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Preface

Water in the GCC… Towards Integrated Strategies

Despite the scarcity of water resources in the region, the GCC countries have done well in providing water for their ever-increasing population and rapidly expanding economic base and activities. However, the GCC countries are at a critical juncture with regard to managing their water and financial resources in a sustainable manner and securing the balanced socio-economic development and environmental conditions for today's and future generations without overburdening the natural resource base and the environment.

Being an important factor for the GCC socio-economic development, there is a need for an efficient and sustainable water management to ensure that the water sector can continue to serve the region's development needs. However, currently the GCC countries are facing several major challenges in managing the water sector and ensuring its sustainability and security for the future. These challenges are manifested by many factors, including increasing water scarcity, increasing costs for infrastructure and service delivery, resources deterioration, increasing environmental and economic externalities of the water sector, and many others. The main driving forces of these challenges are population growth and changing consumption patterns (end-use efficiency), as well as low supply efficiencies, lower rates of water reuse and recycling, and low energy efficiency in the water sector. The intensity of these challenges is expected to increase with time due to additional driving forces, the most important of which is climate change. Climate change is expected to add another pressure on water demands and infrastructure in the various consuming sectors, specially municipal and agricultural.

The persistence of these challenges and problems can be attributed to the dominance of sectoral approaches adopted in the management of water resources. In the last two decades, formulated and implemented water strategies, or rather primarily technical master plans, in the GCC have been mainly sectoral, with little integrated and coordinated planning between the various water sub-sectors; e.g., municipal water supply, wastewater treatment, and water use in agricultural or industries (including energy production, petroleum, and natural gas). Moreover, water master plans and strategies often missed the coordination and integration with the other water-related sectors, especially the energy, agricultural/food, industries, and environment sectors.

Fortunately, the GCC countries have recently realized that water sustainability will require integrated strategic planning and management, which is manifested in the Abu Dhabi 2010 declaration by the 31st summit of the Supreme Council of the GCC, which recommended that "… serious and speedy steps should be taken and endorsed by the GCC Supreme Council towards a long-term comprehensive Gulf water strategy". The Declaration stressed the importance of linking between guaranteeing water security and diversification of energy and food security as vital prerequisite and key strategic priority for the future of the GCC states. Moreover, it recognized that the GCC countries are home of more than 50% of the world's desalinated water to meet demand of population for development, and acknowledged that need of desalination for huge sources of energy. The Declaration called on that the strategy to consider all relevant issues, the most important of these are the possible impact of climate change on water resources, rationalization of water consumption in different development sectors, strategic water supply reserves, unsustainable use of groundwater, reciprocal relation between the agriculture and water sectors, and potential impacts of desalination on the quality of sea water and living creatures and on climate change.

The recommendations of the Supreme Council for a long-term comprehensive Gulf water strategy have been pursued by the GCC Secretariat General (SG). In early 2016, the SG has finalized the "Unified Water Sector Strategy and Implementation Plan for the Gulf Cooperation Council of Arab Members States 2015-2035" (The GCC Unified Water Strategy), which is looked at as a landmark by the GCC countries towards achieving water sector sustainability. The GCC Unified Water Strategy will need to be translated for implementation at the GCC countries levels.

Through addressing the topic of sustainable water management in the GCC countries, the WSTA Twelve Gulf Water Conference focused on the formulation of integrated, comprehensive water strategies. The conference addressed the many relevant approaches and instruments used in the various water-consuming sectors for enhancing the level of security and sustainability of the water sector.

On behalf of the Conference Scientific Committee I would like to thank all authors and for joining our twelve Gulf Water Conference and for presenting and sharing the experiences and best practices from their different countries in improving water sustainability and overcoming the water challenges in the arid GCC and Arab countries.

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

Conference Recommendation

The WSTA 12th Gulf Conference was held in Bahrain during the period 28-30 March under the patronage of Royal Highness Prince Khalifa Bin Salman Al Khalifa, the Prime Minister of the Kingdom of Bahrain, represented by Khalid Bin Abdulla, Deputy Prime Minister and Chairman of Bahrain 'Water Resources Council, and the presence of the representative of the GCC Secretary General His Excellency Khalifa Al-Abri, Assistant Secretary General Economic and Development Affairs, and was attended by more than 250 GCC, Arab and international water professionals from the executive, academic, NGO and private sectors. The Conference was organized by the WSTA during the period 28-30 March, 2017, in Manama, Kingdom of Bahrain, in cooperation with the Water Resources Council of the Kingdom of Bahrain, and GCC General Secretariat, with the support of international regional, and local organizations and the private sector.

Objectives

Based on the directive decision of the GCC Supreme Council, the Secretariat General has prepared a long-term comprehensive GCC water strategy and implementation plan for the years 2016-2035. This developed GCC Unified Water Strategy and its implementation plan has been approved and endorsed by Their Majesties and Highnesses the leaders of the GCC countries in Bahrain 2016 Summit, which is looked at as a landmark towards achieving the water sector sustainability. The WSTA 12th Gulf Water Conference focuses on the formulation of integrated water strategies at the national level that is in line with the GCC unified water strategy. The main objectives of the conference are:

1. Raising awareness and influencing policy and decision making to the importance of the formulation and implementation of integrated water strategies to replace the current sectoral master plans and strategies.
2. Identifying challenges and opportunities in improving water sustainability under the prevailing socio-economic, environmental, cultural, and political conditions in the GCC countries.
3. Facilitating an open discussion platform to share knowledge, experiences, and best practices between researchers, executives, decision and policy makers, private sector, and other stakeholders, on integrated water strategies in the GCC countries.
4. Developing further the network of individuals, institutions, Civil Society, NGOs, and private sector in the GCC and other Arab countries and beyond that are interested in scientific research in the field of water strategies.
5. Exchanging knowledge on case studies from different countries on integrated water strategies and their effective implementation.

Recommendations

The conference calls the GCC countries to:

1. implementing the "GCC Unified Water Strategy and Implementation Plan 2016-2035" approved by the GCC Supreme Council through the development of national water strategies in each country in accordance with the unified strategy, and exchange of information and studies on the implementation of integrated water strategies.

2. Integrating water, energy and food policies in the management of these three sectors, and bridging the current knowledge gap on their inter-linkages by directing universities and research centers their academic programs and applied research towards understanding, management and planning of the water, energy and food nexus.
3. Increasing investments and joint GCC action in the field of localization and ownership of desalination technologies as well as manufacturing desalination spare parts in cooperation and incentivizing national private sector.
4. Implementing economic tools as one of the most effective management tools in the management of water resource, and setting proper pricing policies in the various consuming sector with the objectives of enhancing water use efficiency and resources sustainability as well as to achieve cost recovery of operation and maintenance of the water utilities, and changing the current general subsidies to targeted subsidies aiming at enhancing water efficiency, while taking into account the limited income strata in the society.
5. Adopting an integrated policy that balances local agriculture, agricultural imports, and abroad agricultural investments to achieve food security in strategic food items in the GCC, and setting reasonable agricultural policies and plans that takes into account the limited water resources in the region.
6. Enhancing energy efficiency in the water sector and increasing the reliance on renewable energy, particularly solar, in various water operations and especially in the field of desalination.
7. Establishing effective systems to achieve the sustainability of groundwater through different demand management tools and increase the supply by artificial recharge of groundwater by excess desalination water, rainwater, and treated wastewater.
8. Increasing wastewater collection, treatment, and reuse rates as it represents an important renewable and increasing source in the region.
9. Addressing water losses in an integrated manner and focusing on the administrative and economic aspects of losses and the use of smart solutions to detect and treat networks losses.
10. Intensifying and supporting studies on assessing the impact of climate change on water resources and the development of adaptation strategies and integrating these into national water strategies.
11. Providing accurate and long-term data on water resources enhance water resources monitoring, systems, and capacity building and training of national cadres working in all water fields.

Proceedings

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SESSIONs 1A & 1B: Integrated Water Strategies

Keynote

An Overview of the GCC Unified Water Strategy 2016-2035

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Abstract

The Gulf Cooperation Council (GCC) Countries are situated in one of the most arid regions in the world, with extremely poor endowment of freshwater resources. Despite the water scarcity, the GCC countries have done well in providing water for their ever-increasing population and rapidly expanding economic base. However, this has been achieved only by resorting to relatively very expensive and costly investments in water supply sources and infrastructures manifested by desalination, water treatment, dams construction, as well as groundwater over-drafting. Being an important vector for socio-economic development, there is a need for an efficient and sustainable water management to ensure that the water sector can continue to serve the region's development needs. However, currently the GCC countries are facing several major challenges that are threatening the water sector sustainability. These include increasing water scarcity, increasing costs for infrastructure and service delivery, resources deterioration, increasing environmental and economic externalities, and many others. The main driving forces of these challenges are population growth and changing consumption patterns, low supply efficiencies, lower rates of water reuse and recycling, and low energy efficiency in the water sector. The intensity of these challenges is expected to increase in the future due to the additional driving force of the impacts of climate change. Realizing these challenges, the GCC Supreme Council has issued in its 31st summit (2010) the directive of "*serious and speedy steps should be taken and endorsed by the GCC Supreme Council towards a long-term comprehensive Gulf water strategy*". In 2016, a GCC Unified Water Strategy, 2016-2035 (GCC UWS) has been finalized by the GCC Secretariat General and recently approved by the GCC water ministers. This paper will present the main challenges facing the sustainability of the water sector in the GCC countries, the formulated GCC UWS (main themes and strategic objectives and their policies, key performance indicators and targets), the potential financial, economic and environmental benefits from its implementation, and its expected overall contribution to the water sector sustainability in the GCC countries.

Keywords: Groundwater, Desalination, Wastewater, Municipal, Agricultural, Industrial, Security, Governance.

Keynote

Current water challenges and prospective opportunities in the Arab region: Small Bold Steps in the right direction

Hammou Laamrani,
Advisor, GIZ Adaptation to Climate Change in the Water Sector in MENA region,
Water and Climate Change Expert, Economic Sector, League of Arab States, Egypt
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Abstract
According to "The Global Risks Report 2017" of the World Economic Forum, four of the top ten risk interconnections involve environmental risks, the most frequently cited of these being the pairing of "water crises" and "failure of climate change mitigation and adaptation". Water is thus acknowledged as one of top ten risk factors for global economy disruption. This is even more foreseeable for the Arab region. Water scarcity is not news. The imperatives of the region's geography have historically been determinants of wise allocation and utilization of scarce water resources. Water has indeed shaped the trends and level of development of rising and declining civilizations over centuries. Water will continue to be the most critical determinant of the future of the Arab Region. Other regions in the world will walk the same itinerary once the impacts of climate change will expand and grow in nature and magnitude.

Over the last decades, the water discourse did not evolve much. There seems to be a gap between what science is recommending to secure sustainable water resources in one hand, the political will and citizens behavior towards water on the other hand. We know what to do to secure a better water future in the region. But we don't know why we are not doing it or at least not sufficiently?

Aside from many Arab water paradoxes, it is fair to acknowledge that some progress is taking place in addressing different challenges with differential success in different countries. Arab citizen getting new access, improved access and better services across the region is steadily increasing and in some countries at a faster pace. Progressive policies laws and regulations in favor of a sustainable water future are also increasing. Examples of small but bold steps in the right direction are selected from GCC (Water Unified Strategy), Maghreb (Morocco Green plan) and Mashreq countries (Jordan achievement in waste water treatment and reuse), economic instruments (partial cost recovery) for water demand management are analyzed and ways to expand, replicate and scale them up as well as persisting drawbacks are discussed. The presentation will end with a reflection on what redefinition of roles and responsibilities of the different segments of society is needed to reverse the trend in the way we manage our water resources in the Arab region away for the "sense/illusion of abundance".

Keywords: Environmental Risks, Water Resources, Challenges, Demand Management, Society.

Keynote

Water and the Sustainable Development Goals (SDGs)

Amin El Sharkawi,
UN Resident Coordinator and UNDP Resident Representative, Kingdom of Bahrain

Abstract
Our world is evolving without consideration, and the result is a loss of biodiversity, energy issues, and congestion in cities. The recent food, fuel and financial crisis added to climate change problem have recall our attention to recognize our dependence on the earth's resources, water, oxygen and other natural elements, knowing the connection between the economy and the sustainability. Affecting gravely the future, there are limits to Earth's natural resources and to any economic growth that depends on them. No doubt, that water is at the core of sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself. Today, more than 1.7 billion people live in river basins, a trend that will see two-thirds of the world's population living in water-stressed countries by 2025. More, estimates show that the demand for water will increase by 55% by 2050. Water shortages is one of the top three global risks of highest concern. To address the water and other challenges of our time, the SDGs were elaborated, as an integrated approach to sustainable development and collective action, at all levels, with the imperative of 'leaving no one behind' in achieving the agenda. Reaching our sustainable development goals means organizing ourselves better. One SDG's goal is to "ensure availability and sustainable management of water and sanitation for all". For the first time, all related water challenges are contemplated at once by the different goal's targets. Challenges as achieve universal and equitable access to safe drinking water and equitable sanitation for all, improve water quality, water-use efficiency and integrated water resources management, which cannot be achieved without an international cooperation and capacity-building support to developing countries, as well as the participation of local communities for improving water and sanitation management. The presentation will cover the following topics: Why SDG's? What links with water? How SDG's takes care of water? And the Way forward.

Keywords: Biodiversity, Energy, Climate Change, Natural Resources, Ecosystems, Sustainable Development.

Keynote

Fighting Water Pollution to Achieve the SDGs

Iyad Abu Moghli,
UN Environment, West Asia Office, Kingdom of Bahrain

Abstract
Evidence exists of a polluted planet that impacts human health, ecosystems, and economies. Pollutants are accumulating i.e. in air, fresh water, oceans, biota and land and affecting human lives. Following the climate change global threat, pollution including freshwater pollution from nutrients, chemicals and wastes, is considered the primary threat to the environment and human health. Securing a pollution free (or clean) planet can help achieve the Sustainable Development Goals and multiple benefits of clean water and environment, food security, health, clean, energy efficiency, gender equality, and social justice. The UN Environment is calling its member states to undertake transformative actions and pledge commitments at the global, regional, national and local levels on key pollution risk areas. A Framework of guidance principles and proposed Transformative Actions include: adopting multiple benefits of action, integrated approaches, Leapfrog technologies and access to innovative financing, build capacity and skills to address implementation and take action at all levels of governance to: detoxify the environment; decarbonize the economy; decouple environment degradation from resource use, and enhance ecosystem resilience and restoration, supported by a context-appropriate mix of targeted, integrated strategies.

Keywords: Human Health, Ecosystems, Climate Change, Environment, Food Security.

Keynote

Considering a Nexus Approach to the Water Related SDGs in the Arab Region

Ziad Khyat,
ESCWA

Abstract
The 2030 Agenda for Sustainable Development adopted in September 2015 presents a transformative, universal and people-centered approach to pursuing sustainable development. It includes 17 Sustainable Development Goals (SDGs) that aim to guide global action on the achievement of a common set of development objectives whose progress is monitored and reported upon through 169 targets. The SDGs present a broad comprehensive set of goals covering social, economic and environmental aspects, with several goals aimed at achieving universal access to basic needs and services for all. Given the breadth of this inclusive and visionary agenda, it is of crucial importance to consider and explore the inter-linkages and integrated nature of the SDGs in order to ensure that the objective of the 2030 Agenda is realized.

The water sector is the focus of a dedicated, stand-alone goal (SDG-6), which aims to ensure availability and sustainable management of water and sanitation for all. Although water issues are addressed in this standalone goal, SDG 6, water is evident as a cross-sectoral issue that affects the achievement of almost all SDGs. Several other SDGs are also water dependent, such as those related to food security, health, energy, human settlements, ecosystems and climate change. The cross-cutting nature of water within the SDGs exposes the need to consider the achievement of the water related goals and targets from a nexus perspective that recognizes the inter-dependencies and inter-linkages across the SDGs. A regional perspective that considers nexus dimensions within the context of regional specificities may thus present an appropriate means of considering how to identify the priorities of the relevant water issues within an integrated, cross-sectoral approach to the SDGs in the water-scarce Arab region.

