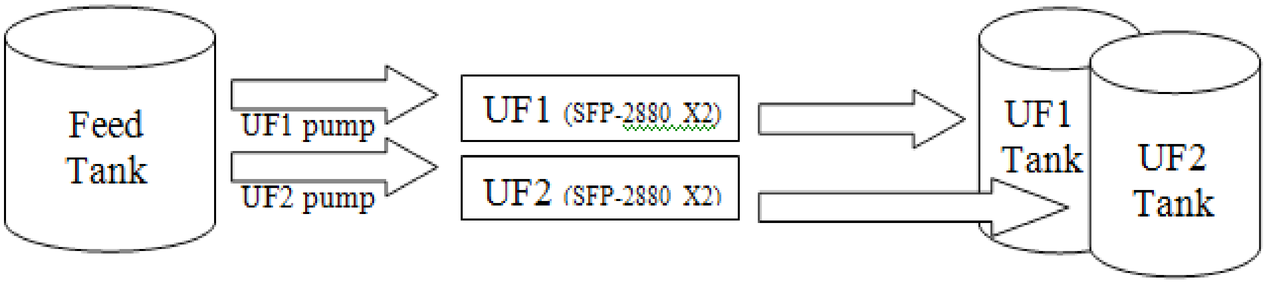


Figure 8: Ultrafiltration Process Overview

3.2. UF Cleaning Protocol

In order to maintain a sustainable UF pretreatment system, a cleaning protocol is required based on the specific characteristics of the seawater. The cleaning protocol comprises of three main components as follows; intermittent Backwash (BW); chemical-enhanced backwash (CEB); and-clean-in-Place (CIP).

A summary of the cleaning protocol components highlighting the main features of each is shown in **Figure 2.**

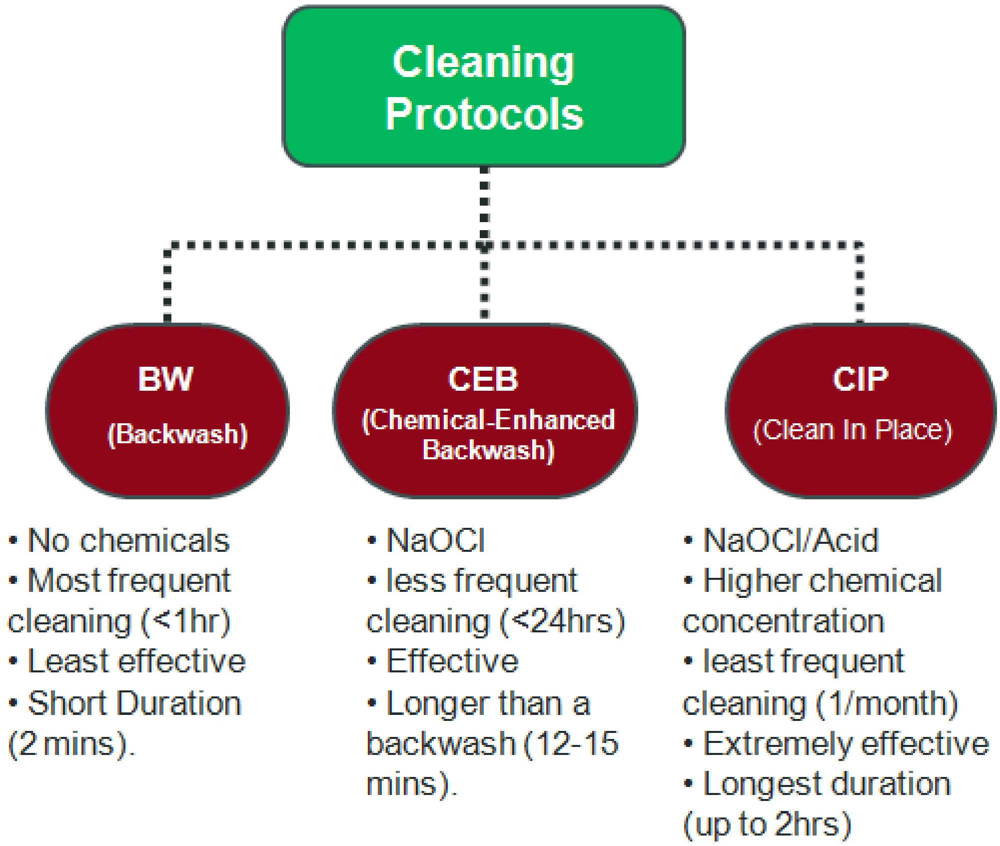


Figure 9: Cleaning Protocols

3.3. Reverse Osmosis (RO)

As mentioned previously, the RO on each train implements a two-stage system as shown in. The water is first driven from the filtrate tank corresponding with that specific train via a low pressure (booster) pump, where Antiscalant and SMBS are dosed. After that, it passes through 5µm cartridge filters to the high pressure pump, finally towards the 1st stage pressure vessel. The brine from the 1st stage feeds the 2nd stage. The permeate produced from the 1st and 2nd stage combine and are directed to a permeate tank shared between both trains. The brine from the second pressure vessel is redirected to a neutralization tank, also shared between both trains, before being discharged back into the sea.

Results and Discussion

1. Operating Conditions

Phase I, which corresponds to the optimization of the UF cleaning sequence, was initially set-up to run on the operating conditions shown in Table 3 below. Note that the conditions for UF1 & UF2 were identical, that is to confirm reproducibility of findings from one unit by the other. Since the results were essentially matching, for simplicity, results from one UF will be shown from now on. Note that the conditions presented in Table 3 below, had undergone certain changes during Phase I in order to determine the optimal conditions. Further details on the performance of Phase I are presented in a separate section below.

Table 2: Initial UF Operating Conditions for Phase I.

Variable	UF	
Flux (lmh)	85	
Backwash Freq. (/min)	60	
NaOCl (350ppm)	CEB Freq. (/ hrs)	24
CIP Freq. (/days)	90	

Phase II, corresponding to the implementation of the cleaning research (on the UF side) as well as the integrated UF-RO performance, was set-up to run on the operating conditions shown in tables Error! Reference source not found. &

. The conditions for the UF have undergone some changes towards the end of Phase II, however, the RO was constantly running on the same conditions. Further details on the performance of Phase II are presented in a separate section below.

Table 3: Initial UF Operating Conditions for Phase II.

Variable	UF	
Flux (lmh)	70	
Backwash Freq. (/min)	35	
NaOCl (350ppm)	CEB Freq. (/hrs)	12
CIP Freq. (/days)	90	

Table 4: RO Specifications and Operating Conditions

DOW FILMTEC RO –SW30HRLE-440i

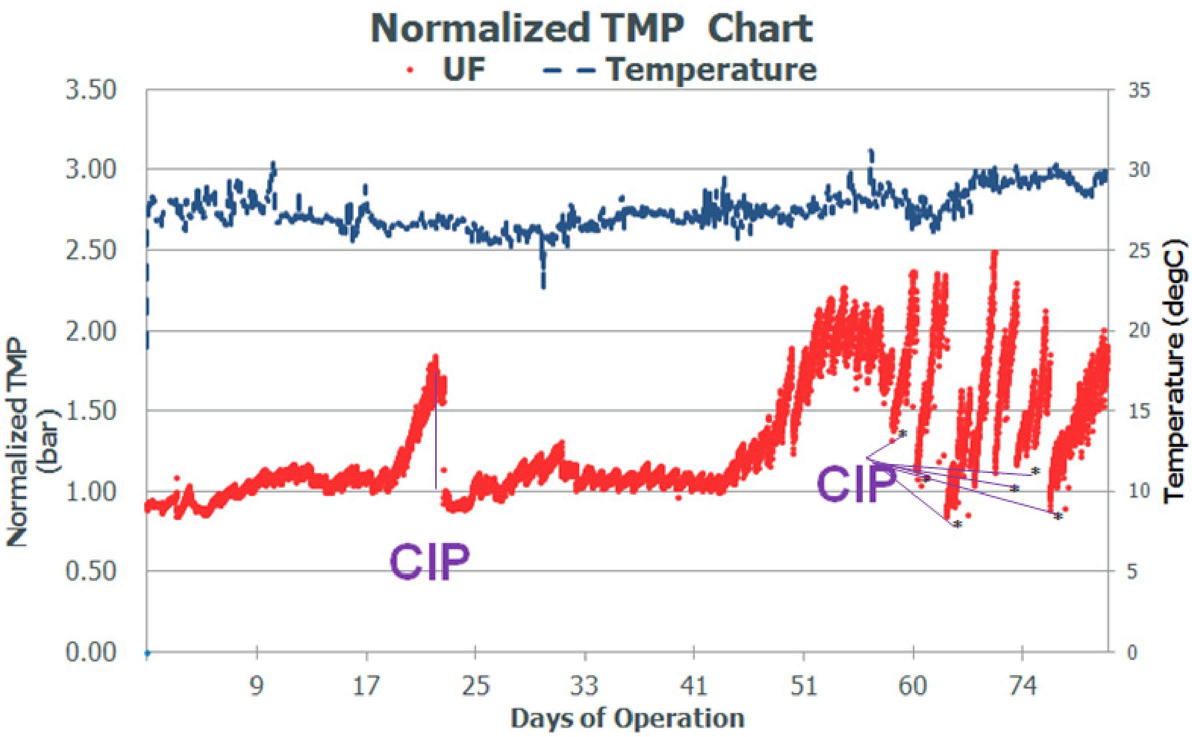
Module Surface Area	440 ft^2
Operating Flux	15.2LMH
Recovery	50%
Antiscalant	1ppm
Rejection* SW30HRLE-440i	99.8%
Flow* SW30HRLE-440i	8,200 gpd

2. Performance

2.1. Phase I Performance-UF Cleaning Research and Optimization

The objective of Phase I was to establish a cleaning protocol for the Ultrafiltration pretreatment system that is suitable for gulf water conditions at acceptable cost and chemical consumption. The operation should allow for sustainable operation of the UF independent of the quality of seawater to the pretreatment system.

The permeability and trans-membrane pressure (TMP) for phase II were normalized to a 25°C temperature. **Error! Reference source not found.** below presents the overall performance during phase 1 which is split into stages 1, 2 and 3 as shown on the figure. It is important to note that the modules had undergone autopsy at the end of Phase I and the reason is explained later in the associated subsection for stage 3 below.



Stage 1 Stage 2 Stage 3

Figure 10: Phase I UF Performance-Phase I was Split into Stages 1, 2 and 3 end of Stage 3 Features the Module Autopsy

Stage1

The initial UF operating conditions were leveraged from other UF installations that operate in similar conditions such as Mediterranean water conditions. In the table below you will find the starting conditions along with the cost. Although the flux and recovery were high, while the chemical consumption was low, the cost of water was 2.50 US¢ due to the elevated operating pressure.

Table 4: Stage 2 Operating Conditions

Operating Flux (lmh)	Backwash Freq. (mins)	CEB Freq. (hrs)	CIP Freq. (days)	Recovery (%)	Cost (US ¢)
85	60	1	0	95	2.53

At the start of this stage, the relationship between turbidity and TMP has been established. It was clear that when the water becomes more turbid due to weather changes or due to low tides (the intake is located in a very shallow area and during low tides the suction power disturbs sands and causes the water to become very turbid), this consequently leads to a TMP increase.

Using the adapted conditions, the UF has performed sustainably for 3 weeks. After, that the modules have started to foul as seen towards the end of stage 1 in figure 5.

Stage 2

After the CIP was performed at the end of stage 1, the UF system has managed to restore its original performance as shown at the beginning of stage 2 in figure 5 but there were signs that some fouling was irreversible due to the inefficiency of the cleaning protocol used. During stage 2, the CEB frequency was extended from one CEB per day in stage 1 to one CEB per week in stage 2. The decision to extend the CEB frequency was to test the UF system performance under milder cleaning conditions to increase the recovery and lower the cost of water as a result of less chemical consumption. After almost 25 days of operation, the modules had shown signs of accelerated fouling. Similar to stage 1, the cost of water for stage 2 was approximately 2.46 US ***¢, only resulting in a small cost saving from less usage of chemical from the CEB operation.*** Modules Installation. Days 158 & 172 Feature the Effective CIPs.

Table 5: Stage 2 Operating Conditions

Operating Flux (lmh)	Backwash Freq. (mins)	CEB Freq. (hrs)	CIP Freq. (days)	Recovery (%)	Cost (US ¢)
85	60	1/wk	0	95.4	2.46

Stage3

As the modules are completely fouled from the previous stage, the cleaning research interest was focusing on evaluating the effective performance of a CIP by restoring the TMP and hence the initial permeability of the UF system. In this stage, 6 CIPs (basic and acidic) were conducted as noted on the graph, and each CIP had was able to successfully restore the initial TMP hence the permeability but the rate of fouling was never restored as the maximum TMP was reached shortly after start-up. At this point, the modules reached advanced irreversible fouling and they were sent to the DW&PS' Center in Tarragona to perform an autopsy to understand the fouling nature and whether a specific cleaning solution could be applied to not only restore but also stablilize the rate of increase of TMP. The autopsy is designed to identify the nature of fouling and is detailed in the section below. Due to the high operating pressure during this stage, the price of water was highest compared to previous stages amounting to 2.76 US ***¢.***

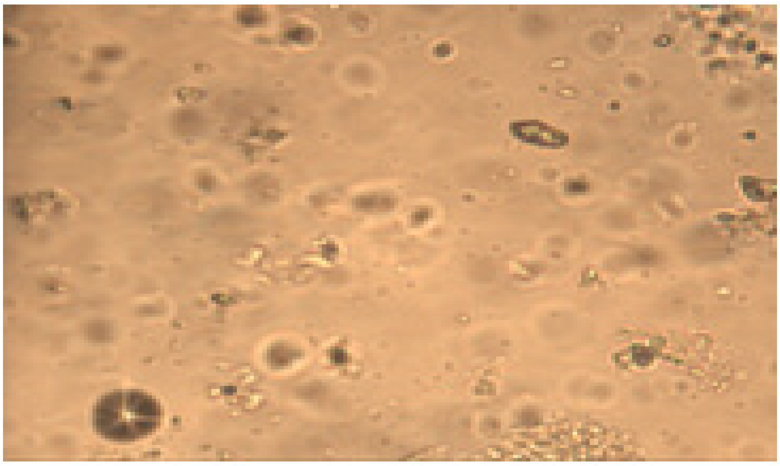
Table 6 Stage 2 Operating Conditions

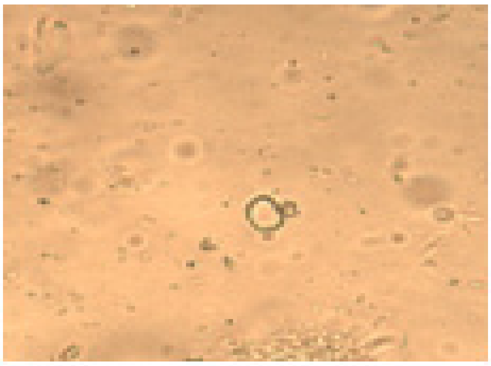
Operating Flux (lmh)	Backwash Freq. (mins)	CEB Freq. (hrs)	CIP Freq. (days)	Recovery (%)	Cost (US ¢)
80	60	0	6	95.4	2.76

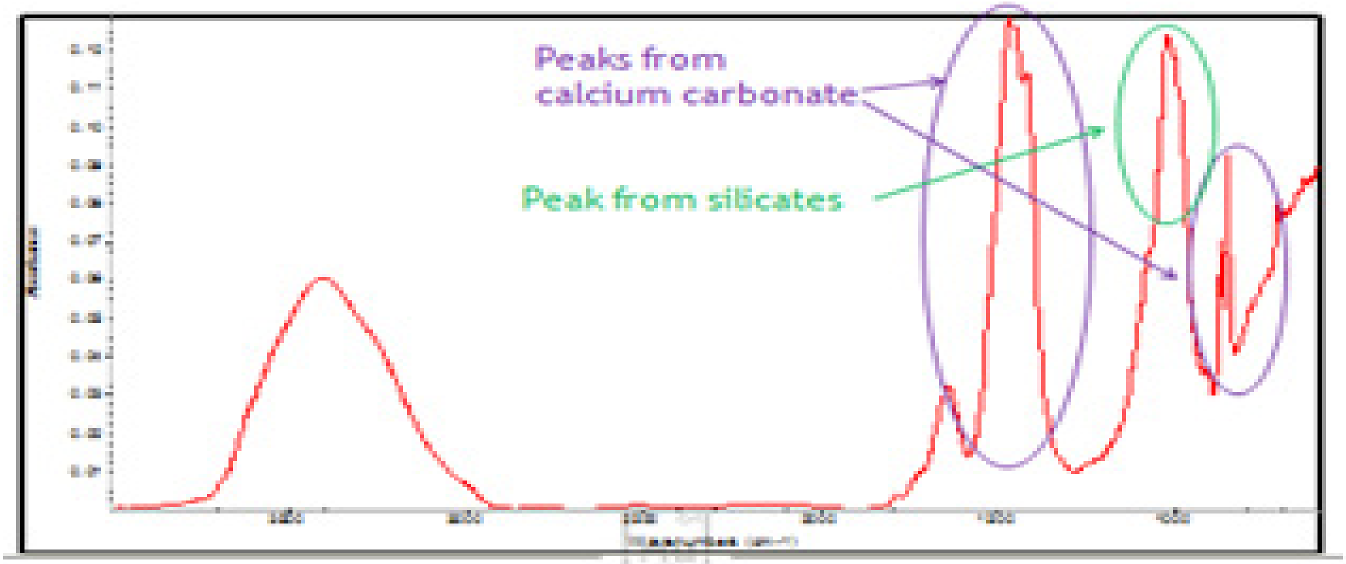
This stage concludes phase 1 of the piloting which was focused on the cleaning research and optimization and all findings from this phase I including the autopsy are to be incorporated in phase II.

UF Module Autopsy (End of Stage 3)

It was determined earlier that NaOCl and acidic CIPs were only able to restore the TMP for a short period of time – meaning, they cannot inhibit the TMP rate of increase. Hence, the UF modules used in Phase 1 were dissected to determine the nature of foulants and a suitable cleaning solution. The results are presented in **Error! Reference source not found.** below. Shown in the figure is A) Moving cells indicating bioactivity and B) Peaks from Alumino Silicates and Calcium Carbonate. Based on these results, the recommended formula cleaning formula was 2% NaOCl CIP with 2-hour soaking, followed by 2% Oxalic Acid CIP with 2-hour soaking. In order to distinguish this CIP from the latter, this formula will be referred to as Effective CIP and will be performed in subsequent stages of Phase II.







(B)

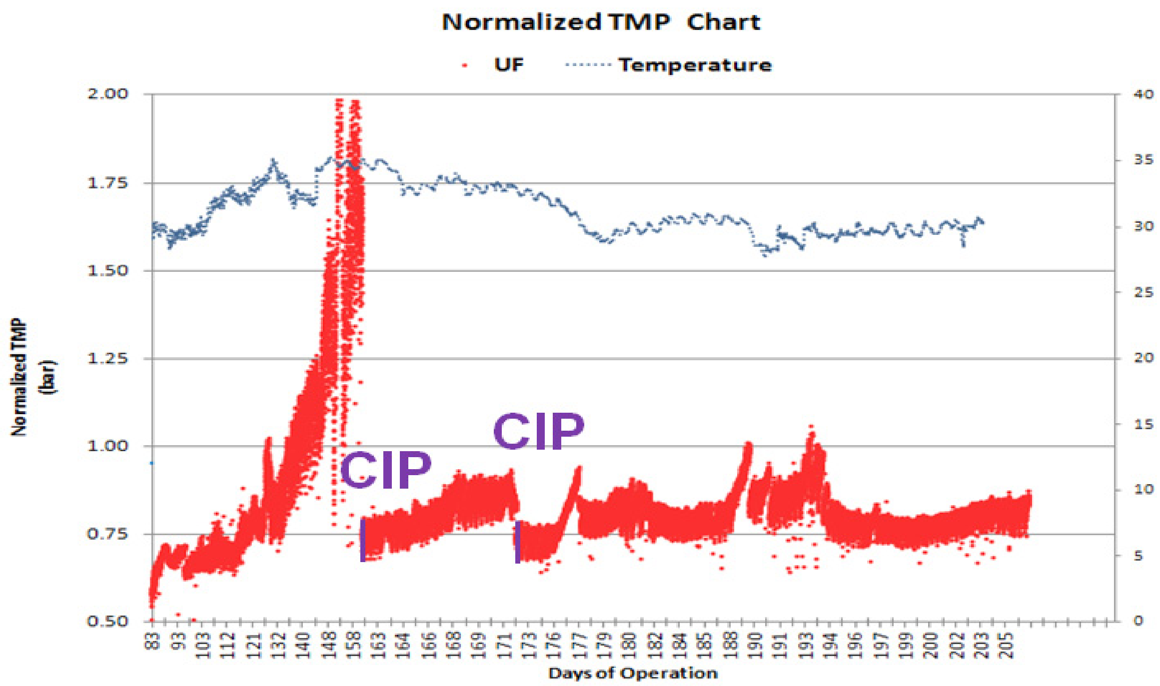
((A) *Moving Cells were detected.* / (B) *Peaks of Alumino Silicates and Calcium Carobonate were Detected*)

Figure 11: Autopsy Results from Modules Dissected at the end of Phase I.

2.2. Phase II Performance-Cleaning Research Implementation and UF-RO Evaluation

The objective of this phase is to implement the pre-determined optimal cleaning protocol of Phase I and results of autopsy and put them into practice in order to validate their effectiveness and efficiency using a new set of UF modules. Furthermore, the integrated UF-RO operation is to be assessed.

below illustrates the overall performance of the UF during this phase. On the other hand, the RO performance will be discussed in a separate section later on.



(*Effective CIP, combines both NaOCl and Oxalic Acid performed subsequently*)

Figure 12: Phase II UF Performance – Day 83 Features New Modules Installation. Days 158 & 172 Feature the Effective CIPs

Stage 4

In this stage, the new modules were installed while the old modules were undergoing the autopsy. It was crucial to start this stage under more conservative conditions (i.e. lower flux, intensive cleaning…etc) compared to the latter stages as the autopsy results had not been determined at the starting time of this stage. The conditions of Stage 4 are presented in below.

Table 7: Stage 4 Operating Conditions

Operating Flux (lmh)	Backwash Freq. (mins)	CEB Freq. (hrs)	CIP Freq. (total)	Recovery (%)	Cost (US ¢)
70	35	12	1	92	2.1

It can be observed that even though the operational flux was reduced to 70lmh, the backwash frequency increased to every 35 minutes and the CEB frequency increased to every 12 hours, still the UF fibers were fouled. In other words, a CIP was needed. The cost of water for this stage was calculated to be 2.1 US ¢, that is majorly related to the high operating pressure.

Stage 5

As noted on a CIP was performed at the end of stage 4 (day 158). However, the chemical formula for this CIP was different than CIPs before-an effective CIP. The TMP trend from Stage 5 proves that this effective CIP was successful in both restoring the TMP as well as providing a sustainable TMP trend-the TMP trend does not undergo rapid increases in short periods of time like in Stage 3 previously; this is summarized in below. Because of this effective CIP formula, the operating pressure was at its lowest among all stages resulting in a total cost of water of 1.81 US ¢.

Table 8: Stage 5 Operating Conditions

Operating Flux (lmh)	Backwash Freq. (mins)	CEB Freq. (hrs)	CIP Freq. (days)	Recovery (%)	Cost (US ¢)
70	35	6	1	91	1.81

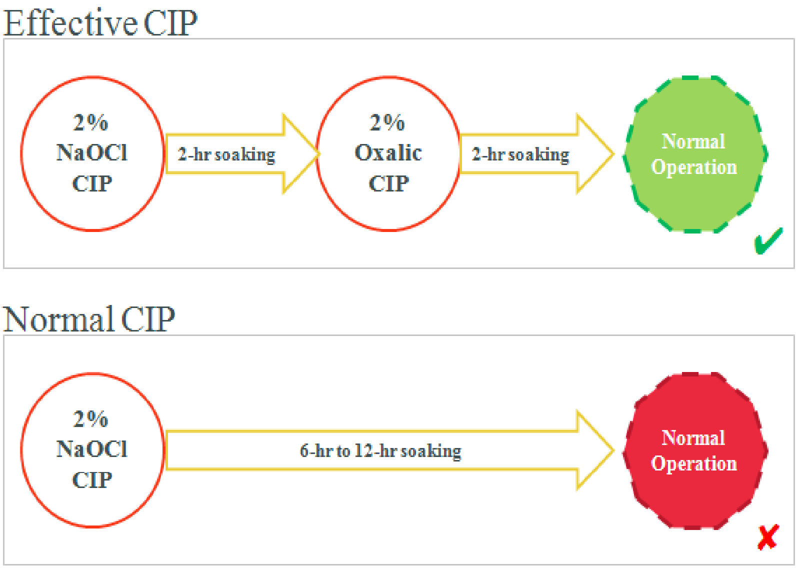


Figure 13: Effective CIP Versus Normal CIP **Reverse Osmosis.**

As stated before in Chapter, the performance of the SWRO is strongly linked to the pre-treatment method, hence the quality of feed water being provided from the pre-treatment to the SWRO. Hence, an outstanding RO performance essentially serves as further indication that DOW's UltraFiltration™ technology is reliable as a pretreatment for challenging seawater.

The RO was in operation for five months from June until November 2013. below shows the actual permeate flow versus the permeate conductivity for the whole period. The permeate quality had very little variation throughout the operational period.

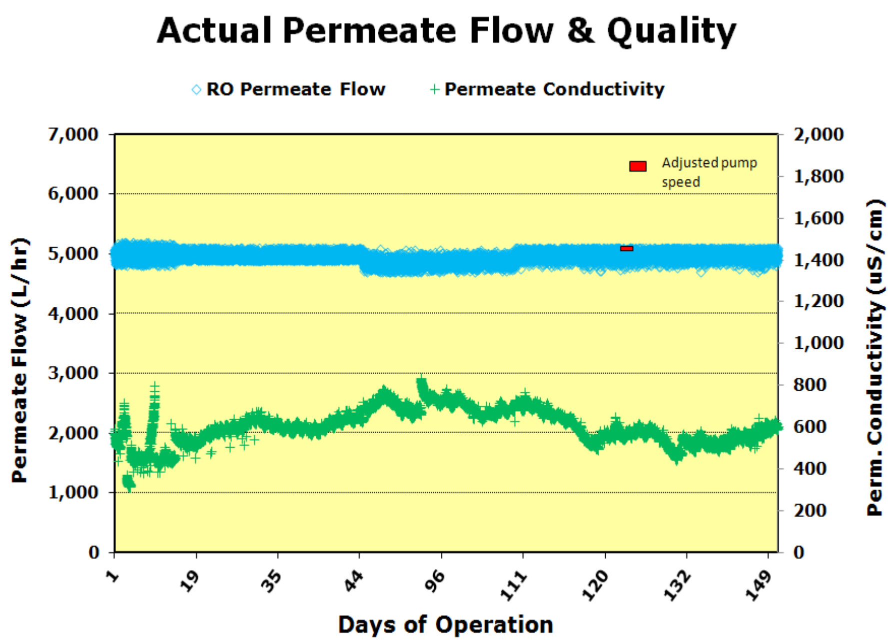


Figure 14: RO Performances over 5 Month Period, Showing Actual Permeate Flow and Quality.

Reverse Osmosis System Analysis (ROSA) was used to simulate the permeate quality for the given temperatures and flow data. The plot in below shows the actual versus ROSA prediction permeate conductivity. The actual salt removal exceeded expectations by 15.6% on average. The feed pressure was also plotted as projection versus actual on The average actual feed pressure was lower than the highest temperature prediction (35deg C) by 4.75%.

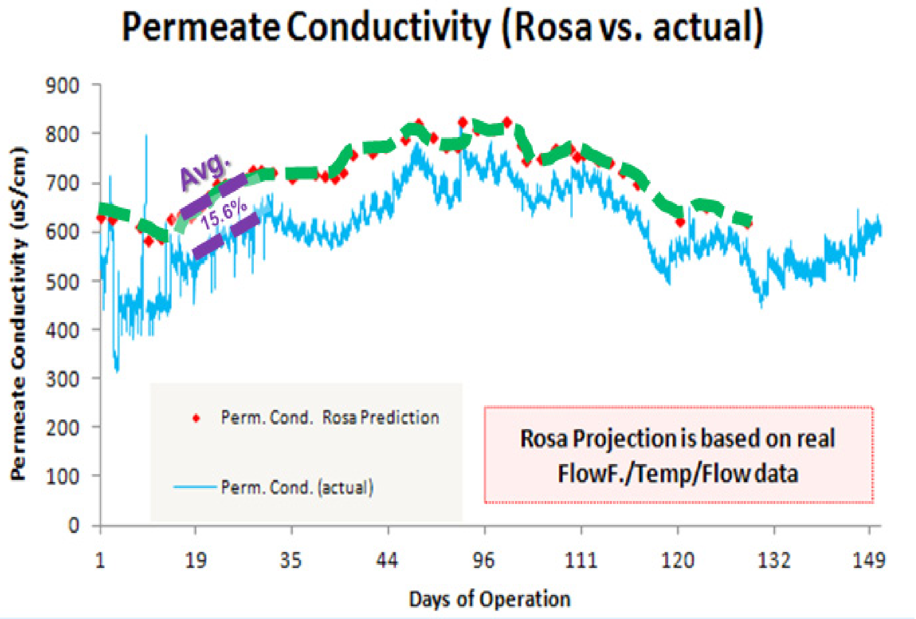


Figure 15: Projected Permeate Conductivity (Red/Green) Versus Actual (Blue).

The actual salt removal exceeded expectations by 15.6% on average. The feed pressure was also plotted as projection versus actual on below. The average actual feed pressure was lower than the highest temperature prediction (35deg C) by 4.75%.

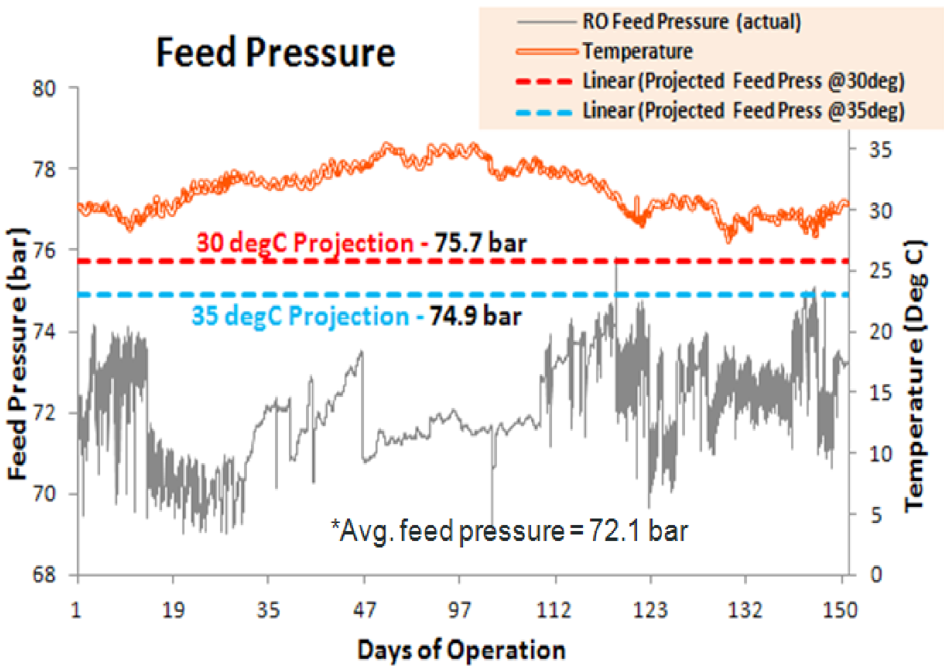


Figure 16: Average Feed Pressure Versus Predicted Feed Pressure at 35 Degc & 30 Degc.

Lastly, it is important to determine whether potential fouling existed or not. Based on DOW™ Filmtec's instruction manual, if any of the following is observed, then chemical cleaning is required: (i) 5%-10% Normalized salt passage increase. (ii) Differential pressure greater than 3.2bar. and (iii) 10% Drop in normalized permeate flow

However, none of these symptoms have been observed. shows the differential pressure throughout the whole period which did not exceed 1.3bar. The absence of these symptoms confirms the reliable quality supplied by the DOW Ultrafiltration™ pretreatment system.

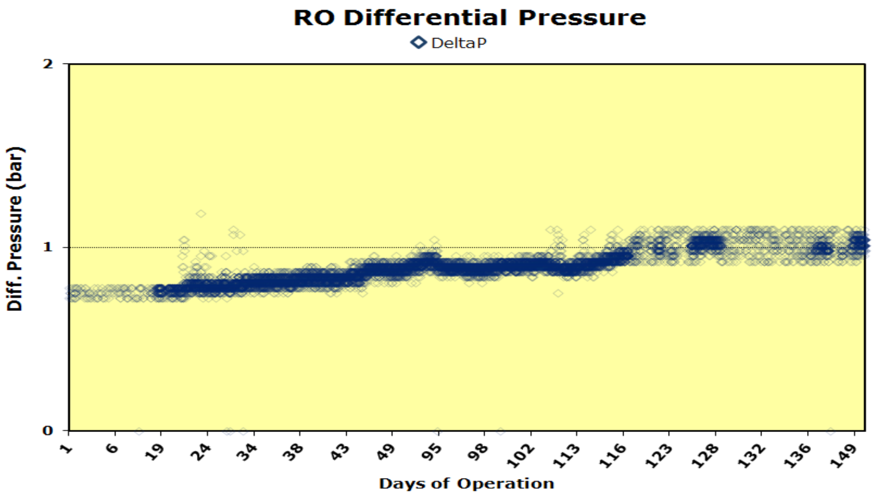


Figure 17: Pressure Drop Across the Pressure Vessel throughout the Period of Operation

Conclusion

The piloting of an integrated UF and RO system for the first time using Arabian Gulf seawater generated significant conclusions at the end of the 12 month study. Some of the conclusions are mentioned below;

1. The UF cleaning research in phase 1 developed a set of operating parameters along with a specific CIP cleaning solution to allow sustainable and reliable operation with Arabian Gulf sea water

2. The SWRO operated at 50% recovery and 15.2 LMH flux continuously for almost 6 months without any noticeable biofouling or scaling

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Biography: Veronica Garcia Molina has a degree

Degree: Master's (with Honours), Chemical Engineering with Industrial Experience (1st Class honors)/ Industry Experience: I am responsible for leading all application development of Water Separation Technologies for Dow Chemical in the Middle East. Ultrafiltration and SWRO are the lead technologies that are tested either at the Dow R&D Water Technology Centre in KAUST or remote customer locations such as SWDRI in Jubail, SWCC in Shuqaiq and potentially SWCC in Al Khobar.I have presented papers of Advanced Cleaning Research for Ultrafiltration Technology and also SWRO Interstaged Design at the Saudi Water and Power Forum alongside the Arwadex conference./ Prior to joining Dow, I was a lead process engineer for Shell Chemicals in the UK. I was a process specialist for Naphtha steam reforming and Alcohol.

SESSION 5
WASTEWATER TREATMENT AND REUSE MANAGEMENT

Keynote

Challenges in the Sewage Treatment and Reuse Opportunities in Arid Areas

Peter Werner
Director, National Water Centre, United Arab Emirates University, Al-Ain, UAE

Summary

Sewage treatment and reuse opportunities should have highest priority in light of a clean and sustainable environment. But in many countries this important aspect is neglected mostly due to cost reasons. Those countries are fostering the industrial development while ignoring all environmental protection aspects. Short term profit is in the foreground and long-term impacts are not considered. Moreover worldwide there is the problem of fast growing cities in which the infrastructure cannot meet the population growth and sewage treatment, discharge and reuse are key factors in the sustainable development in this respect.

But sewage cannot be regarded separately and must be considered in the frame of Integrated Water Resources Management (IWRM). Non treated wastewater released to the environment will have a non repairable impact on the whole water cycle. This is the reason why a good water management must comprise all fields in the water cycle and none of the following aspects can be neglected:

1. Water resources (protection from pollution and sustainable use)
2. Drinking water (appropriate treatment, supply, re-use, safety)
3. Wastewater (appropriate treatment, discharge opportunities, re-use)
4. Waste (appropriate treatment, recycling, safe deposit opportunities)
5. Soil (protection from pollution)

The boundary conditions in arid areas have to be considered for a safe IWRM and especially with respect to sewage treatment, re-use and discharge specific measures are required. Water in general is scarce in arid areas and due to overexploitation shrinking groundwater water resources can be observed. For countries located at the sea desalinated seawater will be the future source for water supply. The desalination process is highly expensive, but especially in the Arab world the water supply is subsidized and drinking water is available almost for free. As a consequence the water consumption in those countries is about 10 times higher than in Europe.

Those high quantities of drinking water turns to wastewater and this ‘overproduced’ sewage is partly recharging the groundwater, which is in many areas even surfacing. The quality of the treated sewage is high with respect to BOD, COD, TSS and nitrogen and phosphorus compounds. But during the treatment chain pharmaceuticals - mainly antibiotics and endocrine disruptors - are not or not sufficiently removed. The treated sewage undergoes disinfection and is used for the irrigation of beautification areas of the cities. This water is normally sprayed during daytime to enforce evaporation with the consequence that people are inhaling the spray containing those hazardous compounds. The consequence is the development of antibiotic resistant bacterial strains. Moreover it could be proved that those compounds are accumulating in the sludge. Turning this sludge to fertilizers will open another access for pharmaceuticals to the environment. In more humid parts of the world the sewage contains the same amount of pharmaceuticals, but the treated sewage is discharged to surface waters which causes an enormous dilution.

There is another important aspect, which should be considered essentially in arid areas, where groundwater levels are declining. Treated wastewater can be applied for groundwater recharge while using the aquifer as a natural and additional reactor for a safe after treatment. The method is called **S**ubsurface **A**quifer **T**reatment (**SAT**). The SAT of treated sewage has the following advantages:

1. Short, middle and long term water storage
2. It is environmental sound, can be flood controlling and keep soil moisture during dry seasons
3. Natural attenuation processes as there are biodegradation, adsorption, settling, chemical reactions and filtration improve the water quality
4. Natural close loop between recharge and discharge units
5. Cost effective by taking advantage of the natural attenuation processes in the subsurface

This method is sustainable and will ensure an adequate safe water supply for the continuously growing population worldwide and treated wastewater can be a substantial source for groundwater recharge;

e.g., at the site of Grau du Roi (France) sewage with a BOD 5 of about 250 mg/l is discharged to the subsurface. The 'bioreactor subsurface' is cleaning the water naturally almost to drinking water quality. Or in Berlin (Germany) polluted surface water, storm water and tertiary treated wastewater is discharged to the subsurface and further cleaned by natural attenuation processes. The result is that after a residence time of several months in the subsurface this water can be used as a drinking water resource almost with no treatment. In Berlin the same amount of water is discharged to the subsurface as is extracted for the water supply of the city. That means that the water balance in Berlin is equalized. Worldwide there are many positive examples for groundwater recharge by treated wastewater (e.g., USA, South Africa, …).

Moreover, due to urbanization and fast growing cities the soil surface is more and more sealed and natural groundwater recharge is prevented and in many cases even land subsidence can be observed with all the negative impacts. This method could be an opportunity to avoid and to solve those problems. There are still a lot of open questions and research required to face the emerging problems in the field of sewage in arid areas.

Biography: Prof. Peter Werner obtained his PhD Degree in 1979 from the University of Saarbrücken on "Microbiology of Activated Carbon Filtration". He served as the head of the Department of Microbiology at the DVGW-Forschungsstelle at the Engler-Bunte-Institute of the University Karlsruhe (later DVGW-Technologiezentrum Wasser). In 1991 he served as the head of the Branch Institute of the DVGW Technologie Zentrum Wasser in Dresden, and was appointed in 1993 as a professor (C4) for "Contaminated Site Management" at the Technische Universität Dresden. He became a Chair holder of the professorship for "Contaminated Site Management" in 1994 at the Technische Universität Dresden, and was appointed as the Director of the Institute for Waste Management and Contaminated Site Treatment at the Technische Universität Dresden from 1995-2004. During the period 2003-2009 he served as the Dean of the Faculty of Forest, Geo and Hydro Sciences, TU Dresden, and during the period 2011 to 2014 he serves as the Dean of the Faculty of Science, UAEU in Al Ain, and have been instrumental in the establishment of the "National Water Centre" affiliated to UAEU, and he serves as the Director of the UAEU National Water Centre. Prof. Werner main fields of research are Integrated Water Resources Management (IWRM), Treatment of oil contaminated water, oil refinery sewage treatment, Microbiological treatment of contaminated soils and waters, Natural attenuation of soils and aquifers, Advanced oxidation, Risk assessment and risk management of sites contaminated with Hydrocarbons, PAH, halogenated solvent, BTEX, MTBE, ammonia. He serves as a member of the Scientific Committee in 3 different journals, and he has more than 250 publications in scientific journals.

Keynote

Treatment and Management of Oil Produced Water

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Summary

Produced water is water trapped in oil or gas reservoirs that is brought to the surface during oil and gas exploration and production operations. The physical and chemical properties of produced water changes significantly from one filed to another. Produced water properties and volume varies considerably throughout the lifetime of a field production. While the highest oil is produced at the beginning of a field life, more water is produced as the field matures. Part of Produced Water is treated and used for water injection to maintain reservoir pressure and also for new Enhanced Oil Recovery (EOR) techniques, e.g., Steam & Polymer injection. Energy Intensive Operation, Deep Water Disposal, is used to inject the remaining excess Produced Water up to 3 km deep into the ground.

For years produced water in the oil industry has been treated as a nuisance. Substantial amount of investment was spent on finding ways of disposing of this water, leading to higher cost of oil production. Therefore, the cost of managing produced water is a significant factor in the profitability of oil and gas production. The total cost includes cost of constructing treatment and disposal facilities, cost of purchasing, operating and maintaining water treatment units, cost of managing any residuals or byproducts resulting from the treatment of produced water and cost of permitting, monitoring, reporting and transportation. However, in recent years with water scarcity problems, highlighted all around the world, this thinking started to shift into a positive one where water is treated as a resource rather than a nuisance by-product of oil production. However to seriously handle this issue the oil industry along with water experts, private sector, and lead by the Policy Makers in the country or region has to work together in handling the produced water from source to a suitable sink; in other words from production to utilization. Oil operators are developing more focused approach towards selecting appropriate water treatment technologies. They have the ability to move fast in developing new water treatment technologies simply because continuous and cost-effective oil production is a necessity for oil producing and exporting countries; however, water experts and policy makers lag behind. This has created a legacy issue to the oil industry.

Many different types of technologies can be used to treat produced water; however, the types of component removed by each technology and the degree of removal must be taken into account to identify potential treatment technologies for a given application. Most produced water treatment projects involve more than one type of treatment technology to meet the removal target; and a set of selection criteria must be developed and applied to limit various treatment options. Water treatment may constitute 30-90% of a project cost. In some cases it is the only cost to oil production.

A number of Oil Operators have managed to identify and apply beneficial uses of produced water that include crop irrigation, livestock watering, and municipal and industrial uses. However, due to the nature of highly classified information in the Oil Industry, such experiences are rarely shared especially in terms of long-term monitoring and reporting. Produced water can also be stored in groundwater reservoirs for future use. The type of beneficial use most appropriate for a produced water application depends on the geographical location of the produced water, the location of the beneficial use, and the constituent concentrations in the produced water.

As time passes water treatment is becoming a crucial factor for optimum oil production. This calls for the establishment of an independent specialized center that has the ability to move fast with technologies taking into account the national and regional needs. A center that:

1. Employs dedicated experts to fully develop and accelerate the process of produced water treatment and management;
2. Focuses on water treatment technologists and guards the intellectual property of these technologies and initiatives;
3. Involves Government representatives who are decision makers and can influence the National Sustainable Development Plans and collaborates with industrialists who can manufacture & develop water treatment technologies as part of "In Country Value" initiatives;
4. Defines and certifies water qualities per produced water utilization requirements and provides continuous monitoring, evaluation and follow up of new initiatives; and
5. Studies and selects appropriate contracting strategies for produced water treatment and utilization.

Biography: *Dr. Yasmeen Al Lawati is an expert on Oil-Produced Water Management and Treatment Expert. She has worked with the Petroleum Development Oman (PDO) for over 20 years in pursuit of turning produced water from a nuisance into a valuable resource through cost-effective treatment. She built a team of water management and treatment experts in PDO, who started to look into all water challenges faced in Oil production. Prior to that she was the Project Manager for the Reed Bed Pilot that proved the potential of growing plants using Produced Water. She started as a concept/process engineer at PDO in 1992, got her PhD in Chemical Engineering from the Imperial College in 2000. She also headed the Sustainable Development Team in PDO for 3 years as part of her broadening assignment. Currently she is a freelance consultant.*

تقييم كفاءة المراحل البيولوجية في محطة حجة في إزالة المواد العضوية من مياه الصرف الصحي

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المستخلص: تقع محطة الصرف الصحي في مدينة حجه بالجمهورية اليمنية. تتكون المحطة من خزان إمهوف، يليه مرشحات بيولوجية بلاستيكية، ثم حجريه، وكون المرشحات البلاستيكية ذات المعدل العالي فقد تم استخدام محطة ضخ لإعادة تدوير المياه. نظرا لشحة المياه في اليمن عامة ومنها مدينة حجة، فقد أنعكس ذلك على ارتفاع تركيز مياه الصرف الصحي مقارنة بالمعايير التصميمية، مما أدى إلى ارتفاع الأحمال العضوية الفعلية عن المعايير التصميمية. تهدف هذه الدراسة إلى تقييم كفاءة المراحل البيولوجية في محطة حجه في إزالة المواد العضوية من مياه الصرف الصحي. تلخصت منهجية البحث الذي أجري خلال الفترة (2012/04/1 وحتى 2013/02/11) على قياس التدفق وجمع أربع عشرة عينة مركبه من مياه الصرف الصحي من المراحل المختلفة خلال فصلي الصيف والشتاء وقياس (BOD-T-pH). من خلال نتائج قياس التدفق اتضح أن المحطة تستقبل تدفق يتراوح بين 1,000-1,300م^3/يوم أي ما يعادل 50% فقط من الطاقة التصميمية الهيدروليكية التي تبلغ 2428م^3/يوم، بينما تراوح الحمل العضوي التشغيلي بين1932-2357 Kg/d قريبا من الحمل التصميمي 2047 Kg/d، بمعنى أن المحطة تعمل حاليا بطاقتها الكاملة. الجدير بالذكر أن خزان إمهوف يعمل بكفاءة معالجة عالية تراوحت في الصيف بين (80-39 %) وفي الشتاء بين (65-49 %)، والتي تفوق الأسس التصميمية والمقدرة بحوالي 30 %، مما يعني أن المعالجة اللاهوائية ناجحة في هذه المحطة. أما فيما يخص المرشحات البيولوجية، فقد اتضح أن الحمل العضوي الحجمي على المرشحات البلاستيكية (عدد 2 على التوازي) يتراوح بين (gBOD/m^3.d1353-1186) والذي يعتبر ضمن الحدود التصميمية (gBOD/m^3.d1500-50،0) مما يعني أنه في حالة تعطل احد المرشحات أو توقيفه عن العمل لغرض الصيانة سيصبح الحمل العضوي على المحطة فوق طاقتها. تتم المعالجة في المرشحات البيولوجية البلاستيكية بنسبة كفاءة 27- 56% في الصيف و 71-51 % في الشتاء، أي أقل من الكفاءة التصميمية والتي قدرت بحوالي81 %. أي أن المرشحات البلاستيكية لم تصل إلى كفاءة المعالجة المطلوبة بحسب التصاميم. يعزو الانخفاض في الكفاءة بسبب نقص عملية التدوير نتيجة الانقطاع المتكرر للكهرباء في المحطة وعدم توفر مصدر طاقه بديل لتشغيل المضخات. وفيما يخص المرشحات البيولوجية الحجرية فقد اتضح أن الحمل العضوي الحجمي يتراوح بين (gBOD/m^3.d 332-259-332) وتعمل بنسبة كفاءة 48-35 % في الصيف و 22-2 % في الشتاء، أقل من نسبة الكفاءة التصميمية والتي قدرت بحوالي 83.% وبذلك نستنتج أنه يوجد تدني في كفاءة المعالجة والذي يتوقع أن يكون سببه الرئيسي عدم وجود حوض ترسيب بعد المرشح البلاستيكي مما أدى إلى دخول المواد البكتيرية إلى المرشح الحجري وسبب له حمل كبير وانسداد لمسامات المرشح الحجري. توصي الدراسة بتعميم استخدام المعالجة اللاهوائية مثل خزان إمهوف في جميع المدن اليمنية نظرا لزيادة تركيز المادة العضوية (BOD) في مياه الصرف الصحي، إضافة إلى إمكانية الاستفادة من الغاز الحيوي الناتج عن المعالجة اللاهوائية، وإنشاء أحواض ترسيب بعد المرشح البلاستيكي، أو استبدال المرشحات الحجرية بمرشحات بلاستيكية بمساماتها الكبيرة، والاستمرار في توفير مصدر طاقه لضمان استمرار تشغيل مضخات إعادة التدوير. كما يوصى بالاستفادة من مياه الأمطار وتجميعها في خزان ومن ثم تصريفها إلى مدخل المرشحات لرفع نسبة التدوير وبالتالي رفع كفاءة المحطة.

الكلمات الدالة: اليمن، حجه، إمهوف، المرشحات البيولوجية، معالجة مياه الصرف الصحي.

المقدمة

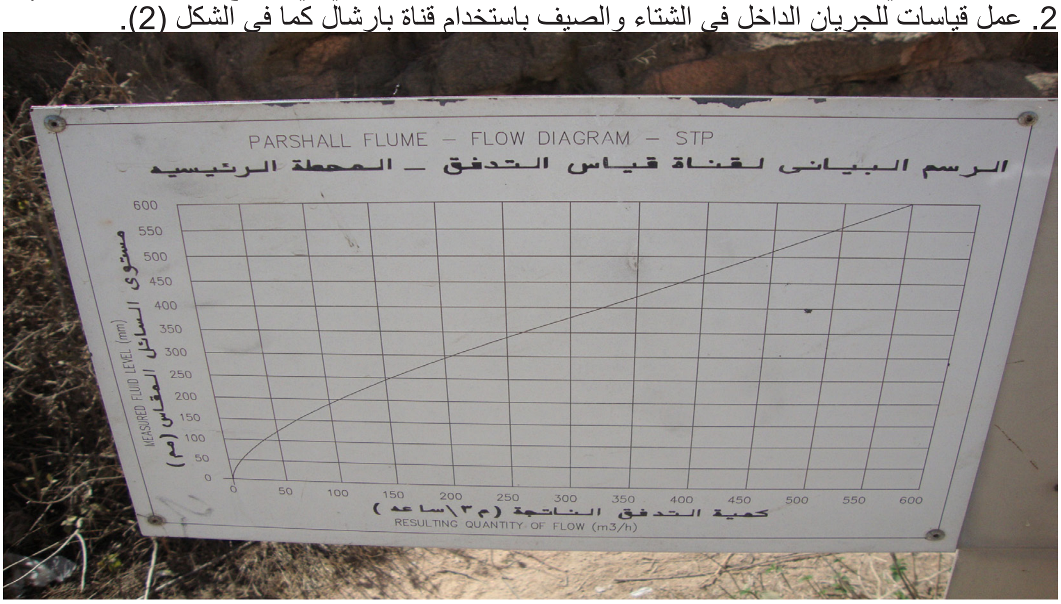
تم تصميم محطة حجه من قبل الاستشاري الألماني جيتيك– دورش، حيث تم تحديد نظام المعالجة البيولوجية بناء على طبوغرافية منطقة حجه كونها منطقة جبليه ويوجد بها أماكن مرتفعة جداً وارضي عبارة عن مدرجات والذي بدوره أدى إلى ضرورة اختيار نظام معالجه من نوع صغير شبه ميكانيكي واختيار نوع المعالجة الذي يبدأ بالنظام اللاهوائي يتبعه النظام الهوائي. يعتبر هذا النوع من المحطات مناسب للتراكيز العالية في اليمن ويعتبر هذا النموذج هو الوحيد في اليمن. نظرا لندرة المياه التي تزداد يوما بعد يوم والتي تعاني منها الجمهورية اليمنية ومنها منطقة حجة والتي دفعت بالمستفيدين إلى ترشيد الاستهلاك وخاصة بعد دخول العدادات فإنه يلاحظ تزايد تراكيز مياه الصرف الصحي طرديا مع قلة استخدام المياه، مما يؤدي إلى اختلاف المعايير التصميمية والتأثير على تشغيل محطات المعالجة، كما يعتبر تطبيق الأبحاث في تقييم هذه المحطات نوع من التدريب للعاملين فيها وتطبيق للعلوم الهندسية التي ترفع من مستوى الأداء في المحطات والمجتمع المحلي والاستفادة من الجامعات. تعتبر مدينة حجة عاصمة لمحافظة حجة وتقع على بعد 120 كم تقريباً شمال غرب مدينة صنعاء في قلب المناطق الجبلية وترتفع أكثر من 1,700م عن سطح البحر (شكل1).تتم معالجة مياه الصرف الصحي عبر محطة مرتبطة بشبكه منفصله. تخدم المحطة23786 نسمه بنسبة 54 % من سكان المدينة، يتركزون في المنطقة الغربية من مدينة حجه. نظرا لشحة المياه في اليمن عامة ومنها مدينة حجه فقد أدى ذلك إلى ارتفاع تركيز مياه الصرف الصحي واختلاف المعايير التصميمية عن المدخلات الحقيقية مما دعى إلى الحاجة إلى تقييم كفاءة محطة حجه بناء على هذه المتغيرات. يهدف هذا البحث إلى تقييم كفاءة المراحل البيولوجية في محطة المعالجة بمدينة حجه في إزالة المواد العضوية من مياه الصرف الصحي.

الشكل 1 : محطة حجه وموقع محافظة حجه في الجمهورية اليمنية

منهجية البحث

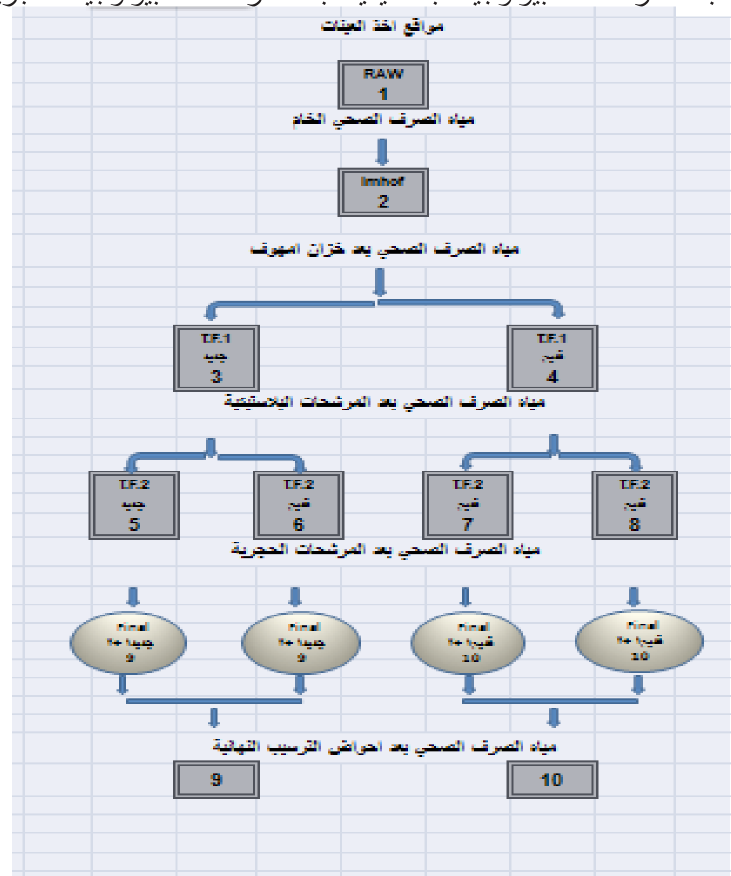
تم تنفيذ البحث مع الأخذ بعين الاعتبار التركيز على دراسة منفصلة لتقييم المحطة في كل من فصلي الشتاء والصيف وتم تنفيذ المنهجية كالتالي :

1.النزول الميداني ومتابعة خطوات سير عملية معالجة مياه الصرف الصحي في الموقع. خلال فترة البحث (2012/04/1 - 2013/02/11)
2. عمل قياسات للجريان الداخل في الشتاء والصيف باستخدام قناة بارشال كما في الشكل (2).



الشكل 2: منحنى قياس كمية التصرف

3. جمع عينات مركبه من كل من مياه الصرف الصحي الداخل والخارج من كل من الوحدات البيولوجية (المدخل، بعد خزان إمهوف، بعد المرشحات البيولوجية البلاستيكية، بعد المرشحات البيولوجية الحجرية).



تم جمع عينات مركبه (عدد7) في الصيف و(عدد7) في الشتاء من (10) مواقع في المحطة في المواقع التالية بأجمالي (140) عينه الشكل (3):

(S1) : مدخل المحطة (خزن إمهوف)/ (S2): مدخل المرشحات البلاستيكية/

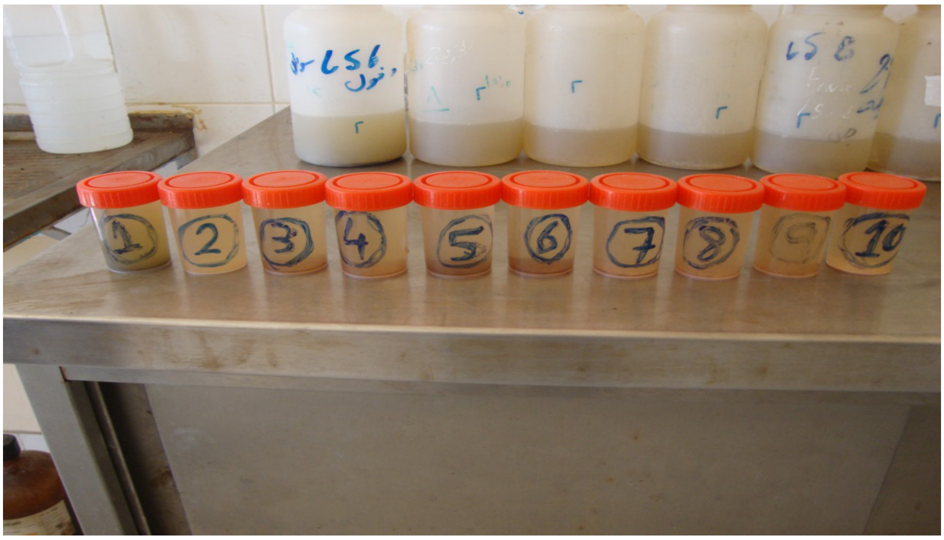
(S4 ،(S3: مدخلي المرشحات الحجرية/ (S6 ،S7 ،S8 ،(S5 : مداخل أحواض الترسيب النهائية/

(S10: ،(S9مخرجي أحواض الترسيب النهائية)

الشكل 3: مواقع اخذ العينات في محطة المعالجة بحجه

من خلال جمع 4عينات فرديه خلال اليوم (شكل 4)، تم تجهيز العينات المركبة بحجم 500 ml لكل عينه (شكل 5) مع الأخذ في الاعتبار تحديد حجم العينة نسبة إلى كمية التدفق عند اخذ كل عينه لتركيب العينة المركبة.

الشكل 4: العينات الفردية الأربعة المجمعة



الشكل 5: العينات المركبة في المختبر

1. خطوات تحديد كمية التدفق عند تركيب العينة المركبه

تؤخذ قراءات عمق التدفق يدوياً من قناة بارشال عند أخذ العينة بواسطة مسطرة مدرجة بالمليمتر وتحول هذه القراءة إلى معدل تدفق ساعي باستعمال المنحنى الخاص بهذه القناة (الجدول (1).

الجدول:1 نسب الحجم القياسية للعينات لقياس BOD_5

م	موقع اخذ العينات	نسبة الحجم القياسي (مليلتر)	عدد العينات المأخوذه
1	المياه الخام	43.5	1
2	مياه الصرف الصحي بعد Imhof tanks	97	1
3	مياه الصرف الصحي بعد المرشحات البلاستيكية	164	2
4	مياه الصرف الصحي بعد المرشحات الحجرية	164	4
5	مياه الصرف الصحي بعد أحواض الترسيب الدائرية النهائية	250	2

1. كيفية حساب نسبة الحجم لكل عينة

$$\text{نسبة الحجم المطلوب للعينة الأولى} = \frac{\text{حجم التدفق الخام بالمتر المكعب لكل ساعة (شكل (2))}}{\text{إجمالي التدفق لكل العينات}} \times 500$$

2. تحديد حجم العينة لقياس BOD_5

يوضح الجدول (2) نسب حجم العينات الفردية

الجدول 2: العينات الفردية لتجربة لقياس BOD_5

نسبة الحجم المطلوب (ملم)	حجم التدفق الخام (م^3)	عمق المياه عبر القناة (سم)	زمن اخذ العينة (ساعة)	العينات
140	57.90	12.00	10.00	الأولى
140	57.90	12.00	10.40	ألثانية
150.13	62.09	12.50	11.00	الثالثة
69.88	28.90	7.50	17.20	الرابعة
500	206.79			الإجمالي

3.تحليل مياه الصرف الصحي الموقعية والعينات المركبة.

التحاليل التي تم تنفيذها في البحث أربعة عشر مجموعة مقسمة على النحو التالي:
(أ) مجموعة الصيف (مارس، ابريل، مايو، يونيو، يوليو، أغسطس، سبتمبر، أكتوبر2012) والتي تمثل 7تحاليل في الصيف من العينة الأولى المأخوذة في 2012/04/1 وحتى العينة السابعة المأخوذة في 2012/07/10.
(ب) مجموعة الشتاء (نوفمبر، ديسمبر 2012 ، يناير، فبراير 2013) والتي تمثل 7 تحاليل في الشتاء من العينة الثامنة المأخوذة في2012/11/11وحتى العينة الرابعة عشر المأخوذة في2013/02/11 .

4.1. القيام بعمل التحاليل الموقعية والمعملية ومن ثم استخدام نتائج قياس BOD ودرجة الحرارة لحساب كفاءة كل من أحواض إمهوف والمرشحات البيولوجية.