At ESCWA, this nexus approach includes examining the inter-linkages between the water, energy and food security goals and targets (SDG-2, SDG-6, and SDG-7) and does so with a view to considering the environmental challenges posed by climate change and the need to pursue a human-rights based approach to sustainable development. ESCWA has also identified other inter-linkages for pursuing a nexus approach to the SDGs, while noting that all 17 SDGs are inter-dependent and universal.

ESCWA is implementing several projects that foster the water-energy-food (WEF) security nexus approach to sustainable development. Such projects include the United Nations Development Account project on developing the capacity of ESCWA member countries to address the water and energy nexus for achieving sustainable development goals, the project on promoting food and water security through cooperation and capacity development in the Arab region and the Regional Initiative for the Assessment of the Impact of Climate Change on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR). These

projects and initiatives along with others serve to inform and strengthen the WEF nexus approach to sustainable development.
The achievement of the 2030 Agenda on Sustainable Development requires action at the global, regional and national levels to achieve the SDGs. Within the context of the water-related SDGs, this requires mainstreaming and prioritizing water in national and sectoral development plans, as well as considering water opportunities and constraints when pursuing development plans in other sectors. Such efforts require integrated approaches to sustainable development and can be supported by ensuring coherence across regional and national plans and commitments related to the SDGs, the Paris Agreement adopted under the auspices of the United Nations Framework Convention on Climate Change (UNFCC), the Sendai Framework for Disaster Risk Reduction 2015-2030, and the Addis Ababa Action Agenda on financing for development.

Furthermore, achieving the 2030 Agenda and any integrated strategy requires a more developed science-policy interface in the Arab region. Scientific advancement needs to be given the prominence it requires to support development in the region. Scientific knowledge is a key ingredient in policymaking where it can provide justification for certain realities and project future scenarios that evaluate the effects of a certain policy. The application of science is particularly important to integrated water strategies and more so in nexus based approaches, where precise measurements, data and analysis are prerequisites for determining appropriate policies.

Keywords: Sustainable Development, Nexus, Agenda 2030, Water, SDGs.

Keynote

Challenges and Opportunities for Implementing Water Resources Management in North Africa

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Abstract
Northern part of Africa as a whole is seriously poor in water resources. The six countries of the sub region are already below the threshold with an average of 260m3/cap/year, five of them are suffering serious water deficiency, since their water capacity is below 500m3/capita/year. Throughout the region, Egypt and Mauritania are almost entirely dependent, with a rate of more than 95%, on water originating beyond their own borders. The groundwater resources are often exceeding natural recharge resulting in a progressive decline of the groundwater table and in a deterioration of the water quality.

The water situation is expected to worse in the future, due to the growing needs generated by population growth and urbanization and also due to the effect of the climate change on the availability and variability of water resources. Because of the increasing demands of water uses in particular for agriculture purposes estimated by an average of 80%, non-conventional water supplies have been developed progressively to offer additional amount of water.

Particular attention has been given by the region governments to improve access to water by focusing on water governance, institutional and technical solutions. In the last decade, all the sub region countries have taken the challenge to improve water resources management by adopting water policies through a master plan for sustainable water resource management. These policies are different across the various countries, and its effective implementation requires a significant commitment among all the partners of the water sector.

As a whole, recommendations targeted to water resources development and management and to the increase effectiveness of water use in the region could be formulated as follows:

- It is important to make water saving a key element of water policy, adopting modern irrigation technologies, control and reducing unaccounted for water.
- Introducing water conservation strategies and encouraging water harvesting by returning to traditional, small scale infrastructures and robust water and soil conservation systems especially in arid areas.
- Sharing out water resources in an equitable way through transfers of water between hydraulic basins and dams progressively developed in Algeria, Tunisia and Morocco
- Water demand management rather than water offer management must be imperatively applied for better developing the already mobilized water resources and for avoiding environmental pollution.
- Decentralize water management responsibility through creation of structures for the decentralized and participative management of water resources. This approach has shown considerable advantages in some countries in the region such as Morocco and Tunisia.

- Engage private sector participation, currently adopted in Morocco and partly in Tunisia, in building, operating, and maintenance of the different water facilities. This implies strengthening the role of the government as a regulatory body.
- Applying incentives and sanctions to achieve encourages conservative use of the resource including water pricing for the various sectors without excluding targeted subsidies to low-income households.
- In the frame of integrated water resources management, reuse of wastewater combined with artificial recharge offers alternate solutions in many countries of the sub-region. Desalination with an efficient and environment friendly renewable energies coupled with inexpensive desalination technologies could be appropriate to produce fresh water on both medium and small scales. This solution is recommended to be adopted for supplying more than 50% of rural population living in the region.
- Promote cooperation for sustainable management of trans-boundary water resources, and creating a framework of cooperation specific to the region. The ongoing experience of Algeria, Libya and Tunisia regarding the North-Western Sahara Aquifer System-supported program implemented by the Sahara and Sahelian Observatory (OSS) is considered a possible model Improvement and enhancement of communication between key stakeholders.

The countries of the region have many competences and can benefit from the exchanges, between them, of successful experiences in various fields such as building dams, drinking water supply, and sanitation. For this consideration it is recommended to create a framework of suitable co-operation for the region taking into account the similarities of problems of water in the countries concerned, and the important possibilities of sharing experiences. Strengthening educational and training capacities at all levels and advance harmonization and improvement of data collection and sharing is an asset too.

Perhaps the most important recommendation that should be made to the scientific community through their scientists and academicians is to create a framework of suitable co-operation and facilitate the implementation of joint action projects driven by research needs in water domain.

On all levels we as, scientists academicians, have to work together with various leaders from state and local levels and both public and private sectors to form various networks and shape research and politics priorities and craft new tools to sustain our precious water resources.

Keywords: Water Resources, Adaptive Management, Water Framework Directive, North Africa, Future.

Water and Oil: The Impact of the Decline in Oil Prices on Water Management in the GCC

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Abstract
The decline in the world oil prices since June 2014 created a challenge to the Gulf Cooperation Council countries. The budget deficit and the way to bridge the gap, encouraged some of the countries to slash or reduce the amount of subsidies that were considered part of the government support to its citizens. Water subsidies were impacted as well have been experiencing a rather remarkable boom in the construction of water and sewerage facilities due to the increase in demand which is being necessitated with the population increase. While the involvement of the private sector is shaping up, there is reliance on government financing schemes. In the meantime, there is an interest in the public sector to engage the private sector in some of its activities including management and financing. This trend needs to be assessed. With the involvement of the private sector, the current tariffs which does not cover even the operating costs of the water sold is going to be an area of revision. Some of the countries in the region allocate a sizable percentage of their oil sales to subsidies the water consumption in their countries.

The paper will focus on assessing the impact of the reduction of the water subsidies and how that might lead to a proper use of the available water resources including consumption. Also, it is going to explore the possibilities of revising the tariff structure in in order to achieve financial stability and conservation of water as well. The argument will be made that the decline in oil prices created a positive impact on the use of water in the GCC countries. Furthermore, that trend may create friendlier environment to attract the private sector to finance water/sewerage projects as well. That current trend of cost recovery process, how does that figure in determining the tariffs structure and considering the increasing involvement of the private sector in this field, what are some the possible financing methods that could be utilized.

The argument will be made that entrusting the financing to the private sector or through a Public Private Partnerships (PPSs) will serve to alleviate the burden on the national treasury and will help to conserve the use of the precious resource and above all, tariffs should be structured to recover part of the cost and not necessarily most of it. Simply put, a more realistic look should be done while formulating the tariffs structure. The method will rely on the analysis of the available data, date that will be collected from the water agencies in the GCC and the researcher's work experience in the financial sector.

Keywords: Oil Prices, Cost Recovery, Financing, Funding, GCC, Subsidies, Tariffs.

Introduction
Since the summer of 2014, the declines in oil prices have impacted the economies of Gulf Cooperation Council (GCC) countries. Many sectors were impacted including construction, education, and healthcare, in addition to some economic indicators such as unemployment

statistics. One aspect is the amount of subsidies that constitute a very visible feature of the governmental attitudes within the region. Several attempts were made in the recent past to reduce the amount of subsidies, including raising the price of oil products in these countries. While the effort of reducing subsidies by some countries was met with natural resistance from consumers, other countries did not experience the same resistance from consumers. While the process of adjusting water tariffs began a few years ago, the intensity is going to increase due to the changes in the government's attitude towards many variables including water subsides. This by itself is cultivating more investor interest from the private sector to invest in water related projects. It is very clear that an attractive return is a requirement for investors considering engaging in the water sector.

Brief Highlights of the GCC

1. Geographic Size

The total geographic size of member countries of the Gulf Cooperation Council (GCC) which include the Kingdom of Bahrain, the Sultanate of Oman, the State of Kuwait, the State of Qatar, the Kingdom of Saudi Arabia and the United Arab Emirates, is 2,410.71 thousand square kilometers. The density per square kilometer varies from 13 inhabitants in Oman to 1705 inhabitant in Bahrain.

2. Population

The total number of the population is approximately 50.4 million, of which approximately 24.2 million (48.1%) are Non-nationals; see below (GLMM, 2015). The highest number is in Saudi Arabia with ~30.8 million versus Bahrain with ~1.3 million inhabitants (GLMM, 2015). The rapid increase in population is a very important factor to assess due to the fact that this increase is placing a heavy burden on the available facilities currently in place, which necessitates building and erecting additional facilities; in addition to the need to rehabilitate current facilities. A point of caution is needed here. In most of the countries in the GCC, Nationals and Non-nationals pay the same rate, while in some countries there is a difference in the payment structure between National and Non-nationals.

Table 1: Total Population and percentages of nationals and non-nationals in GCC countries (latest national statistics, 2010-2015)

Country	Date/ Period	Total population	% in total population	
			Nationals	Non-nationals
Bahrain (1)	mid-2014	1,314,562	48.0	52.0
Kuwait (2)	31 March 2015	4,161,404	30.8	69.2
Oman (3)	25 March 2015	4,149,917	56.0	44.0
Qatar (4)	April 2010	1,699,435	14.3	85.7
Saudi Arabia (5)	mid-2014	30,770,375	67.3	32.7
United Arab Emirates (6)	mid-2010	8,264,070	11.5	88.5
Total*		**50,359,763**	**51.9**	**48.1**

Sources: national institutes of statistics, latest year or period available as of 31 March 2015. * Total provides the sum of population numbers at different dates between April 2010 and March 2015. It is not exactly the total population at any of these dates.

3. Non-Nationals

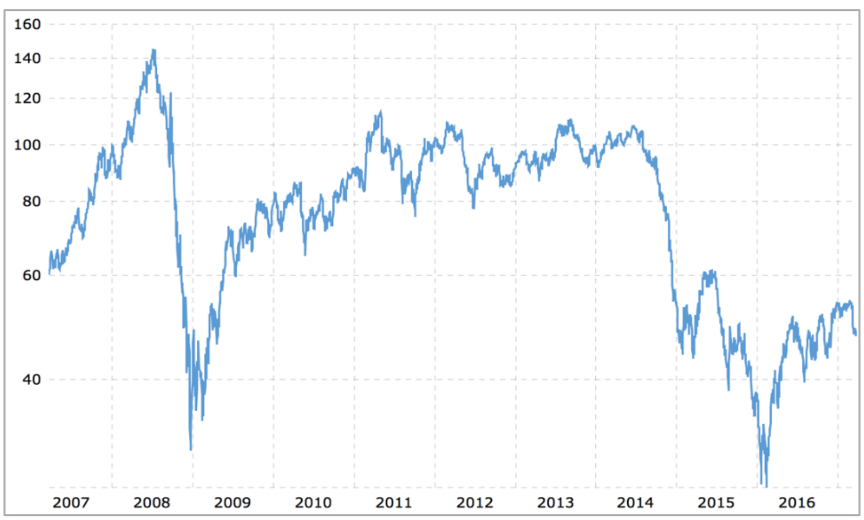
The percentage of the Non-nationals varies from one country to another country. The highest percentage is in the United Arab Emirates (88.5%) and the lowest is in Saudi Arabia (32.7%) (GLMM, 2015). While we don't have data to differentiate the consumer behavior in the use of water between, Nationals and Non-nationals, it is customary to assume that Nationals live mostly in detached units (villas), while most Non-nationals live in apartments. With these assumptions, we can conclude that the volume of water used varies drastically between the two categories of inhabitants. That is in addition to the variation in the size of the household. Nationals tend to have additional people working for them in the household and living with them as well, aside from their own biological family members, whereas, Non-nationals only have biological family members living with them.

4. Major Sources of Income

The sources of income vary among countries, while mostly from hydrocarbon, including oil and gas. The total estimated Gross Domestic Product (GDP) is $3,176.50 billion (PPP basis).

5. Current State of Oil in the World, including the GCC

As of 2013, the total oil and gas reserves were estimated to be at 1.64 trillion barrels, and the GCC is the source of 45% of the total (Xu, 2013). The price of oil dropped from an average OPEC crude oil basket of $92 in 2014 to $50 in 2015, and as of June 2016, the average was $37 which was almost the average price in 2004 (Russell, 2016).



Source: macrotrends.net

Chart 1: Price of Crude Oil (barrel) 2007-2016

The decline in the oil prices and thus the revenue is going to have a significant impact on the way by which the government in the region is going to adapt to the new reality. On one side, the decline in revenue is going to push for more scrutiny in terms of funding projects. Some projects may be abandoned, or postponed, and others may require a more in-depth assessment in order to identify the optimal project size. In a region where consumers (Nationals and Non-nationals) enjoy a certain special amenity that is not available in other parts of the world, including education and healthcare, these benefits must be modified and adjusted to accommodate the new economic constraints. As it was mentioned in a recent report by the International Monetary Fund:

"…. while oil production horizons are long in many GCC countries, oil is an exhaustible resource. Over time, as oil revenues decline, governments will have less ability to provide services to support the economy. Rising employment for nationals in the public sector will consume an increasing portion of the oil revenues, leaving less space for public investment or savings for intergenerational equity. Meanwhile, unless oil exports are replaced by non-oil exports, accumulated international reserves will be depleted owing to large and growing non-oil external current account deficits" (Callen, Cherif, Hasanov, Hegazy, Khandelwal, 2014).

The Budget Deficit

As it was pointed out in the previous section, oil prices have taken their toll on the government budgets. Yes, it is true that some of the GCC countries managed to have relatively diversified economies, such as Qatar and UAE by which they rely less on the sale of oil. Nevertheless, the reliance on the sale of oil and gas is still a major source of revenue for Qatar and the UAE. In most countries, government budgets are based on the expected price of oil. The annual expenditures are allocated to match the expected revenue.

Now, what is the situation with the budget deficit in major GCC countries? According to the latest report from the IMF, "Growth in the GCC countries and Algeria is forecasted to slow substantially in 2016, as the impact of lower oil prices is felt through tighter fiscal policy, weaker private sector confidence and the tightening of liquidity in the banking systems" (Anderson, 2016) It goes on to state i) "…this year's growth rate, forecast at 2.1 per cent, would fall well below 2015's 3.6 per cent, but no oil exporters are expected to fall into recession." and ii) "In addition, the regional deficit will average 7 per cent of GDP by 2021 or a cumulative $900bn during the 2016 to 2021 period, according to the IMF" (Anderson, 2016).

Summary of Subsidies in the GCC

General

The history of subsidies is as old as the oil and gas discovery in the region. Citizens are accustomed to have subsidies. It covers many areas of the economic life of inhabitants. Water, electricity and oil are part of the subsidies list along with other benefits. The following graph shows the degree by which subsidies plays an important role as a percentage of: i) the GDP; and ii) the fiscal expenditures. It shows that subsidies consume almost 20% of the fiscal expenditures in Bahrain compared to approximately 2.5% in Kuwait and Oman, noting the variance in the income of these states (Iosif, 2016).

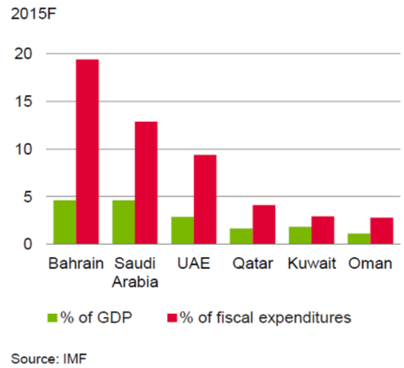


Chart 2: Subsidies weight on fiscal balances (Iosif, 2016)

Impact of Reducing Subsidies:
While governments in the region were energized to adjust subsidies across the board, the process is slow and in some countries, the topic is still being debated. Overall, the adjustment in the amount of subsidies still does not have a noticeable impact on the general fiscal expenditures of the country in question. For example, Moody's estimates that fiscal deficits will average 12.4 percent of gross domestic product across the GCC in 2016.

If we focus, for a moment, on the impact of the recent increase in oil prices in some GCC countries, we can see, it is helpful to alleviate the financial burden but that is insignificant on a micro level. Also, the importance of the transport cost as part of the Consumer Price Index (CPI) varies from one country to another country. From almost 7% in Kuwait to 18% in Oman, the spread is big; see the chart below (Young, 2016).

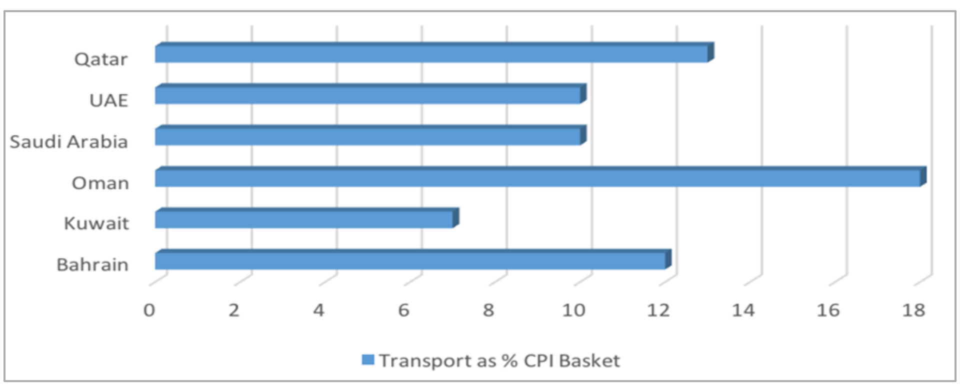


Chart 3: Transport as Percent of CPI Basket

In comparing prices for energy products throughout the GCC and using the USA Pre-Tax as a reference point, the schedule below shows the variation in the price of gasoline and diesel between \$0.19 per liter in Kuwait to the highest in the Oman with \$0.42 per liter. The price of natural gas varies from \$0.75 per MMBtu in Qatar and the UAE, to the highest of \$3.00 in Oman and \$2.75 in Bahrain along with \$1.50 in Kuwait and Saudi Arabia. The most noticeable variation is the price of electricity. From \$0.01per KWh in Kuwait to \$0.12 in the UAE. When comparing the GCC maximum with the USA, the numbers are very close. See the table below.

Table 2: Prices for Energy Products: GCC and the USA (IMF, 2016)

Prices for Energy Products: GCC and the United States
Average January–July 2016 or latest available

	Gasoline	Diesel	Natural Gas	Electricity
	(U.S. dollars per liter)		*(U.S. dollars per MMBtu)*	*(U.S. dollars per KWh)*
Bahrain	0.38	0.32	2.75	0.04
Kuwait	0.19 1/	0.39	1.50	0.01
Oman	0.42	0.43	3.00	0.04
Qatar	0.35	0.37	0.75	0.05
Saudi Arabia	0.22	0.10	1.50	0.10
UAE	0.41	0.43	0.75	0.12
GCC Average	0.36	0.34	1.71	0.06
GCC Maximum	0.42	0.43	3.00	0.12
U.S. Prices	0.51	0.45	2.18	0.10

Sources: Prices for GCC countries come from country authorities and are averages for 90 and 95 octane gasoline. U.S. gasoline (average for mid and high grade) and diesel prices come from U.S. Department of Energy (EIA) and are adjusted for taxes. Natural gas price for the U.S. is the Henry Hub spot price. Electricity tariffs for the United States include taxes and come from EIA.
1/ Kuwait increased gasoline prices to $0.29 per liter, effective September 1st.

So even with an increase in gasoline prices in the GCC, according to Karen Young, the subsidy savings as a percentage of GDP is still very small, as could be seen from the below table on Fiscal Gains of Gasoline Price Increases (Young, 2016).

Table: 3 Fiscal Gains of Gasoline Price Increases (Young, 2016)

	New gasoline prices per liter	Percent change	Subsidy Savings, as Percent of GDP, 2016 Estimate
Bahrain	0.42	55.6	0.9
Kuwait	0.21	0.0	0.0
Oman	0.41	36.7	1.1
Qatar	0.35	34.6	0.1
Saudi Arabia	0.24	50.0	0.8
UAE	0.49	5.1	0.1

Moody's Investor Services, Globalpetrolprices.com as of January 2016, IEA Energy Atlas

As it was pointed out by some analysts, if these increases in prices of oil, water and electricity and in turn a reduction in the subsidies, does not squeeze the household budget, then it could be tolerated. The point is the percentage of that on the whole household budget. Looking at the region in total, "According to the International Monetary Fund, total energy subsidies (including fuel and electricity) cost the GCC states nearly $60 billion in 2015, or on average 3.6 percent of GDP." (This cost has gone down considerably from 2013, at the height of the oil boom, when energy subsidies cost the GCC states as much as $106 billion).

Water Resources

The focus is on water management in the GCC after the drop in oil prices. Therefore, the interest should be on how much water is available to satisfy the demand of the population and the forecasted needs considering the increase in the population for the years to come.

The fact is, there is a shortage in the GCC. As we speak, there was 12,781 mcm/y similar to the period in 2010 and that number is going to increase to 25,855 mcm/y as we approach 2050, as we can see from the Table 4 below:

Table 4: The Potential Fresh Water Shortage in the GCC Region by 2050 (mcm/y) (Droogers et al., 2012)

Country	Current consumption (2010	Current Shortag (2010)	Future Average consumption (2050)	Future shortage (2050)
Bahrain	226	195	391	379
Kuwait	508	0	1216	835
Oman	763	0	1709	1145
Qatar	325	83	395	174
Saudi Arabia	20 439	9 467	26 633	20 045
UAE	3370	3036	3389	3277
Total GCC countries	25 631	12 781*	33 733	25 855**

* 50% of extra water needed

** 77% of extra water needed

Source: Droogers et al. (2012)

Therefore, the GCC needs to plan accordingly (Seetharaman, 2016). Are there sufficient governmental resources to be allocated to meet that shortage? Has the Public Private Partnership (PPP) experience been rewarding?

These are the relevant questions. While there are government resources, the recent decline in oil prices has created a wake-up call to the decision-makers emphasizing the need to focus on encouraging the private sector to participate in financing infrastructure projects in general, including water projects.

The GCC in general has demonstrated a keen interest and encouragement for Public Private Partnerships (PPPs). The latest is Saudi Arabia's decision to "Privatise US$50 Billion of Water Sector Assets… as Kingdom Proceeds with Vision 2030 Privatisation Initiative… SWCC [Saline Water Conversion Corporation] is the world's largest producer of desalinated water with annual production of approximately one billion cubic meters., SWCC can proceed with the privatisation of approximately SAR 200 billion (US$53 billion) of assets. In addition to existing assets, the Kingdom expects that increases in demand will require additional water production capacity of approximately 2.2 million cubic meters per day (cm/d) by 2020. Both the privatisation of existing water assets and the development of new assets present an opportunity for those looking to invest in Saudi Arabia on a public-private partnership basis. With approximately 40% of the overall financing required for Vision 2030 to come from the private sector, the Kingdom is looking to increase the percentage of desalinated water production through strategic partners from 16% to 52% by the end of 2020" (Levy, Witt, 2016).

The above is a unique move in Saudi Arabia to plan on privatizing approximately $53 billion worth of SWCC. Also, the proposition that approximately 40% of its overall financing required for vision 2030 will come from the private sector is encouraging. This has been in the background with initiatives that were taken in Dubai (UAE) when it introduced a new PPP law to secure funding from the private sector (Seetharaman, 2016). Kuwait, with its Kuwaiti Public Private Partnership Law which was published in 2014, "seeks to promote investment opportunities and provides certain tax benefits and exemptions for foreign investors in the Public Sector in Kuwait," (Seetharaman, 2016) and as Seetharaman, pointed out, "GCC governments are expected to pursue private sector financing as a way of plugging the budgetary gaps for public infrastructure development in a weak oil market. Liquidity challenges will have a bearing of banks' ability to participate in PPP projects."

The above will clearly demonstrate the emergence of PPPs as a game-changing force that will facilitate the financing of water projects along with other infrastructure projects in the future. The key point is that funding is going to come from regional banks whose deposits, to some degree comes from the government. If the government is going to compete with other entities to finance its budgetary requirements, then there will be limitations to private sector participation. As one source pointed out, European banks do not have the appetite at the present time to finance projects that exceeds $300 million (Seetharaman, 2016).

The recent changes in water tariffs in the UAE should provide an incentive to other GCC countries to model their tariffs accordingly. For example, the residential customers living in a flat, their tariff went from 0 to a gradual of AED/1000 liters of 1.70 up to 700 liters/day to AED/1000 liters of 1.89 for over 700 liters/day. Also, an increase was increased for government and commercial customers from AED/1000 liters/day of 2.2 to AED10.55 and AED 4 respectively (RSB, 2016). This is a quite an increase. See below:

New water tariffs

Residential customers

Customer	Property	Current tariff AED/1,000 litres	New tariff AED/1,000 litres	Average Daily consumption litres/day
National	Flat	0	1.70	up to 700
			1.89	over 700
	Villa		1.70	up to 7,000
			1.89	over 7,000
Expat	Flat	2.2	5.95	up to 700
			10.55*	over 700
	Villa		5.95	up to 5,000
			10.55*	over 5,000

Social card holders and national beneficiaries of monthly allowances or social assistance

Customer	Property	Current tariff AED/1,000 litres	New tariff AED/1,000 litres	Average Daily consumption litres/day
National	All	0	0**	up to 9,804
			1.70	over 9,804
Expat	All	2.2	0**	up to 2,801
			5.95	over 2,801

Other customers

Customer	Property	Current tariff AED/1,000 litres	New tariff AED/1,000 litres
Government	All	2.2	10.55*
Commercial	All	2.2	4
Agriculture including Ranches	All	2.2	2.20
Industry	All	2.2	4

Chart 4: New Water Tariffs in UAE (RSB, 2016

Conclusion

The paper demonstrated that the recent drop in oil prices resulted in creating a budget gap in the governments across the GCC. Having that said, the expected reaction to remedy the situation is to i) reduce subsidies, ii) increase private infrastructure investment and iii) rationalize the management of public utilities. Sourcing the necessary funding has shifted gradually from total reliance on the government to engaging the private sector. The Public Private Partnership (PPP) model had taken off with a good start but the process is progressing at a slower pace due to the problems of the banking sector in Europe.

What is more important at this stage is to have a more serious look at the way the water sector is being managed, i) from an equitable tariff perspective (that would reduce the waste), ii) to maintaining the current assets that are getting old and are in dire need of refurbishment. Finally, you have the urgency of expanding the number of facilities in order to meet the increase in demand due to population growth.

It is very important to utilize the drop in oil price as an opportunity to re-examine many policies dealing with subsidies and water tariffs. A sound assessment followed by a sustainable action plan will provide more efficient management of the water sector which could lead to a better tomorrow for everyone.

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Development of Regenerative Water Resources in Semi-Arid Regions Methods and Processes - Synopsis of a Package Solution

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Abstract
The rising need of drinking and industrial water through a growing population and higher civilization standards require, especially for interior semi-arid regions, secure solutions for the future of existing communities as well as safe concepts for the development of non-urbanized regions which are suffering till now under water shortage. Alternatives to guarantee regenerative water resources by the seasonal precipitation are producible in semi-arid regions but only in those areas with strong rainfall events. Since the precipitation statistic as per each region is continually negatively influenced by climate changes, which among other points influence the output of springs and the depletion of ground water levels, this consequence must also be compensated for. Regenerative water resources by storm floods can be explored and collected with hydraulic engineering methods and processes in large quantities, whereby a positive side effect is the reduction of the dangers of flooding. After reduction of detritus with hydro-mechanical methods and thereafter cleaning from fine sand and suspended substances, these flood water could be collected in a large volume in underground water cistern, through which longer dry periods could be bridged. Using water management with recycled water, independent island solutions as well as collective solutions are possible, for an ecological urban water economy. In case of a surplus of regional water production national water supply systems could also be supplied.

Keywords: Floods, Water Harvesting, Cistern, Climate Change, Management, Urban.

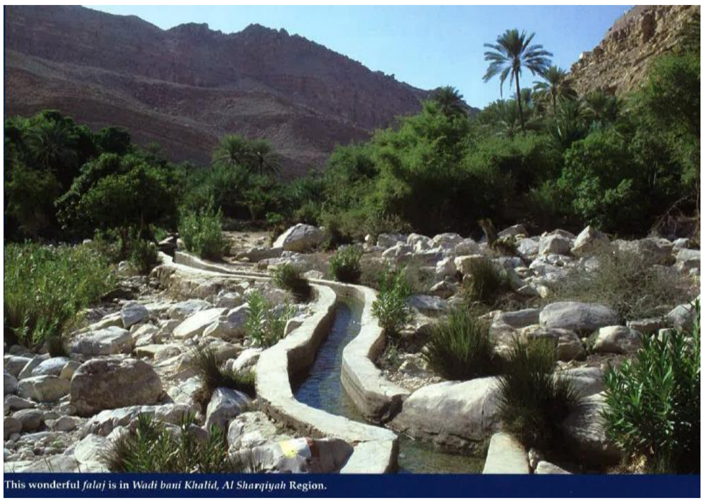
1. Introduction

Already for hundreds of years in interior semi-arid regions springs were already used and by partly complex processes aquifers explored (1). If the aquifers were abundant, wells covered the regional water needs. Only with the possibility of desalinization of sea water there arose the far-reaching options along the coasts for urbanization and extended agricultural development, with the consequence of an over proportional population increase along the coasts, while a growing water deficit the expansion of settlements in the interior limited.

Water deficits often occurred because of salinization of the wells due to excessive water removal and a parallel lowering of the ground water levels. Near the coasts this lead to a salinization of the coastal zones with consequences for the agricultural land use of the soils. Often a reduction of precipitation was further responsible, which at the same time affects the output from the sources in the mountainous regions. This tendency may grow stronger with the continuous development of climate change (2), which will lead, in the interior, to further bottlenecks in the drinking and service water supply. Alternative, to compensate these water deficits in the interior through fossil water resources, however may only be possible in few areas for the next several decades.

Solutions, to compensate water deficits of drinking and service water in the interior of semi-arid regions in the future through desalination of sea water by pipelines, is striven for in various Arabic countries and is been realized, through which large investments will be achieved (3). As the necessary demand for energy are produced by fossil fuels at the moment, leaving an impact supporting climate change. The producing of regenerative energy for this purpose, such as solar energy, is in regions with periodic high levels of atmospheric fine sand, bound with massive side effects. Arabic countries are mostly affected, in which sandstorms occur.