1.5. الأجهزة المستخدمة في التحاليل

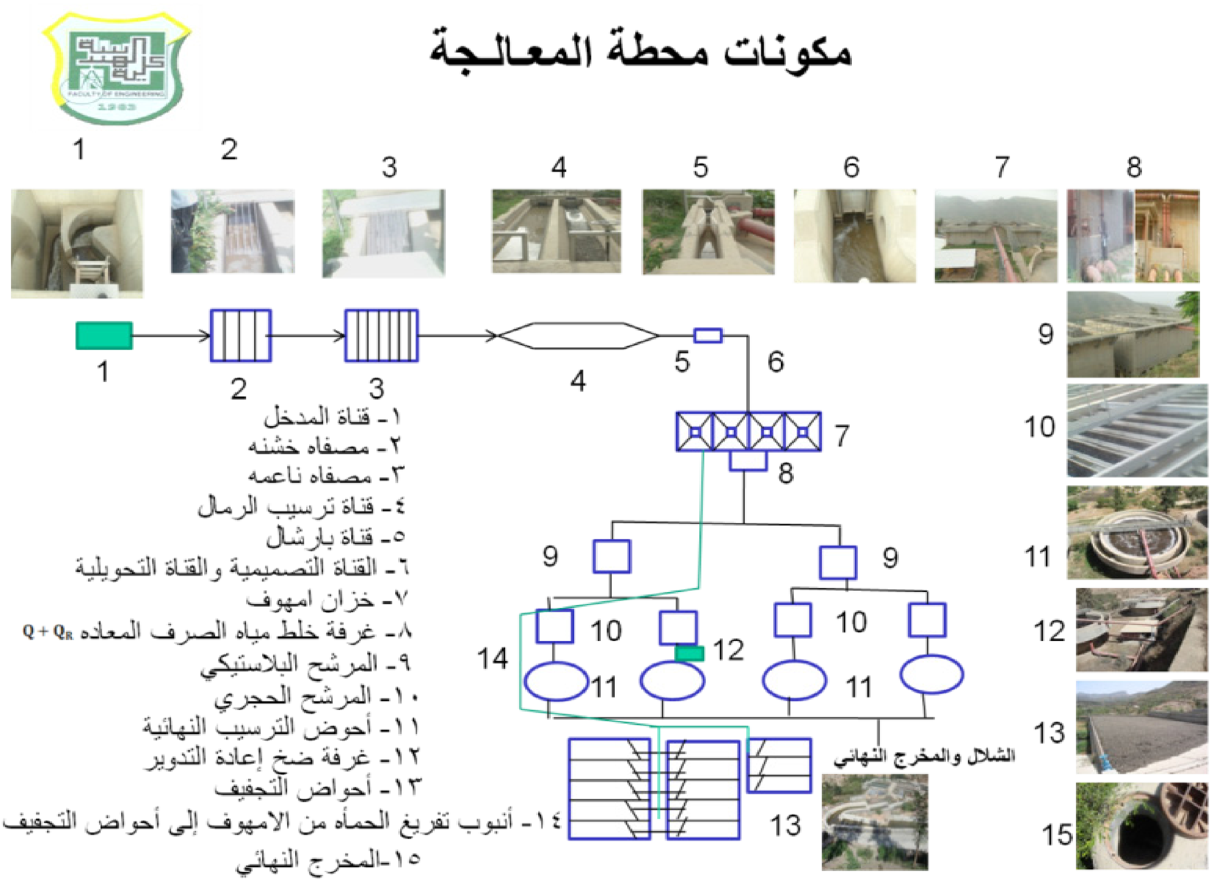
(أ) جهاز قياس BOD_5 ويتكون من رؤوس الكترونية.حاضنة لحفظ العينات.عند درجة حرارة 20 درجة مئوية
Model : MARK – 6 (6pcs), Type : TS 606 / 2.
(ب) جهاز قياسpH وجهاز قياس التوصيلية الكهربية.Made in German .

1.6. تقييم المراحل البيولوجية.

النتائج

(1) خطوات سير عملية المعالجة

تحتوي المحطة بالإضافة إلى مباني الإدارة والمختبر والمستودعات على خطي المياه والحمأة كمايلي:
1.1. خط المياه: ويتكون من الوحدات التالية:
(i) قناة المدخل، المصافي اليدوية (خشنة وناعمه على التوالي) مع قناة تحويلية، قناتين لحجز الرمال على التوازي.
(ii) قناة بارشال، غرفة التهدئة، أنبوب المخرج التحويلي، خزان إمهوف (عدد1) للمعالجة الابتدائية وهضم الحمأة، المرشحات البيولوجية البرستيكية (عدد 2) بمساحة إجمالية قدرها 360م^2، المرشحات البيولوجية الحجرية (عدد 4) بمساحة إجمالية 720م^2.
(iii) محطة ضخ إعادة التدوير، أحواض الترسيب النهائية الدائرية (عدد 4)،أنبوب مخرج المياه المعالجة.
1.2. خط الحمأه: ويتكون من الوحدات التالية:
محطة ضخ الحمأة السائلة إلى أحواض التجفيف أوخزان إمهوف، أحواض تجفيف الحمأة وبمساحة إجمالية قدرها 5,700م^2، منطقة تخزين الحمأة. الشكل (6) يوضح مكونات محطة معالجة مياه الصرف الصحي بحجه(مستقاه من النزول الميداني والمرجعين [12])،[13]).



الشكل 6: مكونات محطة معالجة مياه الصرف الصحي بحجه

2. نتائج قياس التدفق والتحاليل

تم تصميم المحطة عام 1996م لفترة تشغيل زمنية 10 سنوات وبذلك فإن الأفق التصميمي للمحطة هو عام 2005م لمعالجة مياه الصرف الصحي بمعدل تدفق 2,428م^3/ يوم (2.81 لتر/ث) وهذا هو المتوقع إنتاجه من عدد السكان المقدر بـحوالى 47,602 نسمة في عام 2005م (جدول3 (حيث كان عدد السكان عند التصميم عام 1995م هو 22348 نسمة [13]، بينما بلغ عدد السكان الحالي للمنطقة المستفيدة من المحطة بحجه حوالي 23786 نسمة في عام 2013م أي انه وصل فقط إلى50% من عدد السكان عند نهاية فترة التصميم[15]، حيث بلغ عدد التوصيلات للصرف الصحي في المناطق المستفيدة من المحطة حوالي 2823 توصيله حتى نهاية أغسطس 2012م [1].من خلال قراءات جهاز التدفق اتضح أن المحطة تستقبل حالياً تدفق في الصيف 1135م^3/ يوم وفي الشتاء 1052 م^3/ يوم أي (50% تقريبا من الطاقة التصميمية). من خلال سجلات المحطة للفترة السابقة بلغ التدفق اليومي للفترة من (2000م- 2012م) أي بمعدل (1052م^3/ يوم) بينما كان أكثر من ذلك خلال العامين (2008م – 2009م) أي بمعدل (1300م^3/ يوم). مما يدل على أن شحة المياه قد أثرت على استهلاك السكان ورفع تركيز مياه الصرف الصحي (من 1350mgBOD/L إلى 2500mgBOD/L) بين سنتي 2008 إلى 2012 الجدولين4)، 5 (توضح ارتفاع تركيز مياه الصرف الصحي. ومن خلال القراءات يوضح الشكل(7) التذبذب الساعي لمتوسط عينات فترتي الشتاء والصيف.

الجدول 3: خلاصة التقييم التشغيلي للمراحل البيولوجية في محطة حجه (للعام 2012م)

الملاحظة	بيانات تقييم المحطة شتاءً	بيانات تقييم المحطة صيفاً	الاسس التصميمية للمحطة	الوحدة	الوصف
*	23786	23786	47602	شخص	عدد السكان
*	50	47	51	l/c.d	معدل استهلاك الفرد
*	1191	1110	2428	m^3/d	معدل التدفق
***	2500 – 1450	2300 – 1350	843	mg/l	تركيز BOD_5 الداخل إلى المحطة
***	2978 – 1727	2553 – 1499	2047	Kg\d	الحمل العضويBOD-Load
خزان امهوف					
***	1000 – 720	940 – 460	588	mg/l	تركيز BOD_5 الخارج من Imhof tank
***	65% - 49%	80% - 39%	30	%	كفاءة المعالجة فيImhof tank
المرشح البلاستيكي					
*	8.1	7.6	36	m^3/m^2.d	الحمل الهيدروليكي
*	1191 - 858	1043 - 511	1428	Kg/d	الحمل العضويBOD-Load
***	490 – 210	410 – 335	117	mg/l	تركيزBOD_5 الخارج من Trickling filter 1
*	51%- 71%	56% - 27%	81	%	كفاءة المعالجة في Trickling filter 1
المرشح الحجري + أحواض الترسيب النهائية					
*	4.1	3.8	14.4	m^3/m^2.d	الحمل الهيدروليكي
***	384 – 250	455 – 200	284	Kg/d	الحمل العضويBOD-Load
***	215 – 130	190 – 110	20	mg/l	تركيزBOD_5 الخارج من Trickling filter 2
*	44%-48%	58% - 45%	83%	%	كفاءة المعالجة في Trickling filter 2

(لم يصل إلى القيمة التصميمية/ ** وصل إلى القيمة التصميمية / *** زاد عن القيمة التصميمية)*

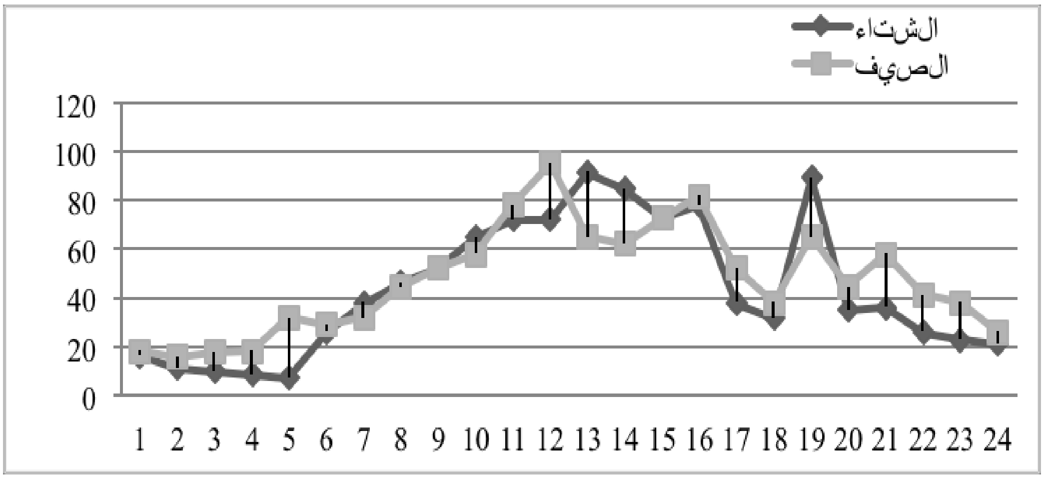
الجدول 4: نتائج قياس تركيز BOD_5 والكفاءة للتجارب التي تم تنفيذها في البحث في الصيف مقارنة بالأسس التصميمية

الكفاءة المتوقعة باستخدام المنحنى للمرشح الحجري ذو مرحلتين (المعدل)		كفاءة المحطه كليا	الكفاءه (%)	بعد المرشحات الحجريه	الكفاءه (%)	بعد المرشحات البلاستيكية	الكفاءه (%)	بعد خزان امهوف	التركيز الداخلي	رقم العينة
% من المنحنى	التركيزالمعدل BOD5 g/ m^3.d	%	%	BOD_5تركيز	%	BOD_5تركيز	%	BOD_5تركيز	BOD_5تركيز	
-	-	98		20	81	117	30	588	843	القيمه التصميميه
76	585	94	62	140	21	365	80	460	2300	S1
65	2023	87	49	175	59	340	39	820	1350	S2
67	1714	92	65	140	52	395	52	820	1700	S3
66	1901	87	51	190	55	385	41	860	1450	S4

S5	1650	740	55	410	45	105	74	94	1355	70
S6	1700	780	54	370	53	155	58	91	1675	67
S7	1800	940	48	335	64	180	49	90	2585	63
متوسط الصيف	1707	774	53	371	50	155	58	91	1691	68

جدول 5: نتائج قياس تركيز BOD_5 والكفاءة للتجارب التي تم تنفيذها في البحث في الشتاء مقارنة بالأسس التصميمية

رقم العينة	التركيز الداخلي	بعد خزان امهوف	الكفاءه (%)	بعد المرشحات البلاستيكية	الكفاءه (%)	بعد المرشحات الحجريه	الكفاءه (%)	كفاءة المحطه كليا	الكفاءة المتوقعة باستخدام المنحى للمرشح الحجري ذو مرحلتين (المعدل)	
	BOD_5 تركيز	BOD_5 تركيز	%	BOD_5 تركيز	%	BOD_5 تركيز	%	%	التركيز المعدل BOD5 g/m³.d	% من المنحنى
القيمه التصميميه	843	588	30	117	81	20		98	-	-
S1	2500	880	65	490	44	215	56	91	1563	68
S2	2100	940	55	455	52	225	44	89	1975	66
S3	2000	720	64	345	52	155	55	92	1497	68
S4	2000	720	64	210	71	160	24	92	2497	63
S5	1500	720	52	280	61	210	25	86	1841	67
S6	1450	740	49	205	72	125	39	91	2615	63
S7	2300	1000	57	405	60	195	52	92	2531	63
متوسط الشتاء	1979	817	58	341	59	184	42	91	2074	65

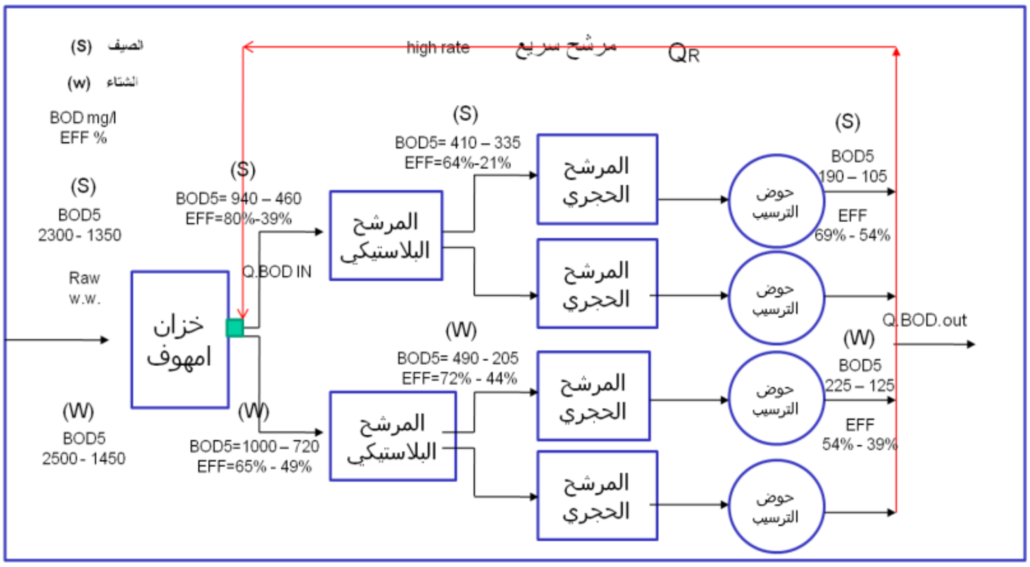


(الخط الأفقي: التذبذب الساعي خلال *24* ساعة/ الخط الرأسي: معدل التدفق في الساعة m^3/h)
الشكل 7: مقارنة التذبذب الساعي خلال 24 ساعة في الصيف والشتاء

3. الكفاءة الكلية للمحطة في إزالة BOD_5

4. تقييم الوحدات البيولوجية للمحطة:

يوضح الشكل 8 ملخص كفاءة المراحل البيولوجية في محطة حجه



(تركيز BOD_5 عند كل مرحله في (الصيف S والشتاءW)
الشكل 8: ملخص كفاءة المراحل البيولوجية في المحطة

5.تقييم خزان امهوف

بلغ معدل التحميل السطحي لخزان آمهوف في الصيف 6.9 $m^3/(m^2.d)$،أما بالنسبة للتحميل السطحي في الشتاء فقد بلغ 7 $m^3/(m^2.d)$، وبذلك يكون التحميل السطحي لخزان آمهوف اقل من الحدود التصميمية.أما فيما يخص كفاءته فقد بلغت 80% أي أعلى من القيمة التصميمية التي قدرت بحوالي 30%

6. تقييم المرشحات البلاستيكية

1.6 تقييم الصيف

نسبة إعادة مياه الصرف (التدوير) R= 0.50، عدد المرشحات 2 ، تركيز BOD_5 =940 mg/l متوسط التدفق=1110m^3/d، التحميل السطحي7.6$m^3/m^2.d$ (مقارب للحدود التصميمية والتي تتراوح بين)[4][10-30$m^3/(m^2.d)$]. أماBOD Volumetric Load فكان 1168 $gBOD/m^3.d$ كما يعتبر المرشح من النوع السريع و ضمن الحدود التصميمية للمحطة (500-1500 $gBOD/m^3.d$)، ويعتبر ضمن المقاييس المتعارف عليها [5].

2.6 تقييم الشتاء

نسبة إعادة مياه الصرف (التدوير) R =0.50، عدد المرشحات 2 ، تركيز BOD_5 =1000 mg/l متوسط التدفق 1191m^3/d =، التحميل السطحي8.1 $m^3/m^2.d$ (مقارب للحدود التصميمية والتي تتراوح بين)10-30 $m^3/(m^2.d)$ أماBOD Volumetric Load فكان 1353$gBOD/m^3.d$ كما يعتبر المرشح من النوع السريع و يعتبر ضمن الحدود التصميمية للمحطة (500-1500 $gBOD/m^3.d$)

7. تقييم المرشحات الحجرية

1.7 تقييم الصيف

يعتبر المرشح من النوع البطيء و يعتبر اقل من الحدود التصميمية للمحطة . عدد المرشحات 4 تركيز BOD_5 =410 mg/l حيث أن التحميل السطحي في الصيف 3.8 $m^3/m^2.d$ وبذلك يكون التحميل السطحي اقل من الحدود التصميمية والتي تتراوح بين)-10 30 $m^3/(m^2.d)$ أماBOD Volumetric Load فكان 259 $gBOD/m^3.d$ وبذلك يكون اقل من الحدود التصميمية (500-1500 $gBOD/m^3.d$) ولا يحتاج إلى عملية إعادة تدوير.

2.7 تقييم الشتاء

وكما يعتبر المرشح من النوع البطيء و يعتبر اقل من الحدود التصميمية للمحطة عدد المرشحات 4 تركيز BOD_5 =490 mg/l حيث أن التحميل السطحي في الشتاء 4.1 $m^3/m^2.d$, وبذلك يكون التحميل السطحي اقل من الحدود التصميمية والتي تتراوح)10-30 $m^3/(m^2.d)$ أما BODVolumetric Load فكان 332 $gBOD/m^3.d$ وبذلك يكون اقل من الحدود التصميمية (500-1500 $gBOD/m^3.d$) ولا يحتاج إلى عملية إعادة تدوير,تم التأكد من أن أحمال المرشح غير مطابقة للحدود التصميمية وبذلك فهو يتطلب إنشاء أحواض ترسيب قبل المعالجة البيولوجية الحجرية لمنع انسداد المرشح الحجري .

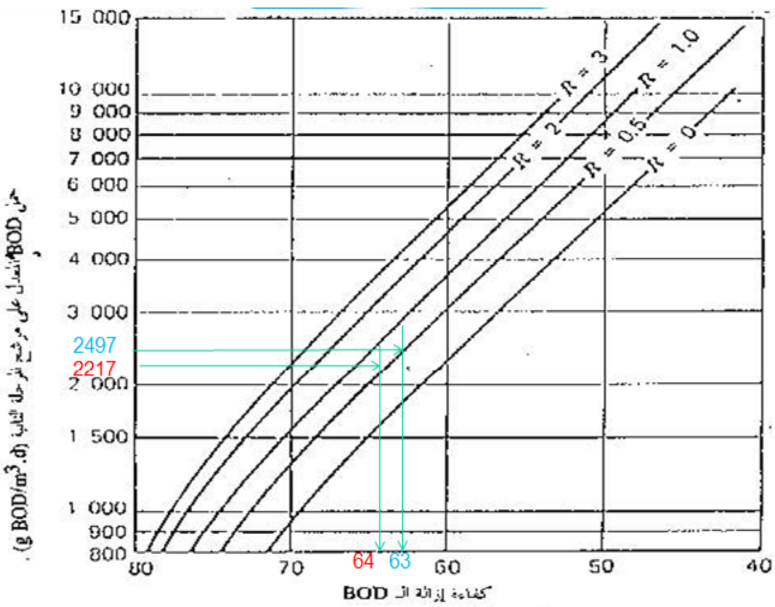
8. التقييم للمرشحات الحجرية باعتبارها معالجه على مرحلتين

1.8. تقييم الصيف

تركيز BOD_5 =410 mg/l، كفاءة المعالجة في المرحلة الأولى للمرشحات 57%=E%، نسبة المياه المعاده R= 0.5 ، درجة الحرارة C^O 20 ، نجد أن الحمل العضوي المعدل على مرشح المرحلة الثانية = 2217 $g/m^3.d$،نوجد كفاءة المعالجة في المرحلة الثانية للمرشحات بواسطة المنحنى (شكل رقم(9 هي64 =E %

2.8. تقييم الشتاء

تركيز BOD_5 =210 mg/l، كفاءة المعالجة في المرحلة الأولى للمرشحات 71% =E% ،نسبة المياه المعاده R= 0.5،درجة الحرارة C^O 20 ، الحمل العضوي المعدل على مرشح المرحلة الثانية = 2497 $g/m^3.d$، نوجد كفاءة المعالجة في المرحلة الثانية للمرشحات بواسطة المنحنى (شكل رقم (9 هي 63% =E في العينة السابعة بتاريخ 2012/07/10



الشكل 9: منحنى تحديد كفاءة مرشح المرحلة الثانية للمرشح الحجري في الصيف والشتاء]4[

3.8. المرشحات البيولوجية الحجرية

من خلال نتائج تحليل العينات التي تم جمعها أثناء البحث لوحظ ارتفاع كفاءة المعالجة في إحدى المرشحات الحجرية الأربعة وهو المرشح الحجري رقم (7) والذي تم التأكد من قبل مشغلي المحطة انه يتم بشكل دوري التنظيف في هذا المرشح والذي بدوره يساعد في عملية الانسلاخ أي أن عملية التشغيل والصيانة تساعد في رفع كفاءة المعالجة. بعد المرشح الحجري اتضح وجود فارق بين المخرجات من المرشح نفسه والمخرجات من خزانات الترسيب النهائي مما يدل على إن الأمر يتطلب ضرورة وجود خزان ترسيب بعد المرشح البلاستيكي حتى لا تدخل البكتيريا والمواد المترسبة الخارجة من المرشحات البلاستيكية إلى المرشحات الحجرية مباشرة دون المرور بخزان الترسيب والتي تؤدي إلى انسداده.

وبالمقارنة مع محطة معالجة مياه الصرف الصحي بالعكاشية في مكة المكرمة بالسعودية والمكونة من مرشحات بيولوجية،فإنه من خلال مقارنة نتائج قياس تركيز BOD_5والذي يتراوح بين(204-298) mg/l والخارج يتراوح (29-42)mg/l أي بكفاءة قدرها 86 % فإن كفاءة محطة العكاشية أقل من محطة حجه مما يعني انه كلما زاد تركيز BOD_5 تزداد الكفاءة[8]،[18].وعند المقارنة مع محطة معالجة مياه الصرف الصحي بحمص- سوريا،فقد وجد أن المرشحات البيولوجية تعمل بشكل متوافق مع المؤشرات التصميمية حيث كانBOD الداخل 524mg/l بينما كان الخارج27mg/l أي بكفاءة95 [17] %،أعلى بقليل من كفاءة معالجة محطة حجه (91 %).من خلال مقارنة تركيز BOD_5 الداخل والخارج وكفاءة المعالجة في خزان امهوف لمحطة حجه وكذلك محطة زبيد. وجد أن تركيز BOD_5 الداخل خزان امهوف في محطة زبيد بمتوسط جميع التجارب التي تم تنفيذها في عام 2011 هو(849 mg/l)،الخارج من خزان أمهوف(277 mg/l)، بمتوسط كفاءة معالجة [2] (67%).ومن خلال ذلك يتضح أن كفاءة المعالجة في خزان امهوف في محطة زبيد أكثر من كفاءة المعالجة لخزان امهوف في محطة حجه وذلك يرجع إلى أن درجة الحرارة في مدينة زبيد أعلى من درجة الحرارة في محطة حجه.

الاستنتاجات

1. تستقبل محطة معالجة الصرف الصحي بحجه تدفق يتراوح بين (1000-1300) m^3/day وهذه القيمة تعادل 50% من الطاقة التصميمية الهيدروليكية (2428 m^3/day).

2. وجود ارتفاع كبير في تركيز BOD_5 الداخل المحطة حيث وصل 2500 mg/l، الذي يمثل 3 أضعاف التركيز التصميمي المقدر [13] 843 mg/l .

3. بلغ الحمل العضوي على المحطة خلال فترة الدراسة 2978Kg/d بينما الحمل التصميمي 2047Kg/d وبالتالي يعتبر هذا الحمل اكبر من الحدود التصميمية.
4. يعمل خزان امهوف بكفاءة معالجة عاليه تتراوح في الصيف بين(39%-80%) وفي الشتاء بين(49%-65%) والتي تفوق الأسس التصميمية والمقدرة 30% ، مما يعني أن المعالجة اللاهوائية ناجحة في هذه المحطة خاصة وبشكل عام في الوحدات اللاهوائيه عندما يزيد الحمل العضوي عن التصميمي[8]،[7].
5. تتم المعالجة في المرشحات البيولوجية البلاستيكية بنسبة كفاءة (56% - 27%) في الصيف و (-71 51%) في الشتاء اقل من نسبة الكفاءة التصميمية والتي تقدر 81% أي أن المرشحات البلاستيكية لم تصل إلى كفاءة المعالجة المطلوبة بحسب التصاميم بالرغم من نقص الحمل العضوي التشغيلي 1191Kg/d عن التصميمي 1428Kg/d، ويعزو هذا التدني إلى قلة نسبة تدوير مياه الصرف الصحي نتيجة لتعطل مضخة التدوير بينما وجد ارتفاع ملحوظ في تركيز الأوكسجينDO عندما تم إصلاح وتركيب مضخة إعادة التدوير. وطالما يعتبر الحمل العضوي قريب من الحدود التصميمية فإن المحطة يجب أن تعمل بكامل طاقتها بتشغيل المرشحين البلاستيكيين وعدم الاعتماد على مرشح واحد أثناء الصيانة.
6. تتم المعالجة في المرشحات البيولوجية الحجرية بنسبة كفاءة (48%-35%) في الصيف و(22%-2%) في الشتاء اقل من نسبة الكفاءة التصميمية والتي تقدر 83% أي أن المرشحات الحجرية أيضا لم تصل إلى كفاءة المعالجة المطلوبة بحسب التصاميم وذلك بسبب أن الحمل العضوي على المرشحات الحجرية يتراوح ((455kg/d–200kg/d في الصيف و ((384kg/d–250kg/d في الشتاء أي يقع ضمن وأكثر من الحمل العضوي التصميمي والذي يقدر 284Kg/d والذي بدوره يسبب انسدادات في المرشح ثم تدني للكفاءة. وطالما يعتبر الحمل العضوي في معظم الأحيان أكبر من الحدود التصميمية فإن المحطة يجب أن تعمل بكامل طاقتها بتشغيل المرشحات الحجرية كاملة وعدم الإعتماد على نصفها أثناء الصيانة. كما يتطلب الأمر أيضا ضرورة إنشاء أحواض ترسيب قبل المرشح الحجري نظرا لأن هناك مواد عضويه (بكتريا) تدخل في المرشح وترفع قيمة الحمل العضوي،أو إمكانية استبدال المرشحات الحجرية بمرشحات بلاستيكية.
7. تراوحت درجة الحرارة في مراحل المعالجة ما بين (21.5-22.8) درجة مئوية والتي تعتبر ضمن درجة الحرارة المناسبة والمطلوبة لحدوث المعالجة البيولوجية والتي تتراوح ما بين(20-30) درجة مئوية .
8. وجود قصور في عملية التدوير لمياه الصرف الصحي بسبب عدم توفير مصدر كهرباء بشكل مستمر ونتيجة للانقطاعات المستمرة للكهرباء وعدم إمكانية توفير مادة الديزل بشكل مستمر.
8. عدم وجود طحالب عند المخرج للمحطة مع مياه الصرف الصحي والتي قد تكون سببا في ارتفاع تركيز BOD_5 مما يعني أن النتائج صحيحه ولا يوجد أي مسببا خارجي، وكذا عدم وجود طبقات بروتينية متراكمة عند المخرج مما يعني انه لا يوجد مواد صناعية تدخل إلى المحطة وأن الزيادة في قيم BOD ناتجة عن قلة استهلاك المياه نتيجة لشحتها.

التوصيات

1. تعميم استخدام المعالجة اللاهوائية مثل خزان إمهوف في جميع المدن اليمنية نظرا لزيادة تركيز المادة العضوية في مياه الصرف الصحي من ناحية ومن ناحية أخرى تحويل الغاز الحيوي إلى طاقه كهربائية يتم الاستفادة منها في محطة المعالجة.
2. تنفيذ أحواض ترسيب بعد المرشحات البلاستيكية لمنع انسداد المرشح الحجري أو استبدال المرشحات الحجرية بمرشحات بلاستيكية لتوسيع مساماتها.
3. عدم توقيف احد المرشحات البلاستيكية أو الحجرية لغرض الصيانة كونه نتيجة للتوقف يؤدي إلى تدني المعالجة وانخفاض الكفاءة عما كان عليه أثناء التشغيل الكامل.
4. توفير مصدر الكهرباء أو المواد البترولية حتى يتم تشغيل مضخات إعادة التدوير بشكل مستمر وعدم توقفها حتى تتم عملية المعالجة بالشكل الصحيح، كما يمكن الاستفادة من مياه الأمطار وتجميعها في خزان ومن ثم تصريفها إلى مدخل المحطة حتى يتم تخفيف تركيز BOD_5 الداخل المحطة ورفع نسبة التدوير وبالتالي رفع كفاءة المرشحات البيولوجية المعالجة.
5. توفير مضخات لعملية التنظيف والصيانة لمنع انسداد الفتحات التي توزع المياه في المرشحات بالتساوي والتي من خلالها ترتفع عملية المعالجة.

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بيوغرافيا: المهندس محمد علي علوي السقاف، مهندس مدني من الجمهورية اليمنية، يحمل شهادة الماجستير في الهندسة المدنية، تخصص مياه وبيئة 2013 من جامعة صنعاء. حاصل على شهادة البكالوريوس في الهندسة المدنية 2007 من جامعة ذمار بالجمهورية اليمنية. يعملُ محاضراً في دورة الصرف الصحي، مركز المياه والبيئة في تأهيل ضباط مشاريع الصندوق الاجتماعيالعمل وكمهندس استشاري بالصندوق الاجتماعي للتنمية في مجال المساقط المائيه، مشاريع الطرق الريفية، تحليل المناقصات للمشاريع، اعداد الدراسات الاولية والتقييمية لمشاريع المدارس. كما يعملُ في القطاع الخاص كمهندس مقاول لمشروع الرصف الحجري والسفلتة، الى جانب العمل العمل في مكتب هندسي كمهندس مقيم لمشروع رصف.

Use of Treated Sludge (KALA Fertilizer) to Improve Water Productivity

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Abstract: Haya Water has developed a "Kala Composting Plant" to enable the efficient reuse of sewage bio-solids and green waste enabling their conversion to a compost product that can be used for agriculture, landscaping and for individual gardens. However, high application of sewage bio-solids could result in heavy metals accumulation and many health problems. Therefore, sewage bio-solids applied to agricultural land must be treated, tested and meet provincial quality standards. The objective of this study was to evaluate the effect of different fertilizers especially Kala compost on the quality of soil and crops. The study was conducted at Sultan Qaboos University, College of Agricultural & Marine Sciences, Agricultural Experiments Station open field with six commercial crops (cucumber, tomato, cabbage, lettuce, carrot and potato). Kala application improved soil physiochemical properties by increasing the water-holding capacity, reducing soil bulk density and adding mix nutrients compared to NPK fertilizer. Good plant growth was observed with higher plant production and better water productivity in Kala compared to NPK treatments. Generally, it can be concluded that Kala compost was a good media for plant growth supporting plant with many elements needed for high production. Chemical analysis did not show any problem of heavy metal accumulation either in soil or plant samples. Using Kala compost as a fertilizer will support organic farming practices but farmers should evaluate its applicability with long run applications.

Keywords: NPK fertilizer, heavy metal, commercial crops, Haya water, compost

Introduction

Sewage sludge or bio-solids, a byproduct of sewage treatment processes, is composed of organic compounds, macro and micronutrients, trace elements including toxic metals, microorganisms, and micro-pollutants. Micro and macronutrients serve as a source of plant nutrients, whereas organic constituents serve as soil conditioner. Sewage sludge pH is neutral to slightly alkaline and organic matter content is generally very high. Sewage sludge contains high concentrations of N, P, Ca and Mg. Potassium is, however, deficient in sewage sludges (Logan and Harrison, 1995). Sludge amendment improves soil properties such as porosity, bulk density, aggregate stability and water holding capacity. The problem related to sewage sludge application arises when it contains high concentrations of potentially toxic heavy metals. The release of heavy metals associated with sewage sludge is strongly influenced by soil pH, cation exchange capacity, organic matter, and mobility and speciation of specific metals (Korboulewsky, *et al.,* 2002). Excessive application of sewage sludge to soil has been found to increase the bioavailability of heavy metals, but the low doses of sewage sludge are not found to cause significant increases in heavy metal concentrations (Kulling, 2001). Sewage sludge amendment increases the production of a variety of plants including vegetables, cereals, grasses and trees. Use of sewage sludge also results in more robust plants with faster development and greater biomass production. Crops grown on excessively higher doses of sludge amendment into soils contain toxic concentrations of heavy metals compared to those grown on a lower dose of sludge amendment, as well as un-amended ones. The consumption of such plants might pose a serious risk to human health. However, the metal concentrations in the sewage sludge depend on several factors such as: (i) sewage origin, (ii) sewage treatment processes, and (iii) sludge treatment processes (Hue and Ranjith, 1994). Sewage bio-solids are often used as a fertilizer on farms to grow corn and cereal crops such as wheat. Using sewage bio-solids as a nutrient source for field or forage crops or for improved pasture could have many benefits: 1. improve soil fertility - offsetting the need for commercial fertilizers; 2. reduces production costs; 3. improves soil fertility; 4. enhances soil structure, moisture retention and soil permeability; 5. add organic matter-enhancing soil structure, moisture retention and permeability, while reducing the potential for wind and water erosion (Ramulu, 2002).

In Oman, “Haya Water” is a government company that is responsible for building, operating, and managing wastewater projects in Muscat Governorate. Haya Water has developed its pioneering Kala Composting Plant to enable the efficient reuse of sewage bio-solids and green waste enabling their conversion to a compost product that can be used for agriculture, landscaping and for individual gardens. With Kala Compost the company is achieving the dual benefits of finding a practical way to reuse water and green waste that will benefit farmers, municipal authorities and individual gardeners, while finding a way to process waste that prevents the build-up of greenhouse gases. However, high application of sewage bio-solids could result in heavy metals accumulation and many health problems. Therefore, sewage bio-solids applied to agricultural land must be treated by an approved process and they must be tested to determine nutrient content and to ensure they meet provincial quality standards. The objective of this study was to evaluate the effect of different fertilizers especially Kala compost on the quality of soil and crops.

Methodology

Research studies were carried out to achieve the set goals through detailed experimentation at Agricultural Experiments Station (AES, SQU) open field and greenhouse facilities. In the first year, new field at AES was prepared by removing rocks and big stones. To improve soil physicochemical properties, the field soil was mixed with sandy soil brought by Muscat Municipality. The field was divided into 9 plots (8x17m) and each plot received either Kala compost (KALA) or inorganic fertilizer (NPK) or a mixture of both fertilizers (MIX). Drip irrigation system was installed all over the field. Commercial cucumber, tomato, cabbage, lettuce, carrot and potato were grown in each plot.

Soil salinity, moisture content and temperature were monitored by using wet sensor device. Moreover, direct soil samples were taken at depths of 0-15, 15-30 and 30-45 cm. Plants growth and yield of each crop treated by different fertilizers was observed. Fruits quality and quantity were assessed. Samples from soil and plants were taken for different physical, chemical and biological analyses. All physicochemical analysis for soil and plants were done in soil and water labs (SQU) following standard methods and using inductively coupled plasma (ICP) machine for metals analysis. Data were analyzed statistically using the analysis of variance and the means were compared at the probability level of 5% using least significant difference (LSD).

Result and Discussion

1. Soil Samples

Soil textural analysis depicts that all plots got almost same soil which is loamy sand. Amending soil with different treatments could change some physicochemical properties of the media such as organic matter, water holding capacity and bulk density. Kala compost had high amount of organic matter (figure1) compared to other treatments.

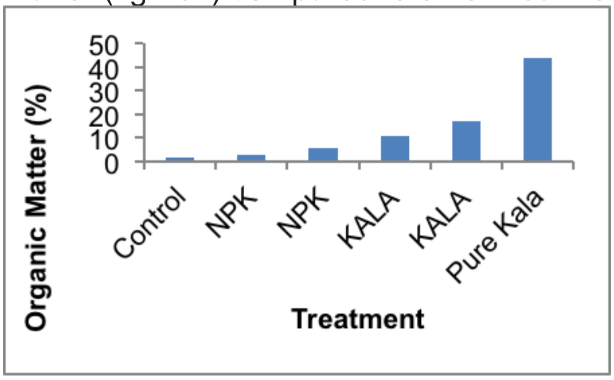

Figure 1: Organic Matter Found in all Treatments

This amount of the organic matter was the main reason for improving water holding capacity of the soil amended by Kala compost (figure 2) and enriching the fertility of the soil by exchanging more nutrients with soil and plants roots. In addition, Kala compost reduced soil compaction problem by improving soil bulk density (table 1).

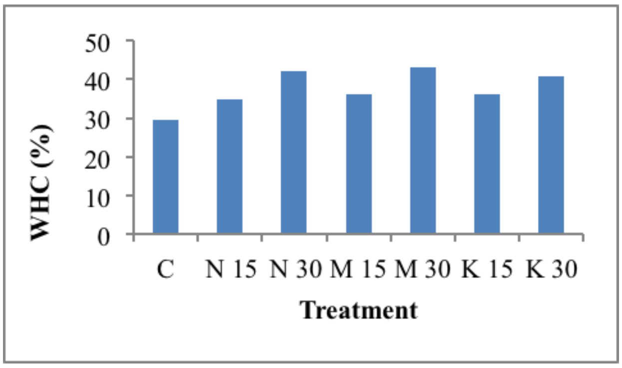

Figure 2: Soil Water Holding Capacity as Affected by Different Treatments

Table 1: Soil Bulk Density

Treatment	g/cm^3
Kala	1.81
NPK	2.07

From figure 2, it can be seen that almost all treatments (KALA, NPK, MIX) with depths of 15 and 30 cm held same amount of water. This was expected because all of them have same texture. However, the extra water that should be held by Kala compost was almost used by better growth of plant grown in Kala compared to NPK treatments. The good result for bulk density under Kala compost was supporting Kala application in which organic fertilizer can reduce soil compaction, improve soil structure and root growth. Ramulu (2002) reported that organic matter added to the soil as sewage sludge composts improved the soil properties, such as bulk density, porosity and water holding capacity.

2. Soil Salinity

Soil salinity is one of the good parameters for evaluating soil fertility and salt toxicity. From Figure 3, it can be seen that pure Kala has high value of salt content (electrical conductivity: EC) but when it was mixed with soil and irrigated with good quality of water, the EC value dropped to low level. Those salts could be diluted or leached to the lower horizons and used by plants as nutrients needed for plant growth.

At the end of the study (figure 3), it is very clear that NPK had high amount of salts compared to Kala compost and most of the salts were leached down to lower horizons whereas salts found in Kala compost was mainly fixed within upper horizon leaving lower horizon with less salts. Generally, Kala compost held less salts compared to NPK treatments but in same time all those salts were used to support plant growth and released slowly so they can be used as nutrients for long term without any problem of toxicity.

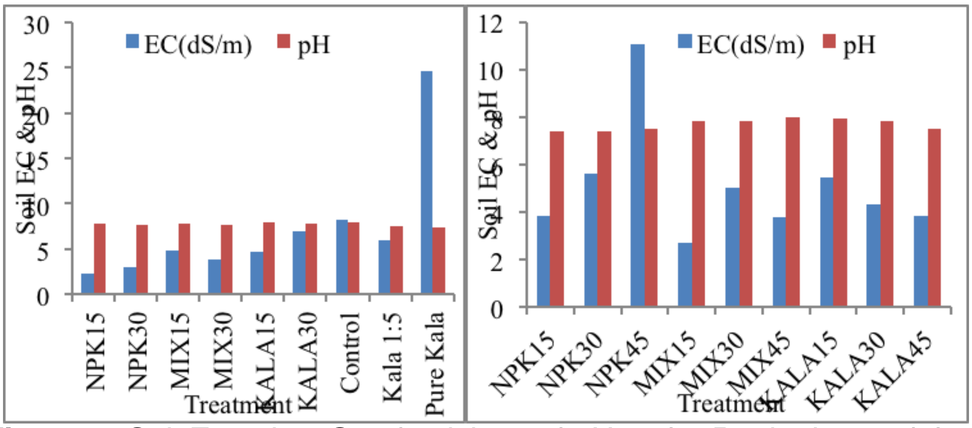

Figure 3: Soil Electrical Conductivity and pH at the Beginning and the end of the Study

Generally sewage sludge is composed of organic compounds, macronutrients, a wide range of micronutrients, non-essential trace metals, organic micro pollutants and microorganisms (Kulling, 2001). The macronutrients in sewage sludge serve as a good source of plant nutrients and the organic constituents provide beneficial soil conditioning properties (Logan and Harrison, 1995).

3. Plant Samples

From figures 4, 5, & 6, it can be seen that the best production for all tested crops was either with Kala compost or mix treatment of both fertilizers. It does not mean that NPK treatment was bad but may be some plants did not get the right amount of fertilizer in the right time. The mix treatment was almost the best and that was confirmed by many studies around the world. In mix treatment plant can get continuous release of nutrients. In other world, fast release of nutrients from NPK fertilizer and slow release of nutrients Kala compost. However, it seems that Kala compost was creating a good environment for plant by releasing multi nutrients, reducing evaporation and keeping much water in the root zone compare to NPK treatments.

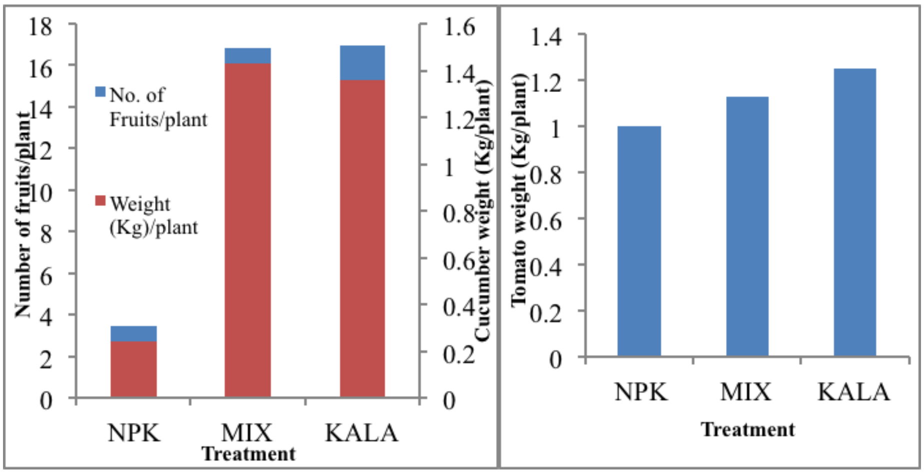

Figure 4: Average Production for Fruit Plants (Cucumber and Tomato).

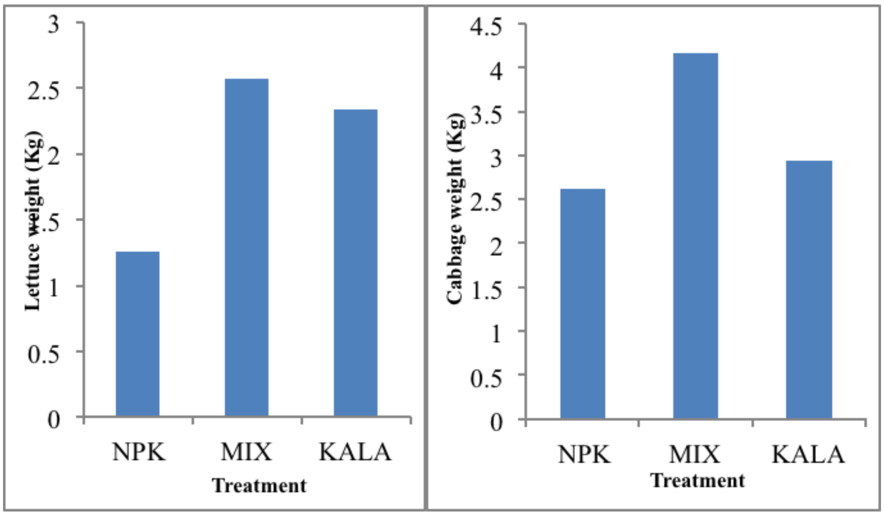

Figure 5: Average Production for Leaf Plants (Lettuce and Cabbage).

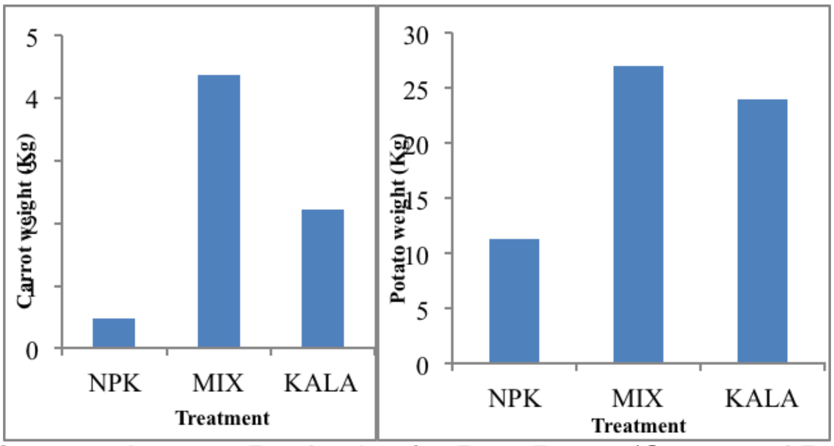

Figure 6: Average Production for Root Plants (Carrot and Potato).

What was found in all figures can be confirmed by statistical analysis shown in table 2. It is clear that Kala and Mix treatments gave almost similar values with non-significant differences between them. However, NPK treatment was the lowest but sometimes it gave non-significant values compared to Kala and Mix treatments.

Table 2: Statistical Analysis for Plant Production (g) under Different Treatments*

Treatment	Cucumber	Tomato	Lettuce	Cabbage	Carrot	Potato
NPK	200.74 c	1122.89 a	529.33 c	1421.21 a	109.83 c	1872.02 c
MIX	830.24 a	1269.27 a	1100.60 a	1808.64 a	729.08 a	4496.77 a
KALA	759.04 a	1402.64 a	1322.43 a	1334.73 a	601.71 a	3990.02 a

**Means in the column with same letter indicate no difference at Duncan's Multiple Range Test at P< 0.05.*

After proper treatment the complex organic and the inorganic compounds of sewage were broken down into simpler forms (Metcalf and Eddy, 2003), and thus the final treated sludge became useful and beneficial to the seedling growth. Boswell (1975) reported an approximately 30% higher yield of fescue (Festuca arundinaceous Schreb.) under excessive application of sewage sludge (5.6 Mt/ha dry wt.) given three times over a 2-yr period compared to the controls. In other study, it was found that the sludge amendment at the rate of 80, 160 and 320 t/ha dry wt. in soil increased the average dry weight of sunflower plants (Helianthus annus L.) (Morera et al., 2002). The municipal biosolids amendment for cultivation of carrots and chard on irrigated soils showed significant increase in yield compared to those grown in unamended soil (Nielson et al., 1998). A similar study with cotton (G. hirsutum) also showed advancement of flowering and fruiting by 2–3 weeks under sludge-amended soil as compared to fertilizer amended ones (Tsakou et al., 2001a). The faster development and greater biomass production in plants grown in sludge-amended soil may be responsible for an early reproductive cycle.

4. Metal Concentrations at Soil Samples (ICP Data)

From table 3, there were differences in metal concentrations between NPK and KALA especially in macro elements such as Ca, K and P. However, the values of most micro elements were almost same in all treatments and not significantly affected by different fertilizer applications.

Table 3: Soil Metal Concentration (mg/l) at the End of the Study*

Treatment	Na		Ca	Mg	K	P	As
NPK	726.96a		1029.51a	164.82b	25.16ab	0.04a	0.66a
KALA	319.98ba		1060.66a	232.89a	21.34bac	0.20a	0.48a
MIX	279.66cb		877.50a	170.82b	19.62cb	0.18a	0.37a
Treatment	Be		Cd	Co	Cr	Cu	Fe
NPK	0.31cb		0.30b	0.30a	0.33b	0.30b	0.30cb
KALA	0.31bca		0.30b	0.30a	0.36a	0.32a	0.31bca
MIX	0.32ab		0.32a	0.29a	0.34b	0.32a	0.32ab
Treatment	Li		Mn	Mo	Ni	Pb	Sb
NPK	0.33a		0.31c	0.48a	0.30b	0.70a	0.11a
KALA	0.32a		0.36a	0.50a	0.33a	0.53a	0.12a
MIX	0.33a		0.34b	0.50a	0.30b	0.63a	0.13a
Treatment	Sr	Ti	V	Zn	Tl	Si	B
NPK	7.88a	0.32a	0.25a	0.47ab	0.43a	1.46b	3.03a
KALA	7.67a	0.32a	0.24a	0.39cb	0.34a	1.89a	2.03b
MIX	7.06a	0.32a	0.26a	0.40bac	0.15a	1.80a	1.05c

**The mean difference is significant at the 0.05 level.*

Hernandez, *et. al.,* (1991) conducted a study to analyze the influence of sewage sludge application to a Calciorthid soil on the soil availability of macronutrients (N, P, and K) and heavy metals (Fe, Cu, Zn, Mn, Ni, Cr, Cd, and Pb). Total N and extractable N and P contents increased in the sludge-amended soil, whereas the extractable K remained unaltered. Extractability of Fe, Cu, Mn, Zn and Pb increased due to sludge application as compared to the control. Relatively high rates of sludge application increased the cation exchange capacity, which helped to retain essential plant nutrients within the rooting zone due to additional cation binding sites (Soon, 1981). Such responses, however, depend upon the sewage:soil ratio. The higher organic matter proportion in sludges decreased bulk density and increased the aggregate stability. These improvements in soil physical properties increased water-holding capacity by promoting higher water retention in sludge-amended soils (Ojeda, *et. al.,* 2003).

5. Metal Concentrations at Plant Samples (ICP Data)

Evaluating micro-elements concentration in fruity plants, it can be seen from Figures 6 & 7, that there were small changes between NPK and KALA treatments. For short season plant such as cucumber (figure 6), it can be seen that in some cases NPK gave higher values for some elements such as in Fe, Zn and B. Whereas Kala gave higher values than NPK for others such as Mo and Sr.

For leafy plants, it can be seen from figures 8 & 9, that similar scenario was repeated and small variations were found between Kala and NPK fertilizers.

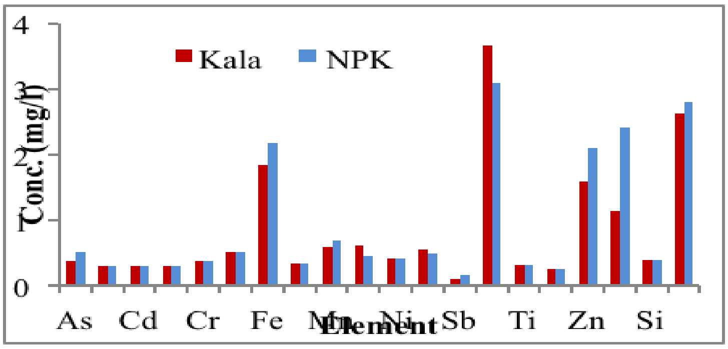

Figure 6: Heavy Metals Concentrations in Cucumber

For long season plants such as tomato (figure 7), it can be seen that NPK was also higher in Zn, As, Sr, and Tl. Whereas Kala elements were almost similar to NPK with slight increment in Pb, B and Fe.

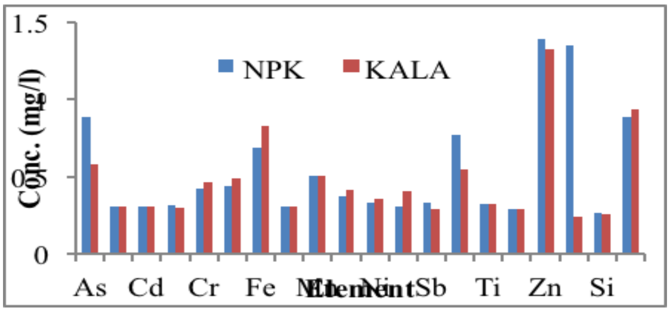

Figure 7: Heavy Metals Concentrations in Tomato

For leafy plants, it can be seen from figures 8 & 9, that similar scenario was repeated and small variations were found between Kala and NPK fertilizers.

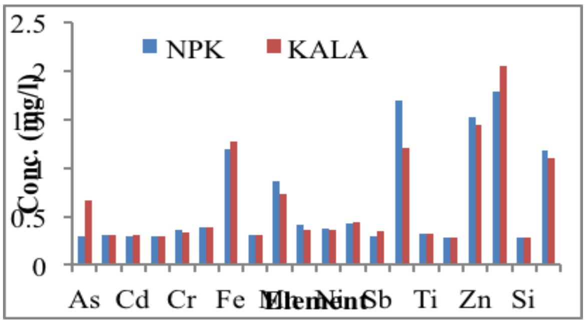

Figure 8: Heavy Metals Concentrations in Cabbage

For very short season plant such as lettuce (figure 9), it can be seen that all elements were in very low concentrations except Fe which was almost found in high concentrations in all crops of both treatments NPK and Kala

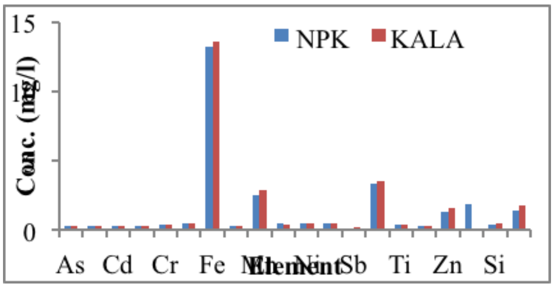

Figure 9: Heavy Metals Concentrations in Lettuce

For root crops such as carrot and potato (figures. 10 &11), Fe was high in NPK treatment of both crops. Whereas, Zn was high in carrot and low in potato.

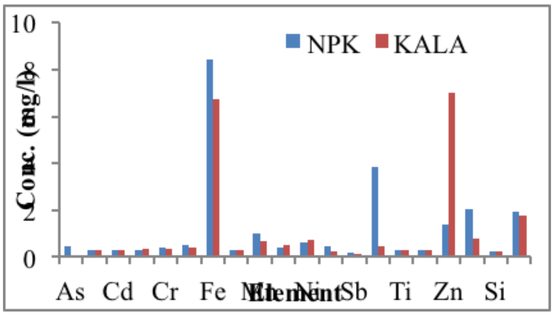

Figure 10: Heavy Metals Concentrations in Carrot

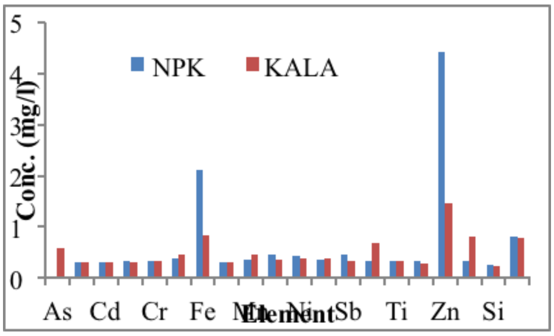

Figure: 11: Heavy Metals Concentrations in Potato

Several studies have evaluated the tissue concentrations of nutrients and heavy metals in plants when grown in the sewage sludge amended soil. The accumulation pattern varied with soil type, plant species, phenology and chelating effects of other metals (Mahler, *et al.,* 1980). The addition of an excessive dose of sewage sludge from an urban industrial area of Atlanta, Georgia, USA to pot grown fescue at a rate of 5.6 Mt/ha (dry wt.) three times over 2 years significantly increased the concentrations of Cd, Cr, Cu, Mn, Pb, Zn and P in plants (Boswell, 1975). K, Ca and Mg concentrations did not show significant difference between the plants grown with and without sewage sludge application. However, no toxic or detrimental effects on fescue were noted (Boswell, 1975). Cd, Zn, Ni, Hg and other toxic metals were found to be increased in sweet corn when grown on sludge-amended soil, but the accumulation was lesser in corn kernels than in leaves and roots (Dowdy and Larson, 1975). Higher amounts of Fe, Cu and Zn were absorbed by the plants grown in sludge-amended soil than those grown in the control soil (Hernandez, *et al.,* 1991). A single application of 0, 112, 225 and 450 t/ha dry wt. biosolids caused increments in Cu and Zn concentrations in snap beans (Phaseolus vulgaris L. Tendergreen) linearly with increasing amendment rates (Dowdy et al., 1978). Concentrations of heavy metals (Fe, Cr, and Ni) were higher in flax plants grown in sludge-amended soil (10:1) and irrigated by STP water (Tsakou, *et al.,* 2002). In the wood tissue of poplar trees (Populus euramericana) the sewage sludge amendments had, however, no effects on concentrations of heavy metals or nutrients (Tsakou, *et al.,* 2003).

6. Water Productivity

Water productivity factor can be calculated by comparing water used in this study with plant production (Water productivity = Total fruit weight, Kg/ water applied, m^3). Same amount of water was used to irrigate all crops and as it was found in Figures 4-6, that Kala compost gave better yield than NPK treatment which means that water productivity of Kala compost was higher than NPK treatment.

Conclusion and Recommendations

From this study, it can be concluded that Kala compost was a good conditioner for soil supporting plant with many elements needed for high production. Chemical analysis did not show any problem of heavy metal accumulation either in soil or plant samples. Biologically, all crops grown in this study were free from any harmful bacteria that could affect human health. The finding of this year must be confirmed by second and third year studies for a long term evaluation, so that all aspects related to Kala compost can be clarified and reported.

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Day 3
Wednesday 22 October 2014

SESSION 2D
GROUNDWATER MANAGEMENT

Keynote

Managed Aquifer Recharge – Aquifer Storage and Recovery: Regional Experiences and Needs for Further Cooperation and Knowledge Exchanges in the MENA Region

Ralf Klingbeil

Regional Adviser Environment and Water, UN ESCWA, Beirut, Lebanon

Summary

In the Middle East and North Africa (MENA) water scarcity is one of the prevailing regional characteristics; challenging water and environmental management as well as the overall sustainable socio-economic development at national and regional levels. Today, in many places traditional renewable water resources from surface and groundwater are not anymore sufficient to sustain livelihoods and lifestyles of the people. Government's attention has often focused primarily on making "new water" available to fulfill ever increasing water demands through desalination, inter-basin transfers, abstraction of renewable groundwater resources beyond sustainable limits and use of non-renewable groundwater. More efforts can still be made to manage water demand, increase water efficiency in all sectors, manage and protect existing surface and especially groundwater resources more sustainable, improve institutional environments and increase water governance at large.

At national level UN ESCWA supports its 17 member states with technical and policy advice. In this context ESCWA has implemented assistance and shared experiences between member states in many areas of sustainable development, environmental, energy and water management. As part of this support ESCWA is also addressing groundwater issues such managed aquifer recharge / aquifer storage and recovery, groundwater governance and groundwater management e.g. in the context of current water scarcity and drought in the Mashreq sub-region, focusing on technical, scientific and governmental as well as regulatory challenges.

This presentation will focus on experiences in the region with managed aquifer recharge / aquifer storage and recovery using storm water runoff, treated wastewater or surplus desalinated water. It will also discuss the specific national or regional challenges for the implementation and propose a number of opportunities to improve national approaches to managed aquifer recharge through more regional cooperation.

Biogrpahy: Ralf Klingbeil holds a PhD in Hydrogeology / Applied Geology from Tübingen, Germany, the equivalent of a M.Sc. in Geophysics from Kiel, Germany and a M.Sc. in Hydrogeology from Birmingham, United Kingdom. Mr. Klingbeil joined UN ESCWA in 2009 as Regional Advisor Environment and Water supporting ECSWA's 17 Member States on issues related to environmental and water policies and management. Since 2014 Mr. Klingbeil acts additionally as Network Coordinator for the Arab Integrated Water Resources Management Network (AWARENET), the Cap-Net regional network for capacity development in sustainable water management. Initially trained as hydrogeologist, geophysicist and geoscientist, he acquired more than 20 years of professional experience in university research, teaching, private consultancies, government institutions, advisory services for UN agencies and German federal ministries, working on water, groundwater and land management in Africa, Europe and the Middle East. Prior to his current appointment Mr. Klingbeil served as Senior Programme Officer at the UN-Water Decade Programme on Capacity Development (UNW-DPC) and as Project Coordinator in International Cooperation for the German Federal Institute for Geosciences and Natural Resources (BGR) managing and coordinating advisory services for the German Federal Ministry for Economic Cooperation and Development (BMZ) in the fields of water and especially groundwater.

Groundwater From Ophiolite Aquifer: Flow Path And Recharge Rate

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Abstract: Ophiolites define the base of the hydrogeological system in Oman in addition to other lithologic types of aquifers such as alluvium, tertiary and Hajar Supergroup formations which play an important role in the recharge of waters in ophiolites. During this study, several water samples were collected from groundwater hosted in ophiolite aquifer in the North of Oman in order to determine the source of recharge and to construct the pathway of water in such aquifer. All samples were analyzed for their major ions, stable isotopes (^{2}H and ^{18}O) and strontium isotopes ($^{87}Sr/^{86}Sr$). All data either hydrochemical or isotopic were combined in this study. Stable isotope data indicate that ^{2}H ranged from -24 to 2.73.0‰ V-SMOW and those of ^{18}O from -4.72 to 1.45‰ V-SMOW. Variations of Sr concentrations in waters (about 0.1 to 0.57mg/L) are larger than those of the $^{87}Sr/^{86}Sr$ ratios (about 0.7084 to only about 0.7086). The relationships between ^{18}O and ^{2}H defined a regression line with a slope of 3.8 and an intercept of -1. Most of water samples do not plot near the global meteoric water line: (a slope of 8 and an intercept of -10) which indicate their enrichment in heavy isotopes due to evaporation while only few groundwater samples have not been subjected to significant evaporation. The plot of $^{87}Sr/^{86}Sr$ ratios versus 1/Sr indicate that groundwater of ophiolite aquifer is recharged from two main reservoirs: alluvium and limestone of HSG with nearly similar $^{87}Sr/^{86}Sr$ ratio but different concentrations of Sr. this paper aim to explore the groundwater flow path through the ophiolite aquifer and its contribution in the recharge processes. Estimation of the contribution of each reservoir indicated that only about 4 % of recharge is from alluvium against 96% from HSG aquifer.

Keywords: Ophiolite, recharge, groundwater, evaporation, Oman.

Introduction

As for many arid countries, the demand for water in Oman is increasing. In addition to saline intrusion, the depletion in water resources threatens hydrological system and quality of waters in Oman. Recharge processes to groundwater, connectivity between different aquifers and identification of sources can be assessed from chemical and/or isotopic composition of waters.

Several studies have been carried out about groundwaters in Oman to investigate the quality and determine the origin of groundwater using chemical and isotopic data (Gartner and Lee, 1986; Clark, 1987 and Weyhenmeyer et al 2002 and others). Clark (1987) collected a large number of rainwater samples from North Oman during July 1985 that he analyzed for their D and ^{18}O.

The study of Weyhenmeyer et al (2002) was concerned by the hydrology of groundwater collected from the eastern Batinah coastal plain of Northern Oman between 1995 and 1998 and reported that there are two sources of water vapor in the study area, one northern from Mediteranean and the other southern (Indian ocean). The study of Gartner and Lee (1986) determined the origin and residence time of groundwater in the alluvial and bedrock aquifers between Manah and Adam areas.

These diverse studies concerned by stable isotopes combined to chemical data of waters hosted in individual aquifers. The main aquifers in Oman consist in Hajar super group, Alluvium, Tertiary limestone and Ophiolite. The concern of this study, waters which are hosted in particular in ophiolite. In addition to stable isotopes used previously, strontium isotopes have been analysed.

The major objective of this study is an investigation of chemical and isotopic characteristics of waters hosted in ophiolite aquifer. This investigation is carried out to identify the source or sources of recharge to the ophiolite aquifer as well the mixing of waters between different sources.

I. Study Area

The study area covers a total geographical area of about (35405km^2). It is bounded by Oman Sea from the North with an extending coast of about 300 kilometers up to the United Arab Emarities (UAE) border. The study area is characterized by apparent differences in topography and rainfall intensities and runoff and therefore expected difference in groundwater occurrence and quality (Graf, 1984).

The study area is characterized by hot summers and cold winters. The average temperature in the summer season ranges between 27^{o}C and 37^{o}C in the plain and coastal areas where it is about 17^{o}C to 23^{o}C in the high mountainous areas (MRMWR, 2005). The evaporation rates unsteady due to the variations in topographical features. The average rainfall calculated for North Oman is about 100 mm.

The study area is characterized by diversified geology that extends from Precambrian to recent. It comprises in general five main rock sequences, Hajar super group (HSG), Hawasina, ophiolite, tertiary limestone and recent alluvial deposits (Glennie, 2005; Al Abri, 2009). In the core of the Jabal Al Akhdar that represents the highest elevation, metamorphosed rocks of pre- Permian age are reported (Glennie, 2005 and others). Away from the core of the jabal Al Akhdar, to both sides of the flanks, the rocks are found in the following order in both sides: HSG, Hawasina, ophiolite and tertiary (Figure 1) forming a major anticline with younger rocks away from the core. The alluvium is formed unconformably on the top of these sequences with increasing thickness away from the core. During this study the investigated groundwater samples will be only those collected from ophiolite aquifer.

Material And Methods

During this study, several groundwater samples hosted in Ophiolite aquifer of North Oman were collected. All samples were collected in a plastic high-density linear polyethylene, each site have been sampled in three bottles of 1L each and in one of 500 mLvolume. The 500 mL bottle was acidified by 5% nitric acid for purpose of anions analysis. All samples were labeled with a clear reference number, time and date and preserved in a cool box during transportation and once in the laboratory they were kept in a very cool environment (T°C<5). All samples were filtered through 0.45*μ* diameter and titrated for alkalinity which was calculated before sending the samples for lab analysis.

Immediately after samples have been taken, temperature T°C, electrical conductivity (EC), pH, dissolved oxygen (DO) and total dissolved solids (TDS) were measured using Aqua-read meter.

All samples were analyzed for their major elements, trace elements, stable isotopes and strontium isotopes (table 1). During this study only major elements, stable isotopes and strontium data will be discussed.

Table 1: Chemical and isotopic composition of rain water collected during this study. Concentrations are in (meq/l).

This study	Ca	Cl	K	Mg	Na	SO4	pH	_^{18}O	_D
	meq/L							per mil	
Arabian sea [1]	0.733165	0.39014	0.04552	0.15576	0.36587	0.23	0.09	-1.98625	-2.175
Indian ocean [2]	0.0785	0.2765	0.00635	0.0423	0.2342	0.06	5.95	nd	nd
	0.009	0.164	0.10256	0.039	0.146	0.05	4.7	nd	nd

(*Ref.* [1] Praveen, *et al,* 2007*)/* [2] Das, *et al,* 2011)

Major and minor ions, alkalinity and selected trace elements were analyzed at the Laboratory of the Ministry of Water Resources (MRMWR) in Muscat within 2 weeks of sampling. Alkalinity was determined by Radiometer autotitrator system TIM 90. Cations were analyzed by standard ICP- OES (inductively coupled plasma spectrometry, Optical Emission Spectrometry) and anions by ion chromatography. The chemical analyses were only accepted when the ion charge balance was better than ±5%.

Analysis of Oxygen ^{18}O and D for most of samples were determined in Ottawa University- faculty of science, Earth Science G.G. Hach Isotope laboratories. Analysis of ^{18}O and D were determined in Environmental Isotope Laboratory ETLAB at University of Waterloo in Canada. Routine precision for hydrogen was +/- 1 permil whereas routine precision for oxygen is +/- 0.25 per mil. The results were reported with respect to International Atomic Energy Association IAEA international standard Vienna standard Mean Oceanic Water VSMOW.

The D/H and ^{18}O/^{16}O ratios are expressed in delta values, δ, in units of per mil relative variation with respect to Vienna Standard Mean Ocean Water (V-SMOW). _ is defined as:

_= Rsample -Rstandard/Rstandard

where R-sample is the ratio of the heavy to the light isotope measured for the sample and R-standard is the equivalent ratio for the standard. Analytical reproducibility was better than 1‰ and 0.25‰ for δ^{18}O and δ D, respectively.

Result and Discussion

In parallel to groundwater hosted in ophiolite aquifer, the isotopic and chemical characteristics of precipitation sampled collected during this study will also be discussed below.

1. Chemical Characteristics

1.1. Precipitations

Geochemical data of precipitations collected during this study are included in Table 1. The available chemical data of rainwater concern those collected from Musandam and Bahla (Figure 1) during the same period and supposed to have the same source. For both precipitations from Bahla and from Musandam, concentrations of elements largely exceed those in the Arabian sea and those in Indian ocean which suggest the enrichment of elements in precipitations due to other sources.

Large difference is observed between concentrations of elements in precipitations collected from Musandam and those from Bahla, which may indicate continental sources such as dissolution of dust more important in precipitations fall on Bahla.

The observed ratio Na/Cl showed that Na and Cl in precipitations (Table 1) collected from Munsandam are most likely from marine source, while in precipitations from Eastern Batinah previously analysed by (Weyhenmeyer *et al,* 2002) and from Bahla collected during this study Na and Cl concentrations seem to be provided from an additional source. The Mg/Ca ratio much lower than those calculated from Arabian sea and Indian ocean, suggest a local source for Ca which is more important in Musandam than in Bahla (Table 1). Previous studies (Adhikary et al., 2007; Das et al, 2011) have attributed Ca in precipitations to transported crustal dust from distant continents. Difference between chemical composition of precipitations collected during the same event with the same source but in different locations should reflect local processes inducing modification of their chemistry, and fractionation of their isotopic composition after their infiltration, which produce groundwater with different isotopic signatures that we will be investigated below.

1.2. Groundwater

The average chemical composition of groundwater collected from Ophiolite aquifer is included in table 2. The data of individual groundwaters are available upon request. According to the total dissolved solute (TDS) classification, groundwaters from ophiolite belong to the brackish type (TDS> 1000 mg/l).

Table 2: Chemical and isotopic composition of groundwater collected from ophiolite aquifer during this study. Concentrations are in (meq/l)

	_^{18}O	_D	EC	HCO3	Ca	Cl	K	Mg	Na	NO3	SO4	Sr	^{87}Sr/^{86}Sr
			_s /cm									(meq/L)	
Average	-1.20	-5.56	1179	3.72	2.33	5.23	0.09	4.72	5.03	0.43	3.02	0.03	0.70842
Min	-4.72	-24.01	393	1.28	0.07	0.84	0.03	0.001	0.23	0.001	0.001	0.001	0.70799
Max	1.45	2.76	4730	5.77	14.25	36.94	0.52	23.28	35.72	5.43	15.53	0.22	0.70864
Standard deviation	1.06	4.81	938	70.79	2.65	6.79	0.08	3.69	6.91	0.83	3.36	0.04	0.00024

The major ion chemistry data revealed that the most predominant cationic constituents consist in Na followed by Mg while the most dominant anion consist in Cl^- followed by SO_4^{2-}. The plotting of chemical data of waters from ophiolite aquifer in Gibbs diagram (TDS=f(Na/Na+Ca)) (figure 1) suggests that the interaction with rocks is the dominant factor controlling the groundwater chemistry except for few samples where evaporation seems the dominant factor. The Ca/Mg ratio in groundwater from ophiolite aquifer is lower than 1 except for waters collected from 7 wells where the excess of Ca over Mg might be contributed from an important dissolution of carbonates (figure 1).

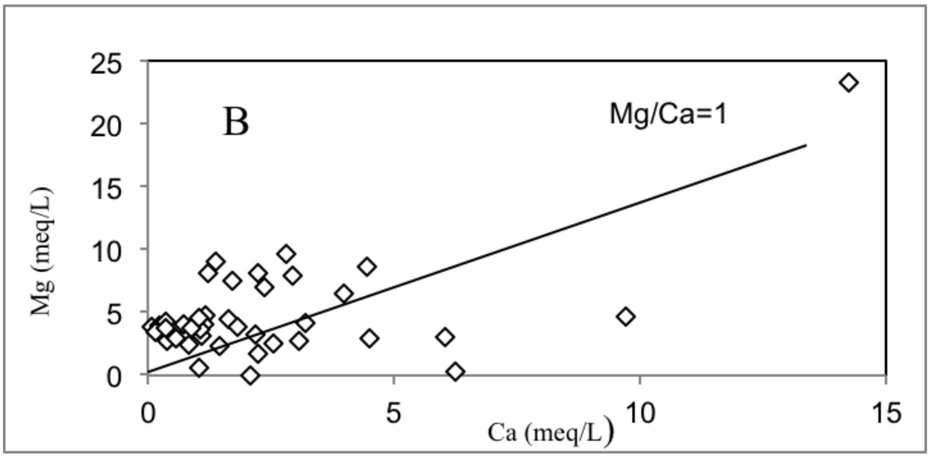

Figure 1: Gibbs Diagram and Variations of Ca/Mg Ratio

The Na/Cl ratio identify 3 groups of waters in ophiolite aquifer, 1) a group with a ratios less than 1, 2) a group with a ratio about 1 and 3) a group with a ratio higher than 1 (figure 2). A ratio lower than 1 indicates an input of Na and Cl from dissolution of halite, while a ratio higher than 1 indicates that dissolution of silicate is an important source of Na in groundwater of the ophiolite aquifer. The excess of Ca+Mg over HCO_3 (figure 2) indicates a contribution of dissolution of either carbonates or silicates in Ca and Mg.

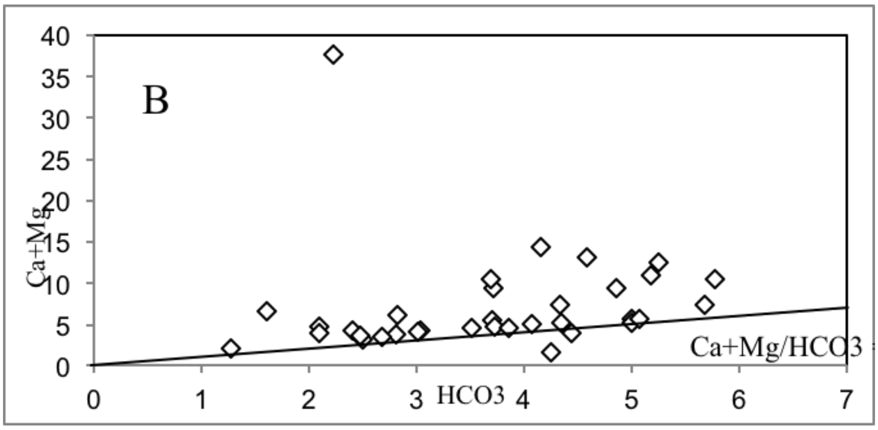

Figure 2: Variations of Na Versus Cl (a) and
Ca+Mg Versus HCO3 (b)

The multidimensional statistical analysis in principal components (PCA) was performed in order to determine the relationships between the different data. The analysis of waters from the ophiolite aquifer showed that Ca, Cl, Mg, NO_3, SO_4, Sr and Na which are well correlated with each other might be controlled by the same processes and provided from a common source. A slight correlation is observed between SO_4 and SiO_2. No correlation has been observed for K and SiO_2 with the other elements. A significant negative correlation between Ca and pH suggest a contribution of Ca from dissolution of carbonates.

2. Stable Isotopes

The data on stable isotopes of the groundwater are included in Table 2. These data have been used to determine the source and rate of recharge of groundwater hosted in the ophiolite aquifer.

2.1. Precipitations

During this study, isotopic composition of oxygen in precipitation ranged between -7.29 and 0.78 per mil while that of deuterium (D) ranged between -56.9 and 4.1 per mil. Mean isotopic ratios in precipitations are -1.98 for oxygen and -2.18 for D.

These values are much lower than those previously measured in precipitations of Oman, and those measured in precipitations of Bahrain and UAE (Rizk and Alsharhan, 1999). However oxygen isotope data are higher than those measured for the pure rain (-1.67) by Matter et al (2005).

The most ^{18}O-enriched value corresponds to rain collected from Manah (Table 2, Figure 4) and the most depleted rainwater was collected from Bahla. The most D enriched rainwater was collected from Musandam and the most D depleted rainwater was collected from Bahla.

No local meteoric water regression line (LMWL) was determined with the collected precipitation waters during this study. However, the precipitations collected from Manah and those from Bahla both plot on called Southern Oman Meteoric Water Line (SOMWL; $\delta 2H = 7.2\delta^{18}O - 1.1$). The other precipitations coincide with Northern Oman Meteoric Water Line (NOMWL; $\delta 2H = 5\delta^{18}O + 10.7$). Both lines have been defined by Weyhenmeyer (2002).

2.2. Groundwaters

The relationship between $\delta^{18}O$ and δD is used in order to highlight the mixing between relatively unaffected waters and those being influenced by evaporative or by mixing with other sources of waters. The study area is under the influence of three types of moisture influx: North from Mediterranean, South from India and local convective clouds.

The isotopic composition of the groundwater from ophiolite aquifer ranged from -24 to 2.73.0‰ V-SMOW for δD and from -4.72 to 1.45‰ V-SMOW for $\delta^{18}O$ (see table 2). The relationships between $\delta^{18}O$ and δD showed that most of groundwater samples collected from ophiolite aquifer during this study plot on a line which is representative of evaporation from ophiolite aquifer and which slope is 3.8 and which intercept is -0.96 (figure 3), between NOMWL N and SOMWL of Al Batinah Area (Weyhenmeyer *et al,* 2002). In comparison to GMWL ($\delta D=8\delta^{18}O + 10$, Craig, 1961), the inclination of most of groundwater from the GMWL indicates an enrichment in heavy isotopes due to evaporation.

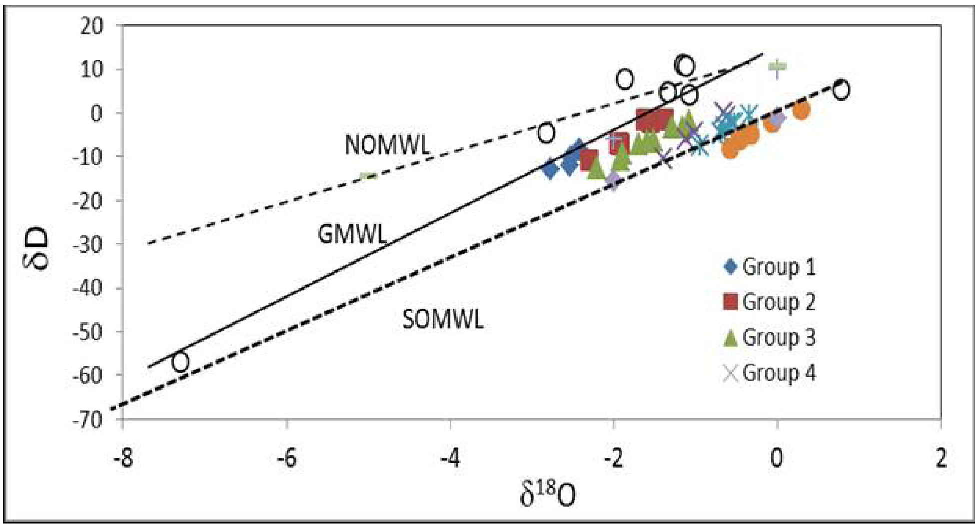

Figure 3: _D Versus _^{18}O Isotopes in Groundwater from Ophiolite Aquifer

Waters from the most enriched well are slightly more saline than waters from the most depleted well due to evaporation, and since TDS and conductivity in the most depleted waters are higher than in the most enriched waters (data are available upon request), we may suggest that groundwater collected from ophiolite aquifer are a mixture between modern waters which undergo evaporation and waters which are depleted in $\delta^{18}O$ and δD isotopes. Similarity between Mg concentration in waters of both wells on one hand and higher concentration of Ca in the depleted waters than in the enriched waters on the other hand, suggest that the end member recharging to waters of ophiolite aquifer result from infiltration of waters from HSG aquifer. The depleted waters should reflect the isotopic signature of waters from HSG prior to their interaction with Ophiolites and the enriched waters reflect the groundwater after infiltration and after evaporation.

A mixing binary equation between waters with the lowest ^{18}O and waters with highest ^{18}O indicate that contribution of waters from HSG are higher than 70% in groundwater collected at high elevation, while in groundwater collected at low elevation this contribution is less than 40%.

The other wells close to the GMWL, have not been subjected to significant evaporation prior to or during infiltration into the aquifers. This may be explained by rapid infiltration of rain water through fractures in the aquifer. The wells slightly deviated from GMWL have undergone a slight evaporation prior to their infiltration. Moreover, not all groundwater of ophiolite aquifer seem undergo the same rate of evaporation and plot near the SOMWL. However, several groups of groundwater are in parallel displacement from the GMWL. According to Weyhenmeyer et al (2000) the parallel offset can be explained by a mixture between rainfall from different sources. Since these groups of groundwater are in parallel distribution, they might have undergone the same rate of evaporation, but different sources.

In summary the distribution of groundwater hosted in ophiolite aquifer relative to GMWL and NOMWL and SOMWL, indicate a differentiation as follows: Groundwaters which plot on the SOMWL and where southern precipitations seem the source of recharge; groundwaters which plot on the GMWL;
groundwaters between GMWL and SOMWL: mixture between vertical infiltration and young waters which have undergone evaporation; andgroundwaters with smaller slope compared to SOMWL.

Although the main sources of recharge in ophiolite aquifer are the waters from HSG and those from alluvium in addition to vertical infiltrated waters, the different groundwaters are segregated in straight groups slightly parallel to each other (**see figure 4).** Although the rate of evaporation prior to infiltration remain similar for most of groundwaters this segregation may reflect diversified mechanisms of recharge such as: rate of infiltration, difference in elevation and depth of waters, rate of mixing between different sources of waters in addition to the continental effect.

3. Strontium Isotopes

It is known that Sr concentration and $^{87}Sr/^{86}Sr$ ratio in waters are the result of their interaction with host rocks. The difference between $^{87}Sr/^{86}Sr$ ratio reflects the type of rocks with which waters have interacted. In case of multiple types of rocks the $^{87}Sr/^{86}Sr$ ratio reflects a mixing of Sr from different sources.

Water-rock aquifer interaction depends on type of rocks and residence time of water. In groundwater from ophiolite aquifer strontium should reflect Sr signature in such rocks. Investigation of Sr concentrations and its $^{87}Sr/^{86}Sr$ ratio in several rocks from Samail ophiolite indicated low $^{87}Sr/^{86}Sr$ from 0.7028 to 0.7040 and Sr concentrations of about 87 ppm to 278 ppm (Marvin et al, 1981).

Sr concentrations in groundwater collected for this study from Ophiolites range from 0.1 to 0.57 mg/L and the $^{87}Sr/^{86}Sr$ ratio is about 0.7084 to 0.7086 (data available upon request). These values are higher than those measured by (Malcolm *et al,* 1981) in ophiolite rocks which indicates alternative sources of Sr in groundwater collected from this aquifer.

The relationship between $^{87}Sr/^{86}Sr$ and 1/Sr is considered to identify the different sources of Sr in this aquifer (figure 4)**.**

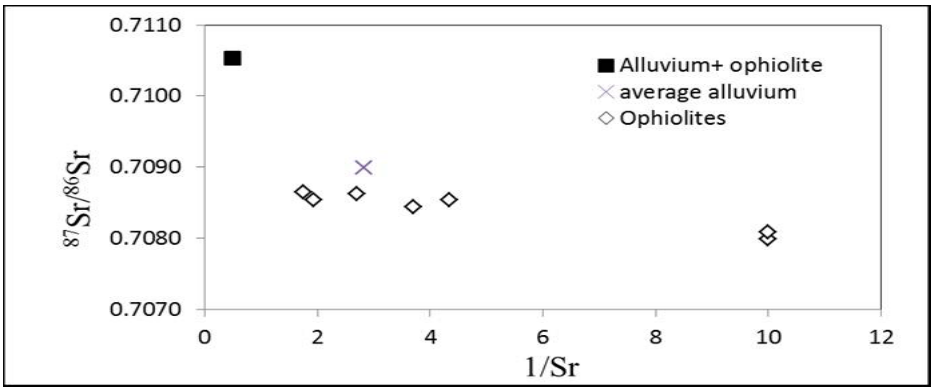

Figure 4: Variations of $^{87}Sr/^{86}Sr$ Versus 1/Sr Measured in Waters Collected from Ophiolite Aquifer

Although the difference between $^{87}Sr/^{86}Sr$ of different wells is not significant (less than 10%), it is clear that Sr in groundwater of ophiolite aquifer is yielded from 2 main sources 1) one with high concentration of Sr and slightly high $^{87}Sr/^{86}Sr$ ratio and 2) the other with low Sr concentration and low $^{87}Sr/^{86}Sr$ ratio.

The variation of Sr concentrations in each well is larger than the variations of their $^{87}Sr/^{86}Sr$ which may reflect the infiltration of water with different concentrations of Sr but the same $^{87}Sr/^{86}Sr$ ratio. The general tendency is that the end member with the slightly more radiogenic Sr (source 1) resulted from water-rock interaction at high elevation compared to the end member with less radiogenic Sr (source 2). The source 1 may reflect an infiltration of waters of high elevation and which have interacted with limestone of HSG (deposited during Crestaceous). During Cretaceous, the average $^{87}Sr/^{86}Sr$ recorded in sea water and limestone deposit was about 0.7073 to 0.7075 (Burke *et al,* 1982).

The source 2 of low elevation may reflect interaction of water with alluvium in addition to an effect of evaporation. There is no change neither for $^{87}Sr/^{86}Sr$ nor for Sr with age (Rashid *et al*, 2014). However the highest concentration of Sr is observed in young wells. The wells with slightly high $^{87}Sr/^{86}Sr$ ratios and high Sr concentrations are appropriate to modern recharge compared to the other wells.

The Sr in waters from ophiolite aquifer is defined by mixing between infiltrated young waters from HSG with limestone signature and old waters with Sr derived from interaction of waters with alluvium. The use of Sr isotopes for determination of water provenance has shown in several previous studies that water interaction with carbonate rocks released Sr with isotope signature around 0.708 to 0.709. Waters which have interacted with Permian to Mesozoic limestones and dolomites are characterized by $^{87}Sr/^{86}Sr$ of 0.7067 to 0.7080 (Weyhenmeyer et al, 2001) within the ranges of $^{87}Sr/^{86}Sr$ sea water during Crestaceous.

Principal component analysis results showed that Sr is highly correlated with Ca, Cl, NO_3 and SO_4 and Mg. The good correlation between Sr and Ca and Cl, suggests a common source for these elements, either carbonate or salt. Moreover the correlations of Sr with Cl and with Ca are stronger than that with Mg which may show that the contribution of limestone in the waters hosted in the ophiolite aquifer is more important than that of the ophiolite rocks.

There is no correlation between Sr concentration and depth of groundwater which may reflect an heterogeneity in ophiolite aquifer. However, fluctuations of Sr concentrations in shallow waters are slightly higher than those in deep waters which indicates that waters are well mixed at depth Rashid et al, 2014). The variation of Sr concentrations with elevation showed that there is less fluctuation of Sr concentrations at high elevation than at low elevation (Rashid et al, 2014).

4. Mass Balance

As was stated above, groundwater hosted in ophiolite aquifer is characterized by the contribution of two main reservoirs. A mixing equation with two end members can be used to evaluate the contribution from each reservoir for recharge of groundwater in ophiolite as follows:

F[Sr]R reservoir1 + (1-F)[Sr]R reservoir2= [Sr]R mixing

F: fraction of groundwater with low Sr concentration and slightly high $^{87}Sr/^{86}Sr$ ratio./ (1-F): fraction of groundwater with high Sr concentration./ R: $^{87}Sr/^{86}Sr$ ratio./ [Sr]: strontium concentration./ Reservoir1: HSG./ Reservoir2: alluvium:/ Mixing: average concentration in waters collected from ophiolite aquifer.

As is was stated above, the groundwater hosted in ophiolite is a mixture between waters which have interacted with HSG aquifer (reservoir 1) and waters from alluvium (Reservoir 2). Our calculations of the strontium budget based on these two end members (HSG and alluvium) indicates that about 4% of groundwater in ophiolite is recharged from alluvium against 96% from HSG. These values are slightly different from what was calculated by Weyhenmeyer (2002) (about 10% from alluvium).

Conclusion

(i) Sources of waters which are hosted in ophiolite aquifer have been identified in this study using stable and strontium isotopes.

(ii) The distribution of stable isotopes in waters hosted in Ophiolites identified waters affected by evaporation and those recharged directly from HSG. Chemical investigation indicated that evaporation should not be the only process in the segregation of groundwaters from ophiolite, other sources such as the interaction of waters with rocks and mixing between waters from different sources can explain the difference between isotopic data of groundwater hosted in ophiolite.

(iii) The distribution of strontium isotope data in waters from ophiolite aquifer indicated that there are two main sources of waters in this aquifer. These sources might be apparently the alluvium and HSG aquifers. A slightly more than 90 % of waters is provided from HSG and less than 10% from alluvium.

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Hydropedology and Water Resources Management: Case study of Al-Khoud Recharge Dam- Oman

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Abstract: A hydropedological study was conducted to investigate the impact of the construction of Al-Khoud recharge dam on soil development in a dry region of Oman. The study involved detailed surface and subsurface soil textural analyses, and tension infiltrometer tests in areas inside and adjacent to the dam. The reservoir area of this 25 years old hydraulic structure has rapidly changed due to spatiotemporally variable deposition of sediments from the ponded water. As a consequence, the capacity of dam to hold water is reduced, hence, causing over spilling and flooding problems. Recharge area downstream the dam receives pulses of sediment water after each major flood, and causes possible translocation of fine particles into the subsurface. The results of the investigation found that a relatively thin layer of silt at a depth of 80 cm has formed in the downstream area of the dam. Infiltration tests indicated that saturated hydraulic conductivity (Ks) drops with depth from 3.9 cm/hr at the surface to 0.37 cm/hr at a depth of 80 cm. The non-monotonic curves of silt and sand contents at this site qualitatively agree with the infiltration tests. This “reversed” textural and infiltration pattern has intricate hydroengineering implications. With a “semi-pervious” invisible silt barrier, the runoff water, released from the dam, instead of a fast vertical infiltration, percolation and recharge to the water table forms a shallow subsurface “stormflow” – a well-known phenomenon in hillslope hydrology. In other words, after a temporary flooding of the recharge area, a shallow horizontal seepage through relatively permeable topsoil takes place. The silt barrier at a shallow depth causes exfiltration into local topographic depressions. We observed this phenomenon after a number of flood events during 2007-2011: several short-lived “springs” discharged into ruts and small (up to 1 m depth) trenches in Wadi Al-Bahais, Wadi Al-Arsh, and Wadi Al-Lawami that are located around 2 km downstream of the dam. These patches of relatively impermeable subsurface silt barriers may also explain the preferential groundwater recharge of an unconfined aquifer reported by Abdalla and Al-Abri (2011) in a number of monitoring wells surrounding our study area.

Keywords: Soil evolution, sedimentation, recharge dam.

Introduction

Recharge dams represents an effective measure to harvest intense flashflood water in arid zone areas like – Sultanate of Oman and the Arabian gulf in general (Abdulrazzak, 1997; and MRMWR, 2010). Those areas characterized with long drought periods followed with intense rainfall shower for short duration. As known, the intercepted runoff water is rich of suspended solid materials, with sediment yield exceeding 678 ton/km^2/year (MRMWR, 2010). Commonly, the incoming sediment-rich flashflood detained by the dam is kept about 2-3 weeks allowing Stocksian settlement of suspended particles. As a result, siltation of the reservoir bed occurs. Siltation could define as deposition/accumulation of fine soil particles carried by runoff water to the dam reservoir (lake). Relatively clear water then released through the dam culverts (sluice gates) to the recharge area downstream the dam.

Siltation problem occurs around the globe as reported by many studies, efficiency of recharge dams drops with time due to siltation (Biswas, 1996; Sichingabula, 1997; Alessandro, 1998; Chanson and James, 1998; Wanyonyi, 2002; Haimerl, 2002 and Devi et al., 2007). Along with reducing storage capacity, siltation also found to shortening the dam lifetime and increasing the maintenance cost (Chanson and James reported in 1998). Overflow and hence flood hazards found to be a siltation-induced problem (Devi et al., 2007 and Joseph, 1953) i.e. as the dam reservoir is full of sediments then the reservoir outflow would almost equal the inflow. Along with scaling and caking problems caused by siltation, a change in the hydrological properties (like reduction in infiltration) of the original porous soil is common (Al-Muttair et al., 1994; Kacimov et al., 2010 and Al-Ismaily et al., 2013a,b, Al-Saqri, 2014). Over time, layers of different soil fractions deposited on the reservoir bed. The infiltration rate decreases (Joseph, 1953; Haimerl, 2002; and Devi et al.; 2007), and hence spilling of ponded water over the dam crest occurs more frequent and therefore, increases the potential hazards of flooding the downstream area.

Several techniques were implemented to combat or bypass the silt-cake layer at the surface of the reservoir bed. Scraping is practiced to mitigate scaling-caking that increases the infiltration to some extent. Scraping does not completely solve the problem of reduced Ks of the dam bed. The fine soil particles (silt and clay size-particles) could be infiltrated into the gravely subsurface layers causing damage to the original alluvium formation throughout the whole vadose zone. Removing even the visible silt cake is costly, taking into account the periodic flooding and new doses of silt after each flood event.

Al-Khoud recharge dam is one of the largest recharge dams in Oman (Fig. 1). The dam like other recharge dams around the world faces the problems highlighted above. Although infiltration inside Al-Khoud dam is not considered as the main function of the dam, the reservoir bed will be closely investigated in this paper. This bed is considered as a generic soil massif subject to rapid hydropedogenic processes that cause easily observable and well-recorded changes in soil's physical, chemical and biological properties due to human (geotechnical) interference into the natural system i.e. wadi flow and original parent soil. It is also essential to develop a way on how to utilize efficiently the huge quantity of incoming flashflood through allowing relatively quick water seepage inside the dam in the reservoir basin that will minimize water losses through evaporation of retained water. Moreover, urbanization takes place widely in the recharge area downstream because of the high economical value of the adjacent land. This results in shrinkage of the originally designed recharge area downstream of the dam that causes both hydrological alterations (pavement of the bare land surface and further reduction of infiltration) and increased flood hazard.

Understanding the interplay between pedology and hydrology assists in better explanations of both soils genesis and water dynamics in surface and subsurface systems (Lin, 2003 and Bryant et al., 2006). Human intervention could accelerate alterations to both properties of surface and subsurface porous media (Bella and Overton, 1971; Peavy et al., 1985; Dalal et al., 1999; George, 2000; Lin, 2003; Hari et al., 2004; Mohamed, 2004 and Pahl-Wostl, 2006). Examples of altered properties include soil texture, structure, mineralogical composition and hydraulic properties of wadies, flood plains and basins. Thus, understanding the soil properties is also important -and has been widely studied in the literature- as it controls the water dynamics, patterns and distribution of water in porous media, especially, flow through the vadose zone (Bell and Cameron, 1906; Watson et al., 1995; Schoelkopf et al., 2000 and Stange et al., 2003).

The main objective of the present study is to assess soil evolutions in the vicinity of a geotechnical structure -Al-Khoud recharge dam- and the consequent impacts on hydraulic properties which are important for the augmentation of water resources of the underlying aquifers.

Description of the Study Area

Al-Khoud dam is located 50 kilometers northwest of Muscat near Seeb and positioned between 23° 36.9′ to 23° 38.8′ N latitude and 58° 10.2′ to 58° 09.6′ E longitude (Fig. 1). The dam is placed in wadi Al-Khoud alluvial fan where many early water resources studies recommended construction of an artificial recharge reservoir over there (Stanley Consultants, 1981). Wadi Al-Khoud is the drainage channel of Samail catchment with an area of 1635 km^2 (MRMWR, 2008). The construction of the dam was completed on 1985. The dam has a crest length of 5100 m and intercept wall height of up to 11 m with reservoir area of 3.2 km^2 (Al-Ismaily et al., 2013a). The highest part of the Al-Hajjar mountain range drained by the Samail catchment, is built up of rocks belonging to the Hajjar Unit, as well as the Oman Ophiolite nappes and interlayered limestone which provide the catchment with gravel and sediments forming Al-Khoud fan system (Al Ghafri, 1991 and Al-Rawas et al. 1998). Original soil of the study area is very gravelly and sandy in texture, mostly dominated by Calcids, Gypsides and Torriorthents (MAF, 1990 and Al-Ismaily et al., 2013a,b). Al-Khoud dam is mostly dry during the year, with little infrequent short-duration highly-intensive precipitation received. Over-spilling of ponded water occurred three times during two major cyclones outbreak which struck Oman in 2007 and 2010 (Kacimov et al., 2010; Abdalla and Al-Abri, 2011 and Al-Ismaily et al., 2013 a,b).

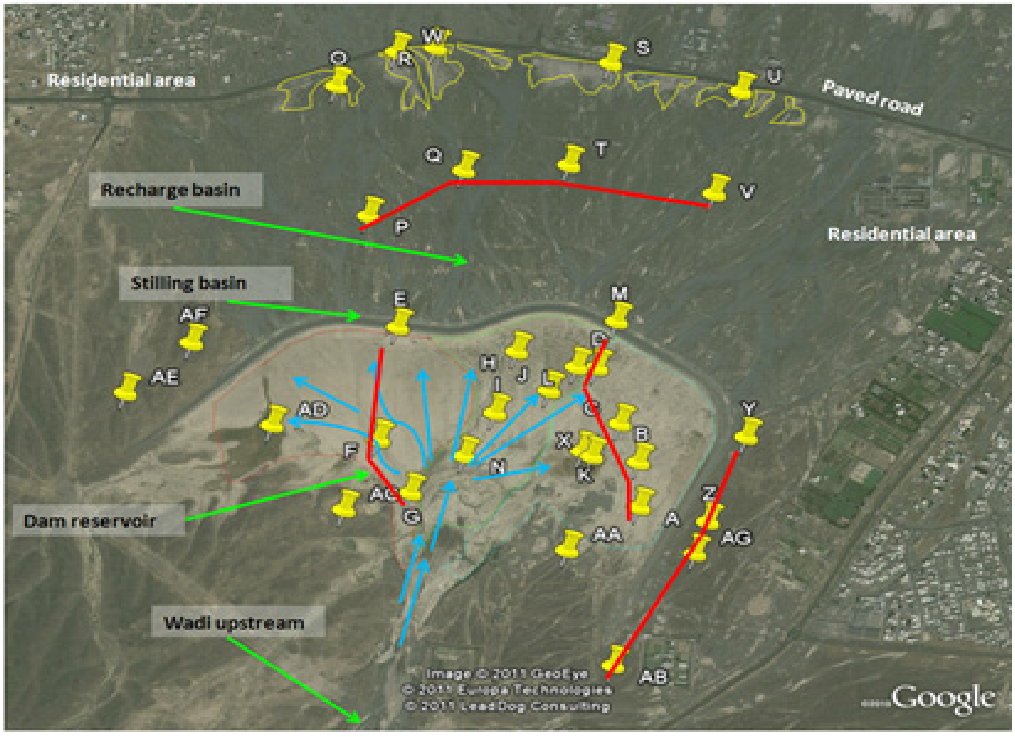


Figure 1: Al-Khoud recharge dam with pedons location (yellow pins), designated transects of selective soil pedons are marked as red lines and blue arrows are water distribution in the study area (Google maps, 2010).

Research Approach

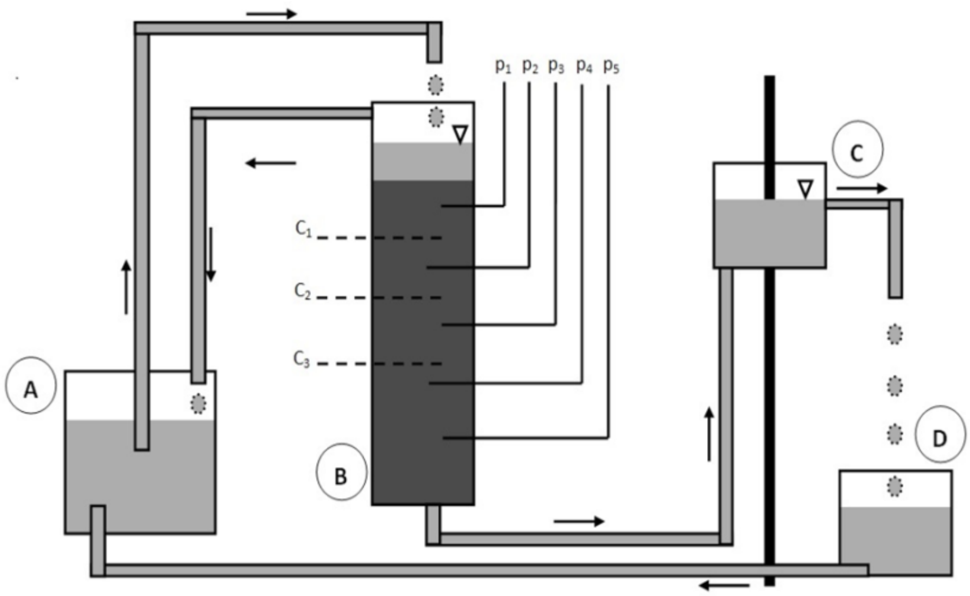
A set of field and laboratory experiments was conducted to study the soil properties. The study area was subdivided into 3 major zones based on topography, geology of the place, vegetation and soils. Location of soil pedons has been selected in order to cover these identified zones. High resolution satellite images, maps and aerial photographs (see fig. 1) were used. Out of 33 pedons 15 were inside the dam reservoir; 18 outside the dam, 12 of the latter in the wadi recharge area downstream the dam and 6 pedons in the upstream area that is considered as a reference point representing the original undisturbed soil prior to the dam construction. The upstream area is not affected by the flooding. Fig. 1, illustrates the distribution of the pedons, which are marked and labeled with upper case alphabetical letters (see, figure 1).

Soil samples were collected from each soil horizon based on its distinctive pedogenic features. Soil texture has been analyzed using the hydrometer method. Sand fraction was also measured by determining its different fractions (Tan, 1996). Extract soil solutions were prepared following a standard procedure as suggested in (Tan, 1996). Extract samples were thereafter analyzed for pHe, ECe (by *DiST4-HANNA and Jenway*) and exchangeable cations like Ca, Mg, Na and K using inductively coupled plasma, (ICP), (Montaser and Golightly, 1992). Soil mineralogical composition was studied using Scanning Electron Microscopy (SEM- by *JEOL JSM-7600F*).

Measurements of Ks for areas adjacent to the pedons were carried out using tension infiltrometers (Reynolds and Elrick, 1991). In this study, Ks is of main interest and sportive number is not, because in conditions of heavy (several meters in depth) ponding of the reservoir surface for days-weeks capillarity is of less importance in infiltration. The soil textural analysis data obtained from the field and laboratory experiments will assist in understanding the Ks data interpretation.

1. Column Experiment for Studying Vertical Translocation of Fine Particles

For better understanding the vertical translocations of fine soil particles into the coarse subsurface system, a column experiment has been conducted. Fig. 2 depicts the experimental setup. The procedure is similar to an experiment conducted by Eliassen (Eliassen, 1935). In Figure 1, (A) represents the supply tank of 105 liter volume containing a suspension with a controlled concentration of silt. The tank is equipped with a mixer to prevent the silt from sinking to the bottom and hence ensuring a constant input concentration of the suspension. The acrylic-plastic column was 1 m tall and had an inner diameter of 11 cm. The suspension is pumped by a continuous duty pump (Pedrollo, 50 Hz, 0.37 kW) to the column which was filled with 72 cm of a porous medium (B). The flow rate to the column is maintained around 18 L/hr, more comments on that will follow below. The top of the column is equipped with a drainage pipe to prevent the column from overflowing. As the bottom of the column has only a small drainage pipe, silt can accumulate on the bottom. In order to prevent such as effect, the bottom of the column was covered with a 5 cm layer of gravel that had a maximum size of 9.5 mm. On top of the gravel a mesh was placed to avoid the sand from migrating between the gravel stones. A total of 25 outlets (standpipes) were positioned at various points along the column. Out of them, 21 worked as piezometers so that the hydraulic head, h, at those points could be measured. The outlets were not only placed vertically above one another, but also placed at different azimuthal angles in horizontal planes, to account for three dimensional effects. The four other standpipes served as suspension sampling points. They are located at different depths, as indicated in Figure 1. To avoid cluttering, only three suspension sampling points and five piezometers are depicted in Figure 1. The sampling tubes were perforated along their horizontal extension into the matrix to avoid clogging and extended through the middle of the column to avoid wall-side effects. The column outlet was connected to a small tank at a changeable height, indicated by (C) in Figure 1. This allowed controlling the head difference between the top and bottom of the column. The volumetric flow rate of the suspension through the column was checked by measuring the outflow from the drainage pipe that leads from the changeable tank to a final drainage tank (D). Also the concentration of the suspension after it has passed through the whole length of the column was measured. From this final tank the suspension concentration can be either checked and supplemented before feeding back to the supply tank (A) or simply disposed of.



(a)

(b)

Figure 1: (a) Setup. A: supply tank; (B): column with porous medium; (C): adjustable drainage tank; (D): final drainage tank; (C_1) through (C_3) represent the suspension sampling points; (p_1) through (p_5) represent the piezometers; (**b**) Pictures of the setup showing the column connected to the adjustable drainage tank

To ensure an air free system and minimize consolidation, the sand was packed under wet condition (Barth 2001, Welty 1997). At the very beginning, the column was flushed at a high flow rate with clear water for a few hours to ensure proper settlement of matrix particles and hence reduce the possibility of having localized heterogeneities as well as ensuring absence of air bubbles. In order to easily measure the hydraulic gradient over the whole column, dh/dx, the length of the matrix-filled column was chosen so that one piezometer tube was left above the matrix in the ponded water (the top most piezometer lies at x=80.7 cm). Furthermore, the piezometer tubes were primed. The sampling tubes are sealed tightly to prevent leakage.

The concentration of silt particles δ(X,t) at varying depth in time and the loss of pressure h(X,t) with depth are measured. NB X=0 is the input point, i.e. the top of the column, in our data representation; however, we decided to use the coordinate 0 for the bottom of the column. As the top of the column lies at L, in the data representation we will have x=X-L. Hydraulic conductivities can be calculated from the head measurements and flow rate using Darcy's law. The average Ks of the sand medium was calculated from the imposed head gradient and measured volumetric flow rate, using Darcy's law, see **Error! Reference source not found.** and checked by measuring Ka with a constant head permeameter as well.

To measure the concentration of silt in extracted samples we used turbidity measurements. In a similar way as Holliday et al. (2003) have done, we established a relationship between turbidity and concentration for the range of concentrations that will be used in this experimental work.

The suspension solution was prepared by mixing silt with tap water as either the silt or the artificial sand react with any of the compounds in the tap water. The suspension was prepared by mixing the silt particles well with water at a concentration of 0.25 g/L. This concentration was low enough, not to have cake formation on the top of the column, but high enough to have a measurable deposition within few days. During the injection of suspension into the column, the change in pressure with depth was measured at time intervals.

Samples should be taken at a low rate of sampling, i.e. lateral withdrawing the seeping suspension from the column, so that the main vertical flow pattern, and therefore the deposition of silt, was not influenced too much by the sampling. Due to the enlarged flow rate Q near the inlet of the tubes during sampling, internal dislodging of particles happens. This influences the concentration of silt in the effluent, δ. Therefore, before taking samples, water was allowed to flow through the tubes until no change of color in the effluent water was detectable anymore. Also, during the experiment, silt diffuses into - and deposits in - the tubes. Before taking samples, this also needed to be flushed out. During the run of the first experiment, it turned out that a slow sampling rate, of say 25 mL/min, was not sufficient to clear the tubes. Instead, the sampling rate needed to be very high, sometimes even higher than Q, so that the supply rate needed to be enlarged to avoid desaturation. After flushing, samples of 40 mL were taken at a rate of approximately 100 mL/min.

Results and Discussion

The amount of fine sediments deposited on the surface of the reservoir basin varies based on topographical features, surface hydrology of water enriched with suspended sediments, and deposition patterns that eventually results in soil layering-caking (Kacimov et al., 2010). This was clearly observed and measured in the areas where topographical depressions act as water detention compartments and, correspondingly, "sinks" receiving higher amount of deposited sediments. The cake thickness reaches up to 3 meters in some cases e.g. pedon N with 40 cm of silt deposits and AD with more than 2 meters.

In the wadi upstream a higher amount of Total Suspended Solids (TSS) is transported with concentrations reaching up to 41 mg/L as measured during the study period from the rain fall even between 28th April 2013 – 8th May 2013. The TSS was reduced 4 times when the flashflood water retained by the dam as the sediments load starts to deposit (Wannyonyi, 2002). Surprisingly, TSS in the stilling basin of the dam and in the recharge basin downstream was almost similar to the wadi upstream (we measured 44 mg/L). This is due to over-spilling of turbid ponded water, which is released to the recharge area. Moreover, previously accumulated sediments in the stilling basin remobilized by turbulent culvert discharge which enriched the relatively clear released ponded water. Part of these sediments reaches the recharge area and hence either accumulates on the surface forming patchy silted area (see, fig. 1) or translocated vertically into the subsurface with the infiltrating water.

Fig. 3 presents soil textural distribution with depth for selected soil pedons as representative of the rest with similar patterns (those are pedons A, B, C, G, I, J, L, M and X). As illustrated, this variation could be characterized by: 1) Normal sedimentation and accumulation of silt on the top, forming thick (20 to 30cm) silt cake layer as in Fig. 3(a). 2) Stratified layers (strata) that indicate sedimentation by major/different flash floods events in Fig. 3 (b). 3) Vertical translocation of silt down through the original parent soils as in Fig. 3 (c).

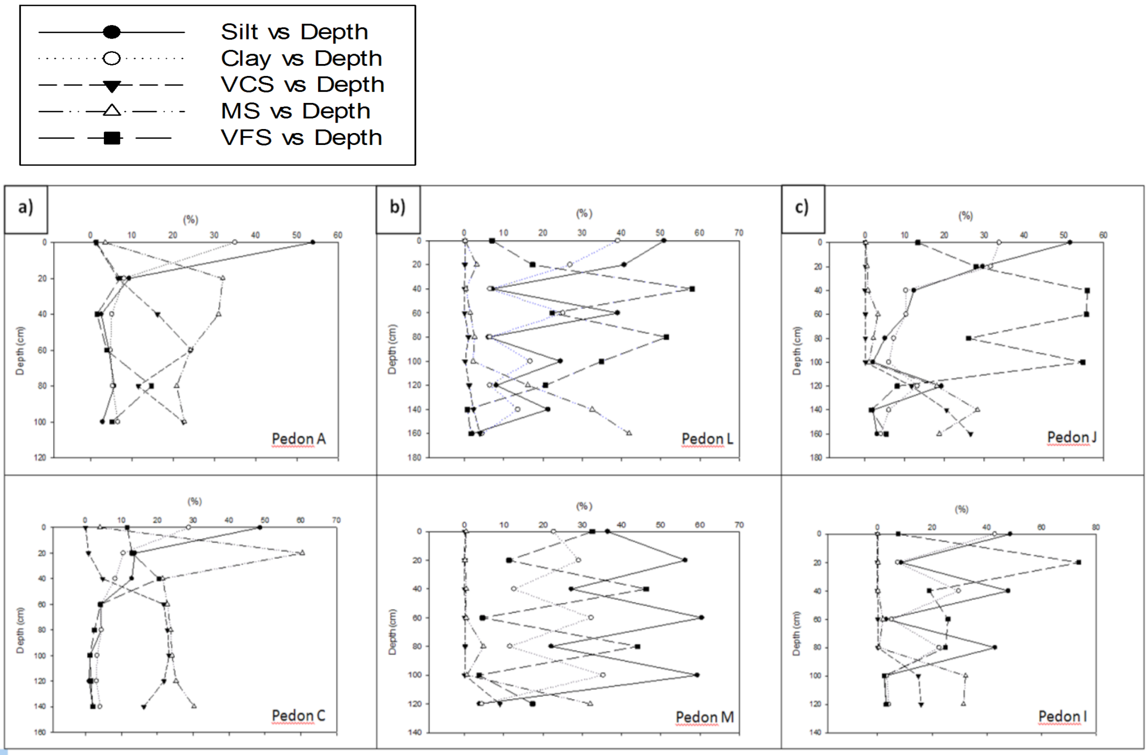


Figure 3: (a) Normal accumulation of silt on top of original soil; (b) Stratified layer of sediment soil after flooding event; sedimentation on top surface and accumulation of silt at lower depth in (c).

Normal accumulation patterns of silt on soil surface were observed in pedons A, B and C. Pedons D, E, G, J and I had the silt accumulated as spikes at bottom layers in the original soil bed (at approximately 100 cm depth) with percentages of silt variation from 19% to 45%. Similarly to a natural sand filter, the reservoir bed causes retention of large sized particulate sediments and allows the translocated particles with average sizes smaller than the pore size to pass through until the particles are trapped by the matrix. Physical clogging of pore openings by sediments and other finer particles, as studied by De Zwart in 2007, are in agreement with present results. The outside area of the dam (Pedons Y, Z, AB and AG, in Fig. 1) represents an undisturbed soil prior to construction, which is mostly gravely and loose (Al-Saqri et al., 2014). Laboratory experiments showed that the soil texture of the ground surface is dominated by sands and loamy sands with sand ranging from 91 to 94% and with very shallow layer of silt (20 cm) with percentages of silt and clay less than 10%. The recharge bed downstream the dam continuously receives pulses of sediments-enriched water over-spilled (as explained earlier); the dynamics of fine soil particles is complex. The complexity is due to the mode of transport of such fine particles within the coarse textured porous materials as it acts as a filter matrix. Small particles tend to be attached to the coarse rough surfaces of the matrix particles while seeping with water (Al-Saqri et al., 2014). Those attached particles get detached again to move further down due to a hydraulic gradient exerted by the ponded water (Fig. 4) (Shekhtman,1961). The intricate relationship between infiltration, mobilization of fine soil particles within the coarse filter material deserves further studies because migration of fine soil sediments deeper into the soil profile is critical (even if the deposited cake is scrapped) and controls the rate of infiltration, hence, more frequent over-spilling to the downstream area. Understanding such unexpected complex occurrences of the formed soil patterns at different depths is of vital importance for predicting the dynamics of surface and subsurface water in the vicinity of recharge dam.

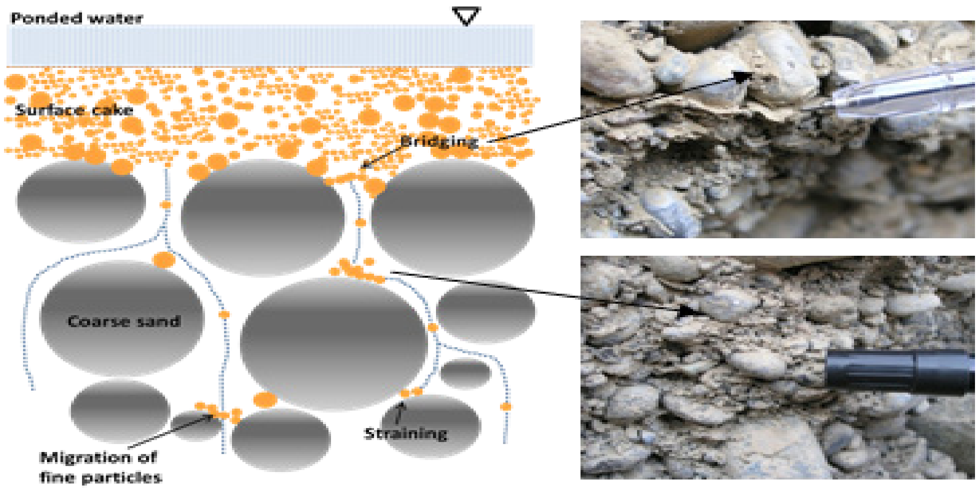


Figure 4: Physical clogging (found at depth of ≈ 80 of pedon O- recharge basin), attachment and detachment of fine soil particles within the coarse parent materials.

Hydraulic properties of the studied soil at different sites inside the reservoir bed and outside in the recharge basin were indirectly quantified by using disc tension infiltrometers at different tension values (e.g. -3 and -6 cm head) (Wooding, 1968 and Reynolds and Elrick, 1991), and from which the rate of water fall in cm/hr in the infiltrometer tube and accumulated infiltrated depth in cm were measured. Table 1 lists the Ks values for the selected soil pedons of the study area.

Table 1:Ks values of the selective pedons of the study area.

Pedon	Latitude	Longitude	Ks (m/day)	Ks (cm/hr)
AA	23.6219	58.1686	2.50	10.42
AC	23.6241	58.1574	2.16	9.00
AG	23.6217	58.1749	7.30	30.42
I	23.6294	58.1649	0.15	0.62
K	23.6273	58.1693	0.02	0.09
O-surface	23.6472	58.1569	3.96	16.50
O- (80 cm)	23.6472	58.1569	0.37	1.54
R	23.6493	58.1619	1.27	5.23

Pedon AG represents “original soil before dam construction that is only subjected to Hortonian flow” had relatively high Ks (7.30 m/day), which corresponds to earlier assessments conducted prior to dam construction (Stanly, 1981). Flood water percolates much faster upstream the dam in the reservoir basin with Ks values ranging from 2.16 to 2.5 m/day as in pedons AA and AC. Places with a high amount of deposited fine sediments (like in pedons I and K) trigger the runoff flow and lower rate of infiltration with values less than 0.15 m/day. Compared to pedon AG, K_s for pedons O and R was reduced to 3.96 and 1.27 m/day, respectively.

During field work, salt crystals deposit as a carbonates' powder just below the "hydropedogenic discontinuity" in a layered sediments or at the bottom surfaces of sand and gravelly materials of the reservoir bed has been observed (Al-Saqri, S. 2014). This has been also reported by Treadwell-Steitz and McFadden in 1999 and Schaetzl and Anderson in 2005. With time, such crystallization forms a hard pan that affects the hydraulic properties of the subsurface (Schaetzl and Anderson, 2005).

Samples has been collected to further investigate this pedogenic structure using the SEM at a scale of less than 100 μm and images are presented in fig.5 Images on the right in fig.5 were taken from outside the dam representing the original porous medium which shows sand particles associated with few coated fine materials and with wide pore openings. Few pedons outside the dam in the recharge basin face the problem of migrated/deposited fine particles as in pedons O, P and Q (Fig. 1). Such sub-samples showed the initial stages of fine particles coating sand grains, which with time, would clog the wide pore openings. SEM images on the left (fig.5) were taken from the reservoir basin just below the deposited sediments at different depths and images show fine particles (including calcite dust) blocking the pore throats and openings (fig.5). Particles attach to the rough surface of sand, while seeping and detached particles move further down. The process of attachment and detachment will occur due to the ponding gradient head on the top that pushes particles further down until they are trapped in the narrow opening as shown in fig.5 (d). The particles accumulate with time and result in a dense blockage of the pores more in the top than lower layers as in (a) compared to (b) fig.5. The column experiment below investigates the translocation process of fine particles into porous media.

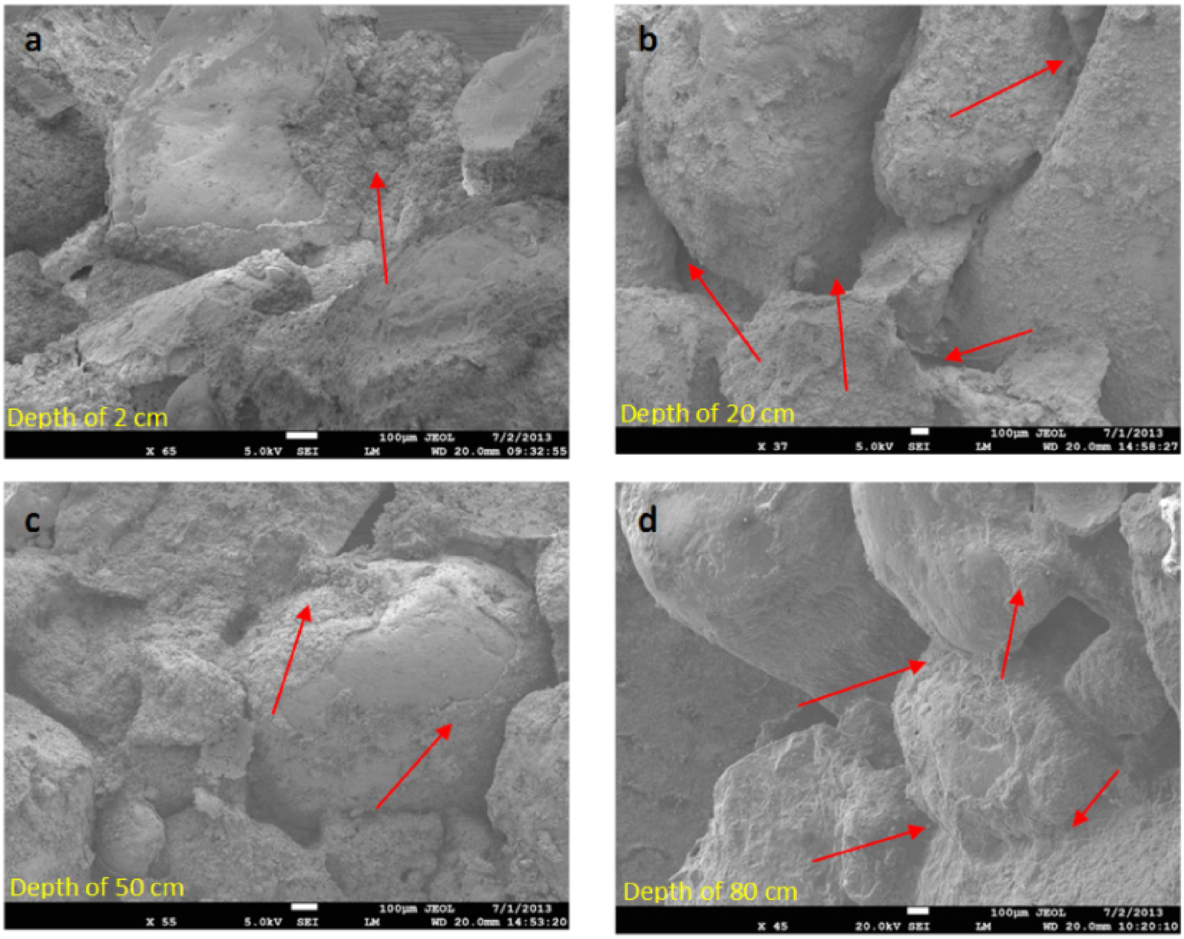
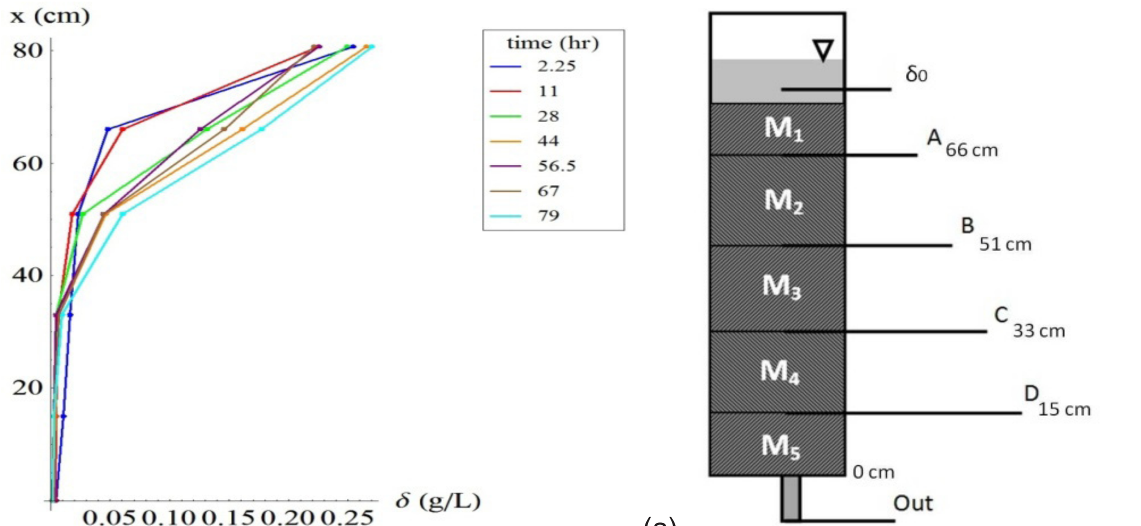


Figure 5: SEM images taken from different depths showgrains coated with fine particles and some pores are clogged.

Results and Discussion of the Column Experiment

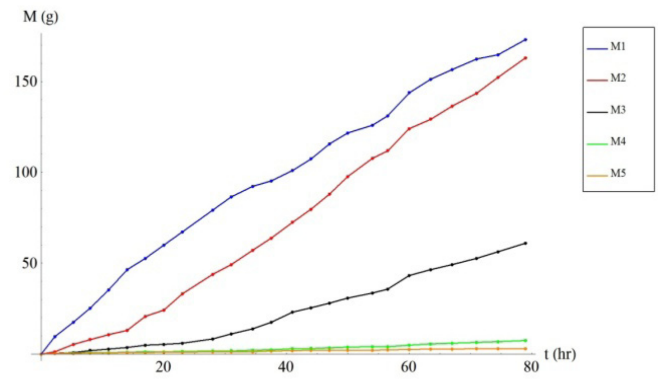
Figure 6-a shows the concentration δ versus depth x in the sand column, at several t. The t = 0 corresponding to the instance when suspension started to seep through the column. For readability, the change in concentration with depth at instances when samples were taken is depicted. The graphs show that there was practically no silt leaving the column in either case, almost all mass was retained by the porous medium. From figure 6-a it is visible that during the first period of 20 hours, the top most layer of the artificial sand column (the upper 21.7 cm) retains a lot of silt. After this period, however, the concentration in the effluent taken from this layer was much higher and did not change much. This indicates that the rate of retention was high during the early stages of the experiment and the matrix reached a maximum retention capacity after which. The next set of graphs shows the amount of silt deposited at five layers across the column at measuring points A, B, C and D that are at 66 cm, 51cm, 33cm and 15 cm respectively (Fig. 6-b).