Many Arabic countries could never the less develop substantial regenerative water resources, as momentarily precipitation occurs mostly seasonally as heavy rain events. This normally affects mountainous regions such as Jabal Hajar (pix. 1), the complete mountain range in west Saudi-Arabia towards the Red Sea as well as regions in central Sahara (exp.: Tibesti, Al Hajjar, Air, Adrar des Iforas).



Pix. 1: Jabal Hajar Source: Ministry of Regional Municipalities and Water Resources, Sultanate of Oman; Water Resources in Oman; 2005, Cap. 2: Surface Water p. 26

The precipitation yield in many of these regions reached partly over 400 mm/year. Since natural barriers, such as vegetation are missing for these severe rainfalls, this precipitation flows off as flood water, endangering the population and creating massive damage to the infrastructure (pix. 2).

Pix. 2: Damage from flooding in the Sultanate Oman after severe rains. Source: Google Earth, SALE, Vol III, ISSUE 38, DEC 18, 2009, p. 1

Based on available regional precipitation statistics, a smaller quantity of this precipitation could be balanced regional water deficits, if storage capacities for drinking and irrigation waters as appropriate where available. Simultaneously not yet developed non-urbanized regions could be developed. Therefore a substantial storage volume would be needed, that would not have been feasible with earlier methods and processes. Presently storage of seasonal flood waters in Arabic countries is frequently regulated with dams, which have substantial side effects (such as: evaporation, seepage, contamination, overturning of water quality).

With the development of regenerative water resources through precipitation of storm events and its underground storage through large volume water cisterns, we can not only balance the present water deficits but develop new settlement regions in the until now non-urbanized regions. This would, in many coastal regions, relieve the population growth. Already at the 9th Gulf Water Conference as well as at the IWRM-Conference 2010 (Karlsruhe/Germany) a solution was discussed (4, 5), that after now a sustainable concept was worked out and has to be proofed for its feasibility with the help of scientific and technical experts.

2. Methods and Processes

To cover the total range of methods and processes for the development and the storage of regenerative water resources, which should be collected from storm events, full-scale collections and analyses, using scientific criteria are necessary. These included: satellite supported mapping, meteorology and climate research, geology and hydrogeology, hydrology, geochemistry, engineering geology, water chemistry, water engineering, hydromechanics, special underground engineering, material sciences, and finally last economic geography to estimate the economic and communal political range effected regionally and nationally after implementing water supply systems.

Methods and processes foreseen are concentrated primarily on the scientific analysis of each water catchment area as well as the building of storage systems, whereby two different geological regions will be chosen as trial regions.

2.1. Water catchment areas

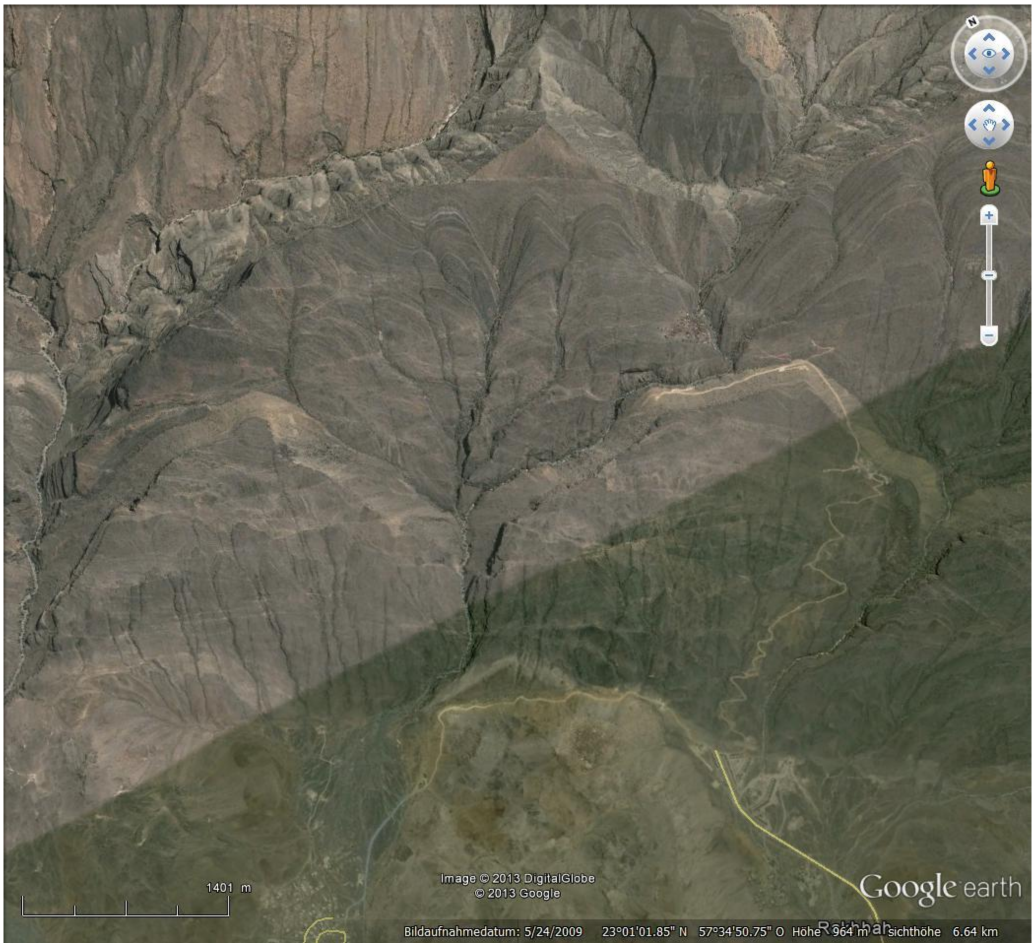
With the choice of appropriate water catchment areas, the hydraulic engineering methods and processes will be defined through hydrologic analysis in each segment. This is necessary, to determine the development of suitable precautions for determining water yield and the water runoff (pix. 3). Necessary, in order to mark the areas that are geographically favorable for urban water economics, are in advance high resolution satellite supported mapping with an expansion radius of approx. 50x50 Km, with which not only regional but collective development of regenerative water resources becomes possible. The areas that come into question for water retention will be marked by priority and adaptability.

Pix. 3: Water containment in a catchment region in Jabal Al Akhdar. Source: Google Earth 2009; 23°01'03.08“ N, 57°35'01.10“ E

To determine the precipitation amounts in the marked regions, a precipitation statistic for each water catchment must first be determined. This can be accomplished by measuring spots at predetermined reference points in the catchment area. As a new measuring technique the mobile networks should also be used, in that service fluctuation of the radio relay stretches during precipitation events are determined (6). If there is data available from earlier years, regional precipitation can be tracked. Reference measuring is also necessary. To secure middle to long term advance precipitation statistics, more climate studies become necessary, in order to justify the hydraulic engineering measures in the planned time span for depreciation.

Geological judgments as well as geochemical analyses serve on the one side to prepare the hydraulic engineering measures and for the building of the storage system, on the other side to determine soluble trace elements and dangerous substances of the surface water. To determine the rock structure and properties, possible water paths and aquifer conditions, this is not only relevant for the tunnel heading engineering, making trial borings normally every 300 to 500 m along the storage piping are necessary. Should abundant aquifer be found by these analyses, these could be additionally used, as long as the existing AFLAJ-systems and foreseen work measures are not negatively influenced. To secure the hydro-geological properties in the water catchment area, losses through evaporation and seepage need to be determined.

With the combined morphological-photo geological mapping, that will be carried out with a resolution of up to 1 m, runoff measurements in all parts of the catchment area in connection with the precipitation event can be determined to define the divisions for the hydraulic engineering measures. In the forefront to this belongs the detritus reduction, an example: with gabions, the specification of the intermediate dams (self-cleaning overspill dams) as temporary water storage, the planning of secondary collection conduits and lastly placing a main dam normally at the end of a canyon in the catchment area before drainage in which the usual wide area debris divisions will be placed (pix. 4).



Pix. 4: Classical steep slope catchment area in Jabal Al Akhdar north east of Nizwa: Canyon at drainage point of a water catchment region by 23°01'03“ N, 57°35'01“ E (Attention: Photo was made from marked position in pix. 3): Picture by HÖTZL, Heinz & HAHN, Günter; December 2009

This detailed planning is necessary because of the high drainage rates in the entire catchment areas, in order to control the exorbitant maximum values achieved by storm events. With this detailed collection in connection with the hydraulic engineering measures will provide following parallel effects:

- An optimal development and usage of the existing aquifer through various measures in the catchment area
- A reduction of flooding risks for the regional population with reduction of damages to the infrastructure

- Plannable building of settlements in regions where water shortages urbanization was previously not possible.
- Underground storage systems and structurally engineered setting

After determining the hydraulic engineering measures in the water catchment areas taking into consideration the climate studies the building of the storage system can start, where as in the “worst case” estimations of the foreseeable water availability is within the depreciation time span. Experience values show that only a percent in each water catchment area is necessary, as long as the severe rain amounts don’t exceed 15 mm per event. In this regard per year only 2-3 such event are needed. It is possible that 100 mm per year already would suffice. If these conditions can’t be meet in the catchment area, because of the insufficient hydraulic potentials, it should be disregarded.

For the cistern building, a storage system has developed for commercial reasons, which consist of two side by side pipes, for security reasons, one above the water level, with a parallel lying clearly smaller servicing tunnel. Out of geographic considerations as well as adjusting to the chosen catchment area(s) blind tunnels or a perforation through the mountain massif would be conceivable considerations for a cistern. Assuming a regional supply area of about 4000 inhabitants with drinking and accordingly service water, which lies near the top edge of rural settlement activity in Arabic countries, with a use of 110 liters per person, per day of drinking water, 160.000 m³ water should be available yearly.

Out of economic considerations as also to fully exhaust the total variation spectrum of the storage systems including a very high storage capacity is a standardization of the storage unit is necessary, because the tunnel heading engineering simultaneously places the outer casing of the storage pipes (pix’s 5 and 6). Because of cost considerations a shield diameter of around 12 m is considered affordable. From this background and the foreseen storage volume of 160.000 m³ to supply around 4000 inhabitants gives a storage pipe length of about 1000 m. At this upper end of storage pipe levels an approx. 3 m diameter supply tunnel can’t be waived, for operation, servicing, and safety reasons, whereby a perforation must have at its end an exit possibility.

Pix. 5: Tunnel building site near Rastatt (Germany), Tubbings before implementation. Picture by HAHN, Günter; September 2016

Pix. 6: Tunnel building site near Rastatt (Germany), Tunnel building site after implementation of tubbings. Picture by HAHN, Günter; September 2016

These are corner stone data for the storage system itself. Based on tectonic influences the existing for traffic tunnel building experience values resulted in the values for the outer casing of tunnel piping. The full-filling of the cistern works opposite of tunnels for traffic simultaneously the inner water pressure on the cistern walls, which must be offset through a special inner casing. That in water usually a chlorine solution is present, metallic reinforced material can't be used for the inner casing, as frequent changes between dry and moist conditions cause the builder steel to corrode faster. That is why fiberglass is foreseen for this use, to simultaneously secure a higher life for the building substances. Beyond this the cisterns need a specific inner casing of about 2 cm thickness, which is resistant to hydro-chemical influences in the long term stored water. Responsible therefore are under others different pH-values, which can lead to substance failure (carbonation) and there with to building substance loss.

Based on the storage temperatures, that even in underground cisterns in tropic and sub-tropic regions normally lay above 25 °C; special decontamination processes because of bacterial contamination are required, whereby negative Ions are used. Experience values show with this process a top level of storage capacity, should not exceed 3500 m³. From this background each storage pipe along the length must be appropriately chambered, for which tests for this standardizing also become necessary. Before the use of stored waters as drinking water, special upstream filters will have been inserted that can also eliminate viral contaminates. Because in the tropics and semi-tropic regions existing favorable conditions for bacterial growth of problem germs in irrigation systems, only bactericidal material should be used in the pipes for drinking water. As needed extra filters can be inserted between upstream points.

Based on the various peculiarities in cistern building are in advance of both water chemical investigations of the inflowing water feeds as well as of the use of the necessary building materials, pertaining especially to the inner casing. Because of the high importance of the stability of the specific construction of the cistern, material tests and possibly material studies of these used building materials, also various studies of the models of storage pipes are necessary, which is a condition for the building control certification of the cistern. Because of possible earth quakes in semi-arid regions, as well as in Arabic countries, the stability shall be simultaneously be tested for a magnitude of 7.0 on the Richter scale.

Because of regional differences in the emergence of storm rain events that can strongly differ yearly, in the long term independent island solutions are not necessarily suitable, which is why collective solutions for several water retention areas are more effective. Water surplus out of this regional water supply unit could be injected into the supra-regional supply systems, such as this example from the GCC which is presently installed in your member states.

2.2. Cost - use- estimate

To reach long term usability of the water catchment and storage systems, with special reference to the underground storage units, special materials will be used for building the underground storage System. This does not change the need for constant monitoring and servicing of the system, which is to be regularly done. As by the water supply system over the AFLAJ-systems, that already for hundreds of years in many Arabic countries through the tapping of springs and the systematic development of water of aquifers built the ground basis of life in the interior. The water supply and storage systems that are foreseen are connected with a comparable high implementation effort, whereas the subsequent costs are relatively low.

From a depreciation of 100 years, while the tunnel building machines for erecting tunnels are based on tunnels used for traffic, it can't be a secure given because of a lack of experience with this complete system. Out of the investigated guarantees for the individual components in hydraulic structures as an example are presently applicable for about 80 years, therefore a depreciation of at least 60 years can become a prerequisite.

Reliable information from participating firms gives for a water containment area of 30-50 Km² and a storage unit from approx. 160.000 m³, which is necessary for supplying 4000 inhabitants with a usage of 110 liter per day per person, an initial expense investment of 84 Million € (~87 Million US $). Therefore as a basis a minimum deprecation time frame of 60 years, which gives a daily expense of under 1 € per person and day during this depreciation time frame of 60 years. The cost expenses include planning costs of approx. 8 % of the total costs, the hydraulic engineering measures in the chosen water catchment area, the underground cistern and the control systems, the infrastructure for quality control of the stored waters as well as the supply lines to the distribution network for the end customer.

3. Conclusion

With the version of extreme precipitation in semi-arid regions the foreseen methods and processes could win substantial amounts of regenerative water resources. This sets out the proof of the feasibility of each individual component. The package solution offers with its components a variety of applicable possibilities, because also the package solution as well as the individual components of this package solution can be applied, and in fact:

- the compensation of already existing water shortages, well suited for semi-arid regions
- as a balance to the through climate change frequently expected water deficits,
- to bridging arid time windows, which are in many regions of the world presently make settlements almost impossible (referencing: especially semi-arid regions in the near and middle East, in north Africa, central Sahara and the Sahel zone),
- the compensation of the supply in through climate change growing water deficit regions, as an example in south Europe (referencing: Cypress, Greece, South Italy and Spain),
- in developing, emerging and industrial countries, in which the water capacities demands for large storage capacity,
- in developing countries, especially in tropic as well as semi-tropic regions, in which the drinking water is endangered through microbial as well as organic contaminants,
- in crisis regions, where water shortage has a continuous conflict potential (referencing as an example: the near East, central Sahara, Sahel zone),
- in from natural disasters endangered regions (example: Haiti, Indonesia, Madagascar, earth quake regions) securing their drinking water and as necessary service water supplies were appropriate through water supply reserves,
- to reducing the precipitation as a positive companion effect, that in semi-arid regions can presently lead to flooding disasters as well
- for agricultural application in regions until now unsuitable therefore, at least contributing to regional self-sufficiency.