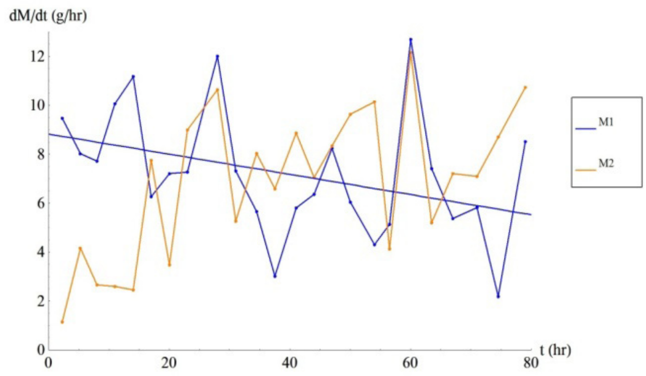
(a) (b)

Figure 2: (a) Concentration, δ, vs depth, x, in the sand column, (b) sketch illustrates the sampling poin ts

Fig. 7-a showing the retained mass, M_{ret} versus time of the experiment with artificial sand, see Figure 7: (a): Total retained mass, M_{ret}, in each layer of the sand column. The figure illustrates that the retention of solid particles started at a maximum rate in the upper layer (the top 6 cm) and that it decreased gradually.7-b shows the mass retention rate, dM/dt, in the two upper layers during this experiment and is found by taking the differences in M at subsequent times. It shows that there is a downward trend in the retention rate of the first layer. The best linear fit is shown by the straight line in blue. In the second layer (from 6 to 21 cm in depth) the rate starts small but increases whilst the rate in the top layer decreased. After about 30 hours the rate of mass retention caught up with that of the top layer and so the maximum rate of removal has moved downward. We notice that the volume of the first layer is smaller than that of the second layer, so when the curves M_1 and M_2 meet, the density of the deposited silt in these two layers is not the same. Silt reached the third layer (21 to 36 cm in depth) after a few hours. The deposition rate started small but slowly increased as the rate in the top layer decreased further. In the two bottom layers the rates stayed very small, but did grow and more so in the fourth layer (36 to 51 cm) than in the fifth (51 to 66 cm). Eliassen found from his experiment that the deposition rate, which is the slope of the M-t curve, in the top layer even, became zero. A saturation value of Eliassen's matrix was reached at this time: no more suspended materials could be retrained by the porous matrix (Eliassen, 1935). The slope of our dM/dt curve does not become zero, indicating that no saturation of the matrix is reached. This could be due to the fact that much deposited material is washed out during sampling. The internal erosion creates new volume where silt can get immobilized, causing us to overestimate the deposition.



(a)



(b)

Figure 7: (a): Total retained mass, M_{ret}, in each layer of the sand column, (b) The mass retention rate, dM/dt, in the first and second layer during the experiment

The Ks across the column has been well studies and analyzed (see Suzanne Faber, 2013). It has been found that the Ks dropped when silt was added to the suspension indicating that the suspension flowed less freely through the matrix than a clear tap water. The results showed that; after 80 hours the Ks reduced by 53% from the initial value. This finding is in agreement with a study performed by Gruesbeck and Collins, as discussed by McDowell-Boyer (1986).

The hydraulic head found to drop quickly over the first ~10 cm of the column (for more details, see Suzanne Faber, 2013). Going deeper into the column the head gradient becomes smaller. This behavior is in congruency with findings by (Shechtman 1961). The originally homogeneous column has turned into a layered system: a top layer with a lower permeability than the rest of the column below it. Note that though an inhomogeneity in conductivity occurs through the column, the average Ks measured over the whole column decreases linearly with the amount of injected mass. We can conclude that once the pore sizes have become small (due to colmatage), a small amount of deposition has a large influence on the permeability and therefore on the pressure drop. This effect has also been noticed by (Eliassen 1935).

Summary and Conclusions

The hydrological properties of Al-Khoud recharge dam in Oman are changing due to scaling-caking problem caused by siltation. Soil textural variation with depth is evident in the Al-Khoud recharge dam area. The Ks varies from 0.01 to 2.16 m/day for the dam lake and between 0.26 and 3.96 m/day in the recharge basin downstream the dam. Ks values at the dam upstream zone -in areas not affected by flashfloods due to dam construction - as per pedon AG is 7.3 m/day.

Due to siltation, it was estimated that more than 30% of the dam's storage volume was reduced since its construction in 1985. This caused reduction of the original designed storage capacity volume of 2275 m^2 per unit width of the dam wall. Total volume that the dam can store is assessed in 2012 to be 7.9 MCM instead of 11.7 MCM, leading to more frequent over-spilling of the sediment rich flashfloods. As a consequence, part of the suspended fine particles translocated vertically into the coarse bed of the recharge basin which at certain depth would be retained causing physical clogging and, hence, reducing the sub-surface conductivity (from Ks = 3.96 m/day at the soil surface to 0.37 m/day at 80 cm depth- close to pedon O).

Presence of calcic materials coating at the bottom of rocks (at depth of 60-90 cm) were observed at the pedological discontinuity with the soil horizons (e.g. pedons I, R, S and AA). This particle coating would grow with time resulting in reduction of the pore size, and hence, decreases of hydraulic properties that ultimately deteriorate the recharge process. Mineralogical analysis conducted proves that coats of fine soil sediments and associated carbonates are evident around sand grains. This may further develop in hard pans that will impede percolation of water to the aquifer.

The conducted column experiment illustrates that a porous medium through which water with fine suspended particles flows can clog and obstruct further infiltration. The porous medium of artificial sand found to retain considerable mass of percolating fine sediments with depth causing reduction in Ks by nearly 53%. For the situation at the Al-Khoud dam, this means water that spilled over the dam crest will have consequences on the dam's recharge efficiency and safety. If the soil clogs, groundwater recharge will be reduced. If the water cannot penetrate the soil it will start to pond and get lost to evaporation. Moreover, ponds can become an environmental hazard by offering a breeding place for mosquitoes.

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Environmental Groundwater Assessment in the Wadi Khulays Basin, Western Province, Saudi Arabia

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Abstract: The aim of the present study is to evaluate the environmental impact on the quality and quantity of the groundwater in two major sub-basins namely Murawani and Ghiran sub-basins of Wadi Khulays in the western part of Saudi Arabia. The present study indicated that several factors operated individually and/ or collectively on groundwater quality and quantity development. These factors were classified into the following (1) Chemical weathering of silicate minerals; (2) Dissolution and precipitation of evaporitic salts as a result of recycling of irrigation water and recharging by surface water runoff and recycling of irrigation water that carried evaporate salts which precipitated as calcite, dolomite and halite as the saturation indices indicate to be existed ; (3) Possible groundwater contaminant by sewage water within Wadi Ghiran sub-basin as observed from elevated nitrate concentrations as well as from the relationship between NO3 and Cl ; (4) Climatic changes that observed from the trend of rainfall amounts over the drainage basin area ; and (5) The nature of drainage pattern and morphometric characteristics of the two sub-basins since the wadi Ghiran is almost less tributaries and characterized by short main channels comparing to the Wadi Marawani sub-basin which is caused, the surface water leave the Wadi Ghiran fastly which almost decreases the amount of natural recharging from floods that generated in the wadi which considered the major source of recharging water of the alluvial aquifer existed. The chemical data, field measurements and saturation indices of evaporitic minerals were treated by using multivariate analysis (Factor analysis) to find out the major factors have affected groundwater chemistry.

KeyWords: Environmental impact, Groundwater, multivariate, Khulays, KSA.

Introduction

WadiKhulays basin is located in the western part of Saudi Arabia and about 100 km northeast of the city of Jeddah, between latitudes 21°55'and 22°15' and longitudes 39°15' and 39°30'. WadiKhulays basin, falls on the western central part of the Arabian Shield extending from the east at Hijaz Mountainous area towards the west until it reaches the Red Sea coastal plain. The Wadi basin consists of two major tributariesnamely: Marwani and Ghiran sub-basins(Figure 1) which are considered the most important source of water supply to Jeddah city, as well as the surrounding villages. WadiKhulays is descended of volcanic Plateau known asHarratRahat east, which rises about 1200 meters above sea level heading towards the west and empties into the Red Sea. Khulays catchment area is about 4500 km^2. WadiKhulays has a drainage trend from east to west toward the Red Sea. The wadisediment and weathered and fractured basement rocks are considered the major aquifer for groundwater supplies. The thickness of sediment from a few meters to about 35 meters at the outlet of both wadisMarwani and Ghiran.

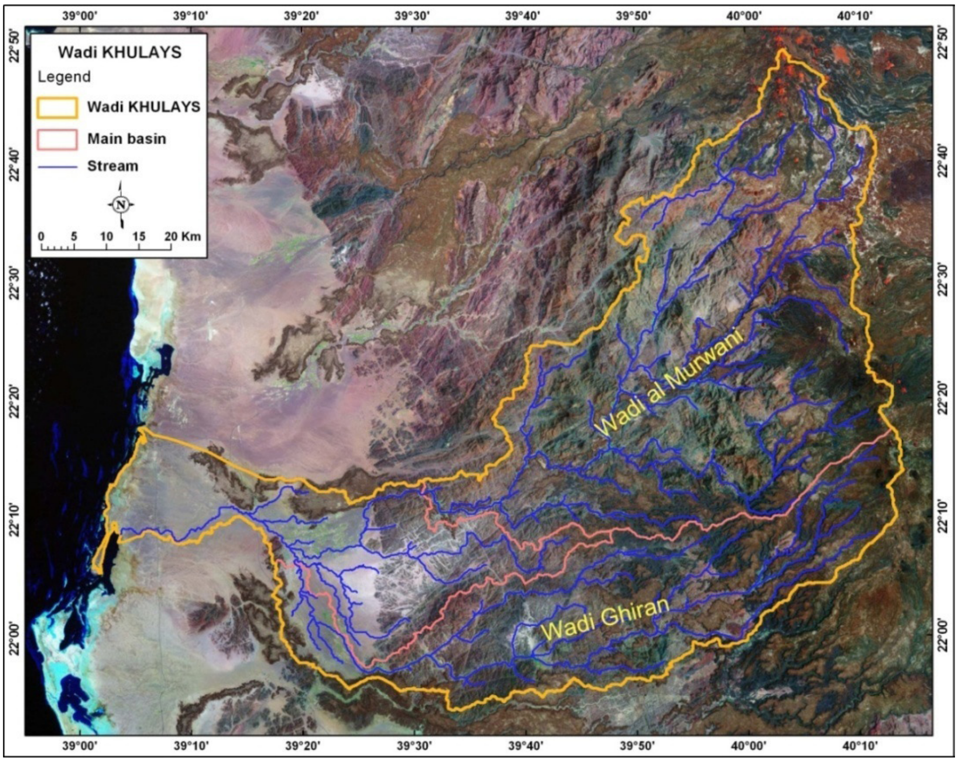


Figure 1:WadiKhulays and its Major Sub-basins (Ghiran and Murwani).

Geomorphology and General Geology

Hijaz-Tihamah region covers the northwestern region of the Kingdom. Tihamah is a plain on the Red Sea coast, while the Hijaz is a plateau. The elevation of this zone is about 1200 m above sea level at the HarratRahat. Most of the wadis, which occur in this zone,flow towards the Red Sea coast (Brown et al., 1963).WadiKhulays basin represents the feeding area of the basin and descends toward the west in the direction of the Red Sea. The basin includes two major tributaries, WadiMarwani andWadiGhiran, they are open to WadiKhulays plain.

The wadi lies entirely within geological complex of the Arabian Shield in the western area of Saudi Arabia.The most detailed study concerning the geology of the area considered is published by Skiba et. al., (1986), Ramsay,(1986), and Moore and Al-Rehaili, (1989).On the other hand, the detailed geomorphology aspects were introduced by Zaidi, 1983 and 1984;According to their works, the following three stratigraphic units were recognized from top to base, (a) Quaternary deposits, (b) Tertiary rocks; and (c) Precambrian layered rocks (Figure2).

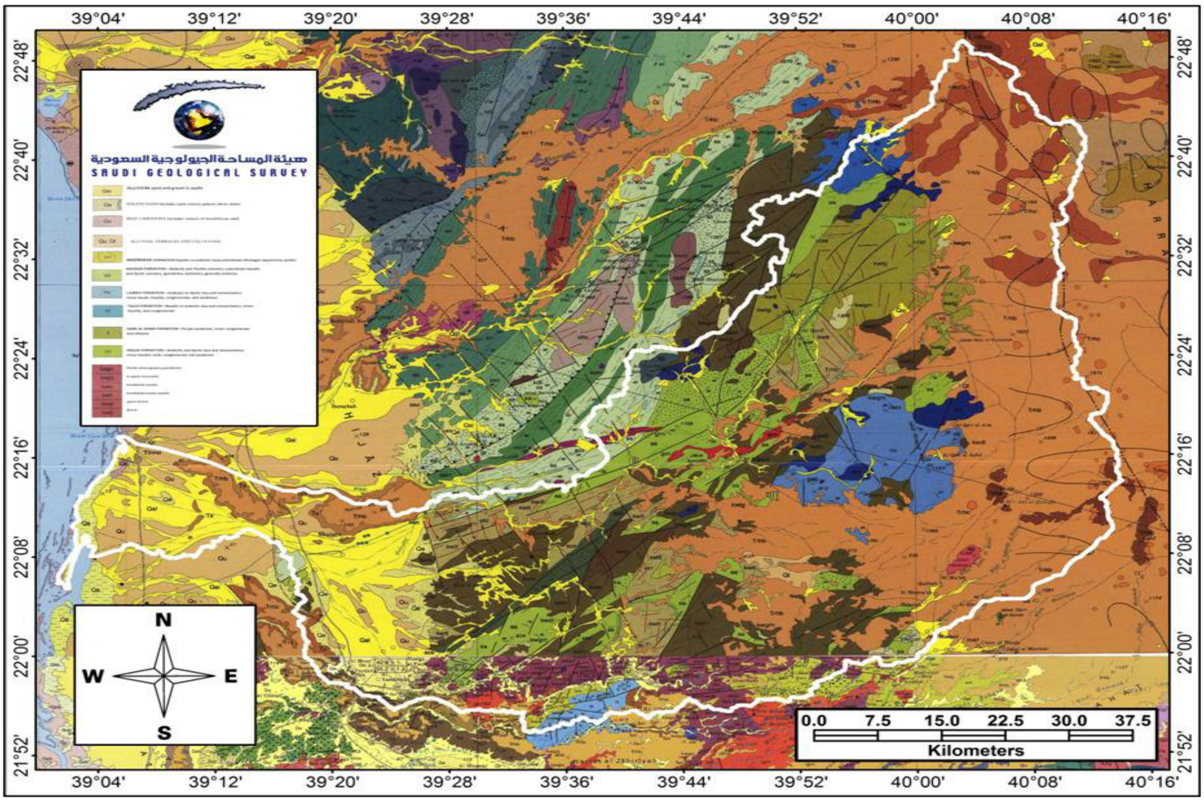


Figure 2. Three geological units of Wadi Khulays Basin.

The dominant folding in the quadrangle is the system of northeasterly trending, Nebert (1969) and Skiba and Gilboy (1975), and there are three main fracture sets in this area as, (1) North-northeasterly set, (2) East-northeasterly set, and (3) Southeast-trending fractures of the Red Sea fracture system.These faults controlled the drainage system but have litter or no lateral displacement.

Hydrology

Khulays basin is considered as an arid region with high temperatures throughout the whole year, the major source of any natural water storage is the rainfall, which is occasional and sporadic within the Kingdom of Saudi Arabia. The annual rainfall of Khulays basin is less than 72 mm per year. This implies high evaporation and relatively less infiltration rates.

Hydrogeological Setting

Information on the hydrogeology of the area was obtained from existing wells.Water levels measured in boreholes were used to construct a groundwater table map, and determine the hydraulic gradient.Well inventory data helped in identifying the quantity and quality of pumped water.Significant water-bearing formations occur in two different lithological units; namely the alluvial deposits together with the Precambrian weathered rocks and the Tertiary sedimentary succession (Bazuhair *et al.,* 1992).A total of seventy two wells were visited during the field season (Figure3).Most wells within the study area are large-diameter handdug wells; generally they are shallow and are tapping groundwater from the Quaternary alluvial deposits. In Wadi Murwani the total depth of wells vary from 11.5m to 32m and the depth to water level ranges between 7.7 to 31m.The average EC of about 3293.7μs/cm, while pH values varying from 7.09 to 7.74.On the other hand, in WadiGhiran the total depth of wells vary from 10.5m to 140m and the depth to water level ranges between 9.5 to 28.4m. The average EC of about 5029.4μs/cm, while pH values varying from 7 to 7.75. All inventoried wells belong to local farmers. Pumping is usually carried out to irrigate crops and it often lasts for 6-8 hours daily.

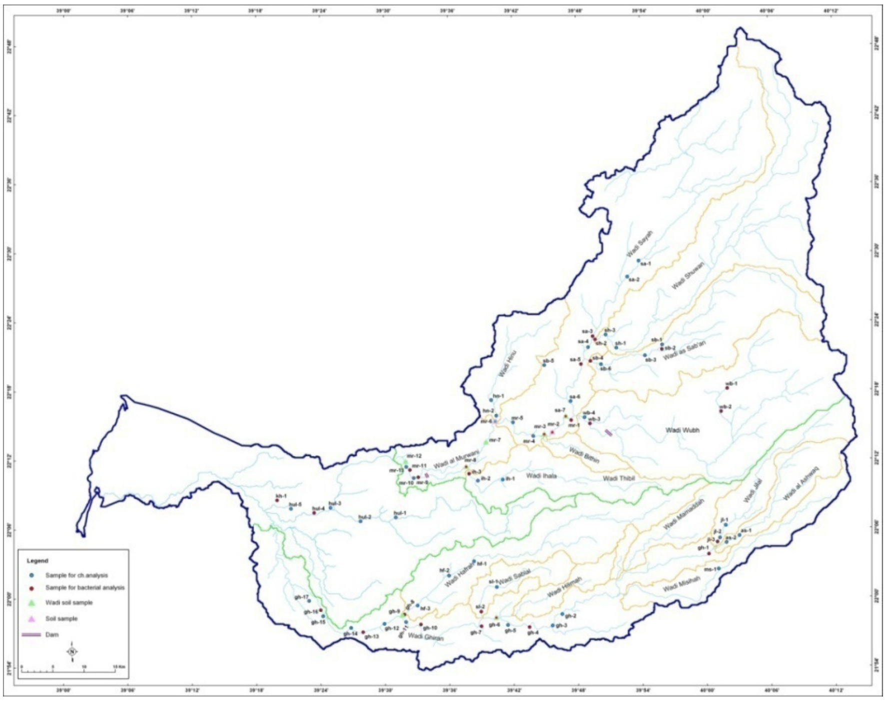


Figure 3: Samples Location Map of Wadi Khulays Basin.

Environmental Assessment of Groundwater

During April, 2012, a total of 72 groundwater samples were collected from private wells in the two major sub-basins. Of these 44 samples obtained from Murwani and 28 samples from Ghiran-subbasin(Figure 3). All the groundwater samples were analyzed for major ions,inaddition,traceelements. Electrical conductivity(EC) in μS/cm, pH and groundwater temperature (°C) were measured in situ.The groundwater samples were biologically analyzed for total coliform, fecal coliform and fecal streptococcik.Inaddition, a number of 6 soil samples were collected from irrigated fields and the wadi sediments. These samples were transferred to laboratories of the Faculty of Earth Sciences, KingAbdulazizUniversity in Jeddah to determine the composition of soil. All the chemical and biological analyses were carried out at the Saudi Geological survey laboratories.

1. Major Ions

Table 2 provides a statistical summary of the major constituentsconcentrations as well as field measurements parameters of EC and pH of the groundwater in both Murawani and Ghiran sub-basins. Generally, the major ionic concentrations of the groundwater in Murawani and Ghiran show the following general pattern:

$Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$

$Cl^{-} \geq SO_4^{2-} > NO_3^{-} > HCO_3^{-}$

The NO_3^- ion is rather higher in most of the samples, which is greater than the maximum contaminant level (MCL) of 45 ppm.(EPA, 2004) and Saudi Standards. In addition, the pCO_2 values obtained are is much higher than the global mean ($Pco2=10^{-3.50}$).

Table 2: Summary of the Chemical Analyses Results of the Groundwater Majorions in ppm.

Elements	Murawani SB (44 samples)			Ghiran SB (28 samples)		
	Max	Min	Mean	Max	Min	Mean
Ca^{++} (ppm)	1140	50	237.5	672	54.4	258.9
Mg^{++}(ppm)	428	21	93.6	272	14.4	129.6
Na^{+}(ppm)	2439.5	46.7	361.2	1712.6	134.2	568.3
K^{+}(ppm)	13.1	1.3	6.7	12.9	0.2	5.9
Fe(ppm)	> 0.10			> 0.10		
NH_4(ppm)	11.3	> 0.04	5.92	> 0.09		
Cl(ppm)	5177	47	769.8	2833	157	1065.9
HCO_3^-(ppm)	321	104	190.3	336	58	172.5
SO_4^{--}(ppm)	1500	60	364.4	2745	137	734.8
NO_3^-(ppm)	470	4	84.4	690	17	189.6
F(ppm)	2.04	0.05	0.41	1.97	0.08	0.65
NO_2(ppm)	0.65	0.04	0.24	0.54	0.05	0.25
PO_4(ppm)	> 0.09			> 0.04		
SiO_2(ppm)	48.5	15	28.8	70.5	15.2	31
TH (ppm)	4258	213	971	2797	231	1181
pH	7.74	6.98	7.47	7.75	7	7.29
TDS (ppm)	11640	477	672	8860	665	3240
EC (μS/cm)	17940	672	3293.7	13660	1224	5029.4
SI (CALCITE)	0.39	-1.19	0.41	0.74	-0.43	0.26
SI (DOLOMITE)	2.11	-1.36	0.86	1.62	-1.33	0.64
SI (GYPSUM)	-0.15	-1.98	-1.16	-0.28	-1.68	-0.89
SI (ANHYDRITE)	-0.32	-2.16	-1.34	0.38	-1.85	-0.99
SI (HALITE)	-3.69	-7.26	-5.87	-4.03	-6.29	-5.13
PCO_2	-1.55	-2.6	-2.08	-1.42	-2.61	-2.03

The results indicate that the mean values of major ions concentrations in Ghiran sub-basin are rather higher than those in Murwani sub-basin. The maximumvalue of Cl ions were observed in Murwani sub-basin, whereas, SO_4contents are dominant in Ghiran basin. The highest value of $NO_3^-$was recorded in Ghiran 690 ppm. In addition, some major ions concentrations, Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were relatively exceed the maximum permissible limit.

2. Trace Elements

The chemical analyses results of the trace elements were summarized in (table 3),all the traceelements concentrations in both sub-basins are rather lower than the national and international standards except for B, Se and U where shown rather high and relatively exceed the Saudi Arabian Standards.

Table 3. Statistical measures for Trace elements in (ppb).

Elements		Murawani SB (44 samples)			Ghiran SB (28 samples)		
		Max	Min		Max	Min	
TRACE ELEMENTS (ppb)	Ag	0.11	1.98	0.94	0.1	0.38	0.19
	Al	0.2	39.7	5.48	0.67	10.16	2.32
	As	0.79	16.96	3.11	0.7	7.86	3.17
	B	145.6	3979.6	672.4	188.3	5518.3	1058.1
	Ba	0.94	155.5	39.7	2.43	102.2	33.57
	Be	<0. 5			<0. 5		
	Bi	<0. 1			<0. 1		
	Br	178.9	24025.3	3241.5	513.4	11172.4	4509.8
	Cd	0.1	0.19	0.16	0.1	0.71	0.32
	Co	0.1	1.95	0.4	0.12	0.87	0.41
	Cs	0.17			<0. 1		
	Cu	0.2	20.9	3	1.31	87.83	10.45
	Cr	0.15	3.96	1.21	0.32	4.37	1.93
	Hg	<0. 1			0.12	0.21	0.17
	I	5.72	679.9	91.6	13.52	891.3	176.3
	Li	0.46	75.1	5.85	0.26	20.49	4.62
	Mn	0.11	4.5	1.11	0.14	1.4	0.48
	Mo	0.87	38.7	5.4	0.32	160.3	18.84
	Ni	0.11	10.78	1.81	0.41	5.55	2.06
	Pb	<0. 1			<0. 1		
	Rb	0.17	1.98	0.96	0.15	4.51	1.16
	Zn	0.55	13.2	6.21	0.5	81.68	20.08
	Se	0.12	39.3	6.28	2.27	123.6	2.27
	V	1.82	65.3	17.12	8.2	64.65	22.09
	Sr	295.8	22103.9	2832.7	229.7	6753.5	2571.5
	Ta	<0. 1			<0. 1		
	U	0.11	10.65	1.72	0.15	5.32	0.95

Factors Governing Groundwater Chemistry

1. Weathering of Silicate Minerals

Within the study areas, the major source of H^+ ions seems to be the reaction between water and CO_2 to form carbonic acid (H_2CO_3). The initial partial pressure of carbon dioxide (PCO2) resulted from the carbonic acid acquired during contact with the atmosphere as well as its relation with the chemical activity of water through its H^+ ion concentration. Based on the geological map, the major reactive minerals in the area for groundwater and recharge water (rainwater) in contact with the dominant rocks, evaporatedsalts as well as sediments derived from the parent rocks.

2. Dissolution and Precipitation of Minerals

The relationship between Naand Clions (Figs.4a & 5a) might be indicated the concentrationef-fects by intensive evaporation processes,and halite is probably the sole source of these two ions. However, high concentration of Na and Cl may be due to leaching of saline soil residues into the groundwater system, which almost considered a typical characteristic ofarid and semi-arid regions (Zaheeruddin and Khurshid, 2004).On the other hand, a similar conclusion has been reached from the ionic relationship betweenCaandSO4 (Figs. 4b and 5b), suggesting that both ions are controlled by gypsum dissolution.On the other hand, the ionic relationship between (Ca + Mg) and HCO_3 and Ca and HCO_3 ions are illustrated in (Figs. 4c and d, 5c and d). It is dem-onstrated an extra source for both Ca_2^+ and Mg_2^+ ions.

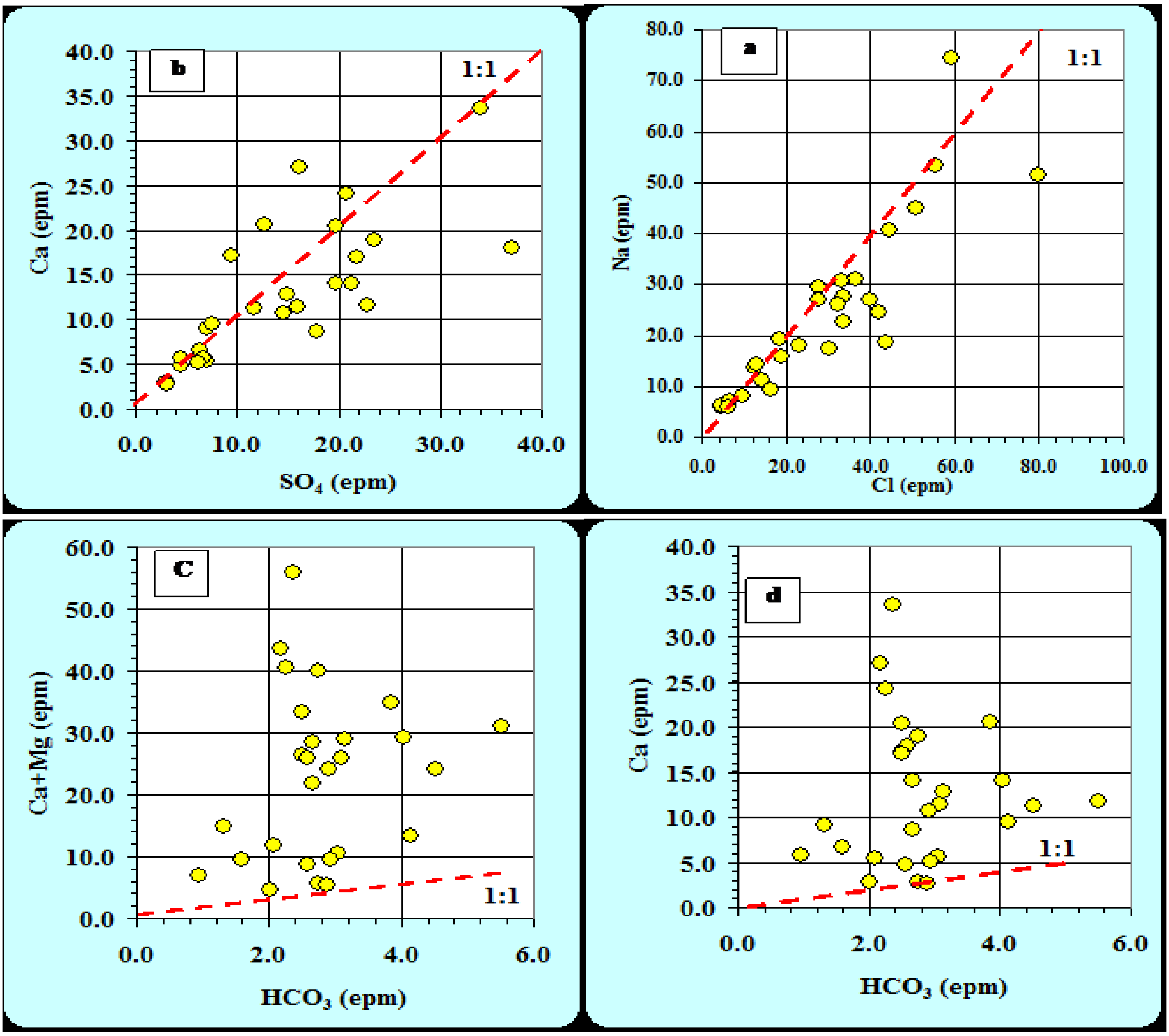
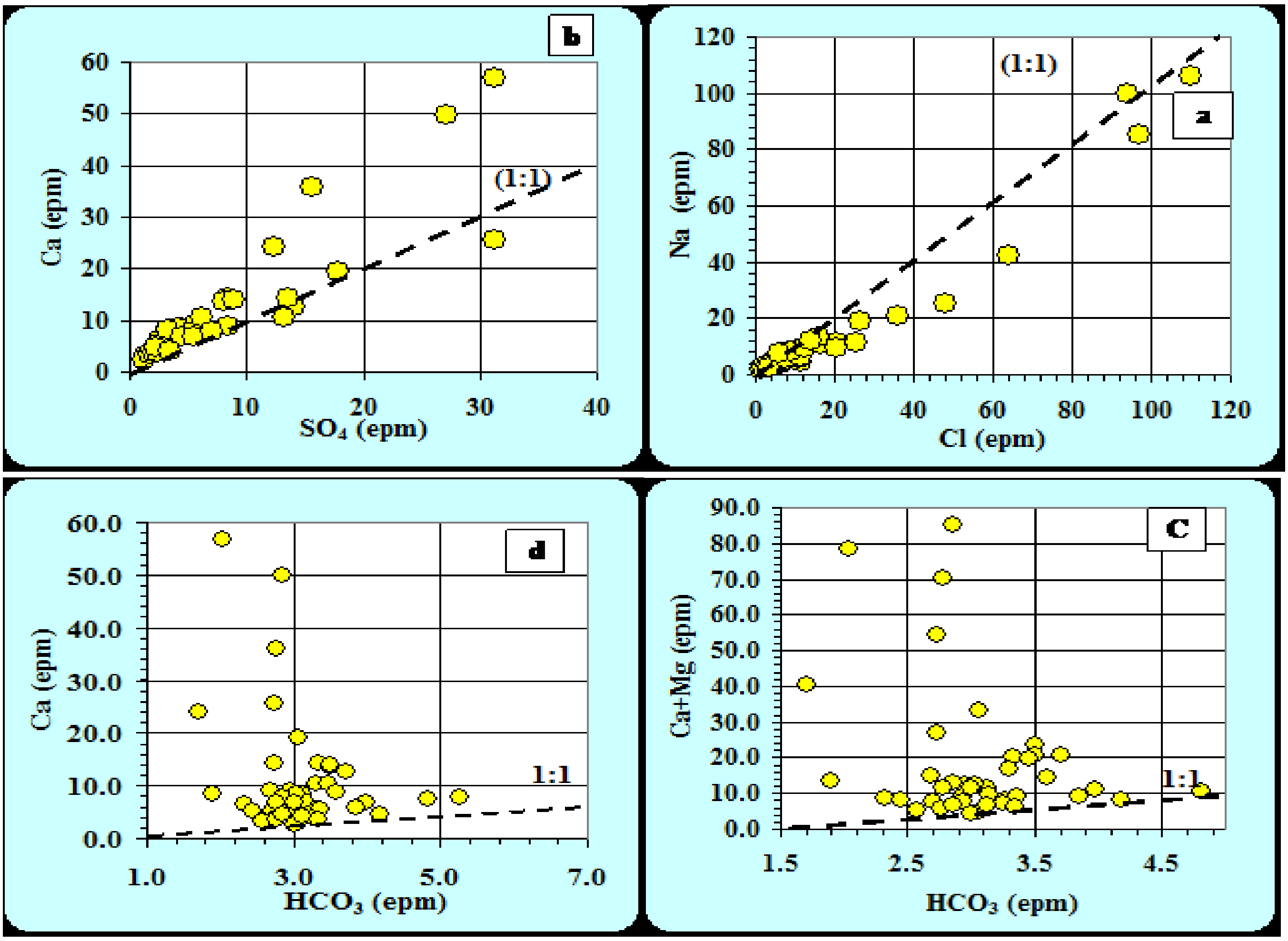


Figure 4.The Relationship between (a) Na-Cl, (b) Ca-SO4, C)



Ca+Mg-HCO3,Ca-HCO3 in Wadi Ghiran Sub-basin

Figure 5: The Relationship between (a)Na-Cl, (b) Ca-SO_4, C) Ca+Mg-HCO_3,Ca-HCO_3in Wadi Murawani Sub-basin.

3. Possible Groundwater Contamination

The shallow alluvial aquifer in Wadi Khulays basin is the principal sourceofwater suppliesto the towns and villages. During the past two decades a rapid growth of population and development in these areas has led to concern about potential water quality impacts, because the absence of municipal sewer services.

In the present study, the average concentration ofNO_3inthe groundwater within Wadi Murawaniabout 84.4 ppm. Which is twice higher than the average background concentrations (45 ppm), whereas, in WadiGhiran, the average of NO_3 about 189.6 ppm.Which is significantly higher by 4 times above the average background concentrations according to the U.S. Environmental Protection Agency (EPA) standards (2000 and 2004)? In the present study will beespecially concentrated on the nitrate (NO_3) content as an indicator for possible groundwater pollution.Generally, the most common sources of nitrate in groundwater are natural and artificial fertilizers as well as the subsurface disposal of human waste. The natural fertilizer consists of animal waste, whereas the artificial fertilizer is commonly depend on nitrogen-based fertilizers used.Inaddition, effluent from cesspools is enriched with ammonium ion (NH_4^+), which can be preferably absorbed onto sediments surrounding a cesspool and under oxidizing conditions ammonium ion (NH_4^+) is converted to nitrate ion (NO_3^-) according to following eqs. 1 and 2:

$NH_4^+ + 1.5\, O_2$ □ $NO_2^- + H_2O + 2\, H^+$ (1)

$NO_2^- + 0.5\, O_2$ □ NO_3 (2)

The low concentrations of NH_4 and agricultural activities in the study area are limited, in which chemical and natural fertilizers are not used intensively, except in some agricultural areas in the WadiGhiran, which was conducted chemical analyzes of its water samples, and results showed that the pollution caused by the use of agricultural fertilizers in these locations (8 wells) as shown in (Figure 6), where we find high rates of nitrates and low rates of chlorine in these locations. While, the wastewater that infiltrates from on-site systems in the residential areas to groundwater might be an importance source of high NO_3 concentrations. This conclusion might be essentially if the high NO_3 observed in the high residential areas (WadiGhiran) compare to that shown low residential areas (WadiMurawani) (Figs. 6 and 7).

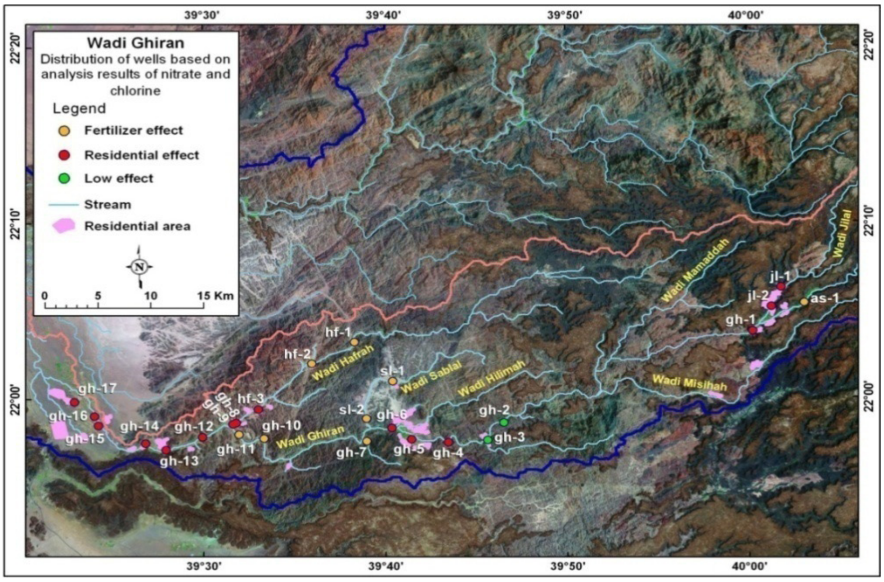


Figure 6.High Concentrations of No3 in Wadi Ghiran

Figure 7: The Up-stream of Wadi Murawani.

4. The relationship between No_3^- and Cl^-

Both NO_3^- and Clare the most significant contaminants associated with domestic wastewater (EPA, 2004).Halite is not only the potential source for Cl^- ion. (Figure 8) shows the relationship between NO_3^- vs Cl with correlation coefficient (r= 0.7). For WadiMurawani, on the other hand, the relationship between NO_3^- vs Clshown in (Fig. 9)with very weak correlation coefficient (r= 0.27). However, the high NO_3 concentrations observed might be derived from agricultural pollution is the leading source of water quality impacts. It considered a major contributor to contamination of ground water due in WadiMurawani to excessive application of fertilizer.

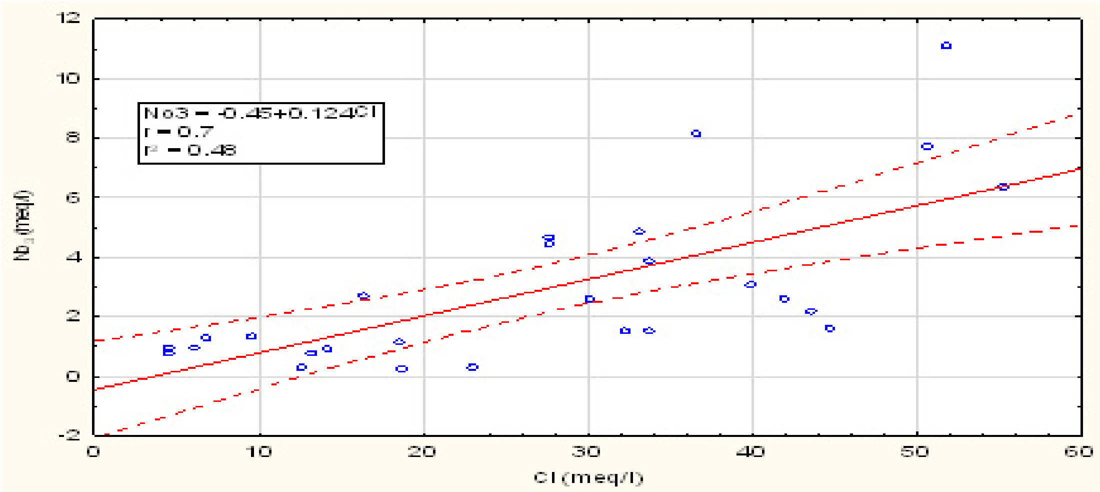


Figure 8: The Relationship of NO3- vs Clof Wadi Ghiran.

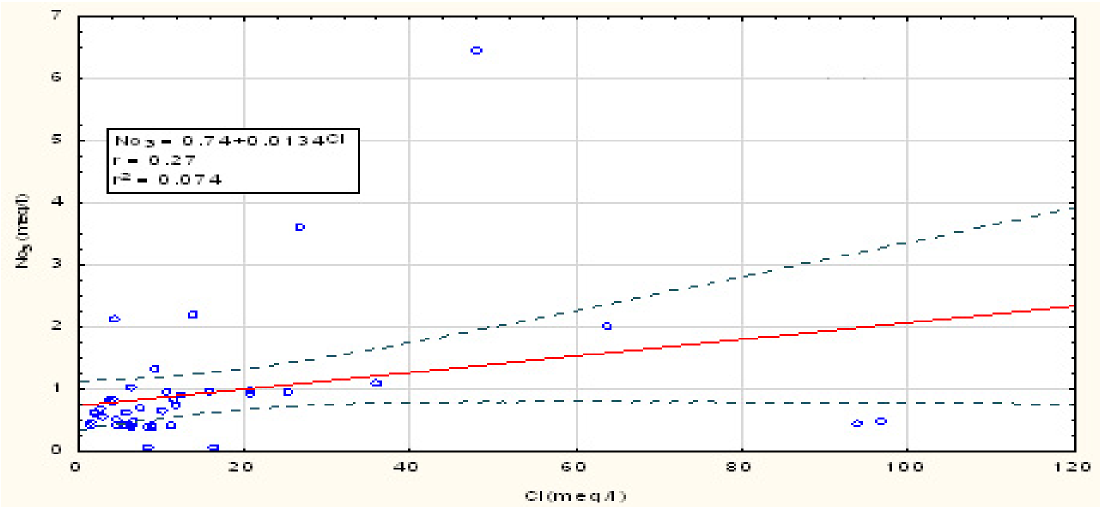


Figure 9:The Relationship of NO3- vs Clof Wadi Murawani

Concentrations observed in both two wadis as well as the WadiGhiran is characterized by population density. Additionally, the residential areas in the wadi are almost closed to the main wadi channel (see, table 2, and figure 6).

5. Other Factors

There are other important factors like a) Low – High Groundwater Level andFlood Regime b) Structural Effects.

Identification of the Major Hydrogeochemical Processes by using Factor Analysis

Due to the complexity of the chemical evolution of the groundwater and the substantially large amount of basic information is available, investigators are often unable to obtain a clear picture of the system under study. The aim of using Factor Analysis is to simplify the quantitative description of a system by determining the minimum number of new variables necessary to reproduce various attributes of the data. These procedures reduce the original data matrix from one having n variables necessary to describe the N samples to a matrix with m factors (m<n) for each of the N samples (Davis, 1973; and Johnston, 1980).

Criteria for selecting factors are: (i) Scree-plot method is only a 'rule-of-the-thumb'; (ii) Its recommend to select only factors whose eigenvalues are >1.

Determination Based on Eigenvalues: Factor Loadings &Item Selection, Comfrey & Lee (1992) proposedl oadings >.70 excellent/ >.63 very good/ >.55 good/ >.45 fair/ and >.32poor

Results and Discussion

The output results for the chemical data for the Murawaniand Ghiran sub-basinsare given in Tables(4 and 5). From, the "sky-slope" diagram suggests that five factors should be retained. Five factors had eigenvalue more than 1, while the other factors reflected the eginvalue of less than 1. The five factors account for 89.6% of the total variance, while the other factors represent 11.4% of the total variance. While In WadiGhiran sub-basin, the five factors account for 84.8% of the total variance, while the other factors represent 15.2 % of the total variance. Therefore, in both wadis the first five factors are assumed to represent, adequately, the overall variance of the data set. Inaddition, the factor loadings in (Tables 4 and 5) indicate that the first fivefactors (1,2,3 4 and 5) are hydrochemically meaningful, which seem to describe the existing conditions of groundwater chemistry. For obtaining an interpretation of the nature of the retained factors in both two wadi-subbasins, these factors will be discussed below:

Factor (1)

In WadiMurawani, it accounts for 52.9 % of the total variance. It has high loading for Ca, Mg, Na, Cl, SO4, NO3, TDS, EC and the saturation indices of Gypsum, Anhydrite and Halite. All are positively correlated with Factor 1. Therefore, Factor 1, is interpreted as relating mainly to the groundwater mineralization due to both intensive evaporation processes, chemical weathering of silicate minerals, infiltration of saline surface water concentrated through evaporation in irrigated areas and the dissolution processes. The main cation exchange elements Ca, Mg, and Na correlate positively indicating the influence of the geologicalmatrix. The importance of the evaporation process of the water might be deduced from the XRD analysis results of sediments samples might be provided conclusive evidence that dolomite, Calcite and Halite salts are very common minerals in the surficial deposits and irrigated areas, which probably resulted from intensive evaporation processes. However, Gypsum and Anhydrite were not detected in the surficial deposits and irrigated areas which both might be due to their extreme solubility. Similar processes probably took place in WadiGhiran except Mg has moderate loading, whereas, NO_3 not loading in this factor.

Factor (2)

In WadiMurawani, it accounts for 12.2 % of the total variance and has loading of Calcite and Dolomite precipitation, whereas in WadiGhiran it accounts for 15.9 % have high loading of HCO_3 and Calcite and Dolomite precipitation. In this factor, it may reflect the initial dissolution and precipitation of carbonate minerals by groundwater. The low variance associated with this factor may indicate buffering of the HCO_3 content by CO_2 exchange between groundwater and the atmosphere, and perhaps the precipitation of calcite and dolomite. However, the XRD analysis results shown that Dolomite and Calcite were common evaportic salts in the sediments samples collected from irrigated areas and wadi sediments.

Factor (3)

In WadiMurawani, it accounts for 11.7 % of the total variance, while in WadiGhiran it accounts for 14.2. Both wadis have a high loading of pH and partial pressure of Carbon dioxide (PCO_2). Mg and HCO_3 are moderately loading in WadiGhiran. However, these variables control and reflect the dissolution and precipitation of carbonate minerals. The sign values of the factor loadings indicate that pH and Pco_2 values are inversely proportional, which expected since when Pco_2 decrease the pH increase. Surprisingly, HCO_3 is not significantly loaded on factor 3 of WadiMurawani.Geochemically, both factors 2 and 3 are associated with $CO_2 – H_2CO_3 – HCO_3 – H_2O$ chemistry of the groundwater. However, such condition usually results from the involvement of more than one process.

Factor (4)

In WadiMurawani, it accounts for 6.6 % of the total variance and has a high loading of K. In WadiGhiran NO_3 and Cl and moderate loading of Ca and Mg are loaded in this factor. In WadiGhiran, this factor may indicate that the groundwater probably affected by polluted source(s), since high NO3concentration ranges between 17 to 690 mg/l with an average of 189.6 mg/l, which is greater than the acceptable maximum contamination level (MCL) of 45 mg/l.This factor might be indicated that groundwater in WadiGhiran probably affected by pollution source (s) provided NO_3 to the groundwater. Major source of NO_3 in the study might be linked to the on-site sewage disposal systems used in the area. This conclusion supported from the relation between NO_3 and Cl as shown above (Fig. 8).

Factor (5)

It represents both partial pressures of carbon dioxide (PCO_2) and HCO_3 variables in WadiMurawani (table 4). However, these variables control and reflect the dissolution and precipitation of carbonate minerals. In WadiGhiran, the factor represents single variables, K (table 5). The fact that K shows high association with an orthogonal factor 5. It confirms that its concentration is largely independently controlled. However, the above conclusions especially within WadiGhiran almost reflected high similarity to that found earlier by (Alyamani and Sabtan, 2009).

Table 4: Variables and Factors Loading after Varimax Rotation (Wadi Murawani)

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Ca	0.969	0.117	-0.057	-0.020	-0.114	0.071
Mg	0.857	0.160	-0.124	-0.014	-0.093	0.140
Na	0.950	0.135	0.090	-0.125	-0.045	0.009
K	-0.087	0.069	-0.144	-0.979	-0.048	0.069
Cl	0.980	0.105	-0.045	0.032	-0.087	-0.035
SO_4	0.887	0.218	0.034	0.024	-0.024	0.311
HCO_3	-0.212	0.092	-0.361	0.070	0.900	-0.017
NO_3	0.792	0.101	0.025	0.192	-0.139	0.029
pH	-0.217	0.249	0.924	0.121	-0.047	-0.079
TDS	0.981	0.141	-0.007	0.044	-0.084	0.065
EC	0.980	0.141	-0.008	0.044	-0.083	0.071
$SI_{Calcite}$	0.200	0.958	0.171	-0.070	-0.002	0.140
$SI_{Dololmite}$	0.299	0.894	0.273	-0.016	0.079	0.009
SI_{Gypsum}	0.762	0.160	-0.166	-0.019	-0.046	0.069
$SI_{Anhydrite}$	0.770	0.165	-0.155	-0.186	-0.020	-0.035
SI_{Halite}	0.845	0. 129	-0.225	-0.004	0.079	0.311
PCO_2	-0.035	-0.235	-0.865	-0.097	0.407	-0.017
Eigenvalues	8.986	2.082	1.990	1.122	1.060	0.943
Variance	0.529	0.122	0.117	0.066	0.062	0.055
Variance (%)	52.900	12.200	11.700	6.600	6.200	5.500

Table 5: Variables and Factors Loading after Varimax Rotation (Wadi Murawani)

Variables	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Ca	0.492	0.171	0.172	0.471	-0.027	-0.659
Mg	0.446	0.279	0.396	0.455	0.309	-0.291
Na	0.981	0.036	-0.033	0.014	-0.120	0.097
K	-0.079	0.190	0.009	0.041	0.973	0.007
Cl	0.750	0.053	0.195	0.510	-0.028	-0.331
SO_4	0.995	0.153	0.010	0.025	0.023	-0.035
HCO_3	0.064	0.675	0.609	-0.040	0.103	0.248
NO_3	0.298	0.174	0.090	0.917	0.038	-0.113
pH	-0.117	0.398	-0.820	-0.118	0.070	0.201
TDS	0.941	0.118	0.106	0.209	-0.029	-0.154
EC	0.943	0.118	-0.168	0.209	-0.024	-0.152
$SI_{Calcite}$	0.147	0.941	-0.168	0.124	0.058	-0.162
$SI_{Dololmite}$	0.115	0.955	-0.059	0.145	0.169	-0.029
SI_{Gypsum}	0.690	0.163	0.294	0.288	0.114	-0.356
$SI_{Anhydrite}$	0.522	0.165	0.094	0.243	0.203	-0.136
SI_{Halite}	0.840	-0. 042	0.135	0.296	0.101	-0.149
PCO_2	-0.092	0.002	0.983	0.089	0.031	-0.033
Eigenvalues	6.269	2.696	2.411	1.909	1.174	0.996
Variance	0.369	0.159	0.142	0.109	0.069	0.059
Variance (%)	36.900	15.900	14.200	10.900	6.900	5.900

Conclusion

Groundwater is the only source for drinking water in WadiKhulays basin. In the present investigation, the groundwater within the basin has been found to be susceptible to nitrate contamination. Waste water from the cesspool systems and to some extent leachate from lawn fertilizer is considered to be the major sources of nitrate in the shallow groundwater aquifer in WadiKhulays basin. The chemical analyses results of the groundwater samples collected from private domestic wells in the residential site, show that Pco_2 content is a widespread pollutant that possesses a serious threat to the public health. The Pco_2 concentration in the groundwater exceeded the maximum contaminant level (MCL) of 45 ppm. It also greater than the average background (24.7 ppm) of the Pco_2 concentration in the unresidential region.

The nitrate concentrations in the two sites are as follows: (i) In WadiGhiran, it ranges from 17.0 to 690.0 ppm with an average of about 17.0 ppm.; (ii) In WadiMurawani, it ranges from 4.0 to 470.0 ppm with an average of about 84.4 ppm.

Two likely sources of NO_3^- in the groundwater were identified: (1) in the residential area, the high NO_3^- contents of the groundwater are more likely attributed to the effects from on-site systems on the shallow groundwater aquifer. It is highly witnessed as evidenced by the relationship between $NO_3^-$and Cl.

In the residential area, distances of the cesspool are critical factor in determining the amount of natural attenuation that occurs between the location where cesspool effluents enter the aquifer, and the nearest down-gradient point of groundwater withdrawal. Additionally, the dominant groundwater movement in the area is another factor that enhanced groundwater deterioration by nitrate that is leaching from on-site wastewater disposal systems.

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The Exploration and Evaluation of Water Resources in Harrat Khybar

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Abstract: Groundwater resources everywhere are often the most abundant and naturally preserved storages for future uses. They are in contact with different minerals and therefore at suitable geological locations their taste and potability cannot be compared with other resources from the quality point of view. In arid and semi-arid regions they are the sole water supply alternatives that occur within the granular voids, fractures and solution cavities according to the geological environment. All three types of voids are available in the Kingdom of Saudi Arabia. The solution cavity groundwater storage facilities are in the eastern provinces with extensive areal coverage, granular voids are present especially in the Quaternary deposits of any wadi everywhere within the country as well as in sandstone formations. Tectonic origin fractures are almost everywhere. They store relatively small amounts of groundwater but more significantly they are high transmissivity networks within the granular basement and surroundings. The volcanic area is composed mainly of lava flows and underlain by alluvial deposits of various types of sediments (gravel, sand, clay) and both are resting on Precambrian crystalline rocks. Such a configuration provides rather potential groundwater possibilities in the region. Significant water-bearing formations occur in two different lithologic units, namely, the sub-basltic alluvial deposits as well as the basalt flows itself. Increasing water demand and limited water resources triggered the necessity of making specialized studies on natural water resources, evaluating its quantity and quality, and suggesting the best means of development and conservation of these resources, also to obtain appropriate technologies to that end. This study is prepared for identification of the aquifer dimensions from geometrical, hydrological and hydrogeologic points in addition to quality variations. This report concentrates on the determination of each individual parameter that plays a dominant role in the groundwater resources evaluation in Harrat Khybar. The study required in the field works to do well Inventory to recording well location and aquifer characteristics, Analysis of the physical properties of groundwater samples in the field, Aquifer Tests, Surveying and Geophysical Investigations.

Keywords: Volcanic area, Harrat Khybar, Hydrology, slope matching, Electrical resistivity, Saudi Arabia.

Introduction

Increasing water demand and limited water resources triggered the necessity of making specialized studies on natural water resources, evaluating its quantity and quality, and suggesting the best means of development and conservation of these resources, also to obtain appropriate technologies to that end. The bottom line is exploring an alternative natural water source in case of emergencies. Investigate the possibility and capability of the groundwater reserves in “harrat Khybar” in case of emergencies at some of the major cities that depend on desalinated water supplies. study the possible development of utilizing periods of heavy rainfall as a water resource, and explore the possibility of supplying other areas from the available water resources in this area. finally highlight of control points in basins through which water could be used for different purposes.

Study Area

Harrat are Cenozoic lava fields composed mainly of basaltic lava flows erupted from many scoria cones. In the Kingdom of Saudi Arabia, these harrats were created during the tectonic and volcanic activities that also formed the Red Sea, the Gulf of Aden and the East Africa Rift Valley System in the Cenozoic era. This is known as a three-armed rift the forms above a mantle plume. Most of the harrats in the Kingdom are in its western part and they constitute one of the largest alkali basalt areas in the world (Figure 1). The extend from south to north along the west side of the Arabian Peninsula. Some harrats extend across the northern border of the Kingdom into Jordan. Some small harrats occur along the Red Sea coastal plains, especially on the Tihama Coastal plain between Jeddah and Jizan. The age of harrats in the Kingdom is less than 30 million years. They extend over an area of about 200,000 km^2 in a belt along longitude 40^{o}E.

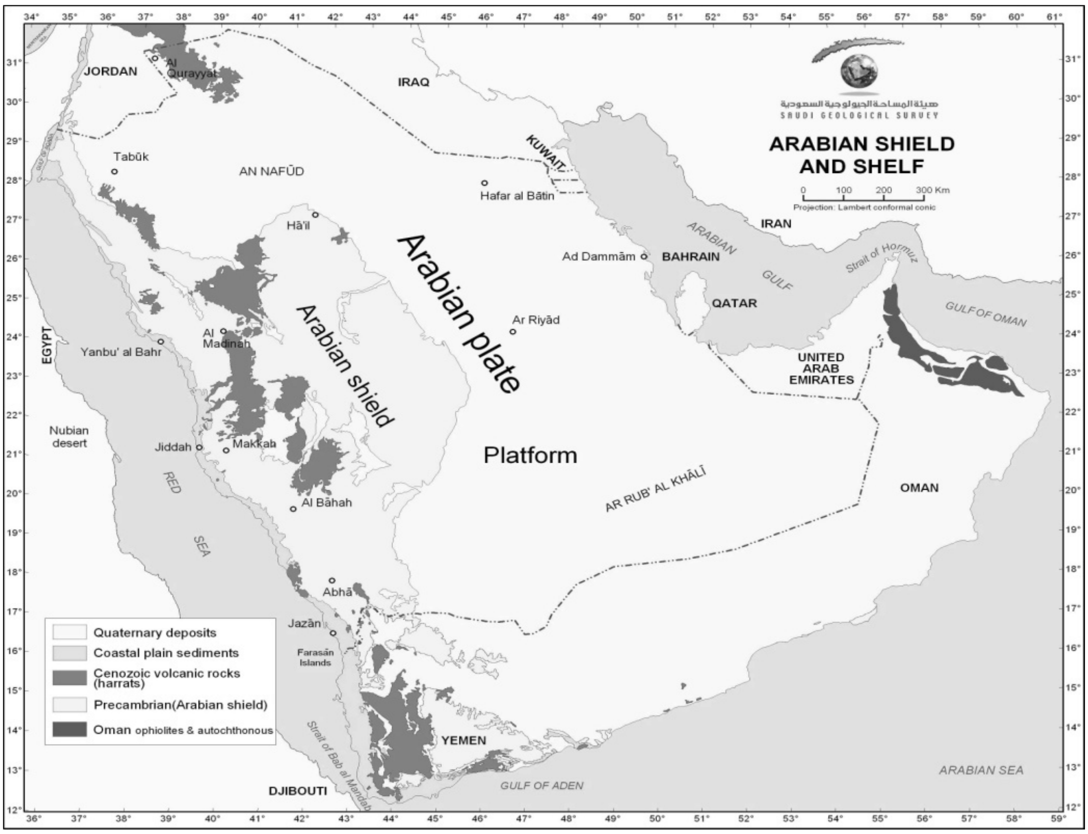

Figure 1: Location map of volcanic area in Saudi Arabia

Harrat Khybar located in the mid-western part of the Kingdom of Saudi Arabia between latitude 25° 00 to 27° 00 N and longitude 39° 00 to 41° 00 E, between the cities of Al-Madinah Al-

Munawarrah and Hail its differs from all other harrats in Saudi Arabia because of the presence of white felsic rocks present as tuff rings and domes with pyroclastic aprons. These are coalesed to form a large single harrat. It lies northeast of Al-Madinah Al-Munawarrah, trending north to south it is 280 km long and 170 km wide. On its edgesconcentrated wells and agricultural activity, there are many villages and small towns.

Hydrology

In Khyber area, the major source of any natural water storage is the rainfall, which is occasional and sporadic within the Kingdom of Saudi Arabia. The rainfall amounts are measured by rain gauges and the records are kept for future use. These records provide a very precious document. Otherwise, the water resources planning, project, construction and especially management and operation cannot be achieved in the best possible manner. This study is concerned with the calculation of rainfall water averages through simple hydrological procedures such as the isohyetal maps (Figure 2). These maps show the regional variation of rainfall amount over the study area. In the present work, the rainfall data were collected from 8 recording stations summarized in (Table 1). However, the rainfall records duration almost from 1980 to 2010. These data were collected from the Hydrology section of the Ministry of Agriculture and from Meteorology and Environmental Protection Administration (MEPA).

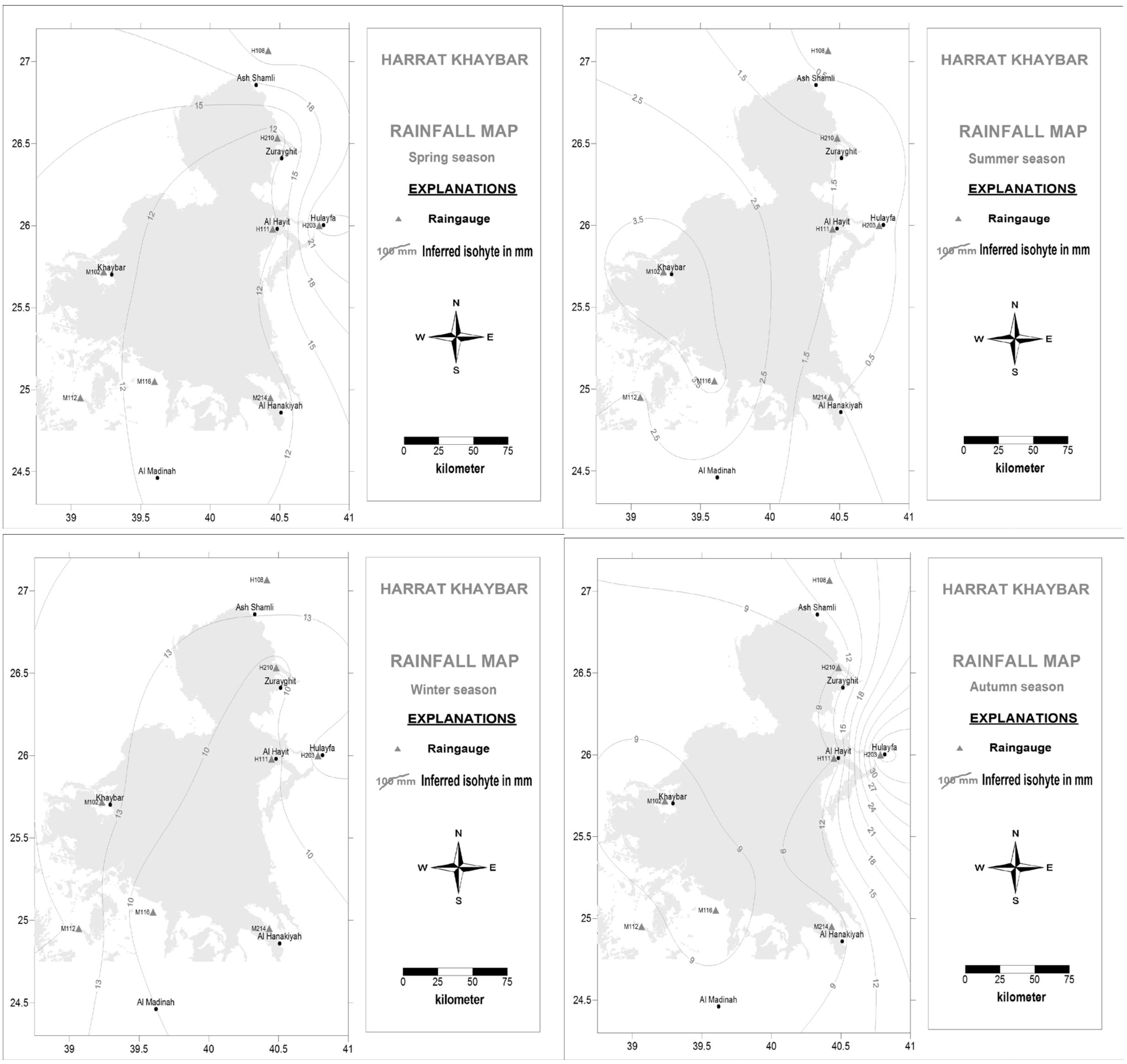

Figure 2: Seasonal Variation rainfall in four seasons from 1980 to 2010

Table 1: Seasonal rainfall variations (mm)over the study area (1980-2010)

Station	Long.	Lat.	Winter	Spring	Summer	Autumn	Annual Average
H108	40.41667	27.06667	15.53	22.86	0	14.26	75.42
H210	40.48333	26.53333	9.1	10.62	1.5	8.98	30.47
H111	40.45	25.97778	9.1	10.62	1.5	8.98	107.74
H203	40.78333	26	13.78	24.75	0.63	37.39	62.8
M214	40.43333	24.95	7.89	10.6	0.55	6.99	34.04
M116	39.6	25.05	7.2	10.42	3.77	10.46	20.84
M112	39.06667	24.95	15.82	14.14	2.4	8.3	30.83
M102	39.23333	25.71667	14.3	13.23	4.02	10.4	43.2

In order to assess rainfall pattern over the study area, it is necessary to define the predominant climatic patterns that have an influence on rainfall distribution over the western province.The climatic pattern over the western province can best be described by considering the various air masses that affect the rainfall distribution over the area considered.

Harrat Khyber is considered as an arid region with high temperatures throughout the whole year with less than 53 mm rainfall per year. This implies high evaporation and relatively less infiltration rates. The annual rainfall amounts varied from year to year and it often occurs as thunderstorms of very high intensity during a local storm followed by dry periods, while the seasonality of the rainfall almost shown strong. However, the rainfall distribution over the study area is also variable in time and space. Data from the eight rainfall gauges were used to establish the annual and seasonal isohytal maps (Figure 2), while averages of these maps were computed in order to give an approximate idea of the seasonal variation in the local rainfall patterns (table 1).

Hydrogeological Setting

The study area is composed mainly of lava flows and underlain by alluvial deposits of various types of sediments (gravel, sand, clay) and both are resting on Precambrian crystalline rocks. Such a configuration provides rather potential groundwater possibilities in the region. Significant water-bearing formations occur in two different lithological units, namely, the subbasltic alluvial deposits as well as the Saq aquifer. Information on the hydrogeology of the area was obtained from the well inventory, pumping tests and geophysical survey that carried out in the study area.

1. Well Description

Groundwater in the study area is used for a wide variety of purposes including water supply, domestic activities and irrigation. Wells are drilled in order to satisfy one or more of these purposes and are designed and completed accordingly. They mainly concentrated closed to the edges of the harrat. Hundred of wells exist in these areas. It was not possible to make a detailed inventory for them due to their huge number in such an extensive study area, the inaccessibility of some wells and the short duration of the field season. More than three hundred wells were visited during the field trips of this study.Local farmers drilled most of the existing wells. In order to give a comprehensive view concerning the type, basic characteristics, and utilization of these wells, the study area is divided into three sectors namely sector A, sector B, and sector C. The inventoried wells in these sectors are shown in (Figure 3). The majority of the wells are drilled wells having between 12” and 16” diameter. The total depths and the levels in the three sectors are shown in the (Table 2)

Figure 3: Well location and sectors in Harrat Khyber area

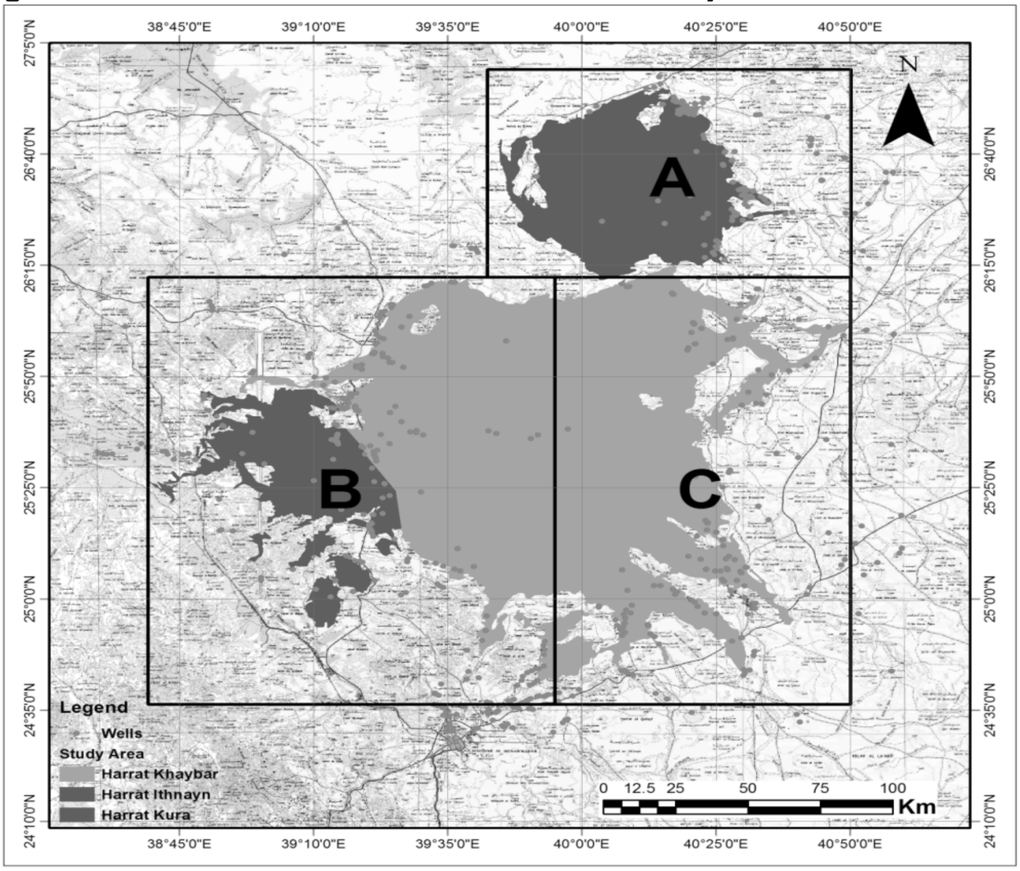

Table 2. Water table and total depths (m) for wells in the study area

	Sector (A)		Sector (B)		Sector (C)	
	Depth to Water	Total Depth	Depth to Water	Total Depth	Depth to Water	Total Depth
Max	207	280	95	315	108	120
Min	3.9	7.71	1.51	3.79	6.54	7.75
Mean	31.96	62.2	21.8	41	45.11	58.1

2. Aquifer Description

The basalt flows and the old subbasaltic alluvial deposits form the most important aquifer system of the Harrat Khyber area. In effect, these are two separate hydrogeological units which on a regional scale, can be considered as being inseparable, giving rise to an aquifer complex in unconfined to semi-confined and confined condition. The extent of these hydrogeological units is more or less the same as that of the basaltic plateau and the saturated thickness of the aquifer is very variable. The basalt lava flows differ with respect to their ability receives recharge as well as to hold water in storage and to transmit it in the form of groundwater. The differences in result of their inherent physical characteristics, such as their porosity and permeability. For example, intercommunicating vesicles distributed throughout the well rock, have a tendency to increase their permeability. Furthermore, the increase in size and number of the vesicles enlarges the porosity and permeability, while topographic setting also affects the movement of groundwater (Adyalkar and Mani, 1974). In addition, the nature, size, number and distribution of vesicles, the number and spacing of joints, and degree and extent of weathering control the productivity of the aquifer in a basalt terrain.The subbasaltic alluvium is composed of conglomerate, cobbles and pebbles formed by materials of metamorphic and basaltic origin, generally angular to sub-angular gravel and sand, poorly sorted with find grained with fine- grained silty sands.

3. Groundwater Discharge

The groundwater in the study area is discharged either naturally by direct evaporation from the shallow water table areas (Table 2) and subsurface outflow or artificially by withdrawals from wells which depend upon the duration and rated of pumping. These factors have caused a great decline of the groundwater level because they exceeded the total recharge. Among these aspects, evaporation is the least important quantitatively, because the depth to the saturated zone is generally large enough to minimize the evaporation processes, with the exception the shallow water table therein. On the other hand, the amount of natural discharge by the subsurface outflow will depend chiefly on the regional hydraulic gradient, the hydraulic conductivity of the aquifer system, and the cross –sectional areas that join the basalt aquifer and the shrouding alluvial deposits. Artificial abstraction by pumping the wells in the cultivated areas accounts for the largest discharge component. To make a reasonable estimate of the total annual volume of water extracted for irrigation, information about pumping hours and days, discharge rates, and total number of pumping wells in the area are needed.

4. Aquifer Parameters

Slope matching method that have been applied in this case has been developed by which the slope between any two successive data points on a time-drawdown plot can be used for determining aquifer parameters in non-leaky and leaky aquifers. The method yields values of transmissivity and storativity, which are in good agreement with the results of the classically known techniques. The method of slope analysis offers several advantages in its use. These advantages include the following: Changes in values for the aquifer parameters that might occur during a pumping test can be identified. Confidence limits can be calculated for average values of aquifer parameters. The method yields meaningful aquifer parameter estimates even for short duration pumping tests.

Twenty pumping tests were performed in the field. The data of the pumping test wells are shown in Tables 3 to 5.

Table 3. Transmissivity&Storativity for Sector **A**

Sector A		
Well No.	Transmissivity (m^2/day)	Storativity
GA-04	14.12	0.091
GB-01	47.41	0.048
GB-05	43.49	0.034
HSHB-017	34.02	0.036
HSHB-102	27.31	0.043

Table 4. Transmissivity&Storativity for Sector **B**

Sector B		
Well No.	Transmissivity (m^2/day)	Storativity
GB-04	34.29	0.042
KA-132	45.30	0.196
KB-081	155.70	0.107
KB-087	135.95	0.102
KB-136	123.74	0.106

KHN-001	123.74	0.106
KHN-002	129.85	0.111
KN-016	113.43	0.132
KN-034	135.80	0.113
R-095	2.75	0.013

Table 5. Transmissivity&Storativity for Sector **C**

Sector C		
Well No.	Transmissivity (m^2/day)	Storativity
GA-012	993.86	0.108
GB-010	654.49	0.021
GB-012	1388.41	0.029
KA-113	161.03	0.064

Groundwater Chemistry

During the field investigation, 301 groundwater samples were obtained from the three sectors (A, B and C), so as to obtain a general picture of the groundwater quality in the whole of the study areas. Of these, 79 groundwater samples were taken from sector (A), 136 groundwater samples from sector (B) and 86 samples from sector (C). All groundwater samples were taken from privately owned wells (Figure 3). A few drilled wells seem to be abandoned for use either due to their providing insufficient water to remain irrigation through the dry season and/or their water has rather high salinity. During the field survey and samples collection, groundwater temperature, electrical conductivity (EC) and pH were measured in situ. Most of the groundwater samples were taken from intensively pumped wells in order to avoid any local contamination or change in chemistry caused by evaporation or gas exchange in the well itself.

(Tables 6) shown the chemical analyses results of the major ions of the groundwater samples obtained from the three sectors (A, B, and C). The pH of the groundwater tends to be slightly alkaline. However, the great majority is between 7.0 and 7.7. The EC measurements generally show that the groundwater salinity varies from low to moderate. High saline waters were also found but less common.

Table 6. Summary of the chemical analyses results of the groundwater major ions in ppm

Elements	Sector A (79 Samples)			Sector B (136 Samples)			Sector A (86 Samples)		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
Ca^{++}	937.5	9.7	132.8	983	10.4	164.9	1716.2	9.5	244.3
Mg^{++}	568.8	1.1	55.01	808.8	5.2	101	799.5	8.19	127.6
Na^{+}	2352	54.8	404.8	2244.5	9.6	414.1	3920	10.1	605
K^{+}	66.3	0.2	9.28	130.6	0.2	11.5	16.8	0.3	4.82
Fe	13.2	0.18	1.98	2.13	0.14	0.69	1.92	0.12	0.73
NH_4	10.2	0.04	1.17	5.2	0.05	1.82	3.2	0.05	0.81
Cl	4773	4.11	440.5	4650	5.5	635.76	8245	4.72	1081.1
HCO_3^-	854	78	333.2	1025	106	348.9	820	67	260.1
SO_4^{--}	3071	15	515.3	2560	7	526.4	4211	9	674.1
NO_3^-	382	9	81.7	450	1	67.4	850	8	163.4

F	5.35	0.3	1.87	2.25	0.01	0.57	3.88	0.04	0.75
NO_2	9.4	0.04	0.79	21.1	0.04	1.19	4.4	0.04	0.36
PO_4	2.66	0.1	0.26	13.8	0.09	1.24	6.28	0.09	0.75
SiO_2	62.7	13.2	27.9	84.4	16.9	41.9	65.5	14.2	32.4
TH (ppm)	4681.6	39.8	544.1	5782.8	47.37	825	6490	62	1123
pH	9.35	5.95	7.45	8.07	6.54	7.39	8.38	0.83	7.41
TDS (ppm)	11120	301	1762.1	10590	225	2488.5	15200	250	2980.3
EC (μS/cm)	17150	463	2713.9	16320	347	3327.9	31100	385	4995.7

On the other hand, the analyses results indicated that the chemical composition of the groundwater varies between low to moderate concentrations in most of the chemical constituents. It also shows that the cation composition varies between almost Na^+ to dominantly Ca^{2+} and Na^+ with relatively lesser amount of Mg^{2+} and K^+. Among the anions, Cl^- and $SO4^{2-}$ are dominant. Generally, the major ionic concentration of the groundwater shows the following general pattern:

$Na^+ > Ca^{2+} > Mg^{2+} > K^+$
$SO4^{2-} \geq Cl^- > HCO3^- > NO3$

The hydrochemical studies show that NaCl and Na HCO3 water types are predominant in the area particularly in sector (C). While in sector (B), the water characters almost NaCl, Ca(HCO3)2, and Ca^-Na (SO4). In sector (A), the prevalent chemical characters are NaCl and Na2SO4, while NaHCO3 water type is less common.

1. Irrigation Water

A number of factors, in addition to mineral content determine whether groundwater is suitable for irrigation use. Therefore, quality standards for irrigation are based on (1) the total salt concentration of the water as it effects crop yield through osmotic effects (2) the concentration of specific ions that may be toxic to plants or that have an unfavorable effect on crop quality ; and (3)the concentration of cations such as Na^+, Ca^{2+} and Mg^{2+} can take part in ion exchange with clay that can cause deflocculation of the clay in the soil and resulting damage to soil structure and declines in infiltration rate. The quality requirements of irrigation water or universal standards for it cannot be formulated, and what might be a poor water at one place could be quite acceptable somewhere else. Nevertheless, quality criteria and classification schemes for irrigation water were developed and can be used as guidelines.Within the study area, the most extensive use of groundwater is for irrigation of crops. As a result s considerable amount in the present work will go into the susceptibility of plant and their growth to the quality of the groundwater used for irrigation, before any final decisions can be made with respect to water use. However, suitability of groundwater for irrigation use can be examined using a number of indices that may provide a good practical guide to water suitability; these are as follows:

1.1. Total Salt Concentration Hazard

Osmotic processes may consider the most important life function in plants so that any changes in osmotic conditions in the root zone could affect the rate of water flow to a plant (Lloyd and Heathcoat, 1985). This parameter often relates directly to electrical conductivity (EC).According to the criteria provided in (Table 7), most of the groundwater is fallen within the satisfactory limits. A number of groundwater samples particularly those collected in the three sectors often reflected low mineralized water, where the EC measurements less than 3000 μS/cm, whereas, a few are over the acceptable limits (Table 8).

Table 7. Guidelines for interpretation of water quality for irrigation and domestic use (Lloyd and Heathcote, 1985)

EC (μS/cm)	SAR (epm/l)	RSC (epm/l)	B (ppm)	TH (ppm)
< 250 Low salinity	0-10 Low	< 1.25 Suitable	< 1.0 Excellent	0-75 Soft
250-750 Medium salinity	10-18 Medium	1.25-2.5 Marginal	1.0-2.0 Good	75-150 Moderately hard
750-2250 High salinity	18-26 High	>2.5 Not suitable	2.0-3.0 Permissible	150- 300 Hard
2250-5000 Very high salinity	>26 Vary high		3.0-3.75 Doubtful	>300 Very hard
			>3.75 Unsuitable	

Table 8: Values of EC, SAR, RSC, MH, B and TH for groundwater samples in the study area

Elements	Sector A (79 Samples)			Sector B (136 Samples)			Sector A (86 Samples)		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
EC (μS/cm)	17150	463	2713.9	16320	347	3327.9	31100	385	4995.7
SAR (epm)	24.5	1.6	7.9	24.8	0.3	6.2	24.3		
RSC(epm)	4.47	-88.7	-5.76	7.9	-109.9	-10.8	3.75	-126.2	-18.5
MH(epm)	75.5	6.36	38.3	84.6	16.6	46.3	73.35	17.04	49.3
B (ppb)	4.17	0.1	0.68	0.7	0.64	0.44	3.55	0.12	0.57
TH (ppm)	4681.6	39.8	544.1	5782.8	47.37	825	6490	62	1123

1.2. Sodium Adsorption Ratio (SAR)

Plants are sensitive to sodium in that a high concentration of Na^+ in irrigation waters comparative to Ca^{2+} and Mg^{2+} contents has potential for adverse effects as mentioned.(Table 7) shows the calculated values of SAR for the groundwater seems to be medium to high according to the recommended water classification (Table 8) for SAR (Lloyd and Heathcote, 1985). High SAR values are less common in the three sectors.

1.3. Residual Sodium Carbonate (RSC)

The residual sodium carbonate is another parameter to evaluate the suitability of water. High concentration of bicarbonate in the irrigation water may lead to precipitation of calcium and magnesium carbonate in the soil as the water is concentrated by evaporation processes, resulting in an increase in the proportionate amount of sodium, with further effects on the soil structure if the sodium is high.The computed values of RSC for the three sectors are summarized in (Tables 7). As can be seen, all the values are negative (< 1.25). This is because $HCO3^-$ is not an important anion compared to Cl^- and $SO4^{2-}$ in the groundwater. However, the RSC values in the range found can be used safely for irrigation purposes.

1.4. Magnesium Hazard (MH)

The magnesium hazard (MH) another factor used to define the groundwater suitability for irrigation use.The calculated values of MH are presented in (Table 7). However, the MH > 50 the effects are considered to be harmful. However, a few samples shown that the MH values are rather high.

1.5. Boron Hazard (BH)

Boron is essential for plant growth in very small concentrations; however, it can become extremely toxic at concentrations slightly above optimum. The criteria adopted for boron are given in (Table 7) It shows that most of the groundwater are fallen with satisfactory limits but some groundwater samples shown to be Unsuitable.

Geophysical Setting

Electrical resistivity sections were carried out in 2 stages in an east-west direction across the centre of Harrat Khaybar in order to determine whether there are any significant aquifers underlying the near-surface basalts. The equipment used was an IRIS Instruments SYSCAL Pro 96-channel setup, with an electrode spacing of 10 m, giving a maximum length for each profile of 950 m. Due to the length of the array and the requirement for good contact of the electrodes with the ground the surveys could only be carried out where there were large areas of alluvial cover on the surface. Hence the spacing of the electrical sites is somewhat irregular, but a reasonably good transect over the full width of the harrat was achieved.

In the first stage 9 profiles (Figure 5) were measured across the eastern part of the harrat, at intervals averaging about 5.5 km, where the profile start near the eastern side of the harrat and then proceed westwards.The resistivity transects in the second stage comprised 9 profiles over the western side of the harrat (Figure 6), at an interval of about 5 km, where the profile locations are numbered from 10 to 18.The profile locations for both stages are shown in the Google Earth image below.From sections 1 to 4 the surface lavas and the shallow underlying aquifer are quite well defined, although these are variable in thickness. The aquifer in section 1 is probably salty, but the other sections indicate that fresh water is present. In section 5 to 7 the lavas are fairly variable in thickness and the saturated zones are also much less continuous, but probably contain fresh water. Lines 8 to 11 mainly show the lavas, as expected for points near the centre of the harrat. The lavas are very variable in thickness, but there are also localised saturated zones throughout the sections that generally are discontinuous and probably have fresh water as well. Line 15 has thin lavas and a more extensive zone that issaturated with fresh water. In line 17 the lava is not so thick and is probably underlain by fresher water, possibly in an aquifer that is not continuous across the section. Sections 14 to 16 show quite variable lavas and localised saturated zones with fairly fresh water at various depths. In contrast in section 17 the lavas are thin and broken up, with discontinuous saturated zones of fresh water. Section 18 mainly shows the effects of the surface lavas and Precambrian basement, although there are indications of a deep aquifer.

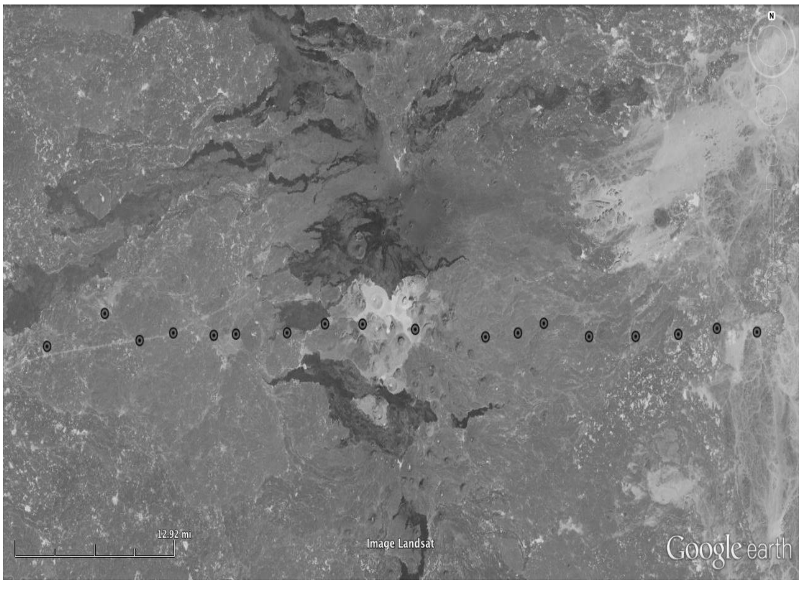

Figure 4: Resistivity with topography

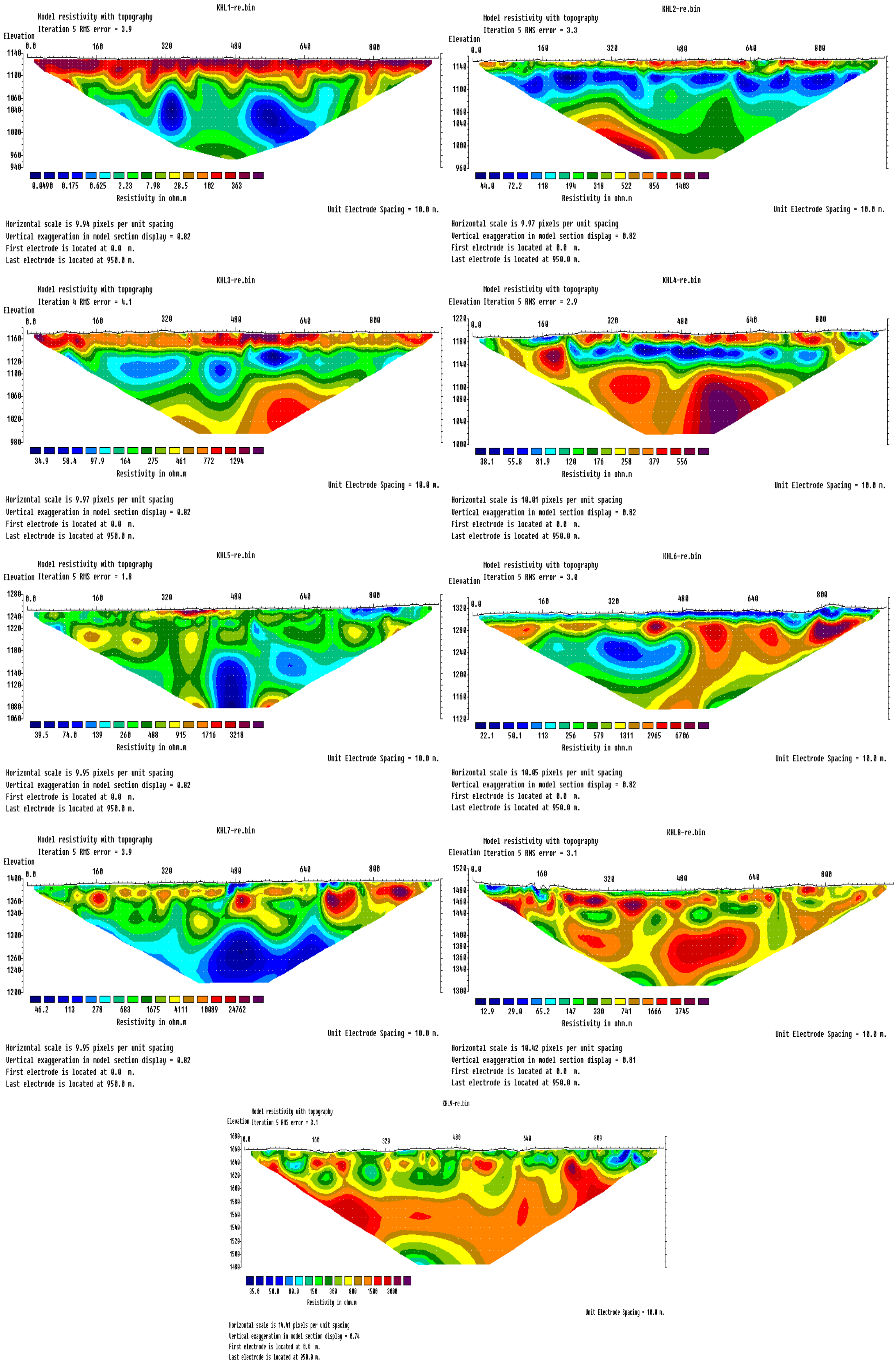

Figure 5. First stage 9 profiles across the eastern part of the study area

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Biography: *Mr. Essam Obaid Alwagdani received his BSc degree in Hydrogeology from Faculty of Earth Sciences, King Abdulaziz University, KSA, and Diploma in Integrated Water Resource Management (IWRM) offered by the United Nations University Institute of Water, Environmental and Health at the Arabian Gulf University, Bahrain. Since 2003 he joined Saudi Geological Survey SGS, Jeddah as a Hydro geologist. He began his career as a member in several projects in hydrogeology section, where he contributed to hydro geological studies in various parts of Saudi Arabia in different environment including the groundwater strategic storage project in the coastal basins, the collection and analysis of groundwater samples of deep aquifer project in the northeastern and Southern parts, the evaluating and developing water resources project in the Southern part, the exploring and developing water resources project in volcanic areas, the generating and drawing the hydro geological and hydro chemical maps projects in Saudi Arabia. He also attended and participated in several specialized training courses in a range of specialized centers in different countries in addition to his participation in several international conferences. Mr. Essam is the co-author in published 2 papers, the 1st entitled "Aquifer Heterogeneity Determination through the Slope Method" published in (Hydrological Processes Journal) & the 2nd entitled "Statistical Evaluation of Parameters in Heterogeneous Aquifers", published in (Journal of Hydrologic Engineering). Mr. Essam also obtained appreciation certificates from Saudi Geological Survey SGS for Designing Computer Software named "Aquifer Test", & for the efforts to achieve hydro geological projects*.

Analysis of Stakeholder's Characteristics for IWRM Implementation and its Application in the Batinah Region of Oman

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Abstract: Sea water intrusion into the coastal aquifer system of the Al Batinah coastal area in Oman as a result of over abstraction has been addressed by the Government since the beginning of 1990s. However, the water situation in the region is still at risk and the sea water intrusion is expanding more and more inland. Agriculture is the main consumer of groundwater in Al Batinah. It is concentrated in Al Batinah, because of more fertile soils and easier access to water in the form of groundwater compared to other administrative areas in the country. In the last three decade, there was a noticeable increase of water abstracted compared to the annual recharge of the coastal aquifer system. Therefore, the region is facing a problem of water deficit which also impacts the sustainability of the agricultural production. The main challenge now is how to provide the necessary water which will meet the requirements of agriculture and regional development and at the same time to conserve the limited water resources. The existing situation might generate conflicts between different stakeholders regarding water availability and profitable agricultural production in South Al Batinah region. In general, to solve such complex problems an integrated water resources management (IWRM) approach is recommended, which allow for assessing different management options and interventions. In this context, the aim of the study is to identify relevant groups of stakeholders as well as potential conflicts which might occur amongst them and to explore stakeholder's opinions and responses regarding several intervention measures. Furthermore, the implementation potential of several interventions is evaluated in order to support a decision making process within the frame of an IWRM. To achieve these aims a social survey has been performed. Questionnaires were designed for collecting data from different groups of stakeholders. These data are analysed statistically for each group separately as well as regarding relations amongst groups by using the SPSS (Statistical Package for Social Science) software package. Data and results are obtained for several types of stakeholders e.g. water professionals, farmers from the study area and decision makers of different organizations and ministries by using either face to face interviews or questionnaires. Amongst others, they have been asked regarding several management interventions like water quotas, subsidies, crop pattern changes, modern irrigation systems which reveal in partly contradicting opinions between stakeholders. However, the need to improve the situation is supported by all groups. Additionally, results indicate the requirement of a better management on the water demand side. In general, the study underlines the importance of a participatory approach with contributions from all relevant stakeholders in order to achieve a real IWRM implementation process and to solve complex, interacting problems which includes social, environmental and economic aspects.

Keywords: IWRM, Stakeholder, Statistical survey analysis, Oman.

Introduction

Sea water intrusion into the coastal aquifer system of the Al Batinah coastal area in Oman as a result of over abstraction has been addressed by the Government since the beginning of 1990s. However, the water situation in the region is still at risk and the sea water intrusion is expanding more and more inland.

The main water resource in the region is groundwater. Increasing population and per capita water use as well as agricultural development and industrial development has a great threat to groundwater. Agriculture is the main consumer of groundwater in Al Batinah. Around 53% of total cultivated areas in Oman are concentrated in Al Batinah (Ministry of Agriculture and Fisheries, 2006). The reason is being this region characterised of more fertile soils and easier access to water, in the form of groundwater, compared to other administrative areas in the country.

In the last three decade, there was a noticeable increase of water abstracted compared to the annual recharge of the coastal aquifer system. Therefore, the region is facing a problem of water deficit which also impacts the sustainability of the agricultural production. Royal Decree 82/88 refers to "the water of the Sultanate of Oman is a national resource to be used according to the restrictions made by the government for organizing its optimum utilization in the interest of the state of the comprehensive development plans". This is the most far-reaching and important piece of legislation on water resources. The main challenge now is how to control the problem of water shortage in South Al Batinah region and at the same time increasing agricultural production.

In the matter of implementing management strategies to maintain the groundwater aquifer in the region, several possible solutions were tried by the government. For example, after completion of the National Well Inventory Project (NWIP) in 1995, the expansion of agriculture was stopped and a ban on construction of new wells was strictly enforced. However, well owners pump as much water from the ground as they want without any restriction (Al Shaqsi, 2004). Another action from the government was construction of several recharge dams in the wadi channels in order to minimize the freshwater losses during flash floods. In spite of that, the current water demand especially for agriculture consumption is still much higher than the groundwater recharge. However, the solutions which have been already tried showed only a limited success (Zekri, 2008). The existing situation might generate conflicts between different stakeholders regarding water availability and profitable agricultural production in Al Batinah region. To solve such complex problems an integrated water resources management (IWRM) approach is recommended, which allow for assessing different management options and interventions.

In many countries Decision Makers (DM's) are responsible for the development process and the long-term planning to improve the quality of life and to maintain the resources for future generations. The Omani governmental structure is strongly a top-down structure, which leads to a high degree of centralization of power in a few governmental organizations, leaving little space for legislative or private sector (e.g. farmer organization) influence (USAID, 2010). Decision making process is a challenge and requires a combination of environmental, political, social and economical data. In this context, it is very important to involve other stakeholders in the community in taking decisions regarding environmental problems; this can be done according to the needs of the people and level of the problem. In history, there are so many projects in many countries have failed due to the neglect of stakeholder participation and involvement (World Bank, 1993). Zekri (2008) argue that the establishment and implementation of low and regulations to improve groundwater management require the consensus of all stakeholders. The report of the conference of water and environment, held in Dublin (1992), stated clearly that "Water development and management should be based on participatory approach, involving users, planners and policy makers at all levels". This was one of the key guiding principles which have played a central role in IWRM (UN, 2005).

The study presented here is part of a cooperation project between MRMWR and TU Dresden for implementing an IWRM process in the Al-Batinah region. To consider the interactions and nonlinearities between the hydrologic, meteorological, agricultural and socioeconomics systems in the region an integrated Assessment, Prognosis, Planning and Management-Tool (APPM) have already been developed and customized on the specific characteristics of the region (Schmitz et al. 2010, Grundmann et al. 2012, Grundmann et al. 2014 (this conference)). Besides an assessment of the existing situation, the APPM-tool allows for an optimisation and evaluation of different management interventions in order to achieve best possible solutions for water allocation, groundwater storage and withdrawal, saline water management and highly efficient irrigation strategies. The aim of this study now is to evaluate the implementation potential of several management interventions and their combinations by incorporating stakeholder's opinions and responses regarding several intervention measures. This is done in order to identify potential conflicts among stakeholders and to support a decision making process within the frame of an IWRM.

To achieve this aim a social survey has been performed. Questionnaires were designed for collecting data from different groups of stakeholders. These data are analysed statistically for each group separately as well as regarding relations amongst groups by using the SPSS (Statistical Package for Social Science) software package. Data and results are obtained for several types of stakeholders e.g. water professionals, farmers from the study area and decision makers of different organizations and ministries by using either face to face interviews or questionnaires. The study area comprises the two *Wilayat* 'Al Musa'ana' and 'Barka' where the farms are located near the coast line and the aquifer is affected by the salinity intrusion.

In this paper we evaluate the collected opinions regarding five major issues: (1) Opinions of farmers and DM's regarding the water situation and agriculture sustainability in South Al Batinah region, (2) Requirements needed to improve the productivity of agriculture, (3) Possible management interventions, (4) Obstacles facing water professionals and decision makers regarding the implementation of different interventions and, (5) Involvement of relevant stakeholders in decision making process. Results are presented and discussed in detail.

Methodology

1. Data collection

One of the most appropriate tools used to explore the opinion of different stakeholders in a domain is through distributing questionnaires and face to face interviews. Regarding environmental and management practices Delmas and Tofell (2004) identified stakeholders to be including government, regulators, customers, competitors, community and environmental interest groups, and industry associations. For our study purposes, questionnaires were designed for collecting data and information from different groups of stakeholders e.g. water professionals, farmers from the study area and decision makers of different organizations.

Two different types of questionnaires were developed; the first one for farmers and the second one for decision makers and water professionals. The survey was done by either face to face interviews or questionnaires distribution (handled to the respondent or via e-mails). The information collected for this work is a combination of environmental, social and economical data. The type of questions included were; selective questions, rating questions, filling gaps and open questions. Each questionnaire included four sections. The sections in the questionnaire for farmers included; (1) General information, (2) Farm survey, (3) Ideas and opinions and (4) Vision for future. While the one for DM's included; (1) General information, (2) Ideas and opinions, (3) Water resources and agricultural management and (4) Vision for future.

To ensure the success of the data collection process there was a need of a support from both; Ministry of Regional Municipality and Water Resources (MRMWR) and Ministry Agriculture and Fisheries (MAF) in Oman. An official letter was provided by MRMWR including an explanation and purpose of the study. This letter was used to arrange meetings with some senior staff in each involved organization.

After official arrangements with the Ministry of Agriculture, contacts were made with agricultural centers in each *Wilaya* to facilitate visiting and meetings the farmers. A list of every farmer in each *Wilaya* was provided by the agricultural centers. From these lists a random selection was drawn. We were able to cover at least 70% of the total number of farmers in each list.

The face to face interviews were mostly used with farmers and they were semi-structured in-depth interviews. Interviewees were contacted by phone to arrange visiting periods in their farms and some meeting were arranged to be in the agricultural center of the *Wilaya*. 64 farmers were interviewed during the survey, 37 from *Wilaya* 'Al Musa'ana' and 27 from *Wilaya* 'Barka'.

Questionnaires were handled and sent by mails to 84 water professionals and decision makers, with 79 % response rate. After distributing the questionnaires several reminder notices were also sent. Finally, thank you notices were posted to all respondents. 67 water professionals and decision makers sent back the questionnaires to us. They belong to different water organizations and research organizations; 23 from MRMWR, 19 from the Public Authority of Electricity and Water (PAEW), 8 from MAF, 5 from Ministry of Environment and Climate Affair (MECA) and 12 from research organizations.

2. Data Processing and Analysis

The data were analysed statistically for each group separately as well as regarding relations amongst groups by using the SPSS (Statistical Package for Social Science) software package.

We examine the differences between opinions of the farmers and decision makers regarding the different interventions. Furthermore, we explore if there is any differences between the farmer's actual opinions and what decision makers believe about farmer's opinion.

Statistical data analysis included descriptive statistics, cross tabulation and independent samples t-test. Descriptive statistics such as frequencies, means, medians and percentages were used to summarise the answers of particular questions. Cross tabulation tables, which are known as well as contingency tables, were used to display the relationships between two or more variables. They are helpful in understanding whether or not some variables have an effect on others.

We used the independent Sample t-test which allows comparing the means for two different groups to know whether the difference between group means is statistically significant. Our null hypothesis (H_0) is that there is no difference between the mean score of opinions of the group of farmers and the group of water professionals and decision makers. Our alternative hypothesis (H_1) is that there is difference between the mean score of opinions of the group of farmers and the group of water professionals and decision makers. A significance or alpha (α) level is usually specified to be at 0.05 (5%). It is also coupled to a P-value which is generated from the results to accept or reject the hypothesis. Knowing that if a P-value was found to be less than 0.05, then the result would be considered statistically significant and the null hypothesis would be rejected. In some studies other significance levels are also used, such as 0.1 or 0.01, depending on the field and purpose of the study. The level of significance are considered high if P-value ≤ 0.01, medium if P-value is between 0.01 and 0.05 and not significant (ns) if P-value ≥ 0.05.
P-values are calculated using Eq. (2.1).

$$p = 2\Phi(\bar{X} - \mu_0)/\frac{\sigma}{\sqrt{n}} \quad \textbf{(2.1)}$$

Where μ_0 is the hypothesized mean, σ is the population standard deviation, $\bar{x}$ is the sample mean and n is the sample size. The test was performed as a 2-tailed test.

Results and Discussion

1. Opinions of Farmers and DM's Regarding the Water Situation and Agriculture Sustainability in South Al-Batinah Region

We tried through the survey to explore the opinions of farmers, water professionals and decision makers regarding the existing situation of water resources and agriculture sustainability in the region. Respondent were asked to rate (according to their opinions) if they prefer to stop all agricultural activities in the coastal zone of Al Batinah. Also, they were asked to rate to what level they agree to leave the system as it is without any changes. The rating levels were either 'Strongly agree', 'Agree', 'I can't decide', 'Disagree' or 'Strongly disagree'.

The results in Figure 1 showed that very small proportions of respondents from both groups rated 'Strongly agree' or 'Agree' as their choices for the issue of 'Stop all agricultural activities in the coastal zone of Al Batinah', 9-16% of the farmers and 3-6% of DM's. The majority choose 'Disagree or 'Strongly disagree', 48% of the farmers and 68.5% of the DM's. Similar for the issue of 'Leave the system as it is without any changes', 8% farmers only and 4.5% DM's only choose 'Strongly agree' and 'Agree', while 83% farmers and 82% DM's choose 'Disagree' and 'Strongly disagree'.

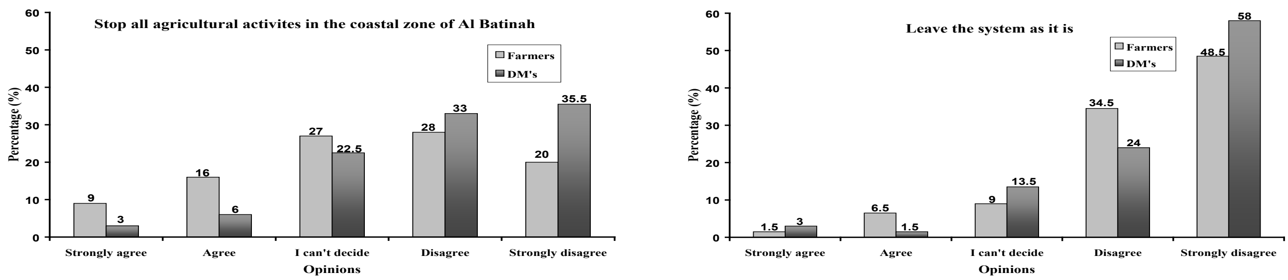

Figure 1: Opinions of farmers and DM's regarding the sustainability of Agriculture in the coastal zone of Al Batinah

In addition to this, Stakeholders have been asked to give their view in an open way. In general, both groups agreed that the water situation in Al Batinah is at risk. In spite of that, some results showed that farmers are not fully aware about the problem of water shortage in form of quantity. Many of them (26 farmers) expressed the situation saying; '*the water is available, but salty*'. This will be explained more in the following section. On the other hand, they know that the salinity is increasing with time and the water situation is getting worse every day. Also, they maintained that the water is not suitable any more for cultivating vegetables and fruit.

Around 60% of the decision makers and water professionals said that, if there is no action taken to solve the problem, the water table will continue to decline, seawater intrusion will increase, farms will be abandoned and farmers will tend to sell their lands to be developed for housing or other projects rather than agriculture.

The results showed that stakeholders prefer the sustainability of agriculture in the region. Additionally, both groups agreed that 'Leaving the system as it is' is not acceptable; this give an indication that the stakeholders, in general, believe that there is a need of improvement which can be achieved by implementing new management strategies.

2. Requirements Needed to Improve the Agricultural Productivity

Survey respondents were asked to indicate the requirements needed by farmers to improve the productivity of their farms. They were asked to rate each issue in the list as either 'Strongly Agree', 'Agree', 'I can't decide', 'Disagree' and 'Strongly disagree'.

According to the results obtained in table 1, there were significant differences in opinions of farmers and the other group of stakeholders in 5 out of 9 items and differences were less obvious between the two groups in the rest 4 items. Farmers are more interested in more income, better quality of water, better marketing facilities and subsidies issues. They are also interested in 'more water' but the mean is approaching 3 which is the level of 'I can't decide' option.

The highest rated requirements by the group of DM' were; guidance and training in agricultural management, guidance and information farming centers, better marketing facilities and more cooperation with other farmers. Most respondents (from both groups) rated the requirement of better marketing facilities as a strongly needed; the mean is less than 2 in each group.

Table 1. Comparison of opinions between Farmers and DM's needed to improve farm productivity, N=131

Requirements	**Farmers (n=64)**	**Decision makers & Water profession-al's believe about farmers (n=67)**	P-value
	Mean	**Mean**	
Guidance & Training in agricultural management	2.05	1.23	.000
Subsidies for modern irrigation equipment	1.69	1.86	.309
More water	2.56	3.64	.000
Better quality of water	1.61	2.59	.000
More labour	2.90	3.60	.000
More income	1.51	2.46	.000
Better marketing facilities	1.62	1.58	.782
Guidance & information farming centers	1.78	1.53	.065
More cooperation with other farmers	1.81	1.71	.530

(Note: (i) *Mean score ranges between 1 for strongly agree and 5 for strongly disagree/* (ii) *The degree of significant differences is based on independent samples T-test /* (iii). *Those shaded are significant*).

It is worth mentioning here that farmers were more concerned about quality of water compared to quantity. The difference in mean between the two options is about 0.95. Additionally, it is interesting to see that in the group of DM's the mean for 'More water' is approaching 4.

Although, the level of significance is high for the option of 'more labour', it can be noticed that among all the requirements there is an agreement between the two groups being less important. It has the highest mean compare to the other requirements. Moreover, DM's are proposing that farmers needs more incentives issues e.g. guidance and training.

3. Possible Intervention Measures

During the survey, the two groups of stakeholders were given a list of interventions and they were asked to select levels from 1 to 5 reflecting to what extent they would agree with each intervention (total 18 interventions) starting from 'Strongly agree' , 'Agree', 'I can't decide' , 'Disagree' and 'Strongly disagree'.

The proposed management strategies are specified as; (1) regulation issues e.g. water quotas, water pricing, and changing crop pattern; (2) issues related to reduction of water consumption by incentives e.g. subsidies, education, and training; (3) infrastructural issues e.g. injection wells, Dams, desalination plants, modern irrigation technologies, using treated waste water for irrigation and water distribution systems for agricultural purposes and (4) public awareness.

It is obvious that in many cases (12 of 18 items) the opinions of farmers were very different from the other group of stakeholders (see table 2). On the other hand, differences were less obvious between the two groups in minority cases (6 of 18 items).

Table 2: Comparison of opinions of farmers and DM's regarding interventions which could be implemented. N=131

Intervention measures	**Farmers (n=64)**	**Decision makers & Water professionals (n=67)**	P-value
	Mean	Mean	
Introducing water quotas.	3.47	1.88	.000
Introducing water quotas with subsidies in form of equipments for modern irrigation systems.	2.75	1.70	.000
Introducing water quotas with subsidies in form of guidance & training in agricultural management	2.94	1.58	.000
Introducing using treated wastewater for agricultural use, if it is available and the quality is acceptable.	2.17	1.61	.001
Encourage the farmer to reduce the withdrawal of groundwater pumped per day by guidance & training.	2.31	1.63	.000
Implementation of centralized well field water distribution system for agriculture which provides water in a good quality to farmers.	2.42	2.27	.458
Convince the farmer to change the type of crops to ones with lower crop water requirements.	2.48	2.03	.017
Encourage farmers to improve their irrigation methods.	2.02	1.45	.000
Encourage farmers to improve their irrigation methods with subsides in form of equipments for modern irrigation systems.	1.66	1.72	.636
Encourage farmers to improve their irrigation methods with subsides in form of guidance and training in agricultural management.	1.86	1.66	.115
Construction of injection wells near the coast line to form a barrier against the sea water intrusion, if water to be injected is available and the quality is acceptable.	2.19	2.13	.764
Construction of more desalination plants for brackish and seawater, in order to use it for irrigation.	2.14	3.09	.000
Increase the effectiveness of water use by public awareness.	1.55	1.46	.424
Introduce water prices for pumped groundwater.	3.92	2.48	.000
Introduce special energy tariffs for agricultural purposes.	1.86	2.49	.001
Forming water managers groups.	1.88	1.91	.819
Forming guidance & information water center to support farmers in farm & water management.	2.11	1.63	.002
Farms need to be evaluated and the government should take a decision to close some of them and change the land use.	1.97	2.52	.006

(Note: (i) *Mean score ranges between 1 for strongly agree and 5 for strongly disagree/* (ii) *The degree of significant differences is based on independent samples T-test /* (iii). *Those shaded are significant*).

Farmers were significantly more likely to the idea of increase the effectiveness of water use by public awareness, encourage farmers to improve irrigation methods with subsides in form of equipments, encourage farmers to improve irrigation methods with subsides in form guidance and training, introduce special energy tariffs for agricultural purposes, and forming water managers groups. However, they were more enthusiastic regarding improving the irrigation methods with subsidies in form of equipment, compare to the other two options regarding improving irrigation methods as the mean is 1.66 (see Table 2). This was the case with water quotas as well as the mean was 2.75 for the option of water with subsides in form of equipments.

The highest rated issues by DM's were; introducing water quotas with subsidies in form of guidance and training in agricultural management, forming guidance and information water centers to support farmers in farming and water management and encourage farmers to improve their irrigation methods with subsides in form of guidance and training in agricultural management. On the other hand, they were less likely to the idea of introducing more desalination plants. Only 35% of them agreed with it, 28% couldn't decide, and 37% disagreed.

All most both groups were significantly more likely to the ideas of centralized wells, change crop patterns, improve irrigation methods (with subsidies), and the construction of injection wells. The two groups also agreed much more about increasing the effectiveness of water use by public awareness, the mean in both groups are around 1.5. Farmers were significantly less likely to accept the idea of water quota and introducing water prices for pumped groundwater than the DM's. Only 29% of farmers accepted water quota.

For the DM's group, it is obvious that in many cases they are more likely to the regulation issues combined with incentives in form of education and training as well as forming guidance and information centers. While farmers are more likely to issues coupled with incentives in form of equipment from the government.

This question was repeated for the DM's, but this time they were asked to rate to what level the interventions might be accepted by farmers. The purpose is to explore if there is any differences between the farmer's actual opinions and what decision makers believe about farmer's opinion. In general, the results showed that decision makers are aware about farmer's opinions. This gives an indication that the existing situation is not in a very bad condition, since DM's understand the needs of farmers.

4. Obstacles Facing Water Professionals and Decision Makers Regarding the Implementation of Different Interventions

Water professionals and decision makers were asked to assess the major obstacles regarding the implementation of different interventions for overcoming environmental problems and the problem of water shortage in South Al Batinah. They were asked to rate the importance of each issue listed in the following table (Table 3) as either "Extremely important", "Moderately important", "Neutral important" "Low important" and "Not important".

From the results and by combing 'Extremely important' and 'Moderately important', it is obvious that all most all of the listed obstacles were rated as important (8 out of 9), by at least 60% of the total respondents. The highest rated obstacles were; absence of a clear mechanism for implementing the proposed solutions, farmers attitude and opinion and political willingness and support. The lowest rated (as important) obstacle was religion commitments. By combing 'Low important' and 'Not important', 34% of the respondents rated it as less important issue.

From the opinions of the respondents it can be concluded that the religion commitments are not considered as a great issue concern most of the DM's. Different other obstacles were rose up by DM's which were not included in the list. For example; shortage in the human resources and limitation of capacity building, absence of future long term outlook, absence of ways of cooperation with farmers, *etc.*

Table 3: Obstacles facing water professionals and decision makers, N=67

Obstacles	Extremely Important	Moderately important	Neutral important	Low important	Not important	NA	Mean
Financial problems (availability of funding or budgets)	46%	31%	10%	9%	3%	1%	2
Political commitments and regulations	43%	31%	21%	4%	0%	1%	1.8
Religion commitments	16%	20%	27%	27%	7%	3%	3
Absence of a clear mechanism for implementing the proposed solutions	35%	47%	13%	4%	0%	1%	2
Decentralization of the governmental institutions relevant to the decision-making with respect to water issues	25%	41%	23%	7%	1%	3%	2
Farmers attitude and opinion	42%	40%	15%	1%	0%	2%	2
Political willingness and support	46%	34%	13%	4%	0%	3%	2
The complexity of the problem	27%	38%	21%	9%	1%	4%	2
Being is water priceless for farmers	31%	43%	16%	9%	0%	1%	2

(Note: (i) *Mean score ranges between 1 for extremely important and 5 for Not important./* (ii) *NA refers to no answer).*

5. Involvement of Relevant Stakeholders in Decision Making Process

Survey respondents in both groups were asked to indicate by 'Yes', 'No' or 'No idea' if water users should play a role in making decisions regarding environmental problems and water management issues. For this question the group of decision makers and water professionals were specified according to the organizations they belong to.

Table 4: Water users involvement in decision making process, N=130

Organization	n	Yes%	No%	No Idea%	No Answer%
Farmers	64	95.3%	1.6%	0%	3.1%
Ministries and Water issue Organizations	54	88.9%	5.6%	10.8%	1.9%
Research Organizations	12	83.3%	16.7%	0%	0%
Total	130	91.5%	4.6%	1.5%	2.3%

Majority of the respondents (91.5%) believe that involvement of water users in the decision making process is important. Only 4.6% of all respondents indicated that they are not agreeing with the idea. Most of the decision makers groups indicated that they agree with the idea, by at least 80% of the total respondents. Researchers were more cautious about the idea, at least 16% of them thought that it is not a good idea.

The groups of decision makers and water professionals (Researchers) supported the idea and gave reasons for why it is important to involve water users in decision making processes. First, users are the main source of water problems and environmental degradation and they have recognised some of the effects in their lands. Therefore, solutions from them will be based on their practical experience to the problem. The second reason is the implementation of proposed interventions will be easier to take place and the time required will be less, as users will be keen to protect their own lands. The third mentioned reason is that during such a process the knowledge of water users about the problems will be increased, which will increase as well the awareness and farmers will be more desire to conserve water.

The different types of stakeholders were asked to specify, within a provided list, the best way of communication between farmers and decision makers. Results are presented in Figure 2 below.

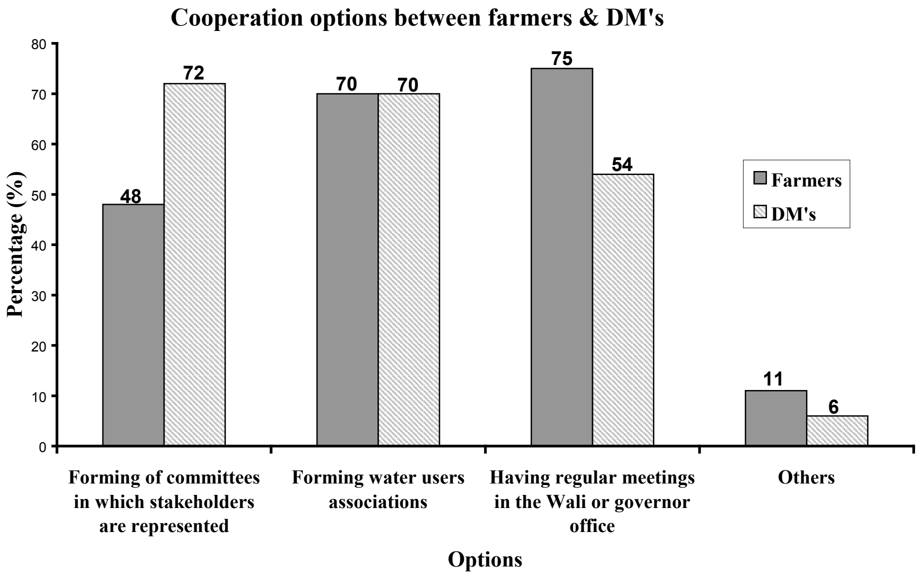

Figure 2: Communication ways between farmers and DM's

Most of the mentioned procedures were accepted by all respondents by at least 48%. DM's were more likely to the option of forming committees in which relevant stakeholders are represented (72%). Farmers were more likely to the idea of having regular meetings in the Wali or Governor Office (75%).

Farmers were asked to identify if they are ready to be members in these meetings or associations. More than half (78%) of them were interested in taking place in meetings and negotiations, while 22% were not interested to be involved in such type of meetings.

Many other ideas were brought up by the different respondents. For example eight farmers suggested formulation of committee from the government to be visiting them periodically and ask them about their opinions regarding the problem and the proposed interventions. They also suggested periodical meetings to be organized by the government in the agricultural centers in the regions.

Through this survey it was noticed that marketing facilities are very important to farmers. Most respondents rated the requirement of better marketing facilities are strongly needed (see Table 1). In this context, five DM's suggested that based on better marketing facilities, farmers can be convinced for so many things. Another way suggested by three DM's is to use new technologies to communicate with farmers, e.g. construction of special web sites via internet to let farmers express their opinions. They even proposed to introduce intervention measures through the web site and ask farmers for their choices. Regarding this issue, it must take into account if farmers are familiar of using computers and other new techniques or not.

Some of the decision makers and water professionals believe that farmers association in Al Batinah or other forms of organisations of farmers should play significant role to facilitate sharing ideas between farmers and other relevant organizations. This is supporting the importance of introducing the participatory approach with contributions from all relevant stakeholders very well. A coordinated response is needed between relevant organization, farmers as well as the media to help this message become part of local understanding (Oman Salinity Strategy, 2012).

Conclusion and Outlook

It is well known that water crises along Al Batinah coast is due to low rainfall ratios and unwise use of groundwater. Groundwater abstraction rates exceed the recharge rates of the coastal aquifer. Therefore, if the current trend of water uses remains the same then the results will be; continuous decline of water table, increase of seawater intrusion and deterioration of agricultural soil which will decrease the agricultural areas, like stated by several stakeholders. Additionally, more environmental and social problems will be generated.

Through this work, a total of 18 intervention measures were analysed. A list of management interventions was presented to selected groups of relevant stakeholders to expose their opinions regarding each of them. The results show that there is a need to improve the situation which is supported by all groups. In most cases, farmers are more likely to the solutions of increasing water availability especially of good water quality, while DM's are more likely to the management issues especially demand management.

On top of the adaption measures or alternatives to be implemented to solve environmental problems, the involvement of all relevant stakeholders in the decision making process is considered an important step. Results show that there is a need of communication improvement among all relevant stakeholders. It is notable that water management strategies should not only focus on the technical means, but should also be directed to improve management practices and social behaviours changes. It is also obvious that the idea is not rejected by the community.

In general, the study underlines the importance of a participatory approach with contributions from all relevant stakeholders in order to achieve a real IWRM implementation process and to solve complex, interacting problems which includes social, environmental and economic aspects. In this context, the obtained data are used for a more advanced statistical analysis in order to identify differences in opinions and conflicts within the same group of stakeholders and the influencing factors behind their choices and opinions. After evaluating a Bayesian Network (BN) approach (Subagadis et al. 2014) will be used to combine environmental, social and economical data. BN allows for mapping the stakeholder's behaviours based on statistical analyses in order to show the strength of relationship between dependant and predictor variables in an easy understandable graphical structure which may also incorporate uncertainties. Based on BN results an analysis of the implementation potential of different water management policies will be possible by combining them with general performance indicators of the management interventions within the APPM framework.

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Hydrogeologic and Hydrochemical Maps of the Aban Al-Ahmar Quadrangle

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Abstract: The objectives of the current study is to conduct hydrological and hydrogeological studies in the Aban Al Ahmar quadrangle through a survey of 144 wells from 176 wells that have been identified in the region. Hydrological and hydrogeological field surveys are implemented in order to determine the distribution of dissolved chemical substances in groundwater, and to identify the environmental impacts related to the possible sources for the contents of heavy metals content in groundwater. The development of these maps can help in the selection of potential groundwater resources that are suitable for the purpose of exploitation of mining projects and as sources of drinking water to large settlements. The results indicated that the total dissolved solids in groundwater are less than 1,000 mg/L in the sandstone rocks, granite, and volcanic conglomerate lenses and some rocks. Seventeen potential areas have been identified for groundwater exploration. Hydrochemical analysis indicates a predominance of sodium chloride type groundwaters with a relatively high salinity of more than 2,000 mg/L in most of the area.

Keywords: Aban al Ahmar, Hydrogeologic Map, Aban Asmar Complex, Hydrochemistry map, Chemical facies.

Introduction

The Aban Al Ahmar quadrangle (1:250,000 scale) is located within the Arabian Shield between latitude 25° 00 to 26° 00 N and longitude 42° 00 to 43° 30´E. The town of Ar Rass lies at the end-most of North-Eastern of the quadrangle Qasim area in the Kingdom of Saudi Arabia (figure 1).

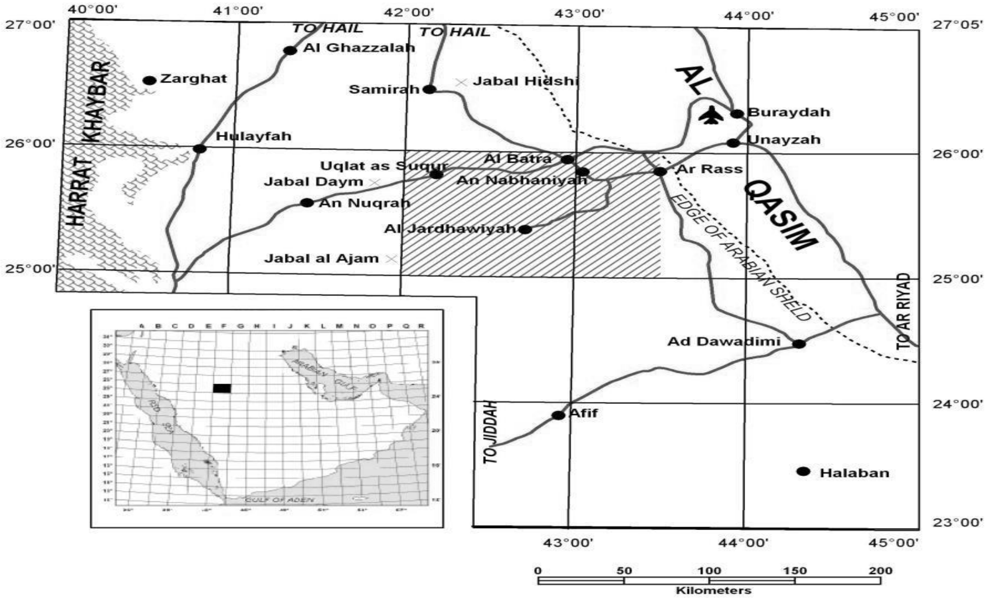


Figure 1: Qasim Area in the Kingdom of Saudi Arabia

Geologic Setting

The geological features in the study area are shown in (figure 2). Most rocks in the Aban Al Ahmar quadrangle were formed during the Proterozoic Eon; the oldest rocks probably formed at about 700 Ma and the youngest Proterozoic rocks formed no later than 570 Ma ago (Stuckless and others, 1984; Cole and Hedge, 1986).

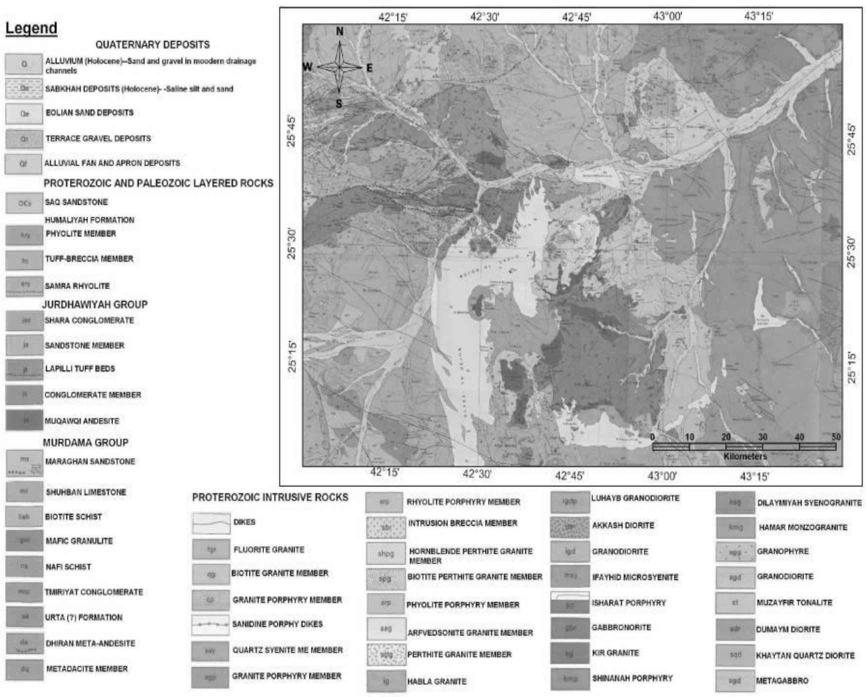


Figure 2: Geological Map of the Region

1. Ahmar Complex

The mountains of Aban Al-Ahmar consist of peralkaline granitic rocks of the Ahmar complex (Cole, 1985c). The inner perthite granite member and a carapace of the arfvedsonite granite member form a steep-walled composite pluton, 20 km long and about 7 km wide, whose roof plunges gently toward the south beneath Jurdhawiyah-group rocks. The rhyolite porphyry member consists of fine-grained, porphyritic rocks in circumferential dikes that dip gently inward toward the center of the composite intrusion, and a second elliptical ring dike that adjoins the intrusion on the west. All rocks of the complex are essentially coeval; the two granite members mutually intrude each other and their contact is locally gradational or marked by pegmatitic cavities lined with quartz and arfvedsonite crystals. The outer arfvedsonite granite member is approximately 2 km thick around all but the western side of the complex, but it is less than 100 m thick along the roof axis.