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Water Demand Management is a Must in MENA Countries….. But Is It Enough??

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Abstract
The majority of MENA countries suffer from chronic imbalance between available water supply and rising water demand. This imbalance is expected to worsen even further in the future as a result of sharp population growth, rapid economic development and climate change, unless major positive measures are implemented to augment water supply and manage water demand. The supply management approach, on its own, practiced by many countries in the region for so many years has so far demonstrated its inability to bridge the 'Water Gap' between available water resources and rising water demand, as most traditional water resourced in almost all MENA countries have been exploited (or over exploited), and the cost of non-traditional water resources has become increasingly prohibitively high, apart from its environmental impact. Demand management is regarded by many water experts in the region as the answer or "panacea" for the water imbalance problem. But, is demand management approach alone able to solve the problem of water scarcity in the MENA region? In other words, if all demand management measures have been fully implemented, would there still be gaps between supply and demand that need to be filled with supply augmentation, and will supply management options still need to be part of the solution? This paper tries to answer this question by reviewing several works in this domain, particularly, recent studies by the World Bank. It was concluded that, although water demand management measures should be given the first priority, especially, in the agricultural sector where it has the maximum impact, demand management on its own will not be able to bridge the "Water Gap", and supply management options, such as sea water desalination and the re-use of treated wastewater, will be part of the solution.

Keywords: MENA Countries, Demand Management, Water Scarcity, Water Gap**.**

Introduction
The renewable water resources in the MENA region are among the lowest in the world. The majority of MENA countries (17 out of 21) have crossed the 'water poverty/scarcity' threshold (set by the UN - Food and Agriculture Organization, FAO, of 1,000 cubic meters of renewable water resources per capita per year, m^3/capita/ year) Table 1 (World Bank 2012, Future Water 2011). And eight countries (out of 21) are under sever water stress conditions (as their total renewable water resources are less than 200 m^3/capita/year). Only four countries in the MENA region, their per capita total renewable water resources exceed the water scarcity threshold.

It is worth mentioning here that the figures mentioned in Table 1 for the various MENA countries are sometimes different from the figures reported in AQUASTAT (the FAO Global Information System on Water and Agriculture). For example, in AQUASTAT, Iran is classified currently as a country with no water stress (i.e. its water scarcity index is greater 1000 m^3/capita/year), whereas in the World Bank study, Iran is classified as a country with moderate water stress (i.e. its water scarcity index is between 500 and 1000 m^3/capita/year). Furthermore, Syria is classified as a country with a current moderate water stress in AQUASTAT (WWAP 2015), whereas it is classified as a country with no current water stress in the World Bank Study. Perhaps the most striking example is Libya. It was classified as a country with severe water stress in AQUASTAT (WWAP 2015), whereas it is classified as a country with no current water stress in the World Bank Study.

Table 1: Per Capita Share of Renewable Water Resources in MENA region, by Country, 2000 – 2009

Renewable Water Resources (Cubic Meters per Capita per year)			
Less than 200	**200 – 500**	**500 - 1000**	**Greater than 1000**
Bahrain	Lebanon	Algeria	Djibouti
Jordan	Morocco	Egypt	Iraq
Kuwait	Oman	Iran	Libya
Malta	Qatar		Syria
Occupied Palestine (Israel)	Saudi Arabia		
United Arab Emirates	Tunisia		
West Bank and Gaza			
Yemen			

Source: World Bank 2012 and FutureWater 2011

The MENA water resources situation will, undoubtedly, deteriorate further in the future mainly due to population growth and the impact of climate change, Table 2 (World Bank 2012, FutureWater 2011).

It is evident from Table 1 and Table 2 that under current conditions (2000–09), countries in the Gulf region face the largest per capita water scarcity in MENA, with an average water availability of less than 300 m^3/capita/year. This situation will become even more severe in the future as a result of global warming and growing population.

It is also evident that, in total, by 2050, 14 of the 21 MENA countries could have less than 200 m^3/capita/year of renewable water resources, putting them under sever water stress conditions.

Table 2: Projected Per Capita Share of Renewable Water Resources, by Country 2020 – 2030

Renewable Water Resources (Cubic Meters per Capita per Year)			
Less than 200	**200 – 500**	**500 - 1000**	**Greater than 1000**
Bahrain	Algeria	Libya	-
Jordan	Djibouti	Syria	-
Kuwait	Egypt	-	-
Lebanon	Iran	-	-
Malta	Iraq		
Morocco	Occupied Palestine (Israel)		
Oman	Iran		
Qatar			
Saudi Arabia			
Tunisia			
United Arab Emirates			
West Bank and Gaza			
Yemen			

Source: World Bank 2012 and FutureWater 2011

Water Demand and the Water Gap

Water demand is expected to increase 50 percent by 2050 in the MENA region if current rates of growth continue and the global climate warms as expected, Table 3 (World Bank 2012). The current total water demand in MENA countries already exceeds naturally available water supplies by almost 20 percent. However, by 2050, the water demand gap is projected to grow 500%, from 42 BCM per annum to 199 BCM per annum, Table 3. This means that by 2030, due primarily to growing populations and partly to a warming climate, lack of water availability will become a severe constraint to socioeconomic development in all 21 MENA countries.

It is worth mentioning here that some of data in Table 3 are unclear and confusing. For example, it is unclear why the World Bank/FutureWater study estimated the current unmet demand gaps for Iraq and Iran at 11 BCM and 9 BCM, respectively. These figures seem unrealistic for countries that normally have positive water balance at the national level. No logical explanation was provided for this data. Similarly, the current demand gap of zero for Djibouti, Kuwait, Libya, and Malta, and especially the figure of zero demand gap for Djibouti until 2050 are also bizarre and unrealistic, and can only be attributed to the poor and unreliable data quality for some of the countries.

Table 3: MENA Current & Future Water Demand and the Water Gap *(MCM)*

	Water Demand			**Water Gap**		
Country	**2000–09**	**2020–30**	**2040–50**	**2000–09**	**2020–30**	**2040–50**
Algeria	6,356	8,786	12,336	0	0	3,947
Bahrain	226	321	391	195	310	383
Djibouti	28	46	84	0	0	0
Egypt	55,837	70,408	87,681	2,858	22,364	31,648
Iran	74,537	84,113	97,107	8,988a	21,767	39,939
Iraq	50,160	67,235	83,803	11,001a	35,374	54,860
Occupied Palestine (Israel)	2,526	3,396	4,212	1,660	2,670	3,418
Jordan	1,113	1,528	2,276	853	1,348	2,088
Kuwait	508	867	1,216	0	313	801
Lebanon	1,202	1,525	1,869	141	472	891
Libya	4,125	4,974	5,982	0	1,382	3,650
Malta	45	62	75	0	22	36
Morocco	15,739	19,357	24,223	2,092	9,110	15,414
Oman	763	1,091	1,709	0	24	1,143
Qatar	325	381	395	83	209	246
Saudi Arabia	20,439	22,674	26,633	9,467	14,412	20,208
Syrian Arab Republic	15,311	17,836	21,337	323	3,262	7,111
Tunisia	2,472	3,295	4,452	0	0	837
United Arab Emirates	3,370	3,495	3,389	3,036	3,243	3,189
West Bank and Gaza	460	680	1,022	308	591	925
Yemen	5,560	7,069	12,889	1,120	2,573	8,449
Total	261,099	319,138	393,082	42,125	119,443	199,183

Source: World Bank 2012 and FutureWater 2011

Currently, the Water Demand Gaps (unmet demands) are filled primarily through over exploitation of groundwater reserves, and partially by increasing water supplies through desalination. It is obvious from Table 4 that the agricultural sector dominates as the largest water consuming sector in all MENA countries, and it will continue to do so in 2050. However, its share of Total water demand for agriculture will drop from 82% to 67% in 2050.

Table 4: MENA Annual Water Demand and Supply, 2000–50 *(BCM)*

	2000–09	**2020–30**	**2040–50**
Total Demand	261	319	393
Irrigation	213	237	265
Urban	28	50	88
Industry	20	32	40
Total Supply	219	200	194
Surface water	171	153	153
Groundwater	48	47	41
Total Unmet demand	42	119	199
Irrigation	36	91	136
Urban	4	16	43
Industry	3	12	20

Source: World Bank 2012 and FutureWater 2011

Water Demand Management Options

Several definitions of Water Demand Management (WDM) exists (Grover 2002). In its simplest form, WDM is defined as getting the most of the water we have (Brooks 2007). Other definitions include: "A practical strategy that improves the equitable, efficient and sustainable use of water" (Deverill, 2001) and "The development and implementation of strategies aimed at influencing demand, so as to achieve efficient and sustainable use of a scarce resource" (Savenjie & van der Zaag, 2002). The Global Water Partnerships state that "WDM requires a holistic approach that recognizes the complexity of the inter-relationships among all the factors affecting water demand. It calls for the creation of an enabling environment based on an adequate set of mutually supportive policies and a comprehensive legal framework with a coherent set of incentives and regulatory measures to support these policies" (GWP 2012).

In summary, WDM is about as the adaptation and implementation of a strategy by a government or a water institution to curb the rising water demand in order to achieve sustainability of water supply and services, economic efficiency, social development and environmental protection.

In water scarce regions such as MENA, WDM tries to strike an acceptable balance between limited water resources and increasing water demands, using policy and technical means. Therefore, it involves measures that are taken on the policy, legal, institutional and technical sides. On the policy side, in MENA countries, reform of policies that encourages inefficient water use should be undertaken. And since the agricultural sector is the largest water consuming sector in the MENA region (81% of water use), reform of agricultural policies should be given high priority.

In most MENA countries, food security has been a major concern, particularly for staples, such as wheat. This desire for food security has led many MENA governments to invest substantially in irrigation systems, and subsidize both inputs (such as pumps, irrigation technology, and electricity) and outputs through price support mechanisms (World Bank 2012). This has led to a huge expansion in irrigated agriculture, particularly groundwater-based agriculture which resulted in over exploitation of groundwater in many countries in the region. A reform of agricultural policies is needed to encourage countries to grow more of low water consuming crops that can be exported, while increasing imports of lower-value crops such as staples. Furthermore, all perverse incentives that encourage excessive water use should be abolished.

It is worth mentioning here that some MENA countries have made significant progress in reforming their agricultural policies to reduce water demand and encourage water conservation. In the United Arab Emirates, for example, groundwater mining was practiced on a large scale to irrigate fodder crops. In 2010, the UAE government eliminated subsidies for irrigated Rhodes grass (grown for animal feed) which has significantly reduced its annual agricultural water consumption. Nevertheless, the UAE Water Conservation Strategy published, in 2010 by the Ministry of Environment and Water, concluded that "polices associated with water demand management have not played a large part in the current water strategies of the UAE, but if properly researched and formulated could achieve a significant reduction in both total consumption and related future investments in production capacity and infrastructure". This constitutes a clear indication that there are still ample water demand management options that could be implemented which could curb the rise in water demand in the UAE.

On the technical side, increasing water use efficiency in the agricultural, municipal and industrial sectors should be given the highest priorities. In the agricultural sector, water use efficiency is still between 50 to 60 percent in the MENA region, despite the predominance of modern irrigation systems. This should be increased to more than 80% by using improved irrigation scheduling, management, and technology.

Furthermore, MENA’s physical water losses in municipal and industrial supplies also exceed world averages. These water losses are approximately 30 to 50 percent in some cities, compared to international best practice of approximately 10 percent (World Bank 2012). Strategies to manage domestic water demand should be developed and implemented. These should aim primarily at reducing physical losses (due to leakage) and nonphysical losses (illegal connections, faulty meters, etc.) in the supply side, and reducing water consumption on the demand side using economic tools such ascending block rate structure for water tariff that penalizes excessive water use.

Demand Management is not enough

The impact of several water demand management alternatives was studied and assessed, (including improved agricultural practice, increased reuse of water from domestic and industrial uses, increased reuse of water in irrigated agriculture, expanding reservoir capacity, reduction in irrigated areas; reduction in domestic and industrial demand of water supply, …, etc.), (World Bank 2012). It was concluded that improved agricultural practice is the preferred technical option as it can reduce the “Water Gap” by 55 BCM per annum if this option is implemented in the MENA region.

Needless to say that the applicability of these options may differ from one country to another in the MENA region, as certain alternatives might not be feasible to implement politically or socially. For example, reducing irrigated area is not an easy option to implement politically given the sensitivities surrounding food security in many countries in the region, and governments may chooses to invest in adding new water (through desalination) rather than reducing irrigated area. However, even if all demand management options are implemented, there will still be a water demand gap in MENA countries of approximately 93 BCM. This Gap has to be filled by new water supplies coming from non-conventional water sources, namely desalination and treated wastewater (World Bank 2012).

Treated wastewater is an assured resource and is expected to increase as the population grows. It constitute a reliable water resource that is available all year round and is independent of climate, especially in arid countries such as GCC countries. The potential for domestic water reuse is large in MENA countries, bearing in mind that actual domestic consumption of water accounts for approximately 10 percent of household demand. If only 50 percent of this potential wastewater were recycled, it could add 20–40 BCM per year to MENA's renewable water resources by 2050 (World Bank 2012). However, wastewater treatment and reuse need investment to extend collection and treatment networks. Most important, wastewater recycling needs to be explicitly included in national water planning policies, and well-designed campaigns are needed to ensure the public's acceptance of its use.

Desalination of seawater and brackish groundwater holds significant potential to bridge the water demand gap in MENA. Desalination already plays a critical role in MENA's water supply, particularly for countries in the Gulf region. This role is expected to extend to most countries in the MENA Region by 2050. Seawater effectively is an infinite water resource. Brackish groundwater reserves could be used to support salt-tolerant agriculture and/or be a source of desalinated water. Brackish groundwater reserves in MENA potentially are large, but extensive exploration is required to better define this resource. Desalination of brackish groundwater usually is much cheaper than desalinating seawater—the only alternative to groundwater in most MENA countries. However, for large-scale applications, seawater desalination provides the most obvious solution to MENA's water supply shortage.

Summary and Conclusion

Currently, the majority of countries in the MENA region (17 out of 21) have crossed the Water Scarcity threshold of 1,000 cubic meters of renewable water resources per capita per year. Most of MENA countries suffer from chronic imbalance between available water supply and rising water demand (Demand Gap). This imbalance is expected to worsen even further in the future as a result of sharp population growth, rapid economic development and climate change. The current water demand gap is projected to grow 500%, from 42 BCM per annum to 199 BCM per annum by 2050. Although Demand Management should be given first priority to bridge the Water Gap, however, it will not be able, on its own, to fill this gap. Even if all demand management options are implemented, there will still be a water demand gap in MENA countries of approximately 93 BCM, which should be met by "new" water supplies coming from non-conventional water sources, namely desalination and treated wastewater. Desalination will continue to play a major role in bridging the water gap in MENA region.

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SESSIONs 2A & 2B: GROUNDWATER MANAGEMENT

Keynote

Modeling the Impacts of Climate Change on Groundwater Resources in Arid and Semi-arid Areas

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Abstract:
Climate change poses a significant challenge for the arid and semi-arid areas, affecting and interacting with both environmental and anthropogenic systems in the region. Among the variables of interest are environmental degradation, agriculture productivity, food security, population growth, and economic and societal (in-) stability. In arid and semi-arid regions, agriculture is only feasible with irrigation. Contrary to surface water, groundwater is available all year round, which has made it more and more attractive for agricultural water users to guarantee reliable yield. About one quarter of groundwater pumped worldwide is not replenished by recharge. Falling groundwater tables do not only increase the energy needed for pumping, they also diminish the aquifer's capability to buffer drought years, lead to decline of base flows in streams and possible degradation of water quality. Morocco is one of the most important physical water resources scarcity due to arid and semi-arid conditions in the world; it experiences highly variable rainfall and recurrent droughts. The limited water resources are threatened by increasing demands and accelerated quality degradation. More than 9.5 million people are living in the coastal cities of Morocco and this number is steadily growing. Indeed, in 2015 more than 50% of total population is living in the coastal zone, with an increasing proportion of rural population due to poverty and rural exodus. This situation makes more pressure on many coastal aquifers leading to salinization in the coastal fringe in some catchments in Morocco. These aquifers are located in North-West part of Morocco and are very well known for their role in industrial, economic and social development. Furthermore, in arid areas in the south of the country, groundwater is the only resource that supplies the rural population and the oasis with water for domestic consumption and irrigation. The average of rain decline is due to the impacts of climate change (CC) and causes the recurrent droughts and decreases in recharge, which directly affect the groundwater level. This is coupled with heavy abstraction rates that are used for industrial and drinking water supply for rural and urban areas, and irrigation. This situation has led to a major decline in the groundwater levels and may eventually cause a deficit water balance of the aquifer as well as a degradation of the freshwater quality by seawater intrusion on the coastal plains. Hence, effective management of groundwater resources in these aquifer systems is necessary and taking into account the CC. The key note reviews the existing results and literature on the impacts of CC on water resources, and in some other areas in Morocco, followed by some case studies. Adaptive solutions are also suggested to cope with the vulnerability of CC and the over pumping at the social and technical levels.

Keywords: Global Climate Changes, Recurrent Droughts, Groundwater Levels, Seawater Intrusion, Groundwater Flow Model, Management Scenarios.

Keynote

Groundwater Management in the MENA Region: Challenges and Opportunities for the Future

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Abstract:
Countries in the wider MENA region face major challenges for a longer-term sustainable socio-economic development due to a variety of factors. Such factors include limitations in the availability of natural water resources due to either natural aridity, inter-annual variations in precipitation and multi-year droughts or intra-annual, seasonal fluctuations of precipitation. Some of these physical constraints are further exacerbated by the impacts of climate change; either directly due to higher temperatures and higher evaporation rates or due to changes in the traditional climate and precipitation patterns, especially with regard to the total annual precipitation and / or changes in seasonal precipitation patterns. The future perspectives for water availability under consideration of the possible impacts of climate change are challenging and require special adaptive measures from the local water users to any water-depending activities of the society at large.

Other physical water-related challenges relate to the continuously increasing population, their increasing direct water demands for domestic purposes and changing dietary intakes and preferences that in turn require larger volumes of water for agricultural production locally or through trade with agricultural products and virtual water imports from elsewhere. Also changing consumption patterns for products of the daily life require water either directly for their consumption or indirectly through the production processes that require a good part of water as well as energy resources.

Further challenges arise from the impact of human activities on the quality of water through inadequate wastewater treatment, through agricultural return flows loaded with fertilizers, pesticides and other by-products of intensive agriculture, or through untreated industrial effluents affecting the natural water resources. Thus, water pollution contributes to making water resources less suitable for other uses and as such to a reduction of available water resources, increasing water scarcity by direct human activity.

The physical water scarcity is accompanied by challenges in finding the appropriate governance mechanism to allocate such scarce water resources and optimize its use among competing uses and users for the wider socio-economic benefit of the societies.

To overcome natural water shortages countries have since long invested into various approaches to provide new water or to make water more and longer available by e.g. producing new water through desalination, intercepting and storing runoff, treatment and reuse of effluents. This increased, i.e. stretched out the “water value chain” from the moment a drop of fresh water precipitates to its discharge to the sea. Along this pathway, water has seen many colors and

shades; from blue through green, grey to black that each represent different values of water under the locally given circumstances.

In the region surface water is limited primarily to a few larger rivers that are often transboundary and require special cooperative arrangements among the riparians plus some smaller rivers and non-continuous, intermittent wadi flows. Thus, the sustainable management of the underlying groundwater resources and reserves is considered essential for the fulfilment of the countries' socio-economic development options and aspirations.

Most countries have over the last decades invested in the assessments of their fresh groundwater resources. In some cases, this led to the development of agricultural irrigation plans to fulfil national ambitions for internal food self-sufficiency and even led to agricultural export plans that we know today did not consider longer-term sustainability, especially if these strategies were based on the steady mining of non-renewable groundwater. Similar to the current review of the internal usage of (non-renewable) oil and gas reserves in the region, also the utilization of such non-renewable groundwater reserves became more and more a strategic issues for the long-term development of the countries.

While these transformation processes towards making optimal use of such non-renewable fresh groundwater reserves are still on-going it becomes evident that groundwater also exists with many different levels of qualities, often linked directly to the salinity of the water and age of the reserve. Between fresh and highly saline groundwater resources there are many slightly brackish, brackish to saline mineral contents of groundwater, part of so-called marginal waters that can offer additional water for selected uses. In some cases, such slightly brackish to saline water could become a local alternative input for agricultural production or desalination for either domestic water uses or industries. The presentation intends to raise awareness of the available brackish to saline groundwater resources, its potential uses and related development opportunities, based on some BGR-internal review activities.

Salinity also plays a major role in limiting groundwater uses in coastal and shallow aquifers especially related to over-abstraction of groundwater in coastal settings, i.e. abstractions beyond the natural replenishment or horizontal inflow rates from the upstream hinterland. Many countries have investigated the extent of saline water intrusions or upconing from below and have started developing remedial actions to reduce abstractions and in some cases to replenish aquifers with other surplus water.

Such replenishment or managed aquifer recharge schemes offer opportunities for intermediate storage of fresh water from either desalination surplus periods, treated wastewater that may not be directly reused or storm water run-off / surplus surface water. They also offer ways to improve groundwater freshness by adding fresh water to the aquifers and developing hydraulic barriers against further saline water intrusion. The presentation will address such situations and provide some example solutions from the SubSol (Coastal SUBsurface water SOLutions: www.subsol.org) project in which BGR cooperates jointly with Dutch and other European partners. Solutions such as the "Freshmaker", "ASR Coastal", and "Freshkeeper" offer different approaches to situations in coastal aquifers that require the management of fresh water lenses, the use of partially penetrating wells or to prevent upconing from deeper saline water and could also be applied in given situations in the GCC and other countries in the region.

The continuous challenges for the management of groundwater in the region require suitable and adapted technical and governance approaches that can maximize and optimize the use of fresh and brackish to saline groundwater as well as technological solutions for subsurface groundwater settings in coastal aquifers. Often technologies already exist but need to be adapted to the local settings to provide new local solutions.

Keywords: Water Scarcity, Groundwater, Marginal Water, Brackish Water, Managed Aquifer Recharge.

Keynote

Water Resources Management Challenge in Sudan and Solutions Using Advanced Tools

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Abstract:
The presentation highlights the water resources potentials and opportunities in Sudan, and the challenges facing their management. Few case studies are discussed in which advanced tools for assessment and management were utilized such as hydrological and hydrogeological modeling, Remote Sensing and Geographic Information System (RS/GIS).
Water is of great strategic importance for Sudan's social and economic development. It is also an important trans boundary factor binding Sudan to 14 of its neighbors. Sudan has various water resources; rainfall, the Nile river, groundwater and Wadi systems. The Nile is shared between 12 riparian countries, major groundwater resources are shared with 4 countries and three other large Wadi systems also cross international borders. Some 80% of the currently identified water resources of Sudan come from shared resources. Therefore trans-boundary water resources management is a major challenge for Sudan. Rainfall in Sudan is highly variable and erratic in nature. Such erratic nature of rainfall and its concentration in a short season, places Sudan in a vulnerable situation especially with regards to rain fed agriculture which covers by far the largest area of the country and provides a main source of food security for the country. Historical rainfall data analysis shows a decreasing trend in annual rainfall in most parts of Sudan and a significant shift of the rainfall isohyets southwards leading to increased desertification in the northern parts of Sudan. Climate change has been identified as a main factor causing high variability in hydrological processes and increased frequency of occurrence of extreme events of floods and droughts. Over the past 50 years Sudan has experienced more than 30 floods and droughts that caused widespread damage to various sectors including agriculture, infrastructures as well as human and animal lives. Climate change studies found a strong correlation between such extreme hydrological events and climate change parameter of the Pacific Ocean Sea Surface Temperature (SST) and the associated El Nino and La Nina events. Furthermore, climate change modeling revealed that , if greenhouse gas emissions continue to rise in the same rate (Representative Concentration pathway RCP 8.5), temperature will increase by 3 to 6 degrees over the Sudan by the end of the 21st century. This will result in compounded stress on water resources management, reduced crop productivity, changes in the incidence and geographic range of vector- and water-borne diseases, increased internal and external migration as well as uncertain river flows and food insecurity. Wadi flow is sporadic and varies considerably from one year to another following the erratic nature of rainfall. Wadis constitute an important source of water in areas away from the Nile. However, management of Wadi water resources is a challenging issue due to lack of adequate understanding of Wadi hydrological processes, absence of monitoring networks and information base and inadequate capacity. Sudan has high potential of renewable and non-renewable groundwater resources which are important sources of water supply for domestic, industrial and agricultural uses. Groundwater management in Sudan is faced with many challenges. The most obvious of these challenges is scarcity of information on aquifers geometry and their hydro geological characteristics. Fractured aquifers in Sudan cover very large areas and provide an important source of water particularly in rural areas. A major problem encountered in

the management of fractured aquifers is the limited understanding of their hydrogeology. Vulnerability and risk of contamination of these aquifers from urban, agricultural and industrial activities are also very high. Other key challenges facing groundwater management in Sudan are the management of shared non-renewable aquifer resources, lack of comprehensive guiding plans and policies, poor governance and legislative framework, inadequate capacity, and lack of coordination among groundwater sub sectors.

The case studies to be presented include the use of modeling and RS/GIS for catchment mapping and water resources assessment and management of Wadi Nyala in Darfur, Western Sudan, assessment of the impact of the Grand Ethiopian Renaissance Dam (GERD) on the river-aquifer interaction and groundwater recharge to the Blue Nile groundwater basin in Sudan and management of rising water table in urban centers: case of the Eastern Alluvium aquifer, Riyadh City, Saudi Arabia.

Keywords: Hydrological Variability, Extreme Events, Climate Change, Trans Boundary, Modelling, Groundwater, Water Harvesting.

Hydrochemical Characterization of Groundwater in Sulaibiya and Al-Atraf Wellfields in the State of Kuwait (in Arabic)
التوصيف الهيدروكيميائي للمياه الجوفية في حقلي الصليبية والأطراف في دولة الكويت

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الملخص
تمثل ظاهرة غزو المياه المالحة للمياه الجوفية أحدى أبرز التهديدات المؤدية إلى خسارتها في المناطق الساحلية، وتتفاقم هذه المشكلة في المناطق الجافة لانخفاض معدلات التغذية وتنامي الطلب عليها من القطاعات المختلفة من جانب، وتزايد خطر ارتفاع مستوى سطح البحر بفعل ظاهرة تغير المناخ من جانب آخر. هدف البحث إلى التوصيف الهيدروكيميائي للمياه الجوفية في تكوين الدمام في حقل الصليبية القريب من الساحل، وتبيان أثر عمليات سحب المياه الجوفية والتوسع في حقل الأطراف على ملوحة المياه الجوفية في تكويني الدمام ومجموعة الكويت. تم الاستعانة بالبيانات المتاحة لكميات السحب ونوعية المياه الجوفية من آبار حقل الصليبية للفترة (1954-2014) وآبار حقل الأطراف للفترة (2007-2013) وبمجمل 136 و85 بئر، على التوالي. تم تحليل التغير الزماني والمكاني لمجموع الأملاح الذائبة لكل خمسة سنوات خلال فترة الدراسة، كما تم تحليل نوعية المياه في حقلي الصليبية والأطراف تبعا لنسبة الكالسيوم للمغنسيوم. ولقد تبين بأن إجمالي السحب من حقل الصليبية منذ بدء تشغيله قد زاد عن مليار متر مكعب، وبأن ذلك قد أدى إلى ارتفاع مجموع الأملاح الذائبة من 3000-6000 ملجم/لتر عام 1965 إلى 3000- 9000 ملجم/لتر عام 2000، ثم انخفضت ملوحة المياه المنتجة منه لتصل إلى نحو 2200-5500 ملجم/لتر في عام 2015 بسبب إغلاق 74% من الآبار والبدء في الإنتاج من حقل الأطراف، الذي تراوحت ملوحته مابين 2500-7000 ملجم/لتر طوال فترة السحب من 2007 وحتى عام 2015. ولقد بينت التحاليل الهيدروكيميائية أن اتجاه غزو المياه المالحة للمياه الجوفية كان من جهة الشرق وذلك بناءاً على ارتفاع الملوحة وانخفاض نسبة الكالسيوم للمغنسيوم في الآبار الشمالية عنها في الآبار الشرقية. يوصى البحث بضرورة تقليل كميات السحب من حقل الصليبية واستخدام التغذية الصناعية بمياه الصرف الصحي الفائضة لرفع مستوى المياه الجوفية ودفع الواجهة الملحية، والمراقبة المستمرة لمستوياتها المائية وملوحتها.

الكلمات الدالة: تداخل المياه المالحة، مجموعة الكويت، مكمن الدمام ، التغذية الصناعية، مجموع الأملاح الذائبة.

1. المقدمة
تعتبر المياه الجوفية في المناطق الساحلية شديدة الحساسية للتغيرات في مستويات السحب منها، إذ يؤدي السحب المستمر للمياه الجوفية في المناطق الساحلية إلى انخفاض مستوياتها البيزومترية فتصبح مهددة بخطر غزو مياه البحر، أو مياه مالحة أو شديدة الملوحة في التكوينات الجيولوجية أسفلها (شكل 1). وفي دولة الكويت تمثل ظاهرة غزو المياه المالحة للمياه الجوفية إحدى التهديدات المؤدية لخسارة موارد المياه الجوفية في المناطق الساحلية فيها.

تتواجد المياه الجوفية في دولة الكويت في طبقتين مائيتين رئيسيتين، هما: 1) مكمن تكوين الدمام (Dammam Formation) التابع لمجموعة الاحساء (Hasa Group) والعائدة إلى عصر الباليوسين (Paleocene) - الأيوسن (Eocene) وهو خزان محصور(Confined) بشكل عام؛ و2) مكمن مجموعة الكويت العائد إلى عصر الميوسين (Miocene) - البليوسين (Pliocene) وهو خزان غير محصور (Unconfined) في معظمه. ويتم تغذية خزانات المياه الجوفية في دولة الكويت بواسطة التدفق الأفقي من الخزانات الموجودة في المملكة العربية السعودية، وبنسبة محدودة بواسطة الأمطار القليلة المتساقطة على مساحة دولة الكويت (Fadlelmawla *et al.*, 2009).

تتوفر المياه الجوفية في هذين المكمنين بنوعيات مختلفة تتراوح ما بين مياه عذبة، ومياه قليلة الملوحة، ومياه مالحة، إلى مياه مالحة جداً (Milton, 1967; السليمي وأكبر، 1999). توجد المياه العذبة (أقل من 1000 ملجم/لتر) على هيئة عدسات محدودة الاتساع ضمن مكمن مجموعة الكويت في شمال دولة الكويت في حقلي الروضتين وأم العيش (Salman,1979). أما المياه قليلة الملوحة (1000- 10,000 ملجم/لتر) فتوجد في الأجزاء الجنوبية والجنوبية الغربية من دولة الكويت ضمن طبقات مكمن الدمام ويتم استغلالها في خمسة حقول هي الصليبية والشقايا وأم قدير والوفرة والعبدلية، بالإضافة إلى حقل الأطراف الذي يستمد مياهه

من مجموعة الكويت. وتزداد ملوحة المياه الجوفية باتجاه تدفقها من الجنوب الغربي إلى الشمال الشرقي (شكل 2). أما المياه المالحة والمالحة جداً (تفوق 10,000 ملجم/لتر) فتوجد في مكمني الرس (Rus Formation) وأم الرضمة (Umm Radhuma Formation) الواقعان أسفل مكمن الدمام (Owen and Nasr, 1958).