2. Aban Asmar Complex

Alkalic granitic rocks that form the Aban Al-Asmar mountains comprise the Asmar complex of Cole (1985c), designated the Aban Asmar complex in this report to avoid confusion with the "Asmar complex" of Rowaihy (1982) in northwestern Saudi Arabia (T. Moore, written commun. 1984). Samra rhyolite in the center of the mountains is intruded by the complex, but it is interpreted to be comagmatic and coeval with it (Cole, 1985c). Very coarse grained granites crop out on the north (biotite perthite granite member) and south (hornblende perthite granite member) margins of the complex, and both units are intruded by dikes and plugs of the rhyolite porphyry member. Small stocks and dikes of the granite porphyry member and the quartz syenite member crosscut the older units of the complex (Cole, 1985c). The main part of the Aban Asmar complex forms a 25 by 15 km elliptical composite intrusion; stocks of hornblende perthite granite member south of Wadi Ar-Rumah describe a discontinuous elliptical ring of similar dimensions.

Hydrogeology of the Aban Al-Ahmar Quadrangle

Interpretation of the hydrogeology of the Aban Al-Ahmar quadrangle, and conclusion on the potential for locating additional water resources for possible mine and quarry exploitation or the different purposes, are based on hydrogeologic data that have been investigated from 176 wells (Figure 3).

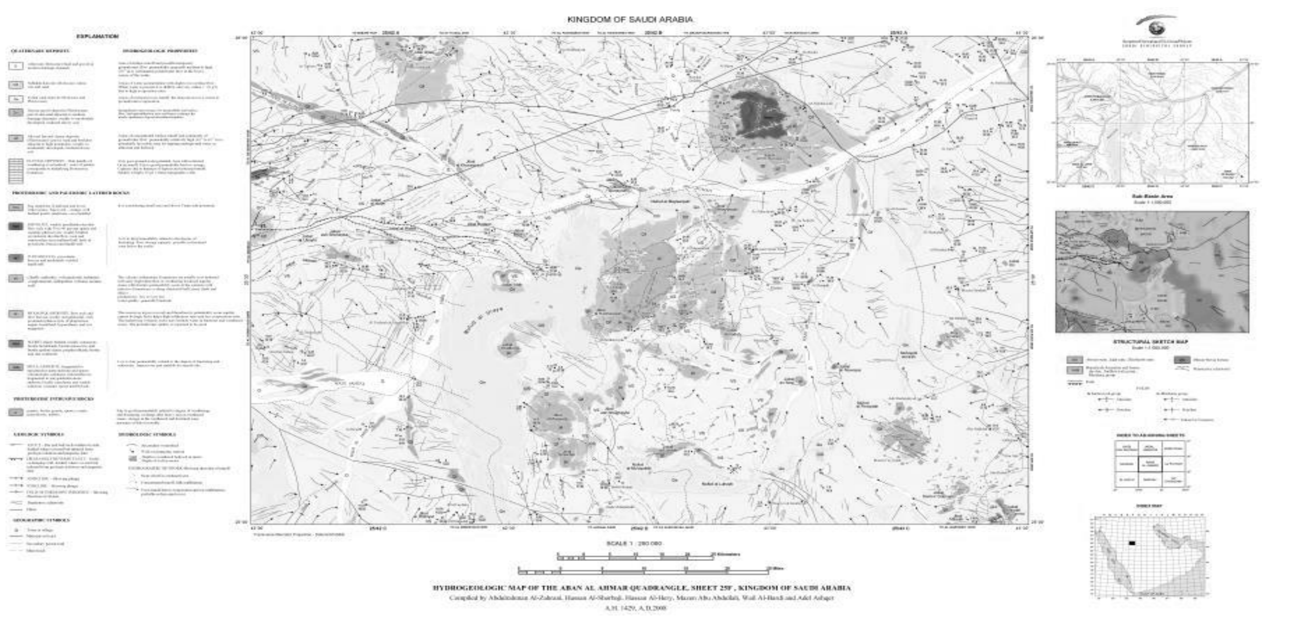


Figure 3: Hydrogeolog**ic** Mapof Aban AL Ahmar Quadrange

Hydrochemistry of the Aban Al-Ahmar Quadrangle

The hydrochemical features of the groundwater in the Aban Al-Ahmar quadrangle are shown in Table 1 and on the Hydrochemical map. Figure (4).

Table 1: Chemical Characteristics of Groundwater in the Aban Al- Ahmar Quadrangl

Sub-basin	Sample NO.		Chemical facies	TDS ppm	Cond. us/cm	PH
Wadi Al-Mahlani	2542A	1		10560	16260	7.27
Wadi Al-Mahlani	2542A	17		3850	5930	6.11
Wadi Al-Mahlani	2542A	20		6640	10210	6.88
Wadi Al-Mahlani	2542A	22		18200	27800	7.1
Wadi Al-Mahlani	2542B	1	Ca-Na-Cl	4440	6860	7.1
Wadi Al-Mahlani	2542B	2		3220	4950	7.4
Wadi Al-Mahlani	2542B	3	Ca-Na-Cl-SO4	7280	11180	7.32
Wadi Al-Mahlani	2542B	4	Ca-Na-Cl-SO4-NO3	13300	20600	7.16
Wadi Al-Mahlani	2542B	5		11090	17060	7.2
Wadi Al-Mahlani	2542C	24	Na-Ca-Cl	6400	9850	7.2
Wadi Al-Mahlani	2542D	12		3670	5650	6.18
Wadi Al-Mahlani	2542D	14	Na-Ca-Cl-SO4	11250	17330	6.81
Wadi Al-Mahlani	2542D	15	Na-Ca-SO4-Cl	7300	11240	6.36
Wadi Al-Mahlani	2542D	16		4900	7540	6.31
Wadi Al-Mahlani	2542D	17	Na-Cl	4860	7470	6.32
Wadi Al-Mahlani	2542D	18	Na-Cl-SO4	5610	8640	6.33
Wadi Al-Mahlani	2542D	19		7090	10920	6.96
Wadi Al-Mahlani	2542D	20		12920	19500	6.9
Wadi Al-Mahlani	2542D	21		6010	9250	7.3
Wadi Al-Mahlani	2542D	23		5200	8010	6.85
Wadi Sahuq	2542A	3		13900	21600	6.44

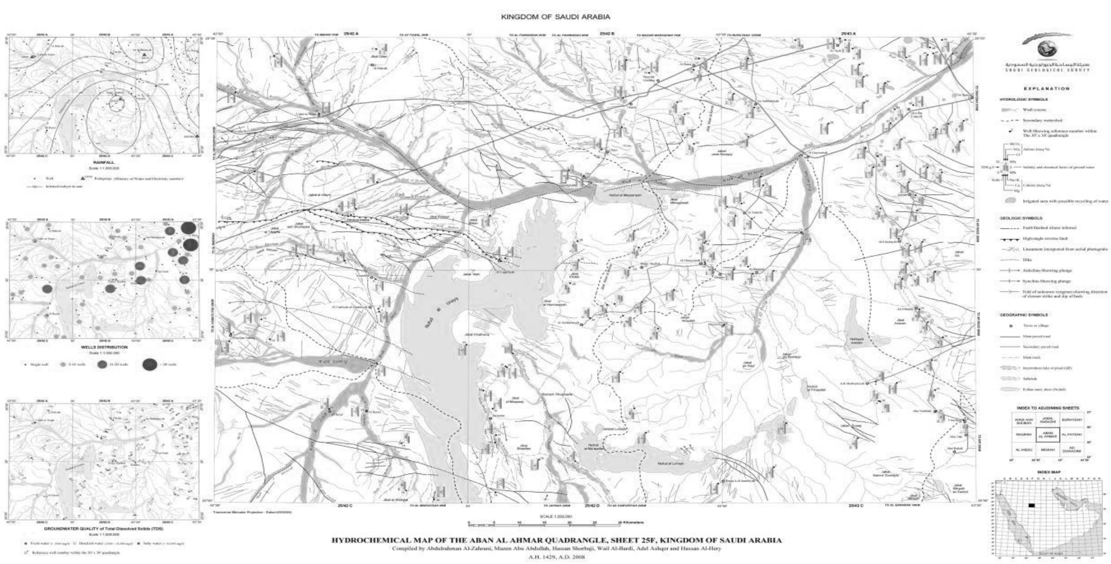


Figure 4: Hydrochemical Map of Aban AL Ahmar

Interpretation of the results indicated that the salinityvalues of the studied wells show that they are relatively high in the area reflecting the generally flat topography. In addition, areas that are characterized by closed depressions display very high salinities. Other areas, such as active sabkhahs contain supersaline waters at shallow depth. Different categories of the salinity values have been discussed as follow:

1. Wells with TDS values less than 1000 mg/l were found in: (a) Sandstone, conglomerate and volcaniclastic sandstone lenses. (b) Alluvial fan and apron deposit. (c) Granite rocks. (d) Monzogranite rocks.
2. Wells with TDS values between 1000 and 2000 mg/l were found in: (a) Alluvial fan and surfical deposit. (b) Monzogranite rocks.
3. Wells with TDS values between 2000 to more than 10,000 mg/l were found in: (a) Alluvium (sand and gravel) in valley bed. (b) Monzogranite rocks.

1. Chemical Facies

The water samples were divided into different chemical facies constitutes a basic classification that can be used for comparison with other geologic indicators, such as the relationship(s) between the geological composition and the water type that found for as the relationship of sulfide deposits with the sulfate contents of the ground water. The chemical fades of the groundwater of the Arabian shield depend more on the nature of the rocks that form the aquifer environments (with which chemical equilibrium tends to be reached) than on the lithology of the environments through which the water has circulated (due to the very brief time available for chemical exchange). It has also been assumed that the aquifers, and therefore also their chemical facies, are more likely to be in chemical equilibrium with the underlying bedrock lithologies than with the overlying alluvium.

Chemical facies of the ground water of the inventoried wells in the 'Aban Al-Ahmar' quadrangle (Table 1) are represented by the three columns to the right of the scale in the schematic diagrams on the Hydrochemical map These columns have three color including blue, green, and purple. They are divided horizontally and represent anions from 0 to 50 meq (milliequivalent) percent above the line, and cations from 0 to 50 meq percent below the line. It is thus possible to deduce the chemical fades of the water by identifying the predominant anion and cation. In addition the chemical analysis results of the wells in the study area were plottedon Piper diagram (Piper, 1944) according t.

2. Trace Elements

The trace elements of the groundwater samples, that have been collected from 14 wells in the Aban Al-Ahmar quadrangle (Figures 5 & 6), were analyzed in Water and Environment laboratory at Saudi Geological Survey. Results data of the trace elements are given. The results indicate that the concentration values are over limits for some of elements in 14 wells, such as: (U, Se, Ni and B) according to Gulf Standardization Organization Contractors (GSO) .

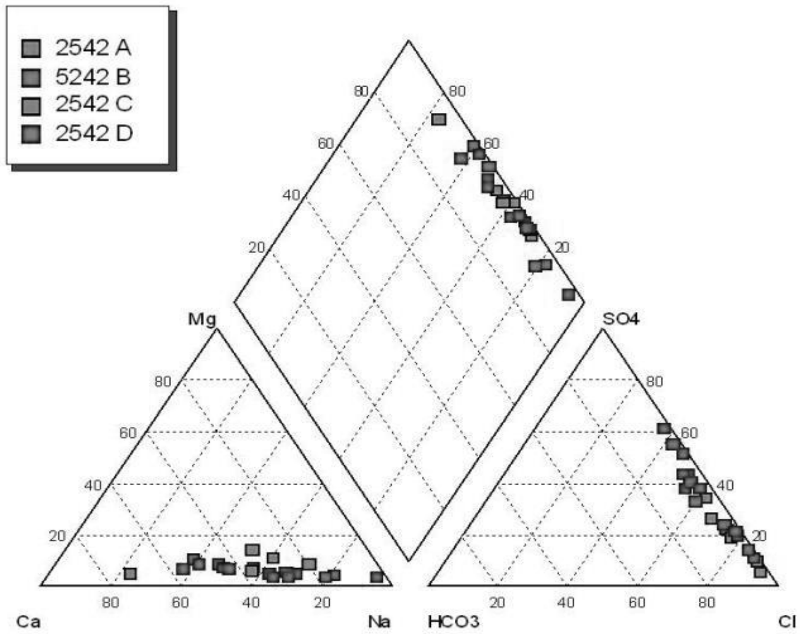


Figure5: Water Analysis Diagram for Wadi Al-Mahlani

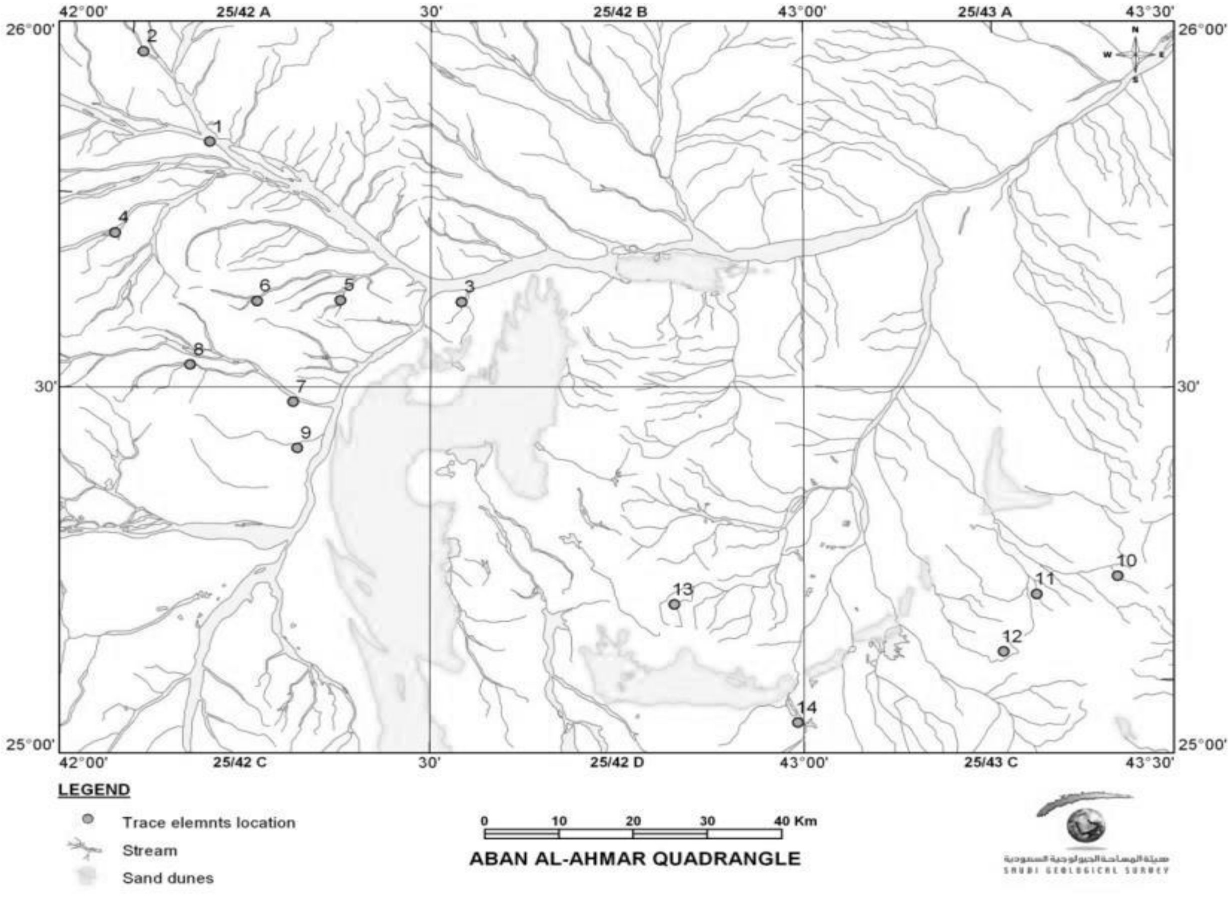


Figure 6: The Locations of Trace elements.

3. Present Exploration

The current days, water being exploited in the Aban Al-Ahmar quadrangle comes mainly from the unconfined alluvial and sub-alluvial aquifers associated with detrital deposits and weathered bedrock zones. It has different usage such as drinking, livestock, and irrigation.

By applying the piper diagram classification to the chemical analyses of these waters of the inventoried wells, it was found as follow:

(i) Wells number 2542/ B012; 013 and 024; 2542/ D006; 2543/ A016; 022 and 027; and 2543/ C009 contains an excellent quality water where the TDS values is less than 500 mg/l;

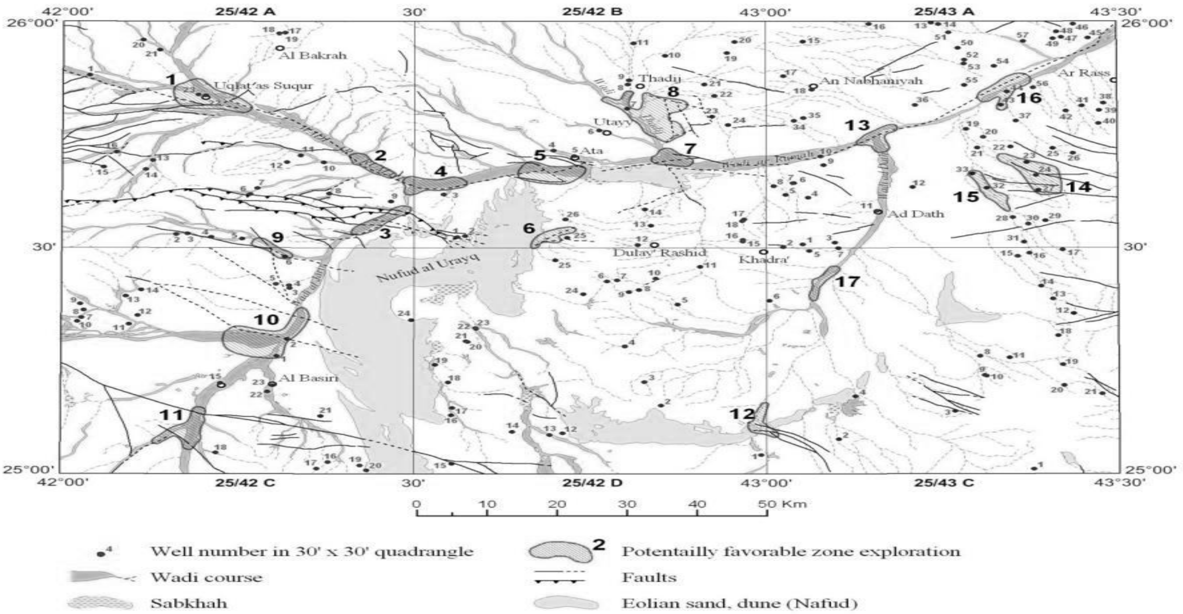
(ii) Eight other wells contain fresh water acceptable for human consumption where the TDS vales are less than 1000 mg/l.They are distributed in the (quadrangle 30´x 30´, 2542 B and D, 2543 A and C);

(iii) The remaining wells which represent 90%of the total well numbers contain;

a- Brackish water where the TDS values range from 1000 to 10000 mg/l

b- Salty water with TDS values more than 10000 mg/l). The water quality of these 90% wells is unsuitable for human consumption according to the World Health Organization (2004) The good-quality water wells are nearly located around Aban Al-Ahmar and Aban Al-Asmar mountains areas where as the eastern part of the quadrangle (Figure 7).These results, however, cannot be considered as fully representative as numerous wells used by the population for drinking water. An assessment of the total discharge pumped from wells in the quadrangle would necessitate an exhaustive inventory, which is beyond the context of this study where it deals with regional hydrogeological study. It should be known that the present well exploitation is discontinuous, with pumping for only a few hours per day. The limiting factor in the present exploited discharge could be related to the depth of wells, than to the size of the resources.. Most of wells in the area are partially penetratedthe fractured bedrock.

Figure7: Groundwater Quality in the Aban Al-Ahmar Quadrangle



4. Potential Water Resources

The Aban Al-Ahmar quadrangle is not a homogeneous aquifer according to its water suitability for different purposes. However, the northern parts can be considered as favorable for exploration. The recharge is dependent on a small annual rainfall, the resources, if exploited on a continuous basis, may be insufficient to counterbalance the effects of a two- to three year drought.

Seventeen potential zones for ground-water exploration for different purposes have been determined (see, figure 7 and table 2). Geomorphological and structural factors have been used to determinethe initial selection of these zones. These factors include the following: Location within wadi beds; zones of hill slope favorable to surface runoff; zones of wadi confluence; and zones of structural trends such as faults. In addition, geologic factors determining the final selection took into account hydrogeologic behavior of the bedrock formations.

Table 2 : Potentially Favorable Zones within the Aban Al-Ahmar Quadrangle for Groundwater Exploration for Different Purposes.

30° X 30° Quadrangle	Favorable Zone	Location	Observations
2542/A	1	Uqlat As Suqur	Along a fault zone and wadis confluences zone
2542/A	2	Wadi Ar Rumah	Along a fault zone and wadis confluences zone
2542/A	3	Wadi Al-Jarir	Intersected faults zone
2542/B	4	Al-Khutaym	Along a fault zone and wadis confluences zone
2542/B	5	Ata	Intersected faults zone
2542/B	6	Jibal Aban Al-Ahmar	Intersected faults zone and hill slope favorable to surface runoff zone
2542/B	7	Wadi Ar Rumah	Intersected faults zone and wadis confluences zone
2542/B	8	Mazari Thuwaydij	Wadis confluences zone and small catchment area
2542/C	9	Sha›ib Mutribah	Along a fault zone
2542/C	10	Al-Busairy	Wadis confluences zone and a fault zone
2542/C	11	Sha›ib Al-Juwayyah – Wadi Al-Jarir	A faults zone
2542/D	12	Sha›ib Al-Mab›uj	A fault zone
2543/A	13	Al-Qaysumah	Wadis confluences zone and along a fault zone
2543/A	14	Nafjah	A faults zone
2543/A	15	Sha›ib Al-khshaibi	A fault zone
2543/A	16	Wadi Ar Rumah	Wadis confluences zone and along a fault zone
2543/C	17	Wadi Ad-Dath	Wadis confluences and dikes zone

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__Biography:__ Mr. Adel Abdulrazk Ashqar received his BSc, 2000 in Hydrogeology from Geology Department, University of King Abdulaziz, Jeddah, Kingdom of Saudi Arabia 2000. He joined the Saudi Geological Survey SGS as a Hydro geologist in 2003. Since joining SGS he participated in hydrological and hydro geological studies. Such as the groundwater strategic storage project in the coastal basins, the collection and analysis of groundwater samples of deep aquifer project in the Southern parts, the generating and drawing the hydro geological and hydro chemical maps projects in Saudi Arabia. He also participated in many national and international conferences. Mr. Adel is a pioneer in some special programs such as ArcGis, AquaChem, Aqtesolve, Rockworks, MapInfo. Additionally Mr. Adel obtained an appreciation certificate from Saudi Geological Survey for the efforts to achieve hydrogeological projects and he is a member in Saudi Quality Council.

SESSION 6
AGRICULTURAL WATER MANAGEMENT

Keynote

FAO's Water Scarcity Initiative Stimulates Sustainable Efficient Management of Agricultural Water through Partnerships and Cooperation: Oman and Jordan Cases

Fawzi Karajeh

Senior Water Resources and Irrigation Officer, FAO Regional Office for the Near East and North Africa

Summary

The water-unfortunate Near East and North Africa (NENA) region is confronted with a wide range of complex issues associated with water resources availability/supply and management. The average per capita fresh water availability in the last three decades for the region has decreased by more than 50% and it is expected to go even much lower by 2050. Most of the NENA countries such as the GCC, Jordan, Yemen, Tunisia, Algeria and Libya are below the absolute water poverty level of 500 m^3 per person year. The potential for developing new conventional water resources is limited due to technical, economic and political factors. About 85% of the available fresh water resources are allocated to agriculture. But with a population increase rate at about 2.5% and higher, the demand on water by urban, services including commercial, and industrial is exerting additional pressure on the country's decision maker to divert additional agriculture water to the other priority sectors.

Natural water scarcity coupled with the anticipated impact of climate change is likely to be the major threat to food security, economic and social development, stability, and the environment. Plan strategically for the water resources supply and allocation becomes a necessity for making the best use of each single drop of water.

To address the water scarcity challenges, FAO has launched in 2013 a Regional Initiative on Water Scarcity in NENA region to assist countries in identifying and streamlining water-related policies and best practices that can significantly improve agriculture productivity and food security in the region.

The initiative is designed to serve, complement and add value to the ongoing major policy processes in the region and it will focus on the following:

a. *Strategic planning & policies* -adopt a water-food-energy nexus approach to water and food-security. Trans-boundary water implications will be considered where appropriate.
b. *Strengthening/reforming governance at all levels* - support countries in reviewing institutional framework governing the inter- and intra-sectoral management of water resources.
c. *Improving water management, performances (efficiency) and productivity in major agricultural systems and in the food chain* - support countries to improve agriculture water use efficiency and water productivity in both rainfed and irrigated agriculture.
d. *Managing the water supply through reuse and recycling of unconventional waters* - support actions to enhance the supply-side of the water budget through the optimal and safe use of unconventional waters (brackish water, urban treated wastewater, greywater, oil-mining industry, and desalinized water)
e. *Climate change adaptation, resilience, distaste risk reduction and drought management* - promote assessment of climate change impact on agriculture, develop and implement adaptation

strategies to climate change and drought management policies and practices.

f. *Building sustainability* - support more solid surface and groundwater governance conducive to higher levels of productivity and reduction of pollution. Soil salinity will be addressed in critical agricultural areas.

g. *Benchmarking, monitoring and reporting on water use efficiency and productivity* - promote mechanisms of benchmarking, monitoring and reporting on progress towards the achievement of agreed national and regional target on water use efficiency and productivity utilizing traditional and advanced space technologies.

The Regional Initiative is designed to promote innovative solutions into the process of finding sustainable strategies to cope with water scarcity and food security problems through adoption and implementation of evidence-based policy decisions, sound governance and institutions, cost-effective water investments and best management practices.

During an initial pilot phase, six countries (Egypt, Jordan, Morocco, Oman, Tunisia and Yemen) started to apply three major approaches constituting the initial analytical framework of the WSI: (i) 'water accounting', reviewing the current status of water availability and use and the potential for further agricultural production; (ii) the 'food supply cost curve', a simple but powerful method for identifying and ranking options for future food supply in terms of both their economic and water-requirements costs; and (iii) 'gap analysis', investigating policies, governance and institutional environments and performance of agriculture water management in the region.

This presentation will illustrate some early results on the food supply cost curve analyses done in Oman and Jordan.

Biography: Dr. Fawzi Karajeh is the Senior Water Resources and Irrigation Officer of the FAO Regional Office for the Near East and North. Prior to that, he served at the International Center for Agriculture Research in Dry Areas (ICARDA) as a Principal Water Resources and Irrigation Management Scientist after he served as the ICARDA's Regional Coordinator for the Nile Valley and sub-Saharan Africa region for five years. From 2001 to 2008, he served as the Chief of the Water Recycling and Desalination Branch of the California Department of Water Resources (DWR). From 1999 to 2001, he was the Senior Marginal-Quality Water Scientist at ICARDA. Prior to that and for seven years he served at DWR as an Associate Land and Water Use Analyst Dr. Karajeh received his PhD in 1991 from UC Davis, USA ; authored and co-authored over 75 publications and received eight Recognition Awards.

Keynote

Groundwater Management in Oman: Institutions, Governance and Sustainability

Slim Zekri

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Summary

Groundwater is the sole renewable resource in most of the Gulf arid region. In Oman the renewable water resources, surface and groundwater, represent about 87 percent of the nation's water resources. The remaining 13 percent comes from desalinated water. Groundwater represents 94 percent of the total renewable water resources. Most of the groundwater is used for agricultural purposes. The Batinah coastal area represents 53% of the total cropped area and uses 36% of the groundwater of the Sultanate. Over-pumping of groundwater in the Batinah has been signaled since the 1990's. The water deficit has been increasing from 285 Mm^3 in 1990 to a pick of 331 Mm^3 in 2000 and regressed slightly to 316 Mm^3 in 2011. The deficit caused sweater intrusion and degradation of the groundwater quality. The water balance improvement over the past few years in the Batinah has been achieved by an expansion of the supply of desalinated water at the cost of a higher dependence on fossil fuels. Most urban water supply has been shifted to desalinated water. There has been no reduction of groundwater pumping despite the government expenditures and active policy of subsidy of modern irrigation systems. The agricultural sector is thus the unique responsible of the groundwater deficit in the Batinah.

This paper presents the results of an integrated simulation-optimization groundwater project in the Suwaiq aquifer in the Northern Batinah. Around 8,000 farms are situated in the study area with a total cultivated area of approximately 10,400 ha. The project consists on the installation of smart Energy-Water Meters installed in 40 farms, to measure online the daily pumping, and the installation of smart irrigation & fertigation systems in 15 farms to evaluate the impact of advanced irrigation technology on groundwater pumping. A numerical groundwater flow and transport model, using MODFLOW and SEAWAT, is used to simulate the effect of policy options on seawater intrusion and groundwater salinity. The model is calibrated using observed data for one year of the groundwater pumping from the 40 monitored farms. The model is used to simulate a steady-state simulation for pre-development state before 1974, a transient simulation for post-development state 1974-2010 and the transient simulation of different scenarios reflecting the policy options towards a sustainable use of groundwater. The model is also used to simulate an extreme scenario of zero pumping to evaluate the remediation potential of the aquifer. Although such a scenario is politically unfeasible the objective is to show how long it takes to recover from damages caused by over-pumping and how this is going to affect future generations. Actually over-pumping could be interpreted as current generation living at the expenses of future generations or an intergeneration subsidy. Another scenario of high interest is the Business As Usual scenario. Such scenario considers the future of the aquifer if there will be no policy changes at all and farmers keep pumping without any restrictions as they are currently doing. The objective of this scenario is to estimate the potential damage for current and future generations.

Besides to the aquifer numerical model a dynamic optimization model is developed. Both models are interconnected. The dynamic optimization model maximizes the net present value over a generation lifetime. The models are interconnected via the salinity of the groundwater. The optimization model starts with a salinity level SL_0 of the groundwater at t_0, optimizes the crop mix and the profit and the volumes of water to be abstracted. These volumes of water abstracted are then

pumped from the aquifer and MODFLOW-SEAWAT simulates the new salinity levels. At year t_1 the optimization model starts with the new salinity level SL_1 which is going to affect the crop yields and yet the profit. The models keep interacting for a period of 45 years.

In order to test for the potential effects of cooperative management an aquifer-level model, called “social planner model - SPM”, integrates all farm-level models in a single framework, including their externalities, to maximize the farming PV(gross profit). The social planner model is a long-term mixed-integer nonlinear program. The nonlinearity and integer variables both appear at irrigation system modeling. The SPM assumes all the agricultural area in Suwaiq as a single farm with spatially different types of crops and salinity levels. This model assumes also that the decision maker has perfect knowledge of the impact of his pumping volumes on the salinity. This model will allow to estimate the maximum possible benefit if the groundwater management is transformed from a non-managed non-exclusive common pool resource to a managed exclusive common pool resource. This model will not only determine the long term optimal extraction volumes of water but also their spatial distribution.

The second model is called agent based model (ABM). This ABM is a farm-level optimization model. The net present value at farm level is maximized for a period of forty years. The solution is constrained by yearly water pumping limit, called quota, which is generated from the SPM model. The ABM modeling is accomplished for 45 sample farms to measure the economic impact of the water quota. Crop prices are constant during the 45 years of analysis. Farm-gate prices differ from farm to farm for the same crop or livestock. The objective of the ABM model is to compare the efficiency of establishing a water quota or a bankruptcy proportional cut down in groundwater pumping on the different farm types according to their initial salinity levels. The model will be enriched by the empirical results obtained from the installation of the smart irrigation systems at farm level and to test the effects of technology in helping the farmers meet the water quota without deterioration of their economic returns.

Finally the models will allow checking for the classical supply side options usually asked for by farmers and considered by the government which consists of building recharge dams. Two recharge dams are planned for the Suwaiq region. The simulation-optimization model will allow measuring the impacts on the aquifer’s sustainability and farmers’ profitability under the BAU, SPM and ABM scenarios.

Biography: Dr Slim Zekri, has an Agriculture Economics Engineering degree, A Master degree in Environmental Planning. He earned his PhD in Agricultural Economics & Quantitative Methods from the University of Cordoba, Spain. Currently he is Associate Professor, at the Department of Natural Resource Economics, Sultan Qaboos University in Oman. Dr Zekri published more than 50 papers in International Journals and in International Conferences. He worked as an expert for national and international agencies. His main research and consultancies deal with natural resource economics, mainly agriculture, water economics, policy and governance.

A Model for Estimating Water Demand Functions for Agriculture in Bahrain

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Abstract: In Bahrain, water for agriculture is mainly met by metered, but not charged for, groundwater and treated sewage effluent. Agriculture is the major user of the available water resources, accounting for more than 70% of the groundwater use. Analysis of water use patterns and forecasting of future water demand for agriculture are, therefore, crucial for water resources planning and management, including water allocation for competing demands. The objective of this paper is to examine the determinants of water use in agriculture and to estimate water demand functions for agriculture in the study area. The study was conducted using data from a country-wide cross-sectional survey of 111 farms. The analysis yielded a monthly average irrigation water requirement per hectare of cultivated land of 3,264 m^3, which reasonably approximates the reported water requirement for the base year. Results showed that water use for agriculture was positively sensitive to the variables gross cultivated area and gross area under irrigation as single predictors. The dummy variables signifying irrigation methods were found to be insignificant, while only the variables vegetable and alfalfa crops (dummies) were statistically significant, and both were indicative of higher consumption. With regard to the seasonality effects, the results indicated that the Summer (March - August) and Winter (September - February) demand models do not vary greatly. In general, the findings from our survey exercise were statistically disappointing. We could, however, argue that this preliminary endeavour provided an appropriate methodological framework for the estimation of irrigation water demand, and that it should open avenues for further research on farm-level water demand; perhaps by incorporating additional explanatory variables and by employing more sophisticated demand modelling methodologies.

Keywords: Cross-sectional survey, irrigation water requirement, seasonal demand, log-linear model, dummy variables, Bahrain.

Introduction

Historical evidence suggests that agriculture in Bahrain was very prosperous. Present agriculture, however, has a limited potential where it suffers from unfavourable climatic conditions, limited natural resources, poor cultivation and farming practices, small farm holdings, land tenure system problems, soil salinisation and drainage problems, and lack of financial incentives (FAO, 2002). In addition, bad management and the absence of appropriate planning within the agricultural authority further contribute in complicating this problem (Al-Noaimi, 2004).

In 1953, the total cultivated area was estimated at about 6,460 hectares (ha), with the area actually under irrigation totalling 3,224 ha. Soil salinisation resulting from deterioration in the quality of groundwater, as well as the increase in urban development and desertification over the last five decades, has generally led to reduction of the cultivated lands. Areas classified as agricultural land are now gradually disappearing due to deliberate negligence and abandonment by some owners, urban and industrial expansion and a lack of enforced legislation. As a result, in 2012, the total cultivated area was considerably reduced to 3,538 ha.

According to Al-Noaimi (2004), in spite of the measures that are being undertaken to restore agriculture through government subsidies for machinery, irrigation equipment, greenhouses and pesticides, subsidised credits to farmers, legislative action to protect agricultural lands and to conserve irrigation water, encouragement of private investment in agriculture, and promotion of treated sewage effluent (TSE) utilisation for irrigation, Bahrain has no clear agricultural policy. In 2012, the contribution of agriculture including fishing (current prices) to the GDP was 0.32% (CIO, 2013). In 2003, agriculture employed 5,524 labourers, or about 1.54% of the total workforce (CIO,2003); this represents a decline of 35.8% from that reported in 1991. Furthermore, in 2012, the per capita share of cultivable land was estimated at only 0.0027 ha.

Farmlands in Bahrain are located according to the availability of suitable groundwater supplies. Thus, agricultural activities are confined to a narrow relatively fertile strip (the so-called green belt) along the Northern and Western coasts. Both traditional open field cultivation and protected agriculture in greenhouses are being practised. Mechanised agriculture is only possible in the large-sized farm holdings operated by the government, and a limited number of privately owned farms. The chief crops grown are perennial date palms and fodder crops, and seasonal vegetables, whilst minor crops include fruit trees. Owing to the harsh climatic conditions, a single crop system is the main cropping pattern; although inter-cropping is common in some farmlands (FAO, 2002).

Irrigated agriculture is the only form of agriculture in the country; rain fed irrigation is absent due to the scarcity and irregularity of rainfall. Agriculture is the major user of the available groundwater, generally consuming more than 70% of groundwater withdrawn from the Dammam aquifer (the main aquifer system). However, the dependency on TSE as an alternative source for irrigation has significantly increased over the last three decades. Because the irrigation water is of high salinity, adequate leaching of excessive salts is of particular importance, as farmers tend to increase their application rates to combat building up of salts. Therefore, irrigation efficiency is very low and reflects primitive and inefficient irrigation practices. Al-Noaimi (2004) calculated the irrigation efficiency for the year 2000 at about 65%, indicating irrigation losses of 35%, but he noted that this figure represents an improvement of about 10% over that reported by Destane and Ayub (1979) for 1978. This is mainly attributed to the widespread adoption of modern irrigation methods since the early 1980s (Al-Noaimi, 2004).

Our research is the first attempt to systematically characterise and model the agricultural water use in the study area. Previous studies on the topic have focused on the assessment of irrigation efficiencies and estimation of irrigation water requirement. Wright and Ayub (1973) measured the groundwater abstraction for irrigation in representative selected farms with different application rates and found that water use in agriculture was in excess of beneficial requirements by at least 50 million cubic metres (Mm^3). Associated Consulting Engineers (1989) postulated that owing to field application losses, the amount of water delivered to farms was greater than the net crop irrigation requirements. FAO (2002) also argued that the size of the cultivated area could not justify the huge amounts of water applied at the farm level.

McGowen (1975) proposed an annual average irrigation water requirement of 82.2 m^3 cubic metres per hectare per day (m^3/ha/day), while annual average estimates of 73.9 m^3/ha/day and 75.3 m^3/ha/day were suggested by GDC (1980) and RMI (1984), respectively. The Agriculture Authority is currently adopting an average annual application rate of about 80.4 m^3/ha/day. This figure is calculated based on planning and sizing of irrigation for new agricultural projects using TSE for irrigation, and includes a wide monthly range from 40 m^3/ha/day in January to 120 m^3/ha/day in July.

Worldwide, there has been little information on the analysis and modelling of agricultural water demand compared to those related to urban water demand. Most of the empirical works on this area of research have used simulation models and linear programming techniques to investigate the relationships between agriculture water use and various determinants, including crop patterns, crop yield, climatic factors, size of cultivated area, agricultural inputs and outputs, price of irrigation water, etc. For example, one early study of agricultural water demand was conducted by Gisser (1970), in which parametric linear programming methods were applied to estimate the agricultural demand function for imported water in Pecos River Basin, New Mexico. The main inputs to the model were land area, total profit, price of local and imported water, and irrigation techniques used. Various agricultural demand functions were obtained which illustrated the expected quantities of imported water that would be demanded at different prices and under a variety of constraints.

Using a quantitative analysis of irrigation requirements in different climatic areas of England and Wales based on crops needs, variation in soil texture, and climate, Bailey and Minhinick (1989) show that, with the exception of one area, the developed model is capable of obtaining an approximate irrigation requirement for a range of crops grown in a range of soils in all of the designated climatic areas (7 areas).

This paper reports on an endeavour to systematically analyse the water use patterns and demand determinants in agriculture, and to estimate water demand functions for agriculture in the study area. The investigation was carried out using data from a cross-sectional sample of 111 farms, which represents more than 10% of the total farm plots.

Agricultural Water Use and Trends

Agriculture water uses include water applied in the irrigation of crops and landscaping, and water used for dairy, poultry and other livestock raising and production (Al-Noaimi, 2004). Agriculture obtains water from two main sources: groundwater withdrawal from privately owned wells and re-use of TSE. Other sources include blended piped water, desalinated brackish water from self-supplied sources and, to a lesser extent, agricultural drainage water (Al-Noaimi, 2004). Water meters are installed for most of the privately owned irrigation wells and at farm connections for farms using TSE. However, charges for volumetric water usage are proposed but are yet to be imposed (Al-Noaimi, 2004). Farms using blended piped water are billed according to the normal tariffs applied for urban water users.

Table 1 presents the amount of water used for agriculture between 2000 and 2012, categorised by the main sources of use, trends in irrigated lands and their calculated irrigation water requirements. he trends clearly reflect a gradual decrease in both cultivated area and total agricultural water use as well as a considerable increase in the reliance on TSE supply at the expense of groundwater. From 2000 to 2012, total water use for agriculture has decreased by 2.1% per year. During the same period, the re-use of TSE has significantly increased from 14.6 Mm^3 to 40.2 Mm^3, or by 13.5% per year. Between 2000 and 2004, cultivated area decreased by about 1.3% per year, but witnessed a gradual increase up to 2008. The following years (2009 - 2012) registered an annual decline rate of 3.2%. The loss in agricultural lands during 2001 - 2004 is closely related to urban expansion and changes in land use patterns. The slight growth in the cultivated area from 2005 to 2008 is possibly associated with the significant increase in TSE supply.

Table 1 Agricultural Water Use by the Main Sources of Supply, Trends in Irrigated Land, and Irrigation Water Requirements 2000-2012

Year	Water use by source (Mm^3) Ground-water	TSE	Piped Water	Total water use (Mm^3)	Cultivated area (ha)	Irrigation requirements (m^3/ha/year)
2000	159.5	14.6	3.0	177.1	4199	42177
2001	137.4	15.4	3.3	156.1	3916	39862
2002	141.9	14.1	3.3	159.3	3681	43276
2003	135.9	18.8	3.6	158.3	3571	44329
2004	123.2	22.6	3.6	149.4	3924	38073
2005	110.8	24.0	3.3	138.1	4644	29737
2006	104.4	29.5	3.1	137.0	4454	30759
2007	98.8	32.2	3.4	134.4	4344	30939
2008	97.6	39.1	3.7	140.4	4219	33278
2009	95.0	36.9	3.2	135.1	4104	32919
2010	92.8	36.1	3.9	132.8	3980	33367
2011	89.9	36.5	4.1	130.5	3875	33677
2012	84.4	40.2	4.3	128.9	3538	36433

(*Source: Compiled and adapted from different sources: Al-Noaimi (2004); Al-Noaimi (2005);* Al-Noaimi (2009); & Ministry of Municipalities Affairs and Urban Planning, (2009); the Water Authorities Abstraction Records; and author estimates).

The annual irrigation water requirement per hectare of cultivated area over the period from 2000 to 2012 averaged 98.8 m^3/ha/day, but had a wide range from 81.5 m^3/ha/day (29,737 m^3/ha/year) to 121.4 m^3/ha/day (44,329 m^3/ha/year). The possible reason for the improvement in irrigation water requirements between 2005 and 2009 is the substantial increase in the adoption of modern irrigation techniques associated with the augmentation in TSE supply.

In terms of supply share, a total of 177.1 Mm^3 was used in 2000 to irrigate 4,199 ha of cultivated land, of which 159.5 Mm^3, or about 90.1% was from groundwater, and 14.6 Mm^3, or 8.2% from TSE. Piped water claimed the balance of 1.7%, or 3 Mm^3. In 2006, agriculture used about 137 Mm^3. Of that amount nearly 104.4 Mm^3, or 76.2% was from groundwater, and 21.5% or 29.5 Mm^3 came from the TSE source. Piped water made up the remaining 2.3%. By 2012, the total water consumed by agriculture was substantially decreased to 128.9 Mm^3. The contributions of groundwater and TSE were 84.4 Mm^3 (65.5%) and 40.2 Mm^3, or 31.2%, respectively. The remaining quantity of 4.3 Mm^3 was supplied from piped water.

Data and Methods

The data used in this analysis are based on farm-level observations obtained from a country-wide cross-sectional survey of 111 farmlands, carried out over a 14-month period from April 2002 to May 2003. Up to the end of December 2002, a total of 1,093 farm plots were recorded. This record represents the entire active and semi-active farm plots and includes a complete listing of these farms with information on plot number, plot size in dunum, location, farm owner, and farm tenant, if any. Information on farm plots supplied by TSE was also made available from the Statistical Department of the Agricultural Authority.

Metered consumption for around 220 farms for the year 2000 were made available for our analysis. Out of this record, a final selection of 143 farms was made on the basis of the quality and reliability of these data. These data were analysed to produce estimates of the population parameters. This was achieved by matching the well numbers with the plot numbers and calculating the average daily consumption for each plot. The obtained average consumption was then simply divided by the plot size to produce the irrigation water requirements for each farm in m^3/ha/day.

The sample data produced a mean consumption of 89.86 m^3/ha/day, and a standard deviation of 54.46 m^3/ha/day. These estimates were used to calculate the sample size using the following formula (Johnson, 1996; Cochran, 1977):

$$E = Z_{a/2} \frac{s}{\sqrt{n}} \sqrt{\frac{N - n}{N - 1}}$$

where ***E*** is the maximum tolerable error (taken at 10 deviation units), $Z_{a/2}$ is the standardised ***t***-statistics at the desired confidence level, ***s*** is the standard deviation estimate, ***n*** is the sample size, and ***N*** is the population size (representing the total number of farms).

A random sample of 111 farms was selected and a survey questionnaire was designed to elicit information on potential determinants of agricultural water demand, including agricultural holding, areas actually cultivated and actually irrigated, water source variables, irrigation variables, consumptive use, and crop patterns.

For most of the agricultural farms sampled, the average water use for irrigation (measured in cubic metres per month (m^3/month)) was computed by matching the well numbers with the plot numbers. This was achieved by calculating the average Summer and Winter consumption from groundwater abstraction records maintained by the Water Resources Authority, then simply computing the average consumption for each farm by dividing the sum of Summer and Winter averages by 2. The classification of Summer and Winter consumption is based on the officially adopted growing seasons, where the Summer season is from March to August, and the Winter season continues from September until February.

Likewise, the average monthly consumption (also measured in m^3/month) for the farms supplied by TSE were calculated from consumption figures made available from the concerned authority by matching the plot number with the farm connection code, which is primarily based on the farm number/owner or tenant.

An added variable representing the average irrigation requirements per hectare of cultivated land (in cubic metres per hectare per month) was also computed by simply dividing the average consumption per month by the gross cultivated area in hectare. The average Summer and Winter irrigation frequencies were summed up and divided by 2 to create a variable reflecting the average irrigation frequency. Similarly, a variable representing the average pumping hours was measured. A set of dummy variables were also created to represent crop patterns and irrigation methods.

Attempts to obtain data on productivity and size of workforce per farm unit, that could have been useful predictors, have failed because such data are not available on a per farm basis and are normally aggregated on a yearly basis using crude assumptions for the purpose of the annual statistical reports. A survey was conducted during 2002 as part of a project carried out by the Food and Agriculture Organisation of the United Nations (FAO, 2002), in which valuable data on important agricultural inputs and outputs, including crop output, fertilizers, seeds, and labour and machinery requirements were collected for each farm sampled. These data were made accessible to this research but, unfortunately, the farms surveyed were not identified by either their farm number or their owner/tenant information. This created problems for the necessary matches between farms in the two surveys, which rendered these data unusable for our analysis. To this it should be added that the data were collected on a per selected crop and growing season basis rather than on a per farm basis.

Results

Table 2 summarises the descriptive statistics for the main consumption and farm variables. On average, farms in the study area consume 5.461.8 m^3/month, but per farm water use varies widely from a minimum of 286.2 m^3/month to a maximum of 23869 m^3/month. The obtained average Summer and Winter monthly consumption showed a seasonal variability of almost 16%. Average irrigation frequencies in Summer exceeded those in Winter by a little more than 28%.

The average irrigation water requirement of 3,264 m^3/ha/month, suggests an annual average application rate of about 109 m^3/ha/day. This average figure is reasonably consistent with that reported for the base year 2001 (see table 1). It is also interesting to note that the median value (2,346 m^3/ha/month), or 78.2 m^3/ha/day (not reported in table 2) is closely in agreement with the application rate of 80.4 m^3/ha/day normally adopted by the Agriculture Authority for irrigation planning and sizing of irrigation systems. Our detailed analysis has shown that the average irrigation requirement tends to decrease as the total irrigated area and the area under protected agriculture increase, indicating a sort of economy of scale.

Average water requirements from TSE suggested strong correlations with average water use and average water requirement from other sources. This is probably understandable in view of the fact that relatively large farms supplied with TSE normally have their own water wells or are connected to the public supply, implying that these sources often serve as supplemental or backup water supplies. We also found that, owing to quality considerations, protected agriculture primarily depends on water from piped supply.

Table 2: Summary Descriptive Statistics on the Main Farm and Irrigation Variables

Variable	Mean	Minimum	Maximum	Std. deviation
Average consumption	5461.8	286.2	23869.0	4180.6
Average Summer consumption	5846.0	307.6	26471.2	4745.4
Average Winter consumption	5050.8	295.5	23914.6	4485.6
Plot area	3.1	0.20	18.1	3.2
Gross cultivated area	2.6	0.16	18.0	2.9
Gross irrigated area	2.2	0.05	14.5	2.6
Area under protected agriculture	0.3	0.00	2.9	0.5
Irrigation water requirement	3264.0	109.3	14017.2	2805.4
Average irrigation frequency	1.3	0.50	6.0	0.61
Average irrigation freq. Summer	1.5	0.30	5.0	0.69
Average irrigation freq. Winter	1.2	0.50	7.0	0.68

(Notes: *Average consumption, and Summer and Winter average consumptions are in m^3/month. Plot area, gross cultivated area, gross area under irrigation, and area under protected agriculture are in ha. Irrigation water requirement is in m^3/ha/month. Average irrigation frequencies are in time/day*)

Table 3 shows the distribution of the cultivated area according to the cropping patterns and their percentages of total cultivated area. Slightly more than 44 % of the total cultivated areas of the farms sampled were reported to have been cultivated with vegetable crops. About 96.11 ha, or 33% of the total area surveyed is covered with perennial date palms. Alfalfa accounts for 6.3%, or 18.3 ha of the total area of the sampled farms. Fruit crops alone cover an area of 27.2 ha, or 9.3%, with the areas under ornamental trees, poultry and livestock raising accounting together for the balance of 6.9%, or 20.1 ha.

Table 3 The Distribution of the Cultivated Area According to the Cropping Patterns

Variable	Mean	Total area under a given crop (ha)	% of total cultivated area
Vegetable crops	1.16	129.5	44.5
Date palms	0.86	96.1	33.0
Alfalfa	0.16	18.3	6.3
Fruit crops	0.24	27.2	9.3
Ornamental	0.02	2.4	0.8
Poultry	0.02	2.4	0.8
Livestock	0.13	15.3	5.3
Total		291.2	100

With regard to the variables signifying irrigation methods, responses from our survey questionnaires were translated into areas under different irrigation methods and proportion of each method to the total irrigated area as presented in table 4. Twenty eight percent of the farms surveyed are still irrigated using traditional flood irrigation, while the majority of the farms sampled (almost 70%) are under mixed irrigation. Drip irrigation alone makes the balance of 2%. Of those using mixed irrigation, a bulk proportion of about 99% combines flood and drip irrigations. The rest of farms either use drip irrigation with lined channel techniques or apply a mixture of flood, drip, and lined channel irrigation methods.

Table 4: Distribution of Areas under Different Methods of Irrigation and their Percentages of Total Irrigated Area

Method of irrigation	Area under particular method of irrigation (ha)	% of total irrigated area
Flood irrigation	69.1	28.4
Drip irrigation	4.7	1.9
Mixed irrigation	169.8	69.7
Total	243.6	100.0
Areas under Different Types of Mixed Irrigation and their Percentage of Total		
Flood and drip irrigation	167.9	98.9
Drip irrigation and lined channels	1.0	0.6
Flood, drip, and lined channels irrigation	0.86	0.5
Total area under mixed irrigation	169.8	100.0

Model Estimations

In general, the results from our survey exercise were statistically disappointing, most likely due to the lack of potential explanatory variables (specification errors). This limits the ability to perform meaningful multiple regression analysis. This finding may also strongly support the assumption that simulation models and linear programming approaches are more effective in modelling agricultural water demand.

However, a cross tabulation of a number of farm and irrigation variables indicated that the variables plot area, cultivated area, area under vegetable crops, area under fodder crops (alfalfa), gross area under irrigation, and average pumping hours had measurable effects on the average amount of water used for agriculture; all were significant at the 1% level and indicative of higher consumption. Economies of scale appear to operate with regard to the relationship between the variable irrigation requirements and both irrigated areas and areas under protected agriculture.

The average monthly consumption for agriculture as a dependent variable was regressed against a set of potential demand determinants. Various functional forms were tested, of which the log-linear demand functions provided better fits. The equations of best statistical fits were represented by bivariate log-linear models relating the monthly water use to the single explanatory variables gross cultivated area and gross area under irrigation (table 5). The models exhibited a high degree of similarity, each accounting for 50% of the variations in monthly irrigation water use. However, Model 1 appeared to be marginally superior in terms of goodness-of-fit statistics and applicability. The estimated coefficient on the variable gross area under cultivation (Model 1) implies that for every 10% increase in the cultivated area, water use will increase by 6.3%.

Table 5 Derived Demand Functions for Agriculture Water Use

Model	Regression Equation	F-Statistics	Adjusted R^2
Model 1	$\ln Q = 7.720 + 0.633 \ln X_1 + \varepsilon$	31.293	0.244
	(56.115) (15.594)	(0.000)	R = 0.502
	(0.000) (0.000)		
	(0.138) (0.113)		
Model 2	$\ln Q = 7.756 + 0.670 \ln X_1 + \varepsilon$	30.868	0.241
	(58.389) (5.594)	(0.000)	R = 0.499
	(0.000) (0.000)		
	(0.133) (0.121)		

(Notes: *In Model 1, lnQ is the natural logarithm of the average monthly consumption in* m^3 *per month,* $\ln X_1$ *is the natural logarithm of gross area under cultivation in hectare, and ε is the error term. In Model 2, lnQ is as defined earlier, and* $\ln X_1$ *is the natural logarithm of gross area under irrigation in hectare, and ε is the error term. t-statistics, p-values, and standard error of estimates are, respectively, in parentheses beneath the coefficients*).

The analysis was extended by adding a set of dummy variables designating irrigation methods to the above models. These variables were found to be not significantly different from zero at the 5% level, though they had the expected signs and the estimation results generally indicated that both water-efficient and traditional irrigation techniques influence water demand. Referring to table 4, it can be seen that these predictors were highly affected by the large number of farms using mixed irrigation which was difficult to isolate. Apparently, the mixed irrigation practice tends to mask the single effect of each of predictor variable, (see, table 4).

The effects of crop patterns on the criterion variable were also introduced to the estimated demand functions by means of dummy variables. From the cross tabulation results, these were already identified as having potential serial correlations. Only the dummies vegetable and alfalfa crops were shown to be significant predictors. The estimated coefficient on the dummy palm trees had the anticipated negative sign, but it did not have a statistically significant impact on the average monthly irrigation water use.

Below is the estimated multiple regression equation with only the significant variables included (*t*-statistics, *p*-values, and standard error of estimates are, respectively, in parentheses beneath the coefficients):

$\ln Q = 7.945 + 0.585 \ln X_1 + 0.816 \ln X_2 + \mathbf{e}$

(78.615) (4.729) (2.563)

(0.000) (0.000) (0.012)

(0.101) (0.124) (0.319)

Adjusted R^2 0.245 F-Statistic 16.25 (0.000) Durbin-Watson Statistics 2.395

where, lnQ is the natural logarithm of the average monthly consumption in m³ per month, lnX_1 and lnX_2 are the natural logarithms of the dummy variables measuring areas under vegetable and alfalfa crops in hectares, respectively, and e refers to the error term. As one would expect, the regression results suggest that both coefficients are indicative of higher consumption, with the estimated coefficient on alfalfa crop appearing to be slightly affected by the lower representation (see Table 3).

The seasonality effect on water consumption for irrigation was explored by developing separate Summer and Winter demand functions. This was to account for the methodological limitations caused by not taking into consideration the influence of climate variables. Table 6 shows the estimation results of the Summer and Winter demand functions. Again, the double-log transformed functions produced more reliable statistical fits, with the natural log of gross cultivated area as a single predictor variable.

Table 6: Estimation Results for Summer and Winter Agricultural Water Use

Model	Regression Equation	F-Statistics	Adjusted R^2
Summer	$\ln Q_s = 7.881 + 0.541 \ln X_1 + \varepsilon$	17.451	0.171
	(50.014) (4.177)	(0.000)	R = 0.425
	(0.000) (0.000)		
	(0.158) (0.130)		
Winter	$\ln Q_w = 7.568 + 0.262 \ln X_1 + \varepsilon$	18.568	0.180
	(42.822) (4.309)	(0.000)	R = 0.436
	(0.000) (0.000)		
	(0.177) (0.145)		

(Notes: *$\ln Q_s$ and $\ln Q_w$ are natural logarithms of the average monthly water uses in Summer and Winter, respectively, in m³ per month. $\ln x_s$ and $\ln x_w$ are the natural logarithms of gross areas under cultivation in Summer and Winter, respectively, in hectares. ε is the error term. Figures in parentheses under each coefficient are, respectively, the t-statistics, p-values, and standard error of estimates*).

The empirical evidence indicates that the Summer and Winter demand models do not vary greatly. Despite the fact that this finding seems to be somewhat surprising, it makes sense in the case of Bahrain agriculture where the cropping density in the Winter growing season is much higher than in the Summer growing season (i.e. the likely typical increase in agricultural water use in Summer is offset by its lower cropping density). This means that because of the harsh climatic conditions during the Summer growing season, farming is partially or entirely halted in many farms.

Owing to the problems created by the high multicollinearity and serial correlations, the inclusion of the other potential demand determinants to the above models using different functional forms did not improve their statistical fits, and generally produced insignificant coefficients.

Conclusions and Policy Implications

We have carried out an analysis of agriculture water use within a very broad water supply-demand analysis study. This did not allow us to investigate the factors that influence water use in agriculture in sufficient detail. The derived water demand functions are dominated by single predictor variables. Failure in developing more reliable multiple regression equations is most likely due to the lack of good explanatory variables. In our view, however, this study offers valuable information on a number of farm and irrigation variables, and that the formulated models provide a reasonable methodological framework for the estimation of water demand for agriculture.

In summary, demand functions for agricultural water use in Bahrain of log-linear forms were estimated. The results show that the average monthly agriculture water use is positively correlated with the single explanatory variables gross cultivated area and gross area under irrigation. In both models, the explained variances are about 0.5. The dummy variables signifying irrigation methods did not have significant effects, though they had the expected signs. Overall, the variable crop patterns (also dummies) appeared to suffer from multicollinearity problems. Only the vegetable and alfalfa crops were found to be statistically significant. The estimated coefficients on these variables suggested that farms planted with alfalfa and vegetable crops demand more water. Analysis of our data did not capture an appreciable seasonal difference in the irrigation water demand. This is because the common increase in agricultural water use in Summer growing seasons is compensated by their lower cropping density.

It is possible to draw a number of policy implications from this study. First, it will open avenues for further research on farm-level water demand, incorporating more explanatory variables such as crop production, climatic factors, agricultural inputs and outputs, size of workforce per farm unit, *etc*., with perhaps a larger sample size and smaller tolerable error. Clearly much further work is needed to adequately address the complexity of this topic, possibly by employing more sophisticated demand modelling approaches such as simulation models and linear programming methods, which are widely known to be more effective in modelling agricultural water demand. Second, there is plenty of room for the improvement of irrigation efficiency; therefore all possible efforts should be devoted to increasing the efficiency of water use in agriculture through further expansion in using water efficient irrigation technologies, changing crop patterns, and the application of new farming practices. Third, our endeavour highlights the importance of establishing and implementing effective agricultural policies and strategies to restore and improve the agricultural sector in Bahrain.

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Biography: *Dr. Mubarak Aman Al-Noaimi is a retired hydrogeologist. He is currently working as a freelance hydrogeologist on matters related to geology, hydrogeology, and environment. He was the advisor of studies and research at the Ministry of Municipalities Affairs and Urban Planning in Bahrain from 2009 - 2013. Dr. Al-Noaimi was the Director of Water Resources at the same ministry from 2005 to 2009. He worked as a part-time researcher at the former Bahrain Centre for Studies and Research from 1991 – 1995 on a major water resources strategy project, and again on a special assignment from 2000 – 2002. He earned his doctorate in 2004 in the Hydrogeology and Water Resources Management from the University of Plymouth of the United Kingdom. He has about 30 years of experience in the hydrogeology and water resources assessment, investigation, and management. Dr. Al-Noaimi has written three books and published and co-published over 25 papers in journals and conference proceedings. His main areas of research interest include water resources assessment, water use analysis, water demand modeling, and total water management.*

تسعير الموارد المائية المستخدمة في إنتاج القمح والتمور بمنطقة الرياض

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المستخلص: مما لا شك فيه بأن تطبيق سياسة الاكتفاء الذاتي دون النظر إلى مبادئ الميزة النسبية والتخصيص الأمثل للموارد الاقتصادية، يؤدي إلى حدوث هدر واضح في الموارد المائية والأرضية والرأسمالية. فقد أدى التوسع الزراعي الأفقي إلى زيادة استخدام المياه في القطاع الزراعي. كما أدى التركز المحصولي في مناطق معينة إلى استنزاف كميات كبيرة من المياه الجوفية غير المتجددة التي تمثل المخزون المائي الإستراتيجي في المملكة العربية السعودية. ونظراً لعدم قيام أي جهة حكومية بنشر البيانات المتعلقة بأسعار الموارد الاقتصادية الزراعية في المملكة وخاصة تكلفة استخدام الموارد المائية في الأغراض الزراعية، فقد استهدفت هذه الدراسة تسعير الموارد المائية المستخدمة في إنتاج القمح والتمور بمنطقة الرياض، استنادا إلى تقدير دالة الإنتاج للقمح والتمور واشتقاق دالتي الناتج الحدي والعائد الحدي للموارد المائية، ومن ثم حساب *قيمة العائد الحدي للموارد المائية والتي تتساوى مع التكاليف الحدية (سعر الوحدة من المورد) عند نقطة تحقيق الكفاءة الاقتصادية. وأسفرت هذه الدراسة عن مجموعة من النتائج أهمها ما يلي:* في ضوء سعر تسليم القمح للمؤسسة العامة لصوامع الغلال ومطاحن الدقيق تقدر التكلفة الحدية للموارد المائية بنحو 208.63 ريال/ ألف م^{3}، أما في ضوء متوسط سعر المساواة للاستيراد (السعر الاقتصادي للقمح) تقدر التكلفة الحدية للموارد المائية بنحو 216.44 ريال/ ألف م3، كما يتوقع في ظل زيادة سعر الوحدة من المياه المستخدمة في إنتاج القمح بنسبة 10%، 20%، 30%، 40%، 50% تناقص كمية المياه المستخدمة في إنتاج القمح إلى 6.73، 5.74، 4.96، 4.34، 3.83 ألف م^{3} / هكتار على التوالي. أما في ضوء متوسط سعر بيع التمور البالغ 10.27 ألف ريال/ طن تقدر التكلفة الحدية للموارد المائية المستخدمة في إنتاج التمور بنحو 642 ريال/ ألف م^{3}، أما في ضوء متوسط سعر المساواة لتصدير التمور البالغ 5078.86 ريال/ طن تقدر التكلفة الحدية للموارد المائية المستخدمة في إنتاج التمور بنحو 317.8 ريال/ ألف م^{3}، وأيضاً يتوقع في ظل زيادة سعر الوحدة من المياه المستخدمة في إنتاج التمور بنسبة 10%، 20%، 30%، 40%، 50% تناقص كمية المياه المستخدمة في إنتاج التمور إلى 22.82، 19.17، 16.34، 14.08، 12.27 ألف م^{3} / هكتار على التوالي. وعليه توصي هذه الدراسة بضرورة إدخال المياه في إطار المحاسبة الاقتصادية وذلك بهدف ترشيد استهلاك المياه وتوفيرها لمستقبل الأجيال القادمة وتحقيق التنمية الزراعية المستدامة، وذلك من خلال تطبيق عدة سياسات أهمها التسعير وفقاً لكمية المياه المستخدمة أو التسعير التصاعدي للموارد المائية أو التسعير وفقاً للمساحة المروية، بالإضافة إلى ضرورة معالجة السحب الجائر من المياه الجوفية غير المتجددة.