تعد المياه الجوفية قليلة الملوحة ذات أهمية قصوى لدولة الكويت حيث تعتمد عليها لتغطية احتياجاتها لعدة قطاعات، وتستخدم في أغراض الخلط مع المياه المقطرة والزراعة التجميلية والمنزلية والحدائق العامة (عبدالجواد وآخرون، 2003). وتم تشغيل جزء من آبار حقل الأطراف وذلك لتوفير المياه قليلة الملوحة اللازمة لاعمال الخلط في محطة الصبية وأيضاً للاستخدام في رش الحدائق وأغراض الزراعة التجميلية وسقاية الماشية. وعند مقارنة معدلات سحب المياه الجوفية مع معدلات تغذيتها بواسطة التدفق الجانبي أو بواسطة مياه الأمطار سنجد أنها تفوقها بدرجات عالية، مما يعد تهديداً لاستدامة هذا المورد. ولقد بينت العديد من الدراسات (Sze´kely *et al.*, 2000) إلى أن هناك انخفاض مستمر في المستوى البيزومتري للمياه الجوفية في دولة الكويت مما سيؤدي إلى خسارة هذا المورد الطبيعي الهام.

توجد في دولة الكويت خمسة حقول رئيسية لاستغلال المياه قليلة الملوحة وتتوزع تلك الحقول في أماكن مختلفة من دولة الكويت كما هو مبين في (شكل 3). ويشكل حقلي الصليبية والأطراف (منطقة دراسة البحث) نحو 14% من كمية الانتاج الكلي للمياه الجوفية قليلة الملوحة في دولة الكويت (وزارة الكهرباء والمياه، 2014؛ شكل 4).

ويعد حقل الصليبية أكبر وأقدم الحقول الساحلية انتاجاً للمياه الجوفية قليلة الملوحة في دولة الكويت، ويبعد 10 كم عن جنوب غرب جون الكويت ويتم استخدام المياه المنتجة منه لأغراض الري وكذلك الخلط مع المياه المحلاة التي تزود القطاع البلدي/المنزلي. وبسبب زيادة عدد السكان، زاد الطلب على المياه قليلة الملوحة مما نتج عنه زيادة في كميات السحب من الخزان الجوفي بصورة لا تتساوى مع معدلات التغذية الطبيعية للمياه الجوفية، مما أدي إلى غزو المياه المالحة لمياه الخزان، ومن ثم عدم صلاحيته للاستخدام، خاصة الحقول القريبة من البحر (العتيبي،2005).

يهدف هذا البحث بشكل عام إلى المساهمة في إدارة المياه الجوفية في دولة الكويت من خلال التوصيف الهيدروكيميائي للمياه الجوفية في حقل الصليبية، وفهم وتحديد العلاقة بين تملح المياه الجوفية ومعدلات السحب، مع ووضع الحلول المناسبة لحماية نوعية المياه الجوفية من التدهور.

2. منهج البحث

لتحقيق أهداف البحث تم اتباع المنهجية التالية

1. تجميع ومراجعة الدراسات السابقة ذات العلاقة الهيدروجيولوجية لدولة الكويت ونوعية المياه وظاهرة تداخل المياه المالحة في المنطقة.
2. تجميع البيانات الهيدروكيميائية لحقلي الصليبية من عام 1954-2014 والأطراف 2007-2013.
3. جمع عينات من حقل الصليبية في عام 2015 لـ 11 بئر وإجراء التحاليل الكيميائية لها، نظراً لعدم وجود بيانات متكاملة عن نوعية مياه حقل الصليبية لعام 2015 وبسبب اغلاق أغلب الآبار وتوفر فقط 35 بئر.
4. التوصيف الهيدروكيميائي من خلال جمع البيانات، وتتبع التغير في معدلات الانتاج ومستويات الملوحة، ورسم الخرائط التناسبية لمجموع الأملاح الذائبة لكل خمس سنوات (باستخدام برنامج Surfer12)، وتحليل العلاقة بين تركيز الكالسيوم إلى المغنيسيوم.

3. النتائج والمناقشة

أ. كميات الإنتاج من حقل الصليبية والأطراف مع الزمن

يبين (شكل 5) تذبذب كميات السحب من حقل الصليبية خلال الفترة 1954-2014، حيث بلغت كميات السحب من عام 1954 عند بدء الإنتاج الفعلي من حقل الصليبية نحو 850 ألف متر مكعب، وتضاعفت بعد سنتين من بدء الإنتاج ليصل في عام 1956 إلى 1.8 مليون متر مكعب. وفي عام 1961 ارتفع الإنتاج إلى عشرة أضعاف الإنتاج الأولي ليصل إلى 8.6 مليون متر مكعب، إلى أن بلغ ذروته في عام 1983 ليصل نحو 27 مليون متر مكعب. بعد ذلك حدث انخفاض في الانتاج تباعاً حتى عام 1996 حيث بلغ 15.5 مليون متر مكعب بسبب ارتفاع ملوحة بعض الآبار. ثم بدأ بالتصاعد التدريجي مرة أخرى حتى عام 2002 ليبلغ نحو 25.7 مليون متر مكعب نتيجة لوقف السحب من الآبار ذات الملوحة العالية، وتكثيفه من الآبار ذات الملوحه القليلة. غير أن ذلك أدى إلى زيادة الملوحة في معظم الآبار مما أدى إلى تقليل السحب في الأعوام المتتالية حتى عام 2006، وبعد ذلك بدء الانتاج

الفعلي من حقل الأطراف. حيث بلغ انتاج حقل الصليبية في عام 2007 نحو 16.3 مليون متر مكعب، بينما سجل حقل الأطراف لنفس العام انتاج بمقدار 2.4 مليون متر مكعب.

ب. التغير في قيم الأملاح الكلية الذائبة للمياه الجوفية في حقلي الصليبية والأطراف
تم جمع البيانات المتعلقة بمجموع الأملاح الذائبة في آبار حقل الصليبية خلال الفترة من عام 1965 ولغاية 2015 وبمجمل 3092 قراءة. كانت أعلى قيمة سجلت في عام 1993 من بئر رقم 70 الذي يقع في الجهة الشرقية للحقل وبلغت 10348 ملجم/لتر، وأدنى قيمة سجلت في عام 2014 من بئر رقم 123 الذي يقع في الجهة الشمالية الغربية للحقل وبلغت ملوحته 2236 ملجم/لتر. وبلغ المتوسط الحسابي لملوحة مياه خزان الدمام خلال مجمل فترة الدراسة 4715 ملجم/لتر (جدول 1).

أما بالنسبة لآبار حقل الأطراف فقد تم جمع البيانات المتعلقة لمجموع الأملاح الذائبة في خلال الفترة من عام 2007 ولغاية 2014 والتي وصل عددها إلى 71 قراءة. سجلت أعلى قيمة في عام 2009 من بئر رقم 76 الذي يقع في الجنوب الشرقي من الحقل وبلغت 7061 ملجم/لتر، وأدنى قيمة في عام 2014 من بئر رقم 63 الذي يقع في الجنوب الغربي من الحقل وبلغت ملوحته 2499 ملجم/لتر. وبلغ المتوسط الحسابي لمياه خزان مجموعة الكويت خلال مجمل فترة الدراسة 4428 ملجم/لتر (جدول 1).

ويبين شكل (6) التغيرات التي طرأت على مجموع الأملاح الذائبة لكل من حقلي الصليبية والأطراف منذ بداية الانتاج في عقد الستينات، حيث تراوحت الملوحة ما بين 3000-6000 ملجم/لتر، ارتفعت عند منتصف عقد السبعينات لتتروح ما بين 4000-9500 ملجم/لتر، واستمرت بالارتفاع إلى منتصف عقد الثمانينات وخاصة في بعض الآبار لما فوق 9000 ملجم/لتر. وسجلت أعلى قيمة لمعدل الملوحة في عام 1993 بلغت 10348 ملجم/لتر، ثم انخفضت الملوحة نتيجة لتوقف السحب من بعض آبار حقل الصليبية ذات الملوحه المرتفعة أو اغلاقها، هذا التحسن الطفيف لملوحة مياه حقل الصليبية يعود لبدء السحب من حقل الأطراف الذي حافظ على مستوى الملوحة فيه والتي كانت تحت 7000 ملجم/لتر في معظم الآبار.

يوضح شكل (7) العلاقة بين كميات السحب (متر مكعب) والمتوسط الحسابي لمجموع الأملاح الذائبة (ملجم/لتر). بشكل عام توجد علاقة شبه طردية بين كميات السحب ومتوسط مجموع الأملاح الذائبة بتأثير متأخر وتراكمي في السنوات. ويلاحظ ارتفاع معدلات السحب خلال الفترة 1965-2008 وبزيادة تدريجية في الملوحة خلالها، وثم انخفاض في معدلات السحب خلال الفترة اللاحقة وحتى العام 2015 ونتج عن ذلك انخفاض تدريجي في مستويات الملوحة للمياه المنتجة. أما أعلى قيمة للملوحة فقد رصدت في الفترة الثامنة وبلغت 9256 ملجم/لتر، وأقل قيمة في الفترة الحادية عشر بلغت 2236 ملجم/لتر (جدول 2).

ج. العلاقة بين عنصري الكالسيوم والمغنيسيوم في حقل الصليبية
تعد العلاقة بين الكالسيوم والمغنيسيوم أحدى المؤشرات الهامة والدالة على حصول تداخل مياه مالحة (Mandal and Shiftion,1981)، وتم تطبيقها أيضاً في دراسة على مملكة البحرين في خزان الدمام الجوفي (Zubari,1999). وتم رسم العلاقة بين الكالسيوم والمغنيسيوم ل 3224 عينة من الآبار الواقعة في الجهتين الشرقية والشمالية لحقل الصليبية للفترة 1975-2015 ومقارنتهم مع عينتين من مياه البحر (شكل 8). ويلاحظ من الشكل ارتفاع تركيز الكالسيوم Ca مقارنة مع تركيز المغنيسيوم Mg في آبار حقل الصليبية، وارتفاع عام لمياه حقل الصليبية في قيم الكالسيوم والمغنيسيوم وخصوصاً في الآبار الشرقية مقارنة بنفس الآبار الواقعة في الجهة الشمالية لحقل الصليبية، مما يدل على تداخل المياه في الحقل، كما يبين بأن هناك نزعة لمياه حقل الصليبية نحو مياه البحر ولكنها غير صريحة بشكل كاف.

د. التوصيف الهيدروكيميائي لمكمن الدمام في حقل الصليبية
يبين شكل (9) خرائط تناسبية لمجموع الأملاح الكلية المنتجة من حقول آبار حقل الصليبية لأحدى عشرة فترة متتابعة من فترات استغلال المياه الجوفية، في الفترة الأولى (1966-1965) وتروحت ملوحة مياه الحقل في هذه الفترة ما بين 3300 -6145 ملجم/لتر. (شكل 9 أ). وأظهرت النتائج أن 37 % من آبار المياه ملوحتها ما بين 2000- 4000 ملجم/لتر منتشرة في أجزاء الحقل، ونسبة 62 % من هذه الآبار ملوحتها ما بين 4000– 6000 ملجم/لتر تنتشر في الأجزاء الشمال الغربية والشرقية للحقل، أما الفترة الثانية (1971-1970)، يلاحظ في هذه الفترة زيادة حفر الآبار في الناحية الشمالية الشرقية للحقل، وتراوحت الملوحة في هذه الفترة ما بين 2825-6303 ملجم/لتر، أظهرت النتائج أن نسبة 45 % من الآبار تتروح ملوحتها ما بين 2000- 4000 ملجم/لتر تنتشر في الأجزاء الشمالية والشمال الغربية للحقل، ونسبة 53 % من هذه الآبار تتروح ملوحتها ما بين 4000-6000 ملجم/لتر تتركز في الجهة الشرقية للحقل والبعض منها في الجهة الشمال الغربي، وبئران ملوحتهما أكثر من 6000 ملجم/لتر في الجهة الشرقية. ويلاحظ زحف الجبهة الملحية في الناحية الشرقية لحقل الصليبية التي تبلغ أعلى من 6000 ملجم/لتر مقارنة بالفترة الأولى(1966-1965) (شكل 9 ب).

وفي الفترة الثالثة (1976-1975)، ويبين (شكل 9ج) ارتفاع الحد الأقصى للملوحة إذ بلغت 7550 ملجم/لتر والحد الأدنى للملوحة بلغت 3534 ملجم/لتر. أظهرت النتائج نسبة الآبار ذات الملوحة ما بين 4000-6000 ملجم/لتر بلغت 84% وهي منتشرة في جميع أجزاء الحقل، فيما تراجعت نسبة الآبار التي تتروواح ملوحتها ما بين 2000-4000 ملجم/لتر إلى 9 % تركزت في الأجزاء الغربية للحقل، أما الآبار التي تتروواح ملوحتها ما بين 6000-8000 ملجم/لتر فقد شكلت نسبة 8 % وتركزت في الأجزاء الشرقية، يلاحظ أن الناحية الشرقية لحقل الصليبية تتسم بارتفاع شديد في قيمة الملوحة التي تصل لما فوق 7000 ملجم/لتر مما يدل على زيادة تدهور نوعية مياه الخزان بواسطة غزو المياه المالحة.

تميزت الفترة الرابعة في عام (1980) بالكم الهائل من رصد وتسجيل البيانات، تراوحت الملوحة في هذه الفترة ما بين 3630-7490 ملجم/لتر. ونلاحظ الآبار ذات الملوحة المرتفعة تزيد عن 6000 ملجم/لتر تركزت في الجهة الشرقية لحقل الصليبية مما يؤكد أن مياه حقل الصليبية بدأت بالتدهور. وبلغت نسبة الآبار التي تتروواح ملوحتها بين 4000-6000 ملجم/لتر 82 % من مجمل الآبار في هذه الفترة ومنتشرة في جميع أجزاء الحقل. كما تزداد نسبة الآبار التي ملوحتها ما بين 2000-4000 ملجم/لتر إلى 11 % من مجمل الآبار الحقل تتركز في الجهة الغربية للحقل، أما الآبار التي تتروواح ملوحتها بين 6000-8000 ملجم/لتر بلغت نسبتها 7 % من مجمل الآبار تتركز في الجهة الشرقية من الحقل، ويرجع سبب الزيادة المتسارعة في ملوحة المياه إلى كثافة الضخ في هذا الحقل الذي أدى إلى زيادة تداخل المياه المالحة للخزان (شكل9 د). ويلاحظ أنه بالإضافه إلى زيادة ملوحة المياه في الآبار الواقعة ناحية جهة الشرق، تظهر قيم عالية في منتصف الحقل وخصوصا في الناحية القديمة للحقل بالجهة الشرقية. ويرجع ذلك للتصميم غير الهندسي لمواقع الآبار (Senay,1986) والذي يؤدي إلى ارتفاع معدل هبوط المستويات المائية في منتصف الحقل بسبب التداخل بين هذه الآبار. ويستمر هذا الوضع في جميع الفترات اللاحقة.