كلمات دالة: السياسة السعرية، الموارد المائية، القمح، التمور، الرياض.

المقدمة

من المعروف أن عملية الإنتاج هي خلط أو مزج لعناصر الإنتاج (الأرض، العمل، رأس المال، المواد الأولية، الإدارة) وذلك بهدف الحصول على كمية معينة من السلع والخدمات. وجرى التقليد الاقتصادي على تعريف النصيب الذي يستحقه عنصر الأرض باسم الريع أو الإيجار، والنصيب الذي يستحقه عنصر العمل باسم الأجور، والنصيب الذي يستحقه عنصر رأس المال باسم الفائدة، والنصيب الذي يستحقه عنصر الإدارة باسم الربح (غانم وفواز، 1998). وتتسم الموارد المائية في المملكة العربية السعودية بالندرة النسبية وقد ساعد على ذلك افتقار المملكة إلى الأنهار والأمطار الغزيرة المنتظمة، إضافةً إلى ارتفاع تكاليف الحصول عليها من المصادر غير التقليدية، بالإضافة إلى عملية نقل البطحاء والرمال من بطون الأودية بسبب الحركة العمرانية في المملكة، التي أدت إلى تلوث المياه الجوفية نظراً لوصول الحفر إليها وبالتالي ظهورها على السطح وزيادة درجة ملوحتها. كما أن حفر الآبار العشوائية بدون مواصفات قياسية، أدت إلى إهدار كميات كبيرة من المياه في الطبقات التي تم اختراقها أثناء الحفر(غانم والرويس، 2004).

وأدت إستراتيجية تحقيق الاكتفاء الذاتي دون النظر إلى مبادئ الميزة النسبية والتخصيص الأمثل للموارد الاقتصادية، إلى حدوث هدر واضح في الموارد المائية والأرضية والرأسمالية. فقد أدى التوسع الزراعي الأفقي إلى زيادة استخدام المياه في القطاع الزراعي. كما أدى التركز المحصولي في مناطق معينة إلى استنزاف كميات كبيرة من المياه الجوفية غير المتجددة التي تمثل المخزون المائي الإستراتيجي في المملكة العربية السعودية. ومن خلال المسح الأدبي للدراسات الاقتصادية التي اهتمت بتسعير الموارد الاقتصادية الزراعية، تبين أنها تتسم بالندرة، كما لا تقوم أي جهة حكومية بنشر البيانات المتعلقة بأسعار الموارد الاقتصادية الزراعية في المملكة وخاصة إيجارات الأراضي الزراعية وأجور العمالة وتكلفة استخدام الموارد المائية في الأغراض الزراعية، ولذلك اهتمت هذه الدراسة بقضية تسعير الموارد أو تقدير تكلفة استخدامها في الأغراض الزراعية.

أهداف وأسلوب البحث

1. أهداف البحث

إستهدفت هذه الدراسة تسعير الموارد المائية المستخدمة في إنتاج القمح والتمور بمنطقة الرياض، وذلك من خلال تحقيق الأهداف الفرعية التالية: تقدير دالة الإنتاج لمحصولي القمح والتمور بمنطقة الرياض، إشتقاق دالتي الناتج الحدي والعائد الحدي للموارد المائية المستخدمة في إنتاج القمح والتمور، تقدير قيمة العائد الحدي للموارد المائية في ضوء أسعار كل من القمح والتمور بمنطقة الرياض، قياس أثر التغيرات في أسعار الموارد المائية على الكميات المستخدمة منها في إنتاج القمح والتمور بمنطقة الرياض، و
إقتراح السياسات وآليات التنفيذ لتسعير الموارد المائية المستخدمة في الأغراض الزراعية.

2. أسلوب البحث

أعتمدت هذه الدراسة في تسعير الموارد المائية المستخدمة في إنتاج القمح والتمور على تقدير دالة الإنتاج وأمكن التعبير عنها بالمعادلة التالية:

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حيث أن: تمثل إنتاج المحصول بالطن، تمثل كمية المياه المستخدمة بالألف م3، تمثل مقدار العمالة الدائمة في المزرعة بالرجل/ يوم، تمثل كمية الأسمدة الكيماوية بالكيلو جرام، تمثل كمية الأسمدة العضوية بالمتر المكعب، تمثل عدد سنوات الخبرة في النشاط الإنتاجي. أما تمثل معلمات parameters النموذج، تمثل الخطأ العشوائي.

وتم تقدير دالة الإنتاج لمحصولي القمح والتمور في الصورة الخطية واللوغاريتمية المزدوجة بطريقة المربعات الصغرى العادية (OLS). وتم إجراء التفاضل الأول لدالة الإنتاج المقدرة بالنسبة للموارد المائية للحصول على دالة الناتج الحدي، ثم الضرب في سعر الوحدة من الناتج، يتم الحصول على دالة العائد الحدي. وبالتعويض في دالة العائد الحدي بمقدار الموارد التي تتضمنها الدالة، يتم الحصول على قيمة الناتج الحدي أي قيمة العائد الحدي للموارد المائية والتي تتساوى مع التكاليف الحدية (سعر الوحدة من المورد) عند نقطة تحقيق الكفاءة الاقتصادية.

3. مصادر البيانات البحثية

أعتمدت هذه الدراسة في تحقيق أهدافها على البيانات الأولية التي تم تجميعها من خلال إعداد استمارة الاستبيان. وتم اختيار مديرية الخرج باعتبارها من المديريات الزراعية الرائدة في منطقة الرياض، حيث تم اختيار عينة عشوائية بسيطة بلغ قوامها 150 مفردة، تم توزيعها على مزارعي القمح والتمور وفقاً للأهمية النسبية للمساحة المزروعة بمحصولي القمح والتمور بمنطقة الرياض البالغة 60.1%، 39.9% لكل منهما على التوالي عام 2008. وتم تجميع الإستبانة من خلال المقابلة الشخصية لأصحاب المزارع في مديرية الزراعة بالخرج. وتم تحديد حجم العينة البحثية عند مستوى معنوية 5% وحد الخطأ المسموح به 8% وفقاً للقانون التالي (حمد وإسماعيل، 2001):

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4. الدراسات السابقة

تم حصر الدراسات التي تناولت تسعير الموارد المائية المستخدمة في الأغراض الزراعية وأهمها دراسة FRCU,(1984) والتي إستهدفت تسعير مياه الري في مصر، إذ تبين أن القيمة الاقتصادية لمياه الري (تسعيرها) تتوقف على التركيب المحصولي، ونوع التربة وأساليب الزراعة، والتسميد، وكل العوامل الأخرى المؤثرة في عملية الانتاج الزراعي. كما تبين أيضاً أن تكلفة مياه الري تراوحت بين 4- 32 جنيه / ألف م^3. وقام الملاح والقزاز(1989) بدراسة استهدفت ادخال مياه الري في منطقة القصيم في اطار المحاسبة الاقتصادية وذلك من خلال حساب العائد الفيزيقي الكلي للاستخدامات البديلة للمياه في إنتاج مختلف المحاصيل، وبالتالي التوصل الى بدائل مختلفة لاستخدامات هذا المورد. وأوضحت هذه الدراسة أن القمح يعتبر أكفأ محاصيل الحبوب، بل وأكفأ المحاصيل الشتوية من حيث عائده الفيزيقي بالنسبة لوحدة المياه وبالتالي يكون لمحصول القمح الأولوية في التركيب المحصولي للزراعات الشتوية. وأجرى شافعي والصيفي، (1991) دراسة استهدفت تسعير كمية المياه المخزونة في الآبار الرومانية، أي تقدير تكلفة التخزين للمتر المكعب من المياه حتى يتسنى رسم سياسة اقتصادية لتوجيه استخدام المياه إلى الاستخدام الأمثل والذي يحقق أقصى ربحية. وتبين من هذه الدراسة أن سعر المتر المكعب من المياه تراوح بين 0.76- 4.24 جنيه. وفي دراسة قام بها شافعي (1991) إستهدفت حساب التكلفة السنوية لاستصلاح فدان أرضي وتسعير مياه العيون في واحة سيوة. وتبين من هذه الدراسة أن التكلفة السنوية لاستصلاح فدان وتجهيزه بالموارد المائية تروا حت بين 426 - 1075 جنيه. كما أوضحت الدراسة أن تكلفة المتر المكعب تراوحت بين 0.64 - 1.54 جنيه.

وقام غانم وقمره (2007) بدراسة استهدفت التعرف على البعد الاقتصادي لنمو القطاع الزراعي المصري وتقدير تكلفة الموارد الاقتصادية الزراعية. وتبين من هذه الدراسة أن تكلفة الوحدة من المياه المستخدمة في الأغراض الزراعية تقدر بنحو 0.11 جنيه /م^3 وفقاً لأرقام عام 2006. وقام الرويس (2008) بدراسة استهدفت تقدير تكلفة أو تسعير الموارد الاقتصادية الزراعية استناداً إلى المرونات الإنتاجية المشتقة من دالة الإنتاج للقطاع الزراعي والمقدرة خلال الفترة 2005-1980. وتبين أن متوسط التكلفة السنوية للمياه المستخدمة في القطاع الزراعي يقدر بحوالي 0.12 ريال/م^3 خلال الفترة 2005-1980 وتزداد تكلفة الوحدة من المياه إلى 0.15 ريال/م^3 عام 2005. وأخيراً قام (العيد، 2010) بدراسة تبين منها أن متوسط تكلفة الوحدة من المياه المستخدمة في الأغراض الزراعية يقدر بنحو 0.33 ريال /م^3. وعلى مستوى الأنشطة الإنتاجية تبين أن تكلفة الوحدة من المياه المستخدمة في إنتاج القمح والطماطم والتمور بمنطقة الرياض بلغت 216.44، 3073.26، 317.8 ريال/ ألف م^3 على التوالي.

نتائج البحث

1. تسعير الموارد المائية المستخدمة في إنتاج القمح بمنطقة الرياض

1.1. تقدير دالة إنتاج القمح في المزارع المتخصصة بمنطقة الرياض

بإجراء التحليل الإحصائي الوصفي للمتغيرات المستخدمة في تقدير دالة الإنتاج لمحصول القمح، تم التوصل إلى البيانات الواردة في الجدول 1، (جدول 1).

جدول1: التحليل الإحصائي الوصفي للمتغيرات المستخدمة في تقدير دالة الإنتاج لمحصول القمح.

البيان	كمية المياه بالألف م^3	مقدار العمالة بالرجل	الأسمدة الكيماوية بالكيلو جرام	القروض بالألف ريال	عدد سنوات الخبرة	الإنتاج بالطن
الحد الأدنى	*120*	*2*	*200*	*0*	*5*	*45*
الحد الأعلى	*2800*	*25*	*1500*	*50*	*31*	*250*
المتوسط	*506*	*14*	*560*	*21.5*	*18.5*	*170.7*
الانحراف المعياري	*63.25*	*3.51*	*70.92*	*23.21*	*5.45*	*355.33*
معامل الاختلاف ٪	*12.5*	*113.9*	*12.7*	*107.9*	*29.5*	*294.4*

المصدر: *جمعت وحسبت من البيانات الواردة باستمارات الاستبيان التي تم تجميعها عام 2008.*

يتضح من استعراض البيانات الواردة بالجدول (1) ما يلي:

i. تراوحت كمية المياه المستخدمة في زراعة القمح بين حد أدنى بلغ 120 ألف متر مكعب وحد أعلى بلغ 2.8 مليون متر مكعب، بمتوسط يقدر بنحو 506 ألف متر مكعب، بانحراف معياري بلغ 63.25 وبمعامل اختلاف بلغ 12.5%.

ii. تراوحت العمالة الدائمة المستخدمة في زراعة محصول القمح بين حد أدنى بلغ 2 عامل وحد أعلى بلغ 25 عامل، بمتوسط يقدر بنحو *14* عمال، بانحراف معياري بلغ 3.51 وبمعامل اختلاف بلغ 113.9%.

iii. تراوحت كمية الأسمدة الكيماوية المستخدمة في إنتاج القمح بين حد أدنى بلغ 200 كيلو جرام وحد أعلى بلغ 1500 كيلو جرام، بمتوسط يقدر بنحو 560 كيلو جرام، بانحراف معياري بلغ 70.92 وبمعامل اختلاف بلغ12.7%.

iv. تراوحت قيمة القروض قصيرة الأجل المتحصل عليها من صندوق التنمية الزراعية بين حد أدنى بلغ صفر وحد أعلى بلغ 50 ألف ريال، بمتوسط يقدر بنحو 21.5 ألف ريال، بانحراف معياري بلغ 23.21 وبمعامل اختلاف بلغ 107.9%.

v. تراوح عدد سنوات الخبرة في ممارسة نشاط زراعة القمح بين حد أدنى بلغ 5 سنوات وحد أعلى بلغ 31 سنة، بمتوسط يقدر بنحو 18.5 سنة، بانحراف معياري بلغ 5.45 وبمعامل اختلاف بلغ 29.5%.

vi. تراوح إنتاج القمح لمزارع العينة بين حد أدنى بلغ 45 طن وحد أعلى بلغ 250 طن، بمتوسط يقدر بنحو 170.7 طن، بانحراف معياري بلغ 355.33 وبمعامل اختلاف بلغ 294.4%.

وبإجراء تحليل الانحدار المتعدد المرحلي باستخدام النماذج الخطية واللوغاريثمية المزدوجة والنصف لوغاريثمية للمتغيرات التفسيرية المحددة لإنتاج القمح للعينة البحثية التي بلغ قوامها 90 مفردة بمنطقة الرياض عام 2008، تبين أفضلية النموذج الوغاريثمي المزدوج في تمثيل البيانات المستخدمة في التقدير، وأمكن التعبير عنه بالمعادلة التالية:

(14.23)** (19.21)** (4.15)**

** معنوية عند المستوى الإحتمالي 1%(

وبدراسة الملامح الاقتصادية للنموذج المقدر يتضح ما يلي:

i. بلغت المرونة الإنتاجية لكمية المياه المستخدمة حوالي 0.45 ، وهذا يعني أن تغيراً مقداره 10% في مقدار المياه المستخدمة (X_1) يؤدي إلى تغير في نفس الاتجاه لإنتاج القمح بمنطقة الرياض مقداره 4.5 %.

ii. بلغت المرونة الإنتاجية للعمالة الدائمة المستخدمة في إنتاج القمح حوالي 0.33، وهذا يعني أن تغيراً مقداره 10% في مقدار العمالة الدائمة (X_2) يؤدي إلى تغير في نفس الاتجاه لإنتاج القمح في منطقة الرياض مقداره 3.3%.

iii. يقدر معامل التحديد المعدل (R^{-2}) بحوالي 0.91 وهذا يعني أن المتغيرات المستقلة التي يتضمنها النموذج تفسر حوالي 91% من التغيرات التي حدثت في إنتاج القمح، بينما بقية التغيرات (9%) تعزى إلى عوامل أخرى لا يتضمنها النموذج.

iv. يتمتع النموذج المقدر بكفاءة جيدة، حيث أقترب معامل عدم التساوي لثيل ((U- Theil من الصفر، إذ بلغ 0.05، مما يعني أن النموذج المقدر يتمتع بكفاءة في تمثيل البيانات المستخدمة في التقدير.

v. تم الكشف عن مشكلة عدم ثبات التباين (Hetero Scedasticity) من خلال إجراء اختبار(White Hetero Scedasticity)، حيث بلغت قيمة (F) حوالي 2.02 وهي غير معنوية إحصائياً عند المستوى الاحتمالي 5%، مما يؤكد عدم وجود مشكلة اختلاف التباين.

2.1. تقدير العائد الحدي للموارد المائية المستخدمة في إنتاج القمح

تنص النظرية الإقتصادية بأنه عند نقطة تحقيق الكفاءة الاقتصادية لإستخدام الموارد الإنتاجية يتساوي العائد الحدي للمورد مع التكلفة الحدية أي سعر الوحدة من المورد وبالتالي يتحدد الحجم الأمثل للمورد. ومن خلال دالة الإنتاج المقدرة لمحصول القمح في المزارع المتخصصة بمنطقة الرياض، فقد تم اشتقاق دالة الناتج الحدي. وفي ضوء متوسط سعر بيع القمح للمؤسسة العامة لصوامع الغلال ومطاحن الدقيق والبالغ 1000 ريال/ طن أمكن إشتقاق دالة العائد الحدي للموارد المائية على النحو التالي:

وفي ضوء متوسط كمية المياه المستخدمة لإنتاج القمح في المزارع المتخصصة والبالغ حوالي 506 ألف م^3 يقدر العائد الحدي للموارد المائية بنحو 208.63 ريال/ ألف م^3، وبالتالي تقدر التكلفة الحدية للموارد المائية أو سعر الوحدة من الموارد المائية المستخدمة في إنتاج القمح بنحو 208.63 ريال/ ألف م^3. وقد إتجهت المملكة العربية السعودية إلى إستيراد القمح منذ عام 2008، نظراً لتطبيق القرار الحكومي رقم 335 وتاريخ 9/ 11/ 1428هـ والقاضي بما يلي:

i. على المؤسسة العامة لصوامع الغلال ومطاحن الدقيق أن تتوقف عن شراء القمح المنتج محلياً في مدة أقصاها ثمان سنوات بمعدل سنوي 12.5%.

ii. الاستمرار في منع تصدير القمح المنتج محلياً.

iii. استمرار وزارة الزراعة في التوقف عن إصدار تراخيص لإنتاج القمح والشعير والأعلاف (الأمانة العامة لمجلس الوزراء، 1428هـ).

ونظراً لإتجاه المملكة العربية السعودية إلى استيراد القمح، فقد تم تقدير تكلفة المياه المستخدمة في إنتاج القمح بمنطقة الرياض في ضوء متوسط سعر المساواة للإستيراد (السعر الإجتماعي للقمح) والذي تم حسابه كما يلي:)سعر المساواة للإستيراد في حالة التقييم الإقتصادي=سعر الإستيراد (السعر سيف) بالعملة الأجنبية، ثم يحول إلى العملة المحلية بإستخدام سعرالصرف التوازني+مصاريف التفريغ+رسوم الميناء+ مصاريف تخليص وميزان+مصاريف النقل من الميناء إلى الصوامع- مصاريف النقل من المزرعة إلى الصوامع(.

وفي ضوء متوسط سعر الإستيراد للطن البالغ 261.83 دولار/ طن عام 2010، يبلغ السعر الإقتصادي للقمح حوالي 1037.46 ريال/ طن، جدول(2).

جدول 2: تقدير السعر الإقتصادي للقمح المنتج محلياً في العامين 2008، 2010.

البيان	2008	2010
سعر الإستيراد (سيف) بالدولار/ طن	353.5	261.83
سعر الصرف التوازني	3.75	3.75
سعر الإستيراد (سيف) بالريال/ طن	1325.63	981.86
مصاريف التفريغ بالريال/ طن	10	10
رسوم الميناء بالريال/ طن	6	6
مصاريف تخليص وميزان بالريال/ طن	5	5
مصاريف النقل من الميناء إلى الصوامع بالريال/ طن	70	70
مصاريف النقل من المزرعة إلى الصوامع بالريال/ طن	35.4	35.4
السعر الإجتماعي للطن من القمح تسليم المزرعة بالريال	1381.23	1037.46

المصدر: جمعت وحسبت من: *(1) المؤسسة العامة لصوامع الغلال ومطاحن الدقيق، إدارة تقنية المعلومات. عقود إستيراد القمح من بداية مرحلة الإستيراد وحتى تاريخه. 2010. (2) شركة الثنيان ونقليات البراك، الرياض، 2010(.*

وفي ضوء متوسط سعر المساواة للإستيراد (السعر الإقتصادي للقمح) والبالغ 1037.46 ريال/ طن وفقاً لأسعار الإستيراد للقمح عام 2010م فقد أمكن إشتقاق دالة العائد الحدي للموارد المائية على النحو التالي:

وفي ضوء متوسط كمية المياه المستخدمة لإنتاج القمح في المزارع المتخصصة والبالغ حوالي 506 ألف م^3 يقدر العائد الحدي للموارد المائية بنحو 216.44 ريال/ ألف م^3، وبالتالي تقدر التكلفة الحدية للموارد المائية أو سعر الوحدة من المياه المستخدمة في إنتاج القمح بنحو 216.44 ريال/ ألف م^3.

3.1. قياس أثر التغيرات في أسعار المياه على الكميات المستخدمة منها في إنتاج القمح

بدراسة أثر التغيرات في تكلفة أو سعر الوحدة من الموارد المائية على الكميات المستخدمة منها في إنتاج القمح بالمزارع المتخصصة بمنطقة الرياض، تم التوصل إلى البيانات الواردة في الجدول 3، (جدول 3).

و يتضح من البيانات الواردة بجدول (3) مايلي:

i. في ضوء سعر تسليم القمح للمؤسسة العامة لصوامع الغلال ومطاحن الدقيق والبالغ 1000 ريال/ طن، يقدر متوسط سعر الوحدة من المياه المستخدمة في إنتاج القمح بالمزارع المتخصصة بمنطقة الرياض بنحو 208.63 ريال/ ألف م^3 . وفي ظل زيادة سعر الوحدة من المياه المستخدمة في إنتاج القمح بنسبة 10%، 20%، 30%، 40%، 50%، يتوقع تناقص كمية المياه المستخدمة في إنتاج القمح بنحو 425.47، 363.21، 314.02، 274.43، 242.08 ألف م^3 / مزرعة، أي يتوقع تناقص كمية المياه المخصصة للوحدة الأرضية (الهكتار) بنحو 6.73، 5.74، 4.96، 4.34، 3.83 ألف م^3/ هكتار على التوالي.

iii. أما في ضوء متوسط سعر المساواة للإستيراد (السعر الإجتماعي للقمح) والبالغ 1037.46 ريال/ طن، يقدر متوسط سعر الوحدة من المياه المستخدمة في إنتاج القمح بالمزارع المتخصصة بمنطقة الرياض بنحو 216.44 ريال/ ألف م^3. وفي ظل زيادة سعر الوحدة من المياه المستخدمة في إنتاج القمح بنسبة 10%، 20%، 30%، 40%، 50%، يتوقع تناقص كمية المياه المستخدمة في إنتاج القمح بنحو 425.50، 363.23، 314.04، 274.46، 242.09 ألف م^3/ مزرعة، أي يتوقع تناقص كمية المياه المخصصة للوحدة الأرضية (الهكتار) بنحو 6.73، 5.74، 4.97، 4.34، 3.83 ألف م^3/ هكتار على التوالي.

البيان	سعر تسليم القمح للمؤسسة العامة لصوامع الغلال ومطاحن الدقيق			سعر المساواة للإستيراد (السعر الإجتماعي للقمح)		
	سعر الوحدة من المياه ريال/ ألف م^3	الكمية المستخدمة (ألف م^3) المزرعة	الهكتار	سعر الوحدة من المياه ريال/ ألف م^3	الكمية المستخدمة (ألف م^3) المزرعة	الهكتار
الأساس	208.63	506.0	8.00	216.44	506.0	8.00
زيادة السعر بنسبة:						
10%	229.49	425.47	6.73	238.08	425.50	6.73
20%	250.36	363.21	5.74	259.73	363.23	5.74
30%	271.22	314.02	4.96	281.37	314.04	4.97
40%	292.08	274.43	4.34	303.01	274.46	4.34
50%	312.95	242.08	3.83	324.66	242.09	3.83

جدول3: قياس أثر التغيرات في سعر الوحدة من الموارد المائية على الكميات المستخدمة منها في إنتاج القمح بالمزارع المتخصصة في منطقة الرياض.

*)متوسط مساحة المزرعة 63.25 هكتار/ المصدر: جمعت وحسبت من النماذج الإقتصادية المقدرة في هذه الدراسة(

2. تسعير الموارد المائية المستخدمة في إنتاج التمور بمنطقة الرياض

1.2. تقدير دالة إنتاج التمور في منطقة الرياض

بصفة عامة يتحدد إجمالي الإنتاج لمحصول التمور (y) بمجموعة من العوامل الاقتصادية أهمها: كمية المياه المستخدمة بالألف متر مكعب، و مقدار العمالة الدائمة والمؤقتة لأداء مختلف العمليات المزرعية عامل/ يوم، و كمية الأسمدة الكيماوية المستخدمة بالكيلو جرام، ومقدار القروض الزراعية قصيرة الأجل بالألف ريال، و عدد سنوات الخبرة في ممارسة النشاط المزرعي.

ومن خلال التحليل الإحصائي الوصفي للمتغيرات المشار إليها، يتضح من استعراض البيانات الواردة بجدول (4) ما يلي:

i. تراوحت كمية المياه المستخدمة في إنتاج التمور بين حد أدنى بلغ 55.2 ألف متر مكعب وحد أعلى بلغ 4.42 مليون متر مكعب، بمتوسط يقدر بنحو 676.92 ألف متر مكعب، بانحراف معياري بلغ 1014.89 وبمعامل اختلاف بلغ 66.7%.

ii. تراوحت العمالة الدائمة المستخدمة في إنتاج التمور بين حد أدنى بلغ واحد عامل وحد أعلى بلغ 1401 عامل، بمتوسط يقدر بنحو 61.02 عامل، بانحراف معياري بلغ 233.47 وبمعامل اختلاف بلغ 25.71%.

iii. تراوحت كمية الأسمدة الكيماوية المستخدمة في إنتاج التمور بين حد أدنى بلغ الصفر وحد أعلى بلغ 50.23 طن، بمتوسط يقدر بنحو 9.03 طن، بانحراف معياري بلغ 18.69 وبمعامل اختلاف بلغ48.31%.

iv. تراوحت كمية الأسمدة العضوية المستخدمة في إنتاج التمور بين حد أدنى بلغ الصفر وحد أعلى بلغ 80 طن، بمتوسط يقدر بنحو 10.22 طن، بانحراف معياري بلغ 17.86 وبمعامل اختلاف بلغ 57.22%.

v. تراوح عدد سنوات الخبرة في إنتاج التمور بين حد أدنى بلغ 6 سنوات وحد أعلى بلغ 35 سنة، بمتوسط يقدر بنحو 19.2 سنة، بانحراف معياري بلغ 6.50 وبمعامل اختلاف بلغ 57.22%.

vi. تراوح إنتاج التمور لمزارع العينة بين حد أدنى بلغ 12 طن وحد أعلى بلغ 1100 طن، بمتوسط يقدر بنحو 163.25 طن، بانحراف معياري بلغ 271.35 وبمعامل اختلاف بلغ 60.16%.

جدول 4: التحليل الإحصائي الوصفي للعوامل المحددة لإنتاج التمور في منطقة الرياض.

البيان	كمية المياه بالألف م³	مقدار العمالة بالرجل	الأسمدة الكيماوية بالطن	الأسمدة العضوية بالطن	عدد سنوات الخبرة	الإنتاج بالطن
الحد الأدنى	*55.2*	*1*	*0*	*0*	*6*	*12*
الحد الأعلى	*4416*	*1401*	*50.23*	*80*	*35*	*1100*
المتوسط	*676.92*	*60.02*	*9.03*	*10.22*	*19.2*	*163.25*
الانحراف المعياري	*1014.89*	*233.47*	*18.69*	*17.86*	*6.5*	*271.35*
معامل الاختلاف ٪	*66.7*	*25.71*	*48.31*	*57.22*	*295.38*	*60.16*

(المصدر: جمعت وحسبت من البيانات الواردة باستمارات الاستبيان التي تم تجميعها عام 2008)

وبإجراء تحليل الانحدار المتعدد المرحلي باستخدام النماذج الخطية واللوغاريثمية المزدوجة والنصف لوغاريثمية للمتغيرات التفسيرية المحددة لإنتاج التمور للعينة البحثية التي بلغ قوامها 60 مفردة بمنطقة الرياض عام 2008، تبين أفضلية النموذج الخطي في تمثيل البيانات المستخدمة في التقدير، وأمكن التعبير عنه بالمعادلة التالية:

(2.76** (2.16)** (2.15)** (2.09)*

*(*معنوية عند المستوى الإحتمالي 5%./ **معنوية عند المستوى الإحتمالي 1%)*

وبدراسة الملامح الاقتصادية للنموذج المقدر يتضح ما يلي:

i . تقدر المرونة الإنتاجية لكمية المياه المستخدمة بنحو 0.50، وهذا يعني أن تغيراً مقداره 10% في مقدار المياه المستخدمة (X_1) يؤدي إلى تغير في نفس الاتجاه لإنتاج التمور بمنطقة الرياض مقداره 5.0 %.

ii. تقدر المرونة الإنتاجية للعمالة الدائمة بنحو 0.04، وهذا يعني أن تغيراً مقداره 10% في مقدار العمالة الدائمة (X_2) يؤدي إلى تغير في نفس الاتجاه لإنتاج التمور في منطقة الرياض مقداره 0.40 %.

iii. تقدر المرونة الإنتاجية للأسمدة الكيماوية بنحو 0.02، وهذا يعني أن تغيراً مقداره 10% في كمية الأسمدة الكيماوية (X_3) يؤدي إلى تغير في نفس الاتجاه لإنتاج التمور في منطقة الرياض مقداره 0.20%.

iii. يقدر معامل التحديد المعدل (R^{-2}) بحوالي 0.74 وهذا يعني أن المتغيرات المستقلة التي يتضمنها النموذج تفسر حوالي 74% من التغيرات التي حدثت في إنتاج التمور، بينما بقية التغيرات (26%) تعزى إلى عوامل أخرى لا يتضمنها النموذج.

iv. يتمتع النموذج المقدر بكفاءة جيدة، حيث بلغ الجذر التربيعي لمتوسط مربعات الخطأ العشوائي (R.M.S.E) 0.25، ومتوسط الخطأ المطلق (MAE) *0.16* . كما بلغ متوسط النسبة المئوية للخطأ المطلق (M.A.P.E) 2.23%، وأقترب معامل عدم التساوي لثيل ((U- Theil من الصفر، حيث بلغ 0.12، مما يعني أن النموذج المقدر يتمتع بكفاءة في تمثيل البيانات المستخدمة في التقدير.

v. تم الكشف عن مشكلة عدم ثبات التباين (Hetero Scedasticity) وذلك من خلال اختباري بارك وجليجسر، ووفقاً لاختبار بارك فقد تم إجراء انحدار مربع البواقي (e^2_i) على المتغيرات المستقلة التي يتضمنها النموذج، أما وفقاً لاختبار جليجسر فقد تم إجراء انحدار القيم المطلقة للبواقي (e_i) على المتغيرات المستقلة المشار إليها آنفاً، إذ تبين عدم معنوية معاملات الانحدار المقدرة عند المستوى الاحتمالي 5% وبالتالي يكون النموذج المقدر خالي من مشكلة اختلاف التباين، كما تم إجراء اختبار (White Hetero Scedasticity) ، حيث بلغت قيمة (F) حوالي 1.86 وهي غير معنوية إحصائياً عند المستوى الاحتمالي 5%، مما يؤكد عدم وجود مشكلة اختلاف التباين.

2.2. تقدير العائد الحدي للموارد المائية المستخدمة في إنتاج التمور

من خلال دالة الإنتاج المقدرة لمحصول التمور بمنطقة الرياض، فقد تم اشتقاق دالة الناتج الحدي. وفي ضوء متوسط سعر بيع التمور والبالغ 10.27 ألف ريال/ طن أمكن إشتقاق دالة العائد الحدي للموارد المائية على النحو التالي:

وفي ضوء متوسط كمية المياه المستخدمة لإنتاج التمور والبالغ حوالي 676.92 ألف م³، يقدر العائد الحدي للموارد المائية بنحو 642 ريال/ ألف م³ ، وبالتالي تقدر التكلفة الحدية للموارد المائية أو سعر الوحدة من الموارد المائية المستخدمة في إنتاج التمور بنحو 642 ريال/ ألف م³. ونظراً لإتجاه المملكة العربية السعودية إلى تصدير التمور، فقد تم تقدير تكلفة المياه المستخدمة في إنتاج التمور بمنطقة الرياض في ضوء متوسط سعر المساواة للتصدير (القيمة الإقتصادية للتمور) والذي تم حسابه كما يلي:) القيمة الإقتصادية للسلعة التصديرية = السعر فوب يحول إلى القيمة بالعملة المحلية بإستخدام سعر الصرف التوازني - تكاليف التخزين والشحن والنقل الداخلي (، وفي ضوء متوسط سعر تصدير التمور للمملكة العربية السعودية البالغ 1374.63 دولار/ طن عام 2009، وسعرالصرف التوازني البالغ 3.75 ريال/ دولار، يقدر متوسط سعر التصدير بالعملة المحلية بنحو 5154.86 ريال/ طن. وفي ضوء تكاليف التخزين والشحن والنقل الداخلي للتمور البالغة 76 ريال/ طن، يقدر متوسط سعر المساواة للتصدير بنحو 5078.86 ريال/ طن. وفي ضوء متوسط القيمة الإقتصادية لتصدير التمور، فقد أمكن إشتقاق دالة العائد الحدي للموارد المائية على النحو التالي:

وفي ضوء متوسط كمية المياه المستخدمة لإنتاج التمور والبالغ حوالي 676.92 ألف م^3 يقدر العائد الحدي للموارد المائية بنحو 317.8 ريال/ ألف م^3، وبالتالي تقدر التكلفة الحدية للموارد المائية أو سعر الوحدة من المياه المستخدمة في إنتاج التمور بنحو 317.8 ريال/ ألف م^3.

3.2. قياس أثر التغيرات في أسعار المياه على الكميات المستخدمة منها في إنتاج التمور

بدراسة أثر التغيرات في تكلفة أو سعر الوحدة من الموارد المائية على الكميات المستخدمة منها في إنتاج التمور بمنطقة الرياض، يتضح من البيانات الواردة بجدول (5) مايلي:

i. في ضوء متوسط البيع للتمور والبالغ 10.27 ألف ريال/ طن، يقدر متوسط سعر الوحدة من المياه المستخدمة في إنتاج التمور بمنطقة الرياض بنحو 642 ريال/ ألف م^3. وفي ظل زيادة سعر الوحدة من المياه المستخدمة في إنتاج التمور بنسبة 10%، 20%، 30%، 40%، 50%، يتوقع تناقص كمية المياه المستخدمة في إنتاج التمور إلى حوالي 560.52، 471.0، 401.32، 346.04، 301.44 ألف م^3/ مزرعة، أي يتوقع تناقص كمية المياه المخصصة للوحدة الأرضية (الهكتار) إلى حوالي 22.86، 19.21، 16.37، 14.11، 12.29 ألف م^3/ هكتار على التوالي.

ii. أما في ضوء متوسط القيمة الإقتصادية لتصدير التمور والبالغ 5078.86 ريال/ طن، يقدر متوسط سعر الوحدة من المياه المستخدمة في إنتاج التمور بمنطقة الرياض بنحو 317.8 ريال/ ألف م^3. وفي ظل زيادة سعر الوحدة من المياه المستخدمة في إنتاج التمور بنسبة 10%، 20%، 30%، 40%، 50%، يتوقع تناقص كمية المياه المستخدمة في إنتاج التمور إلى حوالي 559.43، 470.08، 400.54، 345.36، 300.85 ألف م^3/ مزرعة، أي يتوقع تناقص كمية المياه المخصصة للوحدة الأرضية (الهكتار) إلى حوالي 22.82، 19.17، 16.34، 14.08، 12.27 ألف م^3/ هكتار على التوالي.

جدول 5: قياس أثر التغيرات في سعر الوحدة من الموارد المائية على الكميات المستخدمة منها في إنتاج التمور بمنطقة الرياض.

البيان	متوسط سعر البيع			القيمة الإقتصادية لتصدير التمور		
	سعر الوحدة من المياه ريال/ (ألف م^3)	الكمية المستخدمة (ألف م^3) المزرعة	الهكتار	سعر الوحدة من المياه ريال/ (ألف م^3)	الكمية المستخدمة (ألف م^3) المزرعة	الهكتار
الأساس	642	676.92	27.60	317.8	676.91	27.61
زيادة السعر بنسبة:						
10%	706.2	560.52	22.86	349.6	559.43	22.82
20%	770.4	471.00	19.21	381.4	470.08	19.17
30%	834.6	401.32	16.37	413.1	400.54	16.34
40%	898.9	346.04	14.11	444.9	345.36	14.08
50%	963.0	301.44	12.29	476.7	300.85	12.27

(* متوسط مساحة المزرعة 24.52 هكتار /المصدر: جمعت وحسبت من النماذج الإقتصادية المقدرة في هذه الدراسة)

3. السياسات والآليات المقترحة لتسعير الموارد المائية المستخدمة في الأغراض الزراعية

من خلال التحليل الحدي تم تسعير الموارد المائية المستخدمة في إنتاج القمح والتمور. ويعتبر تسعير الموارد المائية المستخدمة في الأغراض الزراعية من الأساليب المهمة في ترشيد استخدامها والحفاظ عليها لمستقبل الأجيال القادمة. ويمكن تطبيق عدة سياسات لتسعير أو تحصيل تكلفة الموارد المائية المستخدمة في الأغراض الزراعية وأهمها مايلي:

1.3. التسعير وفقآ لكمية المياه المستخدمة كما هو الحال في أسبانيا والمغرب وتونس وقبرص.

يتطلب تنفيذ هذه السياسة عدة آليات هي: تحديد كمية المياه المستخدمة لكل مزرعة على حده وذلك من خلال التزام جميع المزارع بتركيب عدادات لقياس كمية المياه المستخدمة خلال الموسم الزراعي، و قيام وزارة المياه بوضع تسعيره للموارد المائية ومتابعة تحصيل قيمتها.

2.3. التسعير التصاعدي للموارد المائية وذلك بفرض أسعار أعلى كلما ازدادت الكمية المستخدمة من الموارد المائية.

يتم تطبيق هذه السياسة في دولة الأردن. ويتطلب تنفيذ هذه السياسة عدة آليات هي: تقسيم كميه المياه المستخدمة إلى فئات محددة، و قيام وزارة المياه بوضع تسعيره لكل فئة.

4.3. التسعير كنسبة من كمية وقيمة الإنتاج.

ووفقا لهذه السياسة يتم ربط أسعار المياه بكمية الإنتاج لمختلف المحاصيل ومن ثم تختلف الأسعار باختلاف نوعية المحاصيل من ناحية، كما تزداد بزيادة إنتاجية هذه المحاصيل من ناحية أخرى.

5.3. التسعير وفقآ للمساحة المروية.

ووفقا لهذه السياسة يتم وضع تسعيرة للموارد المائية على أساس المساحة المروية بغض النظر عن كمية المياه المستخدمة. ويتم استخدام هذه الطريقة في عدد كبير من الدول أهمها فرنسا واليونان وأسبانيا ولبنان نظرا لسهوله تنفيذها ولكنها تفترض أن المساحة تمثل كمية المياه المستخدمة وهذه الفرضية غير منطقية لاختلاف احتياجات المحاصيل وأنواع التربة.

6.3. إعادة النظر في منح تراخيص وحفر الآبار.

يوصى بإعادة النظر في منح تراخيص وحفر الآباربحيث يتضمن الترخيص الكمية القصوى التي يمكن سحبها سنويا وإلزام المزارعين بكمية الموارد المائية المسموح بها.

7.3. ضرورة معالجة السحب الجائر من المياه الجوفية.

ويتم ذلك من خلال تطبيق الآليات التالية: إنذار المزارع مع تغريمه لعدد من المرات، فإن لم يستجيب يتم سحب رخصة استغلال البئر ومصادرته، و فرض رسوم تصاعدية على الكميات المسحوبة بشكل زائد، بحيث تكون تكلفة المياه المسحوبة أكبر من العائد المتحصل عليه من الموارد المائية.

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Rigorous Irrigation Experiments Together with a Novel Simulation-based Optimization Tool for Optimizing Water Productivity under Saline Conditions

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Abstract: In arid and semi-arid countries water is the limiting factor as regards food production. Notwithstanding this fact, relatively poor management practices constitute the main reason for low water productivity (WP). In this respect - in order to substantially improve crop yield under restricted water availability - this contribution proposes a novel strategy for optimal irrigation scheduling and control and likewise demonstrates its performance by rigorously monitored, comprehensive field experiments in the Sultanate of Oman. The new approach employs the APSIM-SWIM model (Keating et al. 2003) for portraying the plant growth characteristics and a simulation-based optimization within the new evolutionary algorithm for optimal irrigation scheduling of deficit irrigation systems GET-OPTIS (Schütze et al. 2010). Besides the theoretical and application essentials of the optimization strategy, the paper presents in detail the experimental investigations, which were realized on the basis of open field experiments. We employed current micro irrigation techniques and the crop selected for this study was Maize (Zea Mays, maize sow cultivar = pioneer_3527). The experiments were performed in three replicates and featured a randomized complete block design at the Agricultural Research Station, Oman. Key objectives of this research were: (1) to evaluate the practical benefit of the GET-OPTIS optimization methodology, (2) to directly validate controlled deficit irrigation schedules (CDIS) and thereby potential new management strategies and (3) to investigate a highly relevant irrigation phenomenon – namely, the salt accumulation in different soil depths. To achieve these goals we used two categories of irrigation water (fresh water with EC 1 and 6 dS m^{-1}) and six different irrigation rates. Three irrigation rates corresponding to 85%, 100% and 125% of potential crop evapotranspiration (Etc, FAO) were applied. The other three irrigation rates were provided by GET-OPTIS optimization runs which were calculated (1) for fresh water, (2) for a deficit irrigation strategy with fresh water and (3) for full irrigation using water with 6 dS m^{-1}. When comparing WP from irrigation rates in line with the deficit irrigation treatment - as obtained by GET-OPTIS runs - with irrigation procedures in accordance with Class A-pan, this unveiled significantly superior water productivity (WP) of the former. Applying GET-OPTIS for deficit irrigation yielded a WP of 4.3 kg m^{-3} whereby using just Class A-pan procedure produced a WP of 3.5 kg m^{-3}, respectively, even though they had been irrigated with the same total amount of water. Furthermore, the monitoring results of the soil water content with respect to the water application rate corresponding to a specified soil depth were compared to the outcome of the modeling approach; they showed that a transfer of the calibrated models to different conditions is feasible as long as certain adaptations to the differing conditions are accomplished.

Keywords: Optimal irrigation scheduling, field experiments, APSIM-SWIM, GET-OPTIS, Oman.

Introduction and Literature Review

In arid and semi-arid countries water for irrigated agricultural land is the limiting factor as regards food production. The fresh water resources available for agriculture are declining quantitatively and qualitatively. Furthermore, irrigated agriculture faces several challenges such as decreasing groundwater tables, lower soil moisture levels due to temperature increase as projected for climate change, and salinization.

Most countries rely on increasing the application efficiency of irrigation systems to save water, but this will not solve the problem – they will not have enough water to increase productivity sufficiently to achieve food security. Part of the solution should come from increasing water productivity (ICARDA, 2012). Water productivity (WP) can be expressed as agricultural production per unit volume of water (m^3 ha^{-1}).

Increasing WP is a challenge at various levels: The first level is to continue to increase crop yields without increasing transpiration. This can be reached through breeding and certain agronomic practices – bearing in mind that the opportunities for substantial gains in water productivity by any of these techniques are rather small (Andrew Keller et 2013). The second level is to reduce losses on field, farm and at system level, which can be achieved by appropriate irrigation methods; irrigation control and irrigation strategies like controlled deficit irrigation. The third level is to increase economic productivity of water and thus profit. The latter depends on the relationship between crop yields and applied water and, especially in the case of drip irrigation, on the field design (Walser S., 2012).

Efforts to investigate WP are numerous and can mainly be divided into two groups; (a) field experiments which focus on crop growth and the evaluation of its effects on plants sustaining drought stress and (b) simulation-based studies in which parameterized crop growth models - which were calibrated and validated by appropriate field experiments in advance - calculate the impacts of drought stress for a diverse range of environmental boundary conditions (Kloss et al. 2012).

Today, computer-based technology already plays an important role in identifying, comparing and/or assessing the sustainability of water resources management in irrigation. These modern techniques, however, are only applied in relatively few cases. Unfortunately, current practice still employs outdated, simplistic tools which do not really allow for a physically sound consideration of the interacting water transport processes from the field entrance to the roots of the plants and down to the groundwater level (Schmitz et al. 2007).

This contribution proposes a novel strategy for optimal irrigation scheduling and control and demonstrates its performance by rigorously monitored, comprehensive field experiments. The field experiments were combined with a new approach which employs the APSIM-SWIM model (Keating et al. 2003) for portraying the plant growth characteristics and a simulation-based optimization within the new evolutionary algorithm for optimal irrigation scheduling of deficit irrigation systems GET-OPTIS (Schütze et al. 2010).

Experimental Setup, Data and Methods

1. Study Site Description

The experiment was conducted in the Directorate General of Agricultural and Livestock Research in Rumais, Sultanate of Oman (latitude 23.6° N, longitude 58.0° E at 24 m above MSL). The experimental site is located in semiarid climate with a mean annual precipitation of 100 mm. The soil properties for the experimental site are presented in table 1.

Table 1: The experimental site's soil properties at Rumais, Sultanate of Oman with van Genuchten/Mualem parameters. θs and θr ($cm^3\ cm^{-3}$) are saturated and residual water content, α (cm^{-1}) and n are empirical parameters determining the shape of the retention curve, Ks ($cm\ h^{-1}$) is saturated conductivity, and l is a pore connection parameter.

Soil layer (cm)	Clay (%)	Silt (%)	Sand (%)	θs	θr	α (cm^{-1})	n	Ks ($cm\ h^{-1}$)	l
0-15	7	7	85	0.32	0.058	0.036	1.2	5.4	0.5
15-35	7	9	84	0.32	0.058	0.036	1.2	4.8	0.5
35-75	10	12	77	0.28	0.1	0.036	1.3	5.4	0.5
75-200	7	7	85	0.32	0.058	0.036	1.2	5.4	0.5

2. Experimental Treatments and Design

The experiment consisted of two main investigation factors; irrigation water quality (electrical conductivity of 1 & 6 dS m^{-1}) and six irrigation rates. Two applied irrigation rates were corresponding to 85% (T5) and 100% (T4) of potential crop evapotranspiration (Etc, FAO) using water quality of 1 dS m^{-1} and 125% (T3) of potential crop evapotranspiration (Etc, FAO) using water quality of 6 dS m^{-1}. The other three irrigation rates were provided by GET-OPTIS optimization runs which were calculated for fresh water (T6), for a deficit irrigation strategy with fresh water (T7) and for full irrigation using water with 6 dS m^{-1} (T1). In addition, three more treatments were also involved, but due to technical problems they do not feature in this paper. The two factors were replicated 3 times in a split block design as shown in figure 1. Total numbers of plots were 27 (9 x 3 = 27). Area of each plot area was 14 m^2 (3.5 x 4 m). The plots were 0.5 meters apart from each other and 1 m was kept between the replicate.

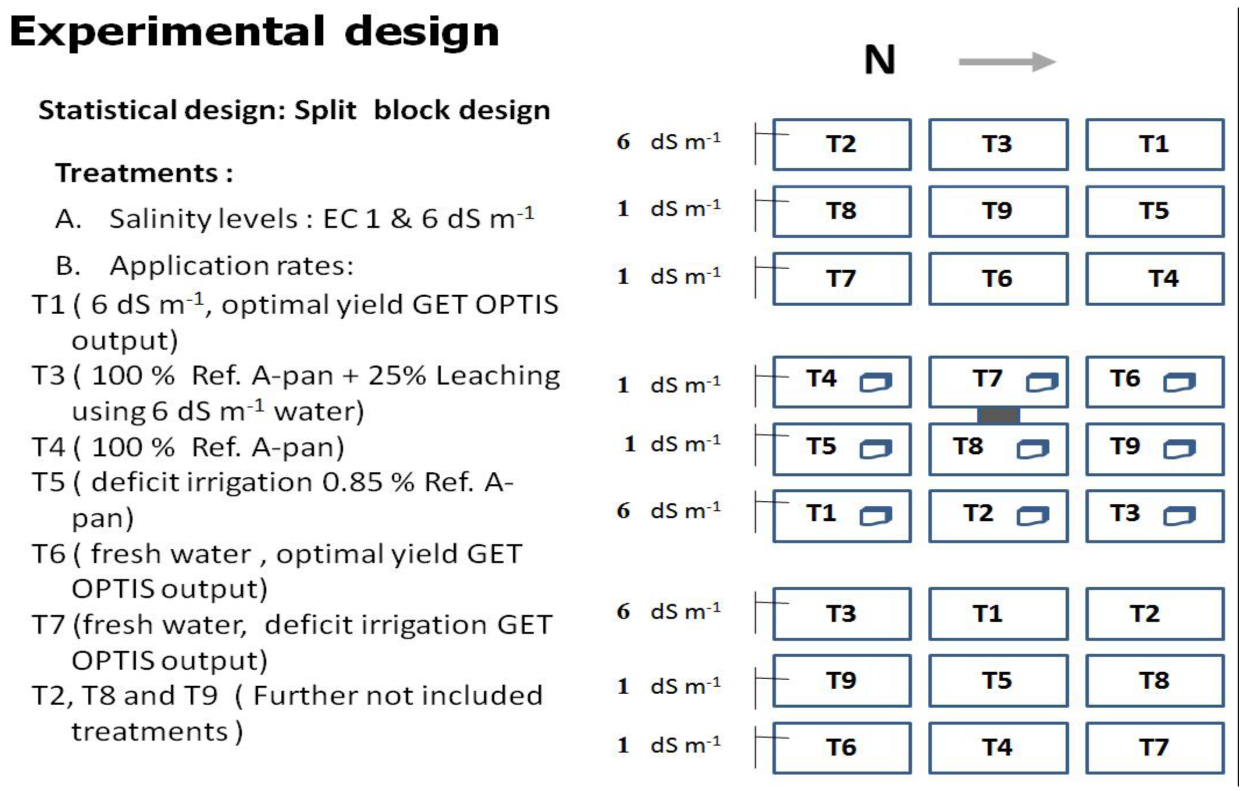

Figure 1: The experimental design (boxes indicate the plots with TDR and pF meter sensors).

3. Seeding, Fertilizing and the Irrigation System

Maize (Pioneer_3527) was planted for grain on 29 November 2012 and harvested on 24 March 2013. It was sown with a row spacing of 0.5 m and the seeds were planted 25cm apart along eight rows. The planting density was 9.7 plants m^{-2}. The surface drip irrigation system (DI) with an emitter spacing of 50 cm was installed with two drip tubes for one plant row resulting in an emitter spacing of 0.25 m. The emitter flow rate was 4.2 L h^{-1} at a pressure of 1 bar with dripper uniformity of 92%. Plants that were irrigated based on Class-A Pan evaporation measurements were irrigated every two days. Water meters were used to measure the applied amount of irrigation.

The soil surface was leveled and chemical fertilizer was applied before sowing with 100 kg ha^{-1} P_2O_5 (200 kg ha^{-1} triple super phosphate) and 50 kg ha^{-1} K_2O (100 kg ha^{-1} potassium sulphate) for grain. The plants were fertilized by 150 kg ha^{-1} nitrogen (326 kg ha^{-1} Urea) in three split doses as follows: ¼ before sowing, ½ one month after germination and ¼ at flag leaf stage. The fertilizers were applied manually at 8-10 cm distance from the plants. Necessary preventive measures were taken to protect plants from pests, diseases and birds during the growth period. The plants were kept under an agril cover for the first two weeks.

4. Data Collection during the Experiment

Meteorological data were obtained from a meteorological station on the site. Hourly data were obtained for maximum and minimum temperature, radiation, wind speed and relative humidity. Soil samples were obtained before planting and at the harvesting day. These soil samples were analyzed for 1:5 ECe. Time domain reflectometry (TDR) probe (used to measure soil water content, Campbell Scientific, USA) and a pF-Meter (measurement range of about pF 0 to 7) next to each other as one sensor pair were installed at four different soil depths (10, 20, 50 and 100 cm) at the second replication (see,figure 1). Soil tensions and soil water contents were observed by TDR probes and pF-Meters every 15 minutes as shown in figure 2.

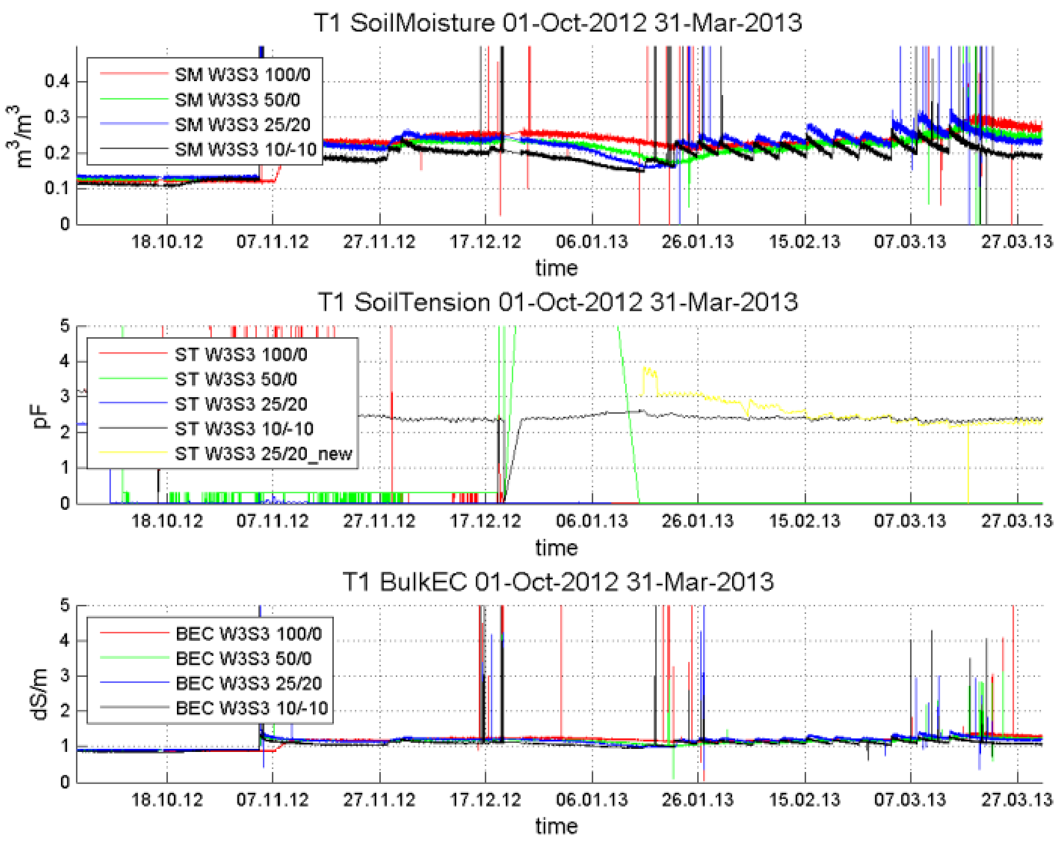

Figure 2: TDR probes and pF-Meters data for T1 treatment for different depths.

At each development stage three plants at each plot were randomly selected and recorded for plant height, number of leafs, leaf length and leaf width. In addition, LAI data were collected at different stages of plant development.

During the actual harvesting day, the green forage yield and plant parameters were recorded for each plot separately. In addition to this, four plants were randomly selected at each plot and recorded for plant height, number of leaves, leaf length and leaf width. Furthermore, wet and dry matter weight for leaves, stem, cob and seeds were recorded for each selected plant in each plot.

4. Model-based Optimal Scheduling of the Deficit Irrigation Treatment

The SVAT 1D mechanistic crop growth model APSIM (the Agricultural Production System Simulator) (Keating et al. 2003) was used within the frame of a stochastic simulation-based approach on field level figure 3. It was set up for maize (which was sown at a crop density of 9.7 plants m^{-2} and row spacing of 0.5m). Simulation was set to start 7 days prior to crop sowing in order to allow the model to properly simulate a bare soil water balance.

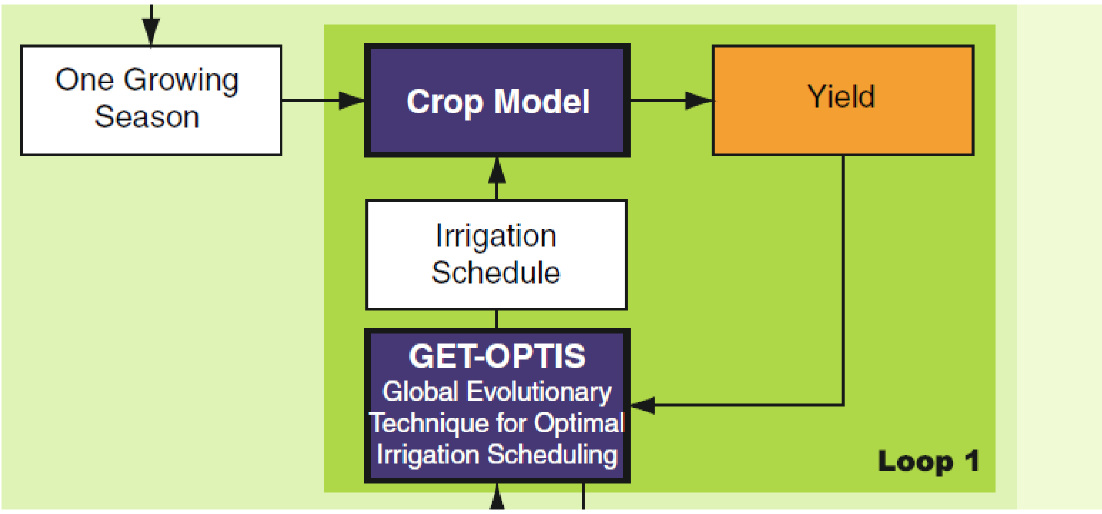

Figure 3: Framework for generating crop water production functions (Schütze and Schmitz 2010)

For the soil water balance, APSIM-SWIM is designed to run within APSIM and calculate all flows of water and nutrients through and out of soil for a given simulation. It is used based on a numerical solution of the Richards equation combined with the convection-dispersion equation to model solute movement. These flows include infiltration, runoff, plant uptakes, movement through soil, etc. and related nutrient flows. SWIM is a one-dimensional model and does not consider lateral flow or horizontal heterogeneity.

6. Optimized Irrigation Scheduling and Control

The optimization technique GET-OPTIS was applied with the calibrated APSIM-SWIM model in order to determine the optimal irrigation scheduling. The optimization run was set to start one month after the sowing day. The optimization results were used to calculate the potential yield and WP.

This paper presents the second trial of the study investigation, the corresponding preceding study can be found in Al-Dhuhli *et al.* (2013).

Results

1. Crop Yields and Water Productivity

The results of the experiments showed that increasing the amounts of irrigation water with 6 dS m^{-1} water quality by more than 25% between the irrigation rates that were provided by GET-OPTIS optimization runs for full irrigation (T1) and 125% (T3) of potential crop evapotranspiration (Etc, FAO) had increased dry grain yield by 4% (from 13.48 to 14.04 ton ha^{-1}). However, T1 proved superior with a WP of 2.9 kg m^{-3} as compared to 2.3 kg m^{-3} for T3.

The results also showed that the treatment provided by GET-OPTIS optimization runs for fresh water deficit irrigation (T7) with a WP of 3.9 kg m^{-3} proved to be clearly superior as compared to 3.5, 2.6 and 3.7 kg m^{-3} for the treatments of 100% (T4), 0.85% Etc (T5) and also with respect to the treatment provided by GET-OPTIS optimization runs for attaining an optimal yield (T6), (figures; 4 and 5).

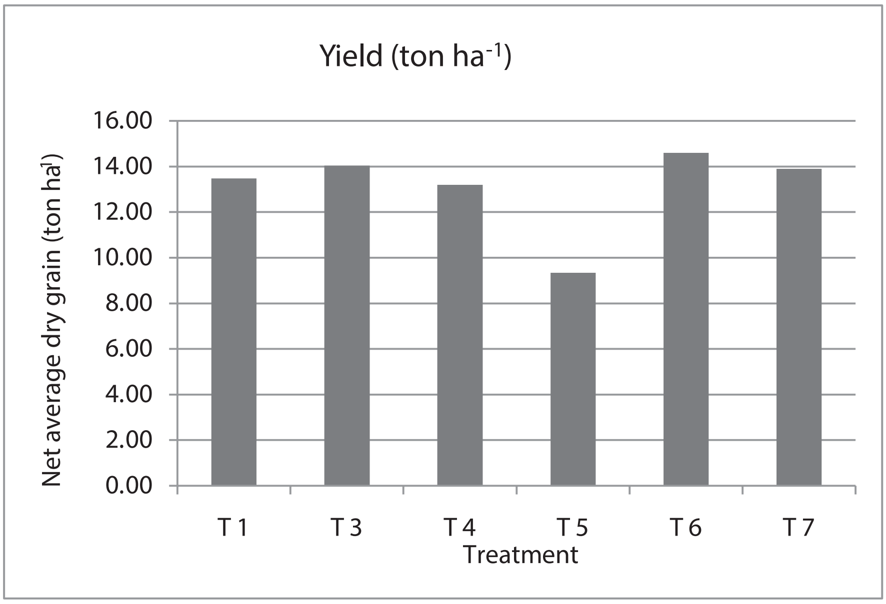

Figure 4: The Net average dry grain weight (ton ha^{-1}).

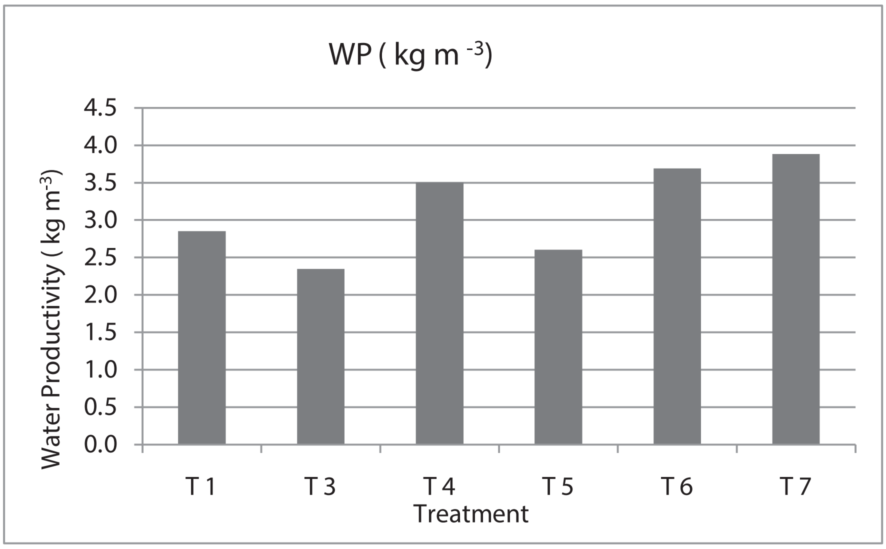

Figure 5: The water productivity (kg m^{-3}) out from the dry grain weight and the total water used.

2. Simulation Runs for Calibration Soil Water Contents

The simulated soil water contents showed mostly a fit agreement with the observed data for mostly all the treatments within the four depths, for example T7 (the treatment provided by GET-OPTIS optimization runs for a deficit irrigation strategy with fresh water) as shown for the different depths in figure 6.

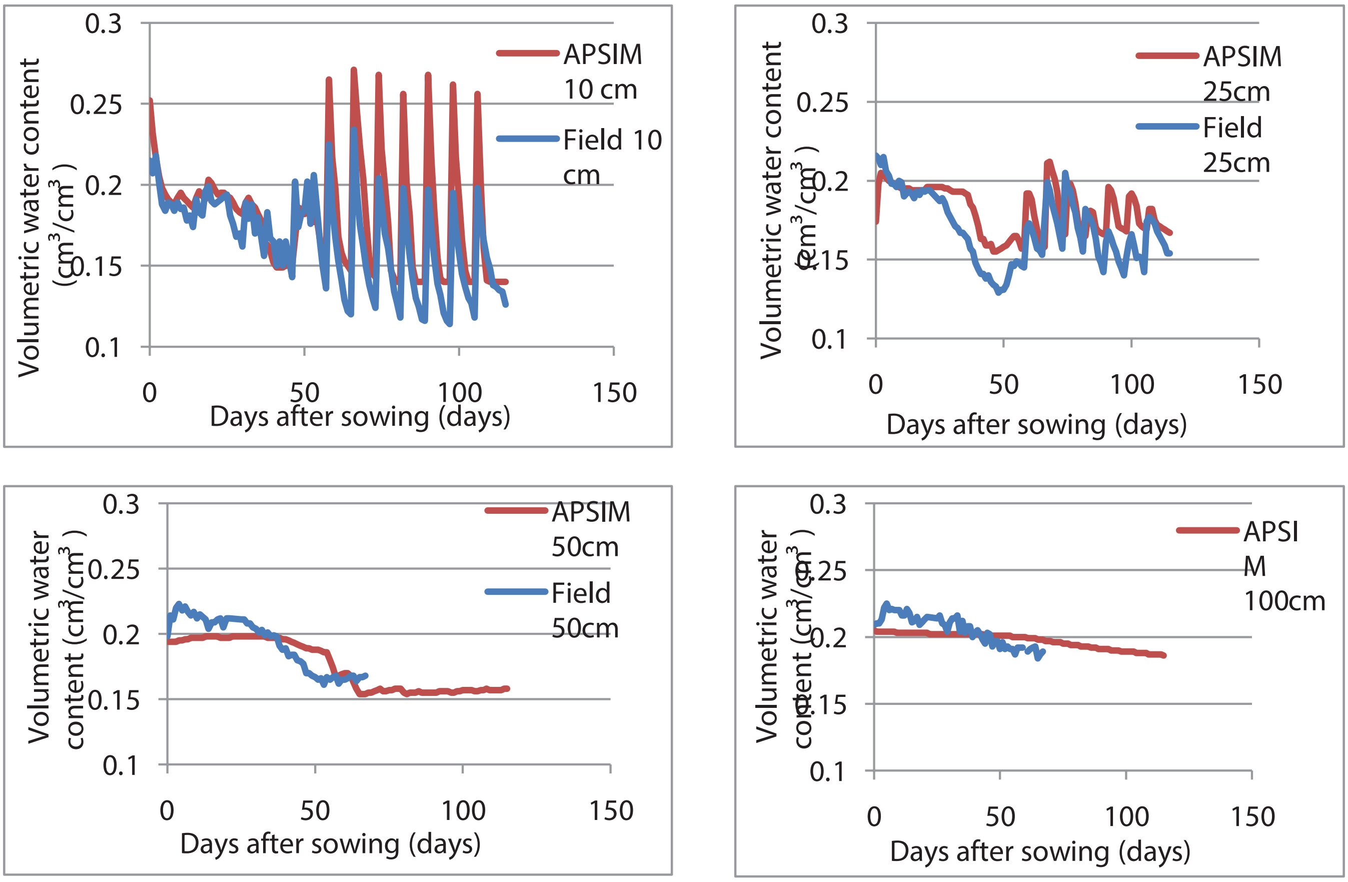

Figure 6: Model validation (The simulated soil water contents vs. the observed for T7 at different soil depths).

3. Model Validation by the Plant Data

The simulation run showed a good fit for the plant data as compared to the observed experiment data as shown in the table 2.

Table 2: The model validation (plant data), Ob. = observed, Calc. = calculated

	T1		T6		T7	
	Ob.	Calc.	Ob.	Calc.	Ob.	Calc.
Yield (grain yield dry weight) (ton ha^{-1})	13.48	15.05	14.60	12.57	13.90	12.05
Biomass (total above-ground biomass)(ton ha^{-1})	28.13	22.94	31.65	19.86	31.27	19.14
Height (m)	2.36	2.39	2.33	2.38	2.33	2.27

4. Soil Salinity

Mean soil ECe was recorded to be higher in 5-10 cm depth as compared with 20-30, 40-60 and 80-100 cm depth indicating that leaching of salts was not complete and some portion of salts was still left in the surface depth. The results of soil ECe in 5-10 cm depth indicated that the decreased amounts of irrigation water from 100% ETc (T4) to 0.85 % ETc (T5) increased soil water salinity by around 30% (from 698 to 912 ppm). However, this was not the case while using the output from the GET-OPTIS optimization runs; using less amount of irrigation water with T7 (the treatment provided by GET-OPTIS optimization runs for a deficit irrigation strategy with fresh water) there was a decrease in the soil water salinity by 15% compared to T6 (the treatment provided by GET OPTIS optimization runs for fresh water) as shown in figure 7.

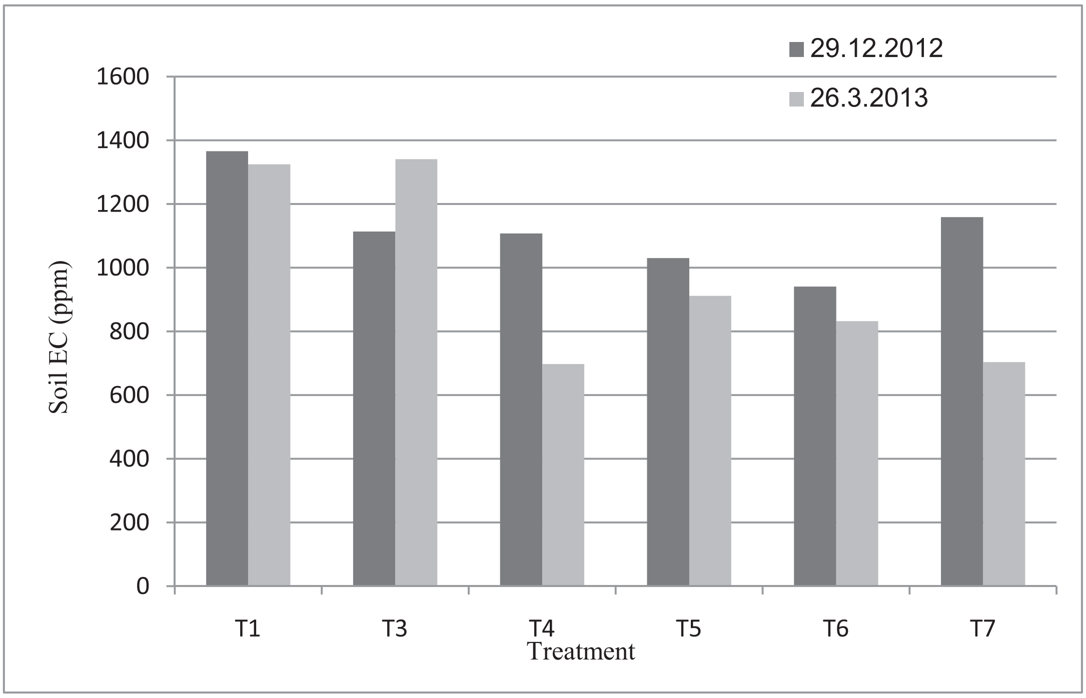

Figure 7: Pre and post harvest EC (Soil samples analysis) at 5-10 cm depth.

Summary and Conclusion

In this study, rigorously monitored comprehensive field experiments were conducted. Employing a micro irrigation system, we investigated the performance of Maize under different treatments i.e., applying varying water quantity and quality. Within these treatments the impact on crop yield was calculated by the new evolutionary algorithm GET-OPTIS for optimal irrigation scheduling of deficit irrigation systems together with the SVAT-model APSIM-SWIM. The simulated outcome showed a good agreement with the field observations. Thus, the new optimization strategy unveiled a high potential for increasing water productivity. In the light of these results it becomes apparent that considerable savings in irrigation water are feasible and the optimized irrigation schedule would greatly increase WP as compared to the current practice.

The outcome of the study clearly indicated that the optimal irrigation schedule with controlled deficit irrigation schedule (T7) treatment was the most suitable for obtaining an improved crop yield - at the same time - less accumulation of salt. Irrigating Maize with water of even relatively low quality (EC 6 dS m^{-1}) provided only nominal reductions in WP if using the treatment (T1) obtained from GET-OPTIS optimization runs. Nevertheless, more investigations by e.g. including different soil conditions are still necessary to further validate and generalize these highly promising results.

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Analyzing the Effects of Climate Change on Crop Water Requirements in Kingdom of Saudi Arabia

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Abstract: Agricultural activities consume more than 80% of freshwater supplies around the globe. The crop water requirements (CWR) are likely to be affected by climatic conditions and crop growing seasons. This study investigated the possible implications of climate change and growing seasons on CWR in Saudi Arabia. Assuming constant agricultural productions, CWR were predicted to be 8,713 and 9,176 million cubic meters (MCM) in 2011 and 2050, respectively, representing a linear increase of 11.9 MCM per year. Such increase is equivalent to CWR for producing approximately 4,900 tons of wheat per year. Average increase of CWR was estimated to be 5.3% with ranges of 3.3–11.9%, 3.3–12.1% and 3.9–15.6% for dates, alfalfa and wheat, respectively. On average, increase in temperature by 1°C can increase CWR by 1.8–2.9%. This study indicates that 732–903 MCM per year of water may be conserved by shifting growing seasons of the major crops. CWR for wheat showed an exponential decay pattern for a shift of up to 75 days earlier from the current growing period. The findings of this study might be useful in developing strategies related to water conservation in agriculture and better planning for water resources management.

Keywords: Water conservation, crop water requirements, effects of temperature, effects of growing seasons, Saudi Arabia.

Introduction

Saudi Arabia is an arid country with low annual rainfall, limited groundwater reserves, no natural freshwater flow system and harsh climate (CDSI 2010). The country produces different types of crops, including wheat, maize, millet, vegetables, alfalfa, dates, grapes and citrus fruits (MOA 2009; CDSI 2010). Wheat is considered to be the most important crop for food security of the country (MOEP 2010). Agriculture in Saudi Arabia relies on the availability of seasonal water, surface water stored through dam reservoirs, valley basins, treated wastewater and shallow/deep aquifers, while most of the water comes from non-renewable groundwater sources (MOEP 2010; Chowdhury and Al-Zahrani 2013a). However, the usual practices of agriculture might have detrimental effects on groundwater reserves in future (Al-Sheikh 1998). To avoid such implications, the country has adopted a policy to lower freshwater withdrawals from the non-renewable groundwater sources by reducing agricultural activities and introducing advanced irrigation practices. For example, in 2005–2009, approximately 2.65, 2.63, 2.56, 1.99 and 1.15 million tons (MT) of wheat, respectively, were produced in the country (CDSI 2010). However, the policy on reducing freshwater withdrawals by reducing agricultural activities can have negative effects on the future agricultural activities of the country (CDSI 2010).

In addition, harsh climate in Saudi Arabia can impose stress on agricultural water demands. Past studies have predicted 1.8–4.1°C and 2.5–5.1°C increase in temperature in Saudi Arabia by 2050 and 2070–2100, respectively, which can increase reference evapotranspiration (ET_o) by 10.3–27.4% (Chowdhury and Al-Zahrani 2013a). The evaporative demands of crops greatly depend on growing seasons, temperature and type of the crop (Allen et al. 1998). For example, water demands for wheat, vegetables and fodder crops in Saudi Arabia were reported to be 13173, 18000 and 39000 m^3 per hectare, respectively (Al-Sheikh 1998). Al-Omran and Shalaby (1992) estimated CWR for wheat, maize, tomato, citrus and dates as 883, 751, 1703, 2259 and 4021 mm/yr, respectively, for the Eastern and Central regions of Saudi Arabia. Saifuddin et al. (2004) reported CWR for alfalfa, potato and wheat as 34864, 6522 and 6473 m^3/ha/season, respectively, in Wadi Sirhan of Al-Jouf. CWR in Makkah were predicted to be 727.8, 518.5, 452.6 and 1922.5 mm/yr for millet, wheat, maize and alfalfa, respectively (Hashim et al. 2012).

The crops produced in summer are likely to consume more water than that of the winter (Allen et al. 1998), due mainly to higher temperature and lower rainfall. Understanding the effects of climate change and growing seasons on CWR is important to better manage water resources. This paper aims to understand the effects of climate change and growing seasons on CWR in Saudi Arabia from 2011 to 2050. Effects of temperature on CWR were investigated through sensitivity analysis. The growing periods of major crops were systematically differed and CWR were predicted for the new growing periods. Effects of such shifts on CWR were assessed. Conservation of water due to the differed growing periods was predicted. Finally, strategies to conserve groundwater were outlined.

Methodology

1. Data Collection

CWR depends on climatic conditions, crop area and type, soil type, growing seasons and crop production frequencies (Allen et al. 1998; George et al. 2000; FAO 2012). These data were obtained from literature (Alsadon 2002; TVTC 2004; MOA 2009; CDSI YB 2010). Data on changes of temperature and rainfalls in 2050 were obtained from Chowdhury and Al-Zahrani (2013b), which were adjusted for different regions using linear interpolation. Data on crops and cultivated areas in different regions of Saudi Arabia were obtained from Saudi Statistical Yearbook (CDSI 2010).

2. Predicting CWR

CROPWAT software predicts CWR using the Penman-Monteith method (Allen et al. 1998; FAO 2013). It predicts reference evapotranspiration (ET_o), crop evapotranspiration (ET_c) and develops irrigation water management strategy. The Penman-Monteith method has been recommended by the Food and Agriculture Organization (FAO) for its appropriate combinations of relevant climatic parameters to predict ET_o (Smith et al. 2006; Mhashu 2007). The CWR was estimated for each crop and added through irrigation scheme planning to predict total water requirements. ET_c was predicted on decadal basis as:

$$ET_c = ET_o \times K_c \quad (1)$$

where, ET_c = actual evapotranspiration of crop (mm/day); ET_o = reference evapotranspiration (mm/day); and K_c = crop coefficient at a specific growth stage. K_c depends on the type of crop and soil and climatic parameters (Allen et al. 1998; Smith et al. 2006). It varies over the growing period of crop, which results in variable CWR at different growing stages (Allen et al. 1998; Smith et al. 2006). The Penman-Monteith method can be presented as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (2)$$

where R_n = net radiation at the crop surface (MJ/m^2/day); G = soil heat flux density (MJ/m^2/day); T = mean daily air temperature at 2 m height (°C); u_2 = wind speed at 2 m height (m/s); e_s = saturation vapor pressure (kPa); e_a = actual vapor pressure (kPa); Δ = slope of vapor pressure curve (kPa/°C); and γ = psychrometric constant (kPa/°C). The effective rainfall plays an important role in quantifying CWR, which can be predicted as:

$$P_{eff} = P_{tot} \frac{125 - 0.2P_{tot}}{125} \quad (3)$$

where, P_{eff} = effective rainfall (mm) and P_{tot} = total rainfall (mm). Equation (3) is valid for a rainfall of $P_{tot} < 250$ mm. In Saudi Arabia, major parts of the country have monthly average rainfall less than this value (CDSI 2010). The monthly average agricultural water requirement is predicted as:

$$Q = \sum_{i=1}^{n} A_i (ET_{c_i} - P_{eff}) \times 10 \quad (4)$$

where, Q = monthly average agricultural water requirement (m^3/day); *i* = crop index; A_i = crop planted area (hectare); ET_{ci} = crop evapotranspiration (mm/day); and P_{eff} = the effective rainfall (mm/day) and 10 conversion factor. Further details on the Penman-Monteith method can be found in Allen et al. (1998).

Results

1. Input Data

Annual Average Temperature In 2011 Varied Between 11.8 And 34.5°C In Different Regions, While The Overall Range Was 3–42.8°C. The Predicted Range Of Temperature In 2050 Is 5.5–45.9°C. Increase In Temperature From 2011 To 2050 Was Reported To Be 1.8–4.1°C (Chowdhury And Al-Zahrani 2013b). In 2011, Total Annual Rainfall Varied In The Range Of 49–264 Mm/Yr With An Average Of 123 Mm/Yr. The Overall Yearly Rainfall Has Been Predicted To Increase In 2050 (Chowdhury And Al-Zahrani 2013b). The Distributions Of Cultivated Lands And Crops In Various Regions Are Shown In Table 1. The Largest Area Was Used For Cultivating Wheat, Followed By Dates And Alfalfa, While The Total Cultivated Area Was Highest In Riyadh, Followed By Qaseem And Al-Jouf (Table 1). The Growing Periods And Growth Coefficients (K_c) For Different Crops Are Shown In Table 2.

Table 1: Cultivated area for each type of crop in each region in Saudi Arabia (hectare)

Crops	Riyadh	Makkah	Madinah	Qaseem	Eastern Region	Aseer	Tabouk	Hail	Jazan	Najran	Al-Baha	Al-Jouf	Total Area
Wheat	30896	371	194	22792	30691	3155	17889	23558		763	413	65162	195884
Millet	-	1255	2	-	-	78	-	-	2422	-	3	-	3760
Sorghum	1037	5853	-	-	-	2173	-	-	83618	-	76	-	92757
Maize	2212	619	1	5983	282	201	20	16967	935	-	99	2179	29498
Barley	652	306	12	55	226	660	278	360	16	33	60	801	3459
Tomato	4383	2041	1050	920	1605	1547	389	611	1221	540	108	693	15108
Potato	3446	172	2	3826	135	67	2342	5800	-	32	6	1837	17665
Vegetables	40879	9080	983	6671	4926	1142	1082	3885	2486	927	251	1601	73913
Alfalfa	50090	638	2485	14786	2673	1419	9008	7127	-	1914	52	11908	102100
Dates	43178	10771	18576	39303	13548	5075	2249	18743	288	3367	1395	5470	161963
Citrus	3582	1711	755	2014	820	329	1868	1350	182	1833	43	727	15214
Grapes	1378	727	3105	1058	177	434	1154	1139	-	41	194	1628	11035
Total	181733	33544	27165	97408	55083	16280	36279	79540	91168	9450	2700	92006	722356

Table 2: Growing stages and crop growth stage coefficient (K_c)

Crops	Different stages and duration (day)				Total	Crop growth stage coefficient (K_c)		
	Initial	Development	Mid-season	Late season	(days)	Initial	Mid-season	Late season
Wheat	20	30	50	30	130	0.55	1.15	0.30
Maize	20	35	40	30	125	0.30	1.20	0.35
Millet	15	25	40	25	105	0.30	1.00	0.30
Sorghum	20	35	40	30	125	0.30	1.00	0.55
Barley	15	25	50	30	120	0.30	1.15	0.25
Tomato	30	40	45	30	145	0.60	1.15	0.80
Potato	25	30	45	30	130	0.50	1.15	0.75
Vegetables	20	30	30	15	95	0.70	1.05	0.95
Alfalfa	150	30	150	35	365	0.40	0.95	0.90
Dates	140	30	150	45	365	0.90	0.95	0.95
Citrus	60	90	120	95	365	0.70	0.65	0.70
Grapes	150	50	125	40	365	0.30	0.70	0.45

The planting dates and growing periods vary depending on the regions and type of crops (Al-Saif 1999; Al-Sadon 2002; TVTC 2004; Kader and Hussein 2009). The growth stage with K_c greater than 1.0 indicates that the crop consumes more water than the corresponding ET_o during this period. The average monthly wind speeds vary in the range of 5.4–18 km/hr, while significant variability in wind speed was reported from region to region (FAO 2012). The annual average relative humidity ranged between 26 and 65% in all regions (FAO 2012). The net radiation was in the range of 18.2–19.8 MJ/m²/day, with higher values in summer than those in winter (FAO 2012). The Saudi Geological survey reported that soil surface in agricultural areas is sandy and sandy loam, which was similar to light sand (SGS 2012).

2. Crop Water Requirements

Total CWR were predicted to be 8713 and 9176 MCM/yr for Case I and Case II, respectively. CWR in Riyadh, Qaseem, Al-Jouf and Hail were higher with values of 2803, 1426, 873 and 867 MCM/yr, respectively (Case I). For Case II, CWR in these regions were 2945, 1494, 931 and 923 MCM/yr, respectively, indicating an increase of 4.8–6.6%. Similar increase in CWR was predicted for the other regions (figure 1).

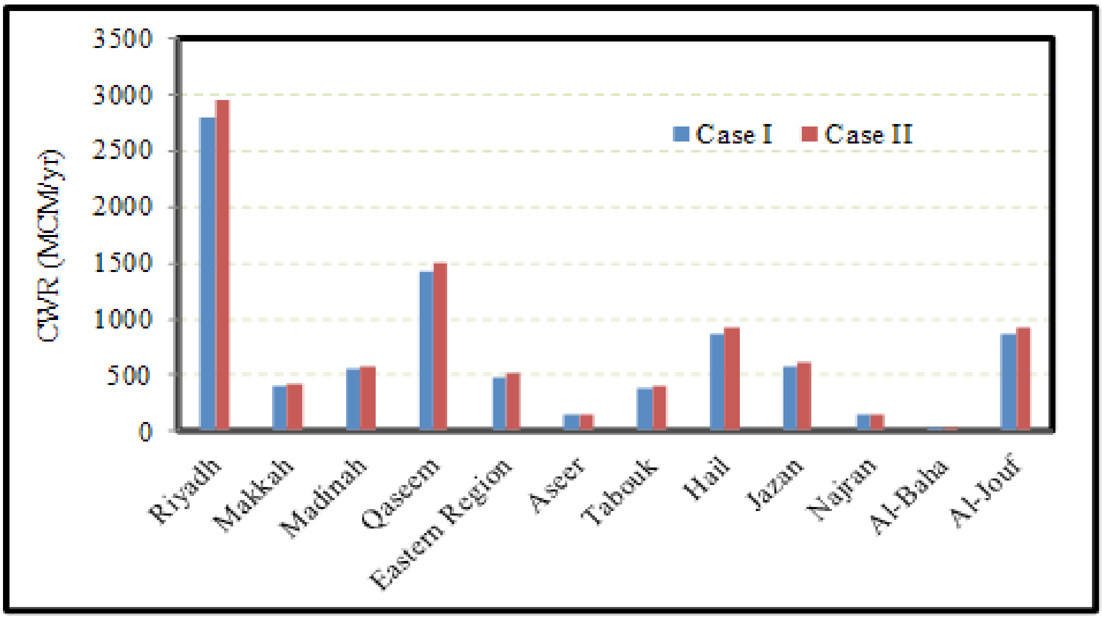

Figure 1: Predicted total CWR for each region in

Saudi Arabia in Case I and Case II

The region and crop specific CWR are variable. The countrywide CWR for dates was highest (3492 MCM/yr), with 1032, 837 and 429 MCM/yr in Riyadh Qaseem and Madinah, respectively. The 2nd highest CWR was for alfalfa (1837 MCM/yr), in which Riyadh and Qaseem contributed 989 and 252 MCM/yr, respectively. The 3rd largest CWR was for wheat (1210 MCM/yr), in which Al-Jouf had the highest (476 MCM/yr), followed by Riyadh (200 MCM/yr). Qaseem, Tabouk, Hail and Eastern Region had CWR for wheat in the range of 117–135 MCM/yr. In Jazan, sorghum is the main crop having CWR of 525 MCM/yr, while maize is mainly produced in Hail with CWR of 144 MCM/yr. CWR for tomato was highest in Riyadh (60 MCM/yr), while CWR for potato was highest in Hail (48 MCM/yr). Vegetables are mostly produced in Riyadh. The regional distributions of CWR (Case I) and crop wise total CWR (Case II) in each region are shown in Figures 2 and 3, respectively. CWR for dates were highest in Riyadh, Makkah, Madinah, Qaseem, Eastern Region, Aseer, Hail, Najran and Al-Baha (Figure 2). In Al-Jouf, CWR for wheat was highest (54.6%), while in Jazan, CWR for sorghum was highest 91.5% (Table 4). Alfalfa is mainly grown in Riyadh, Tabouk, Qaseem, Al-Jouf and Najran, contributing approximately 35.3, 38.8, 17.7, 21.5 and 21.3% of the corresponding CWR (figure 2).

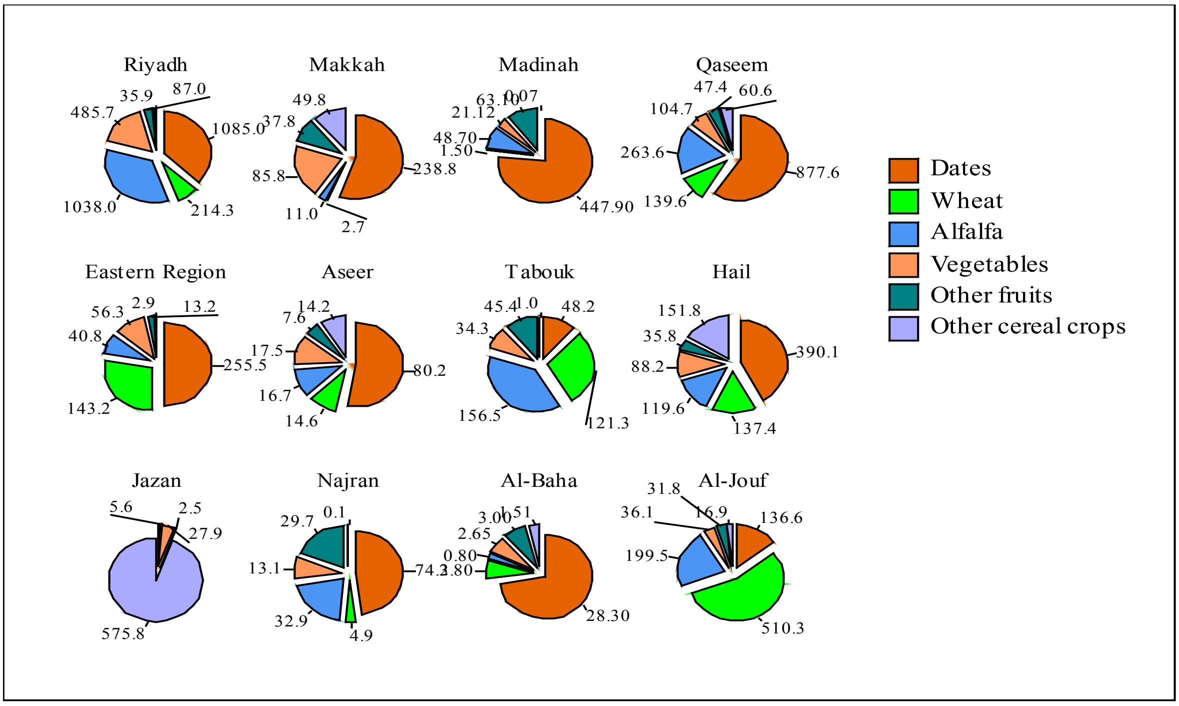

Figure 2: Distribution of CWR (MCM/yr) in different regions of Saudi Arabia for Case I. Other cereal crops: millet, sorghum, maize and barley; other fruits: citrus and grapes.

Figure 3 shows that Riyadh, Qaseem, Hail and Madinah are the main contributors of dates. Riyadh is also the highest contributor of alfalfa, vegetables and some fruits. Al-Jouf and Riyadh are the main contributors of wheat, while significant amounts of wheat are also contributed by Qaseem, Eastern Region, Tabouk and Hail. Moderate supplies of some fruits (citrus and grapes) are obtained from Makkah, Madinah, Qaseem Tabouk, Hail, Najran and Al-Jouf. Among the other cereal crops, sorghum is mainly produced in Jazan (figure 3).

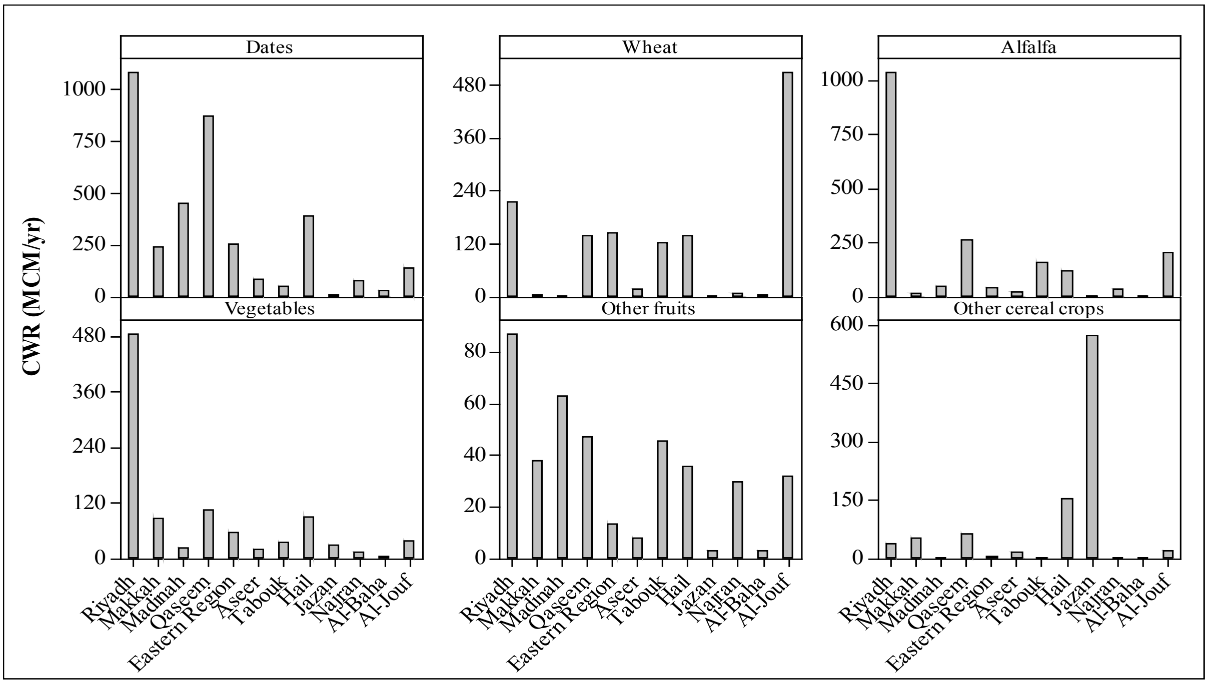

Figure 3: Crop wise distribution of CWR in different regions of Saudi Arabia. Other cereal crops: millet, sorghum, maize and barley; other fruits: citrus and grapes.

3. Seasonal Variability Of CWR

Seasonal variability of CWR was observed in all regions (Figure 4). Total CWR in Saudi Arabia was higher during Apr–Jul (1113–1439 MCM/month) while Jun–Jul had the highest CWR (1426–1439 MCM/month). The highest CWR was predicted for Riyadh during Jun–Jul (489–494 MCM/month), while the lowest was estimated for Jazan in Oct–Jan (1.3–2.1 MCM/month). In Qaseem region, CWR was highest during May–Jul (217–223 MCM/month) and lowest in Dec (23.8 MCM). In Al-Jouf, wheat is the main crop grown during Jan–May, leading to higher CWR in Mar–Apr (164–205 MCM/month). The lowest CWR in Al-Jouf was 17 MCM in Dec (figure 4).

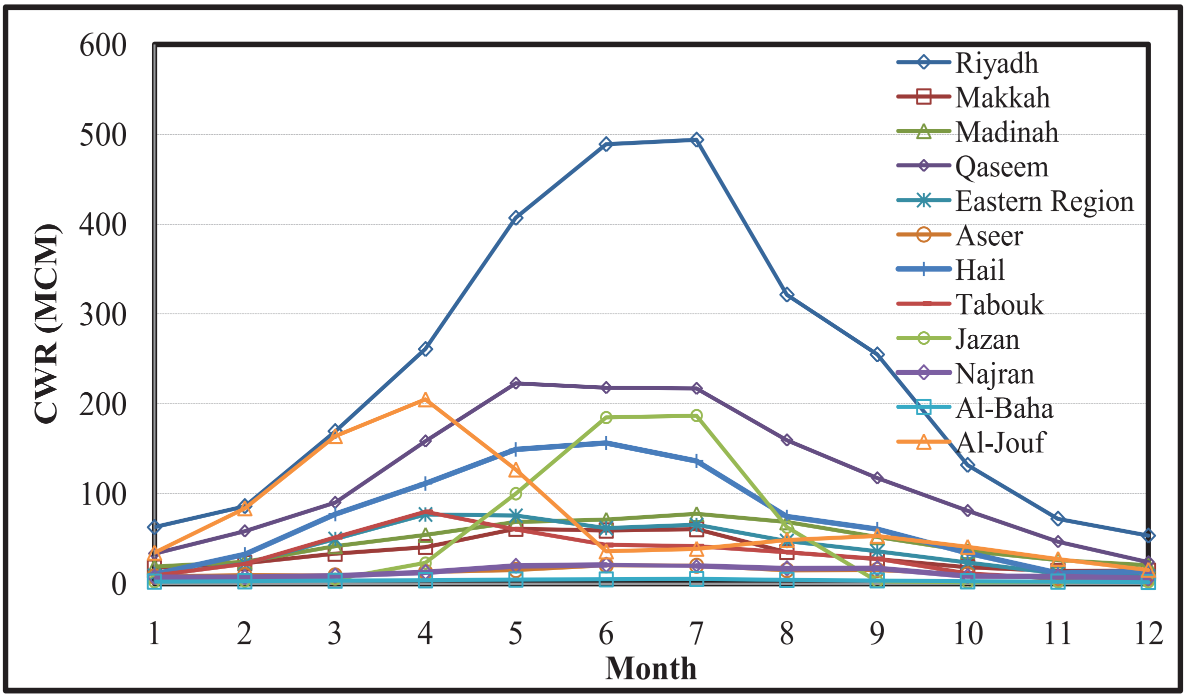

Figure 4: Seasonal variability of CWR in different regions (Case I) [1: Jan–12: Dec]

Higher levels of CWR in summer can be attributed by several factors, including crop type, lower rainfall, growing stage and higher temperature. For example, dates and alfalfa are the major crops in Riyadh. These are perennial crops with the growing periods of Dec–Nov and Oct–Sep, respectively. These crops have their mid-seasons of growing stages in summer (Table 2). Crop requires more water during the mid-season of growing stage. Further, ET_o is higher during summer. Interaction of higher temperature and mid-season of growing stages might have resulted in the higher levels of CWR in summer (Figure 4). Shifting the mid-season of growing stage from summer to a period of lower ET_o may conserve water for a crop. However, interaction effects of ET_o and K_c on the yield of crop needs better understanding prior to making such a shift. In the absence of appropriate understanding of the effects of these factors, such shift may have detrimental effects on agricultural productions.

4. Effects of Temperature

Sensitivity analysis was performed through increasing temperature by 0.5 to 5°C, while the other factors were kept constant. CWR was increased from 8713 to 9716 MCM/yr for an increase of temperature of 5°C, which had a positive slope of 201 MCM CWR/°C. An increase of temperature by 1°C increases the overall CWR by 2.3% with a range of 1.8–2.9% in all regions. The responses of different crops on CWR were different. Averages of increase of CWR per 1°C are 2.3, 2.3 and 2.8% for dates, alfalfa and wheat, respectively, while their corresponding ranges are 1.9–2.9%, 1.9–3.0% and 2.2–3.8%, respectively.

Increase in temperature from 2011 to 2050 in different regions was predicted to be 1.8–4.1°C (Chowdhury and Zahrani, 2013b), which can increase the CWR of crops. Total CWR was estimated to be 9222 MCM/yr in 2050, indicating an overall increase of 5.8% (5.0–7.1%). CWR for wheat may be increased by 5.8 and 6.5% in Riyadh and Al-Jouf, respectively. For dates, CWR may be increased by 5.5 and 5.8% in Riyadh and Qaseem, respectively, while for alfalfa, increase of CWR is 5.5% in Riyadh. Assuming linear increase from 2011 to 2050, the slope of CWR was estimated to be 11.9 MCM/yr from 2011. Approximately 2430 m^3 of water is needed to produce 1 ton of wheat, meaning that the increase in CWR is equivalent to water necessary for producing approximately 4900 tons of wheat per year. If water supply is maintained at the same level, wheat productions may need to be reduced by ~4900 tons per year. In Saudi Arabia, the yield of wheat is 5.4–5.7 tons/ha, meaning that 860–907 ha of agricultural land has to be abandoned every year. The effects were further analyzed in context to CWR per ha of cultivated lands in Riyadh. In Case I, CWR for dates, alfalfa and wheat have been estimated to be 23896, 19742 and 6467 m^3/ha, respectively, while for Case II, these values can be 25203, 20803 and 6839 m^3/ha, respectively.

5. Effects of Growing Periods

This study performed sensitivity analysis by shifting the growing periods of major crops. The major crops are wheat, dates, alfalfa and sorghum, which are produced in 196, 162, 102 and 84 thousand ha of lands, respectively. The growing season of wheat is Nov–May (Mustafa et al. 1989), while many regions plant wheat during Jan (Saifuddin et al. 2004; Almisnid 2005). Wheat needs approximately 130 days from planting to harvesting, meaning that wheat planted in Jan can be harvested during Apr–May. Five scenarios of wheat growing periods: S_1 (Jan 01–May 10); S_2 (Dec 15–Apr 23); S_3 (Dec 01–Apr 09); S_4 (Nov 15–Mar 24); and S_5 (Nov 01–Mar 10) were investigated to understand the effects of growing periods. Table 3 presents CWR for wheat in different growing periods. The current practice had CWR of approximately 1210 MCM/yr in the country, while the S_1, S_2, S_3, S_4 and S_5 scenarios had CWR of 1046, 870, 757, 672 and 638 MCM/yr, respectively. The data showed an exponential relationship between CWR and planting dates, which can be represented as:

$$Y = 1192.9e^{-0.00934X} \qquad (5)$$

Where, Y = MCM CWR/yr for wheat in the entire country, and X = shift of planting date (day) from Jan 15 (e.g., current practice). The shift represents early plantation of wheat. It is to be noted that the above Equation (5) was obtained by considering Jan 15 as the current planting date and maximum shifting period of 75 days earlier (e.g., Nov 01). Beyond this period, the above equation may not be appropriate.

For dates, the growing cycle is variable. Past studies considered a growing cycle of Jan-Dec for Riyadh, Qaseem, Madinah, Makkah and Najran (Alamoud et al. 2012). In Riyadh, the growing period for dates of Dec 01–Nov 30 has CWR of 1032 MCM/yr. Four additional scenarios with growing cycles of S_1: (Nov 15–Nov 14); S_2: (Nov 01–Oct 31); S_3: (Dec 15–Dec 14); and S_4: (Jan 01–Dec 31) have CWR of 1037, 1044, 1022 and 1010 MCM/yr, respectively. In Qaseem, the growing period for dates is Oct–Sep. Considering Oct 01–Sep 30 as the current growing cycle, four additional scenarios: S_1 (Sep 15–Sep 14); S_2 (Sep 01–Aug 31); S_3 (Oct 15–Oct 14); and S_4 (Nov 01–Oct 31) were assessed. CWR for the current practice and S_1–S_4 scenarios were predicted to be 837, 832, 832, 834 and 835 MCM/yr, respectively.

Table 3: CWR for wheat in different regions at different growing periods

Regions	Current	S_1	S_2	S_3	S_4	S_5
Riyadh	199.8	172.6	146.1	131.5	120.7	117.4
Makkah	2.6	2.4	2.3	2.1	2	1.9
Madinah	-	-	-	-	-	-
Qaseem	131.6	109.8	88	75.2	68.6	70
Eastern Region	135.1	113.7	92.4	78.3	68.5	67.6
Aseer	13.5	12.8	12.2	11.8	11.8	12.1
Hail	125.5	108.3	90	77.8	65.2	56.5
Tabouk	117.1	102.8	85.7	73.3	63.2	58.2
Jazan	-	-	-	-	-	-
Najran	4.7	4.4	4	3.8	3.8	3.9
Al-Baha	2.6	2.4	2.2	2.1	2	2
Al-Jouf	476.2	417	347.5	301.1	265.7	248.7
Total	1208.7	1046.2	870.4	757	671.5	638.3

(*Current: Jan 15–May 24; S_1: (Jan 01–May 10); S_2: (Dec 15–Apr 23); S_3: (Dec 01– Apr 09); S_4: (Nov 15–Mar 24); S_5: (Nov 01–Mar 10)*)

Alfalfa is produced in the 3rd largest area of the country. This perennial crop is mostly produced in Riyadh, Qaseem, Al-Jouf and Tabouk with variable growing periods. In this study, the growing period of alfalfa in Riyadh was considered to be Oct 01–Sep 30, which has CWR of 989 MCM/yr. Four additional scenarios with growing cycles of S_1: (Sep 15–Sep 14); S_2: (Sep 01–Aug 31); S_3: (Oct 15–Oct 14); and S_4: (Nov 01–Oct 31) have CWR of 978, 952, 996 and 986 MCM/yr, respectively. In Qaseem region, CWR was 252 MCM/yr for the current practice, while in the S_1–S_4 scenarios, CWR were 251, 246, 255 and 252 MCM/yr, respectively. In both cases, shifting planting date toward summer by 15 and 30 days has shown reduced CWR for alfalfa. Future study is essential by varying the planting date throughout the year and their yields. In Jazan, sorghum is the main crop, which has a growing cycle of Apr–Aug. Using the growing period of Apr 15–Aug 17 (125 days), CWR was estimated to be 525 MCM/yr. For the shifted growing periods of S_1: (Apr 01–Aug 03); S_2: (Feb 01–June 05); S_3: (Jan 15–May 19); S_4: (Jul 01–Nov 02); and S_5: (Jul 15–Nov 16), CWR were predicted to be 518, 457, 430, 490 and 468 MCM/yr, respectively. The lowest CWR was predicted for S_3: (Jan 15–May 19), which might be due to the shift of mid-season growing stage from the summer months toward the winter months.

6. Water Conservation

Total CWR in Saudi Arabia was predicted to be 8713 MCM/yr in 2011. Using the ministry data, agricultural water use in 2011 was estimated to be 14,300 MCM, which is 5,587 MCM higher than the total CWR (e.g., 39% water loss). Based on the regions, the loss was estimated in the range of 26–69.6%. The highest loss of water was noted for Jazan (1315 MCM/yr), followed by Riyadh (984 MCM/yr), Qaseem (680 MCM/yr) and Al-Jouf (526 MCM/yr). The loss may be due to leakage in the water distribution systems, water percolation through soil and inefficient irrigation practices.

Significant amount of groundwater might be conserved by shifting the growing periods for the major crops. The major crops in each region were identified and the growing periods of these crops were shifted within the limits of current practices. Details of the current and shifted growing periods for different crops are shown in Table 4. The total CWR for shifted growing periods was estimated to be 7982 MCM/yr (Case I), which is 731 MCM less than the current practice (Table 4). Water conservation was estimated to be highest in Al-Jouf followed by Riyadh, Qaseem and Hail. In Case II, total water conservation is approximately 904 MCM/yr.

Table 4: CWR before and after shifting growing seasons and water conservation (MCM/yr)

		Growing Periods		CWR – Case I			CWR – Case II		
Regions	Shifted Crops	Before shifting	After shifting	Before shifting	After shifting	Water conser-vation	Before shifting	After shifting	Water con-serva-tion
	Wheat	Jan 15	Nov 01						
Riyadh	Alfalfa	Oct 01	Sep 01	2802.5	2661.4	141.1	2945.4	2797.6	147.8
	Dates	Dec 01	Jan 01						
Makkah	Dates	Aug 01	Sep 01	402.3	400.3	2	425.8	423.6	2.2
	Wheat	Jan 15	Nov 01						
	Dates	Oct 01	Nov 01						
Madinah	Grapes	Mar 01	Apr 01	558	552.8	5.2	582.4	576.9	5.5
	Alfalfa	Oct 01	Nov 01						
	Wheat	Jan 15	Nov 01						
Qaseem	Alfalfa	Oct 01	Sep 01	1425.9	1351.5	74.4	1493.6	1413.2	80.4
	Dates	Oct 01	Sep 01						
Eastern Region	Wheat	Jan 15	Nov 01	485	415.7	69.3	511.9	435.4	76.5
	Dates	Aug 01	Sep 01						
	Wheat	Jan 15	Nov 01						
	Dates	Aug 01	Sep 01						
Aseer	Alfalfa	Oct 01	Sep 01	145.6	139.9	5.7	150.6	144.8	5.8
	Sorghum	Apr 15	Jan 15						
	Wheat	Jan 15	Nov 01						
Tabouk	Alfalfa	Oct 01	Nov 01	390.6	327.4	63.2	406.6	338.2	68.4
	Dates	Oct 01	Nov 01						
	Wheat	Jan 15	Nov 01						
Hail	Alfalfa	Oct 01	Sep 01	867.3	793	74.3	923	843.2	79.8
	Dates	Oct 01	Nov 01						
Jazan	Sorghum	Apr 15	Jan 15	574.3	516.8	57.5	611.8	426.5	185.3
	Wheat	Jan 15	Nov 01						
	Alfalfa	Oct 01	Sep 01						
Najran	Dates	Oct 01	Nov 01	150.4	147.9	2.5	154.9	152.3	2.6
	Citrus	Mar 01	Mar 15						
	Wheat	Jan 15	Nov 01						
Al-Baha	Dates	Aug 01	Sep 01	38.8	38	0.8	39.1	38.2	0.9
	Wheat	Jan 15	Nov 01						
Al-Jouf	Dates	Apr 01	Mar 01	872.7	637.2	235.5	931.4	683	248.4
	Alfalfa	Mar 01	Feb 01						
Total				8713.4	7981.9	731.5	9176.4	8272.8	903.6

(Case I: Current state (2011); Case II: (2050))

Water conservation was further investigated in context to the major crops. In Case I, total conservation was estimated to be 731 MCM/yr, in which shifting the planting date of wheat to Nov 01 can save 572 MCM/yr (78%). In Case II, this conservation was estimated to be 612 MCM/yr out of 904 MCM/yr total (68%). The shifts for the other crops (planting time as shown in Table 4) may conserve some water. For example, by shifting the growing periods of dates, alfalfa, sorghum and grapes, 37, 61, 61 and 1 MCM/yr of water can be conserved.

Following the current planting dates, changes in climatic conditions from Case I to Case II have increased CWR from 8713 to 9176 MCM/yr, representing an increase of 5.3% in 39 years (2011 to 2050). In case of shifted planting dates, these values were 7982 to 8273 MCM/yr in Case I and Case II, respectively (3.6% increase). The data show that a shift in planting dates may reduce the effects of climate change, possibly due to avoidance of the period of higher temperature and/or association of higher rainfall periods. Future study might look into the implications of a shift on the effects of climate change. It is to be noted that the shift in growing periods is not straightforward. Any shift must be verified in context to yields, economic viability and technical feasibility. Future study may further look into these effects for better management of water resources.

Summary and Discussions

This study investigated the possible implications of climate change and growing seasons on crop water requirements (CWR) with focus on water resources management. CWR showed considerable variability among seasons and regions. An overall increase of CWR by 463 MCM/yr (5.3%) was predicted from 2011 to 2050. An increase in temperature by 1°C increases the overall CWR by 2.3% with a range of 1.8–2.9%. By 2050, CWR of dates, alfalfa and wheat may be increased by 3.3–11.9, 3.3–12.1 and 3.9–15.6%, respectively. Effects of temperature may be minimized by introducing greenhouse cultivation and/or shifting crop growing periods. Future study should investigate the feasibility of full and/or partial greenhouse cultivation.

Shift of growing periods for wheat may conserve significant amount of water. CWR for wheat was found to follow exponential decay pattern when planting dates were shifted from January to an earlier date, with the maximum shifting period of 75 days (e.g., Nov 01). Several strategies have been identified for further investigation, which might be useful in comprehensive management of water resources. These include shifting growing periods of major crops, relocating the major crops from higher CWR/unit to lower CWR/unit regions, comprehensive reuse of treated wastewater for agriculture, minimizing water loss through efficient irrigation and conveyance systems, installation of leak detection devices, etc. Future research must investigate the other related issues, such as yields, product quality, technical feasibility and cost of productions for any future planning of shifting.

This study tries to explain the possible effects of climate change and growing periods on CWR in a typical arid country. However, different arid regions show different behavior with respect to seasonal variability of rainfall, temperature change, agricultural activities, soil types and crop types. As an example, Al-Jouf is well known for agriculture in Saudi Arabia, while the Empty Quarter does not have significant agricultural activities. Despite few limitations, this study sheds light on the possible implications of climate change on CWR and its direct and indirect effects on water resources management. Future study must understand the overall implications of climate change in Saudi Arabia and investigate the possibility of shifting growing periods and/or relocating the production areas.

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Improving Water Productivity by Applying Magnetic Technology

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Abstract: Long spell of drought and competing water demands in most parts of Oman have put enormous pressure on water resources. Steps need to be taken to conserve both the quantity and quality of water and appropriate strategies will have to be developed to avoid risk to future water supplies. This study examines whether there is a beneficial effect of magnetic treatment of irrigation water on water productivity and yield of Rhodes grass. For long term effect, a magnetic device was installed in the irrigation pipe line at Agricultural Experiment Station, College of Agricultural & Marine Sciences, Sultan Qaboos University, Oman, that is watering half area of the Rhodes grass field. The analysis of the data collected during the study suggests that the effects of magnetic treatment varied with plant type and the type of irrigation water used, and there were statistically significant increases in plant yield and water productivity especially with long term study. For Rhodes grass which was irrigated with magnetized slightly saline groundwater ($EC_w \approx 2$ dSm^{-1}), there was a gradual increase with grass yield by 16%, 20%, 20% and 35.4% for February, April, May and July, respectively. The water productivity of Rhodes grass in four months increased by 91.4% for magnetically treated groundwater. As for soil properties of Rhodes grass field irrigated by magnetic water, the soil physiochemical properties were improved in which the magnetized water increased the solubility of minerals and therefore improved the transfer of nutrients to plant.

Keywords: saline groundwater, yield, cucumber, sweet corn, Rhodes grass, Oman.

Introduction

Using saline water or treated waste water for agriculture could add salts and accumulate heavy metals. Magnetic technologies could be a tool to improve the properties of soil and water quality. The possibility of using magnetized water to desalinate the soil is accounted for the enhanced dissolving capacity of the magnetized water, which has been registered repeatedly. Moreover, magnetized water could improve plant growth and enhance its productivity. The experiment of Oleshko, *et al*., (1981) and Tkatchenko (1997), highlighted the usage of cheap magnetic energy to improve the properties of soil and water quality. Tackashinko (1997) stated that the possibility of using magnetized water to desalinate the soil is accounted for the enhanced dissolving capacity of the magnetized water, which has been registered repeatedly. He added that magnetized water removed 50 to 80% of soil Cl^- compared to a removal of 30% by normal irrigation water. Zhu , et al., (1986) has also reported that laboratory tests have showed that desalination of a saline soil was 29% greater in the first leaching and 33% greater in the second leaching with magnetized water compared to untreated water. Hilal and Hilal (2000) reported that full wheat germination of 100% was obtained after 6 days for magnetic treatment compared to a rate of 83% after 9 days for normal practice. Guo Liang *, et al.,* (1994) reported that magnetizing seeds is very efficient to increase the number of germinating seeds and to hasten the germination process. Field experiments that were carried out in soil with hard salty water, rich in calcium sulphates, magnesium and sodium chlorides, were all successful, even during irrigation of agricultural lands with magnetized water taken from Caspian Sea with mineralization of 14000 ppm. The results of these experiments have not only proven that this method can be used, but also that it is essential for some agricultural lands. For example, sorghum crop/harvest increased by 45%, and corn by 30%, compared to a control area that was irrigated by normal (non- salty) and non-magnetized water.

Under Oman conditions, application of magnetic technologies is a new concept. However, Oman has limited freshwater and suffering from salinization problem. Using magnetic technologies with saline ground water could help in desalinating many saline soils, reducing heavy metals accumulation and improving soil quality and plant production. Therefore, the objective of this study was to evaluate the effectiveness of magnetizing underground brackish water and treated waste water to increase the applicability of water for irrigation, soil desalinization, mobility of nutrient elements in root zone, which are favorable to plant growth and its interaction on yield and yield component characters of the tested crops.

Methodology

This study was conducted at Sultan Qaboos University (SQU), College of Agricultural and Marin Sciences (CAMS), Agricultural Experiments Station (AES) in open field (١٠٠*٨٠ m٢) grown with Rhodes grass. The field was irrigated by groundwater ($EC_w \approx 2$ dSm^{-1}) with sprinkler system. Magnetic device was installed in the pipelines feeding three rows of sprinklers. Other part of the filed was left as control. Grass growth was monitored and during cutting stage, number of bales (Tones) in each row was counted (figure ١). Soil samples at ٢٠-٠ cm depth were collected from both magnetized field and control. Chemical analysis for soil samples were done in soil and water labs (SQU) following standard methods and using inductively coupled plasma (ICP) machine for metal analysis.

Figure 1: Rhodes Grass Irrigated by Magnetized and Non-magnetized Waters

Result and Discussion

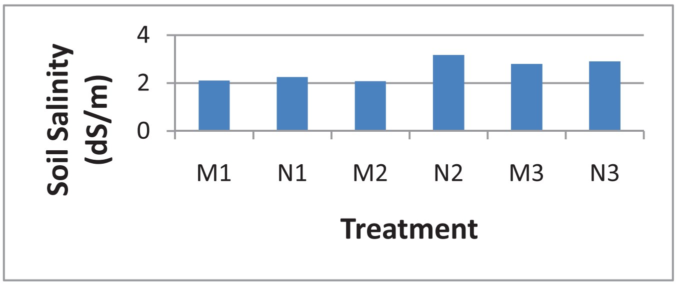
Soil Samples

Following soil textural analysis method, it can be seen from table 1 that all plots got almost same texture which is loamy sand. This soil usually good for leaching salts when saline water is used for irrigation. However, this texture has low water holding capacity but with intensive growth of grass, this criterion could be improved.

Table 1: Soil Textural Analysis

Control	(%) Clay	10.8	
	(%) Silt	5.2	loamy sand
	(%) Sand	84	
Mag	(%) Clay	7.6	
	(%) Silt	7.2	loamy sand
	(%) Sand	85.2	

Soil salinity or salt accumulation is an indicator for soil fertility and plant growth. From figure 2, it can be seen that soil samples taken from magnetized locations (M) had lower salinity than non-magnetized locations (N). Magnetic device usually supporting leaching process by increasing salts solubility.



(M*: magnetized*; N: *Non- magnetized*)

Figure 2: Soil Salinity as Affected by Magnetic Device

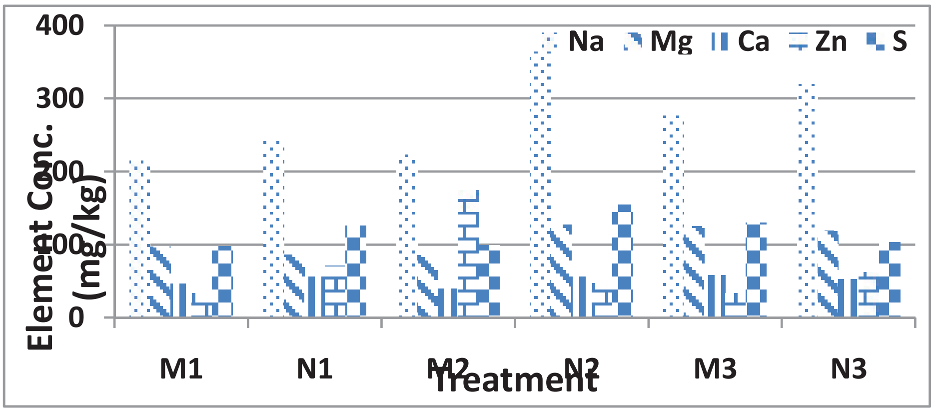
Table 2 is confirming what was found it figure 2. Most salts were in lower values when the field was irrigated by magnetized water.

Table 2: Soil Cations as Affected by Magnetic Device

	Na	Mg	Ca	Fe	Zn	Co	Pb	Mo	Si	Ni	B	S
M1	214.9	97.44	46.23	0.207	33.63	0.023	0.001	0.042	1.745	0.018	0.193	97.58
M2	223	85.55	39.36	0.184	174.5	0.025	0.001	0.09	1.391	0.009	0.247	99.31
M3	276.6	125.5	58.16	0.223	33.57	0.034	0.001	0.05	1.572	0.001	*0.244*	130
N1	243.7	86.25	56.61	0.27	71.22	0.023	0.016	0.109	1.141	0.011	0.251	125.8
N2	363.9	127.2	55.96	0.361	47.37	0.027	0.023	0.077	1.038	0.015	0.246	155
N3	320	119.1	52.53	0.413	62.24	0.027	0.023	0.072	1.311	0.02	0.292	103.1

(M*: magnetized*; N: *Non- magnetized*)

The good findings that even heavy metals and harmful salts such as Na were affected by magnetic field and their concentrations were lower than control (figure 3).



(M*: magnetized*; N: *Non- magnetized*)

Figure 3: Soil Salinity as Affected by Magnetic Device

It was noticed that, irrigation with magnetically treated water lead to an increase in all elements content in plant tissues except sodium. This is because sodium is paramagnetic element which has a small, positive susceptibility to magnetic fields, while other elements are diamagnetic which are slightly repelled by a magnetic field (Nave, 2008).

As a result of low salts with magnetic water and improvement in the surrounding conditions, it can be seen from figure 4 that plants irrigated by magnetic water gave better yield than control with big reduction in the yield when the whole period was counted (figure 5).

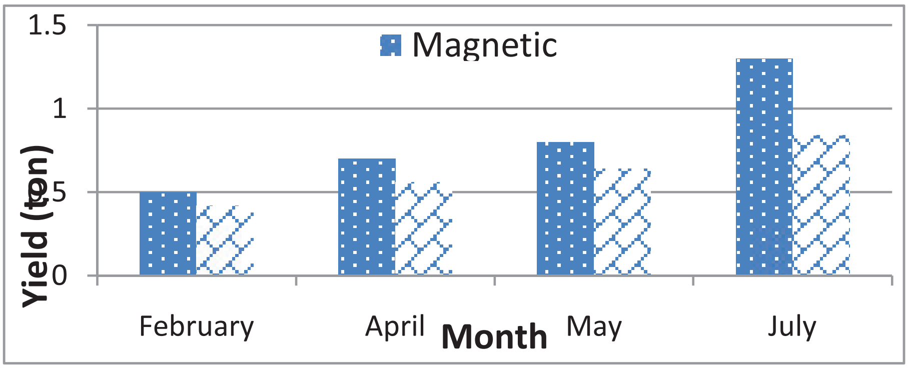


Figure 4: Yield of Rhodes Grass as Affected by Magnetized and Non-magnetized waters

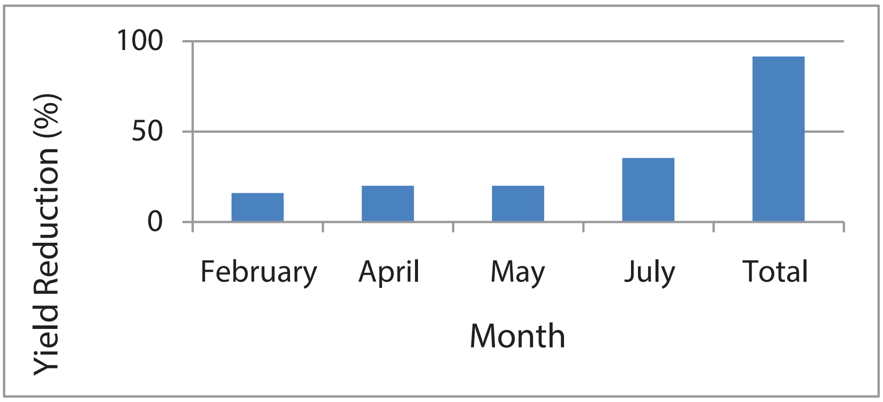


Figure 5: Yield Reduction as Affected by Magnetized and Non-magnetized waters

Magnetic water treatment has found to have a pronounced effect on plants productivity. Thus, magnetized water treatment increases plant metabolism in terms of photosynthesis and water uptake (Yano, *et al.,* 2004). The stimulatory effect of magnetic water may be attributed to their role in increasing absorption and assimilation of nutrients consequently increasing plant growth. Alikamanolu , *et al.,* (2007) suggested that, magnetic water treatment improved seed inhibition, vigor and germination rate, and seedling treatment promoted NPK absorption and increased roots number, stem thickness, dry weight/100 plants and tillers number. Moreover, Celik , *et al.,* (2008) and Nasher (2008) concluded that, magnetized water increased growth and consider an important factor for inducing chick pea plant growth. In other study, Souza , *et al.,* (2006) showed that, magnetization on tomato increased significantly the mean fruit weight, the fruit yield/plant, the fruit yield per area and the equatorial diameter of fruits in comparison with the controls. Under saline conditions, Basant and Singh (2009) indicated some beneficial effects of magnetically treated irrigation water, particularly for saline water and recycled water, on the yield and water productivity of celery and snow pea plants under controlled environmental conditions.

Conclusion

The present findings have shown that irrigation with magnetic treated water can be considered as one of the most valuable modern technologies that can assist in saving irrigation water and reducing salt accumulation in plants. Plants irrigated with magnetized water gave better production than control. Rhodes grass study showed a positive effect toward irrigation with magnetic water. However, magnetic technology is not a very fast technology in reducing salt stress and improving plant productivity. Therefore, continuous studies should be done to confirm what was found in this study.

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