أما الفترة الخامسة (1986-1985) وتتروواح الملوحة في هذه الفترة ما بين 3607- 7698 ملجم/لتر. ويلاحظ ارتفاع شديد في الملوحة بالناحية الشرقية، حيث تتركز فيها الآبار ذات ملوحة ما بين 6000-8000 ملجم/لتر والتي تصل نسبتها إلى 15 % من العدد الكلي للآبار. فيما سجلت الآبار التي تتراوح ملوحتها بين 4000-6000 ملجم/لتر نسبة 76 % من العدد الكلي للآبار وتنتشر في جميع أجزاء الحقل. فيما انحصرت الآبار ذات الملوحه المنخفضة بين (2000-4000 ملجم/لتر) والتي تصل نسبتها إلى 9 % في الجهة الغربية من الحقل (شكل9 هـ). ويلاحظ انخفاض معدلات السحب في عام 1985، وذلك لقرب المسافات بين الآبار المحفورة أدى ذلك إلى التداخل المخروطي للمستويات المائية الجوفية وانخفاض المستويات البيزومترية باتجاهين الرأسي والعمودي (Senay,1986). الفترة السادسة (1990) تتروواح الملوحة في حقل الصليبية ما بين 3428- 8486 ملجم/لتر واستمر ارتفاع الملوحة في الناحية الشرقية للحقل وبدء ظهور قيم تزيد عن 8000 ملجم/لتر حيث سجل بئر رقم 70 أعلى ملوحة بلغت 8486 ملجم/لتر. فيما بلغ نسبة الآبار التي تتروواح ملوحتها ما بين 6000-8000 ملجم/لتر نحو 7 %. مما يدل على حدوث تدهور وتملح عام لنوعية لمياه الخزان في هذه الفترة بسبب انخفاض المستويات المائية لخزان الدمام وهجرة المياه المالحة من النطاقات السفلى رأسياً إلى خزان الدمام وتلوث مياهه ويؤكد هذا ما أشار اليه (العنزي، 2014). أما بقية الآبار المنتشرة في الحقل فقد تراوحت ملوحتها ما بين 4000-6000 ملجم/لتر وتشكل نسبة 77 % من العدد الكلي للآبار. أما الآبار ذات الملوحة المنخفضة فتوجد في الجهة الشمالية والشمال الغربية من حقل الصليبية وتتروواح ملوحتها ما بين 2000-4000 ملجم/لتر بنسبة 14% (شكل9 و).

الفترة السابعة (1996-1995)، حيث تم اغلاق بعض الآبار الشرقية لارتفاع ملوحتها، تتروواح ملوحة الآبار ما بين 3678-8164 ملجم/لتر. وبلغت نسبة الآبار التي تتروواح ملوحتها ما بين 4000-6000 ملجم/لتر نحو 75% من مجمل الآبار وتنتشر في جميع أجزاء الحقل. فيما بلغت نسبة الآبار ذات الملوحة المنخفضة ما بين 2000-4000 ملجم/لتر نحو 9% من جملة الآبار ويتركز وجودها في الأجزاء الشمالية للحقل. أما الآبار ذات الملوحة المرتفعة فتتركز في الجهة الشرقية من الحقل، حيث بلغت نسبة الآبار التي تتروواح ملوحتها بين 6000-8000 ملجم/لتر 14% من مجمل الآبار، فيما سجل بئراً واحداً مستوى ملوحته عالي جداً وصلت قيمته إلى 8164 ملجم/لتر (شكل 9 ز). ويلاحظ ارتفاع مستمر للملوحة في الناحية الشرقية بالحقل مما يدل على تدهور للخزان وحدوث تداخل للمياه المالحة لمياه الخزان بسبب استمرار الضخ المفرط من الطبقات المائية في خزان الدمام، وفي عام 1996 انخفضت كميات السحب للمياه الجوفية من خزان الدمام في حقل الصليبية نتيجة لارتفاع الملوحة في بعض الآبار.

أما الفترة الثامنة (2001-2000)، حيث تم اغلاق 50% من آبار حقل الصليبية، وتبين أن الملوحة تتروواح ما بين 3340- 9256 ملجم/لتر. وكانت نسبة الآبار التي تروواحت ملوحتها ما بين 4000-6000 ملجم/لتر إلى 67 % منتشرة في جميع أجزاء الحقل، فيما بلغت نسبة الآبار ذات الملوحة المنخفضة ما بين 2000-4000 ملجم/لتر 14% وتتركز في الجهة الجنوبية الغربية للحقل. أما الآبار التي سجلت ملوحة مرتفعة فتركزت في الجهة الشرقية، حيث تراوحت الملوحة فيها ما بين 6000-8000 ملجم/لتر وشكلت نسبة 13 % من مجمل الآبار، أما الآبار التي تراوحت ملوحتها ما بين 8000-10000ملجم/لتر فبلغت نسبتها 6 %

(شكل9 ح). خلاصة هذه الفترة يتبين أن هناك تملح واضح لمياه الخزان من الناحية الشرقية وتدهور ملموس في مجموعة محدودة من الآبار في الجهة الشرقية التي أدت لأغلاقها ووقف السحب منها، وهي بئر رقم 62 الذي يقع في الجهة الشرقية للحقل حيث وصلت ملوحته في عام 2000 إلى 9040 ملجم/لتر ولم يتم استخدام هذا البئر بعد هذه الفترة، وبئر 64 الذي وصلت ملوحته إلى 8256 ملجم/لتر في عام 2000 وتوقف السحب منه في عام 2004 بسبب ارتفاع الملوحه فيه؛ وبئر رقم 70 الذي وصلت ملوحته إلى 9256 ملجم/لتر في عام 2000 وتوقف السحب منه لمدة 14 عام.

في الفترة التاسعة (2006-2005)، يلاحظ أن هناك انخفاض واضح في عدد الآبار المسجلة، اذ تم اغلاق 60 % من آبار حقل الصليبية، تتروح الملوحة فيها ما بين 3234-7983 ملجم/لتر. ووصلت نسبة عدد الآبار التي تتروح ملوحتها ما بين 4000-6000 ملجم/لتر إلى 52 % من مجمل الآبار تنتشر في الغالب للجهة الشرقية للحقل. أما الآبار ذات الملوحة المنخفضة ما بين 2000-4000 ملجم/لتر فبلغت نسبتها 25 % ويتركز وجودها في الجهة الشمالية للحقل. الآبار ذات الملوحه المرتفعة ما بين 6000 -8000 ملجم/لتر، فقد تركزت في الجهة الشرقية من حقل الصليبية، وبلغت نسبتها نحو 23 %من مجمل الآبار. فيما لم يسجل اي بئر خلال هذه الفترة ملوحة تفوق 8000 ملجم/لتر (شكل 9 ط). ويعود سبب انخفاض الملوحة التدريجي من الناحية الشرقية للحقل لتصل إلى اقل من 8000 ملجم/لتر إلى تقليل كميات السحب من الخزان واغلاق الآبار ذات الملوحة المرتفعة.
الفترة العاشرة (2010) نظراً لاغلاق بعض الآبار الشرقية لارتفاع ملوحتها، وتروواحت الملوحة في هذه الفترة بين 4100-6990 ملجم/لتر. سجلت الآبار التي تتروواح ملوحتها ما بين 4000-6000 ملجم/لتر نسبة 77% من مجمل الآبار منتشرة في جميع الأجزاء الشرقية للحقل. ومازال هناك آبار ملوحتها مرتفعة تتركز في الجهة الشرقية، حيث تصل نسبة الآبار التي تتروواح ملوحتها ما بين 6000-8000 ملجم/لتر إلى 23% من مجمل الآبار (شكل9 ي). ويرجع انخفاض الملوحة لتصل لأقل من 8000 ملجم/لتر مما أدى إلى حدوث تحسن بدرجة ملوحة الخزان بسبب اخفاض السحب واغلاق بعض الآبار ذات الملوحة المرتفعة.

خلال الفترة الحادية عشر (2013-2015)، 2015. ويلاحظ هنا انخفاض شديد في عدد الآبار المسجلة، حيث تم اغلاق نحو 74% من آبار حقل الصليبية. وقد تروواحت ملوحتهم بين 2236-5544 ملجم/لتر. سجلت الآبار ذات الملوحة التي تتروواح ما بين 4000-6000 ملجم/لتر نسبة 18% من مجمل الآبار تركزت في الجهة الشرقية من الحقل، فيما ارتفعت نسبة الآبار ذات الملوحة المنخفضة ما بين 2000-4000 ملجم/لتر لتصل إلى 82% تركزت في الجهة الجنوب الشرقية والجنوب الغربي والشمال الغربية من حقل الصليبية (شكل9 ك) فيما بدأت ملوحة مياه حقل الصليبية بالانخفاض من الناحية الشرقية لتصل إلى اقل من 6000 ملجم/لتر، وذلك بسبب انخفاض كميات السحب، والتوجه بالإنتاج لحقل الأطراف واغلاق الآبار ذات الملوحة العالية.

4. الاستنتاجات
تتطلب الادارة المستدامة للمياه الجوفية موازنة كميات السحب من الخزان مع كمية التغذية للخزان لتحقيق أكبر مردود منه بأقل تكلفه ودون حدوث أضرار فيه، كما أن المياه الجوفية تمثل مخزوناً استراتيجياً يمكن الاستعانة به في حالات الطوارئ. ولذا، يجب العمل على ضمان استدامة هذه المياه في خدمة أهداف التنمية والأجيال القادمة، وذلك من خلال تخفيض معدلات السحب منها لتساوي معدلات تغذيتها الطبيعية وبالتالي تحسين ملوحتها لتزداد جاهزيتها للأستخدام المباشر.

هناك علاقة وثيقة بين كميات السحب والملوحة، وبشكل عام توجد علاقة شبه طردية بين كميات السحب ومتوسط مجموع الأملاح الذائبة بتأثير متأخر وتراكمي في السنوات ويلاحظ ارتفاع معدلات السحب خلال الفترة 1965-2008 وبزيادة تدريجية في الملوحة خلالها، وثم انخفاض في معدلات السحب خلال الفترة اللاحقة وحتى العام 2015 ونتج عن ذلك انخفاض تدريجي في مستويات الملوحة للمياه المنتجة.

تبين من خلال التوصيف الهيدروكيميائي لمياه خزان الدمام الجوفي في حقل الصليبية، تم تقسيم المراحل الزمنية لإحدى عشر فترة زمنية لتتبع ملوحة مياه حقل الصليبية للأعوام (1965-2015) لكل خمس سنوات لتتبع ملوحة مياه حقل الصليبية للأعوام (1965-2015) من خلال الخرائط التناسبية، أن مجموع الأملاح الذائبة لعينات المياه الجوفية في حقل الصليبية والأطراف كان يزداد بزيادة السحب، وأظهر البحث أن كميات السحب التي تعرض لها خزان الدمام في حقل الصليبية خلال 57 سنة قد أدت لاستنزاف كبير لمياهه وأدت إلى تملح معظم آباره. وعندما تم تخفيض كميات السحب واغلاق الآبار المتملحة والتوجه للانتاج من حقل الأطراف فبدأت الملوحة بالتحسن. وتبين أن ملوحة المياه المنتجة من حقل الصليبية كانت في زيادة مستمرة منذ الأعوام (1965-1966) حتى الأعوام (2000-2001)، ثم بدأت بالانخفاض التدريجي بعد ذلك.

بدراسة العلاقة بين عنصري الكالسيوم والمغنيسيوم، والعلاقة بين التوصيل الكهربائي والكلور في حقل الصليبية، تبين أن مياه خزان الدمام الجوفي في حقل الصليبية تتعرض لتداخل مياه مالحة من الجهة الشرقية.

5. التوصيات

للحد من ظاهرة تداخل المياه المالحة للمياه الجوفية وضمان استدامتها يوصى بالتالي:

1. رفع مستوى المياه الجوفية في الحقل لدفع الواجهة الملحية عن الحقل، ويمكن عمل ذلك من خلال زيادة مخزون المياه الجوفية وتحسين ملوحته بواسطة التغذية الصناعية للمياه الجوفية من مياه الصرف الصحي المعالجة رباعياً التي تنتج من محطة الصليبية، وخصوصا أنها تحتوى على مياه ذات نوعية أقل في مجموع الأملاح الذائبة عن مياه الخزان الجوفي.
2. تقليل كميات السحب من حقل الصليبية بواسطة إحلال المياه المعالجة رباعيا محل المياه المستخدمة من الخزان الجوفي في الزراعة وترشيد استخدام المياه الجوفية في الزراعة.
3. المراقبة المستمرة لمكامن المياه الجوفية كما ونوعا من خلال شبكة مراقبة مستمرة ومراقبة معدلات السحب منها مع تكثيف المراقبة للحقول التي زادت ملوحتها بهدف حمايتها.
4. إعطاء المياه الجوفية قيمة اقتصادية للمساهمة في استخدامها بكفاءة ويقتضي ذلك وضع نظام تسعيرة مائية تصاعدية بحسب كميات الاستهلاك ونوع الاستخدام، مع مراعاة فئات المستهلكين ذات الدخل المنخفض.

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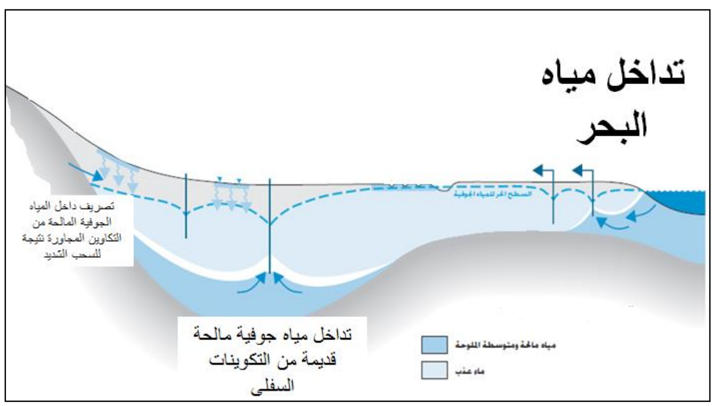
جدول (1): التحليل الإحصائي لمجموع الأملاح الذائبة في حقل الصليبية من عام 1965-2015 وحقل الأطراف من عام 2007-2014 (مصدر البيانات: وزارة الكهرباء والمياه، 2015)

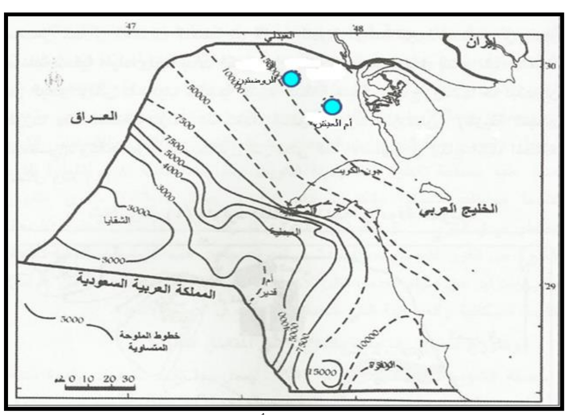
	حقل الأطراف	حقل الصليبية
عدد العينات	71	3092
أدنى قيمة	2499	2236
أعلى قيمة	7061	10348
المدى	4562	8112
المتوسط الحسابي	4428	4715
الانحراف المعياري	1048	1002

جدول (2): مجموع الأملاح الذائبة لأحدى عشر فترة زمنية التابعة لحقل الصليبية

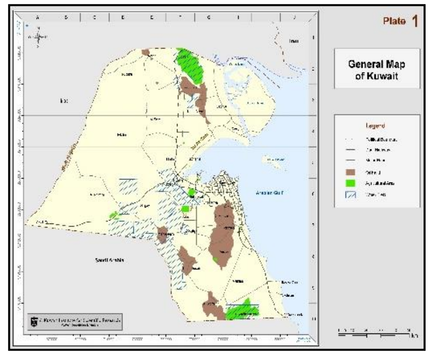
الفترات	الفترة الاولى	الفترة الثانية	الفترة الثالثة	الفترة الرابعة	الفترة الخامسة	الفترة السادسة	الفترة السابعة	الفترة الثامنة	الفترة التاسعة	الفترة العاشرة	الفترة الحادية عشر
السنوات	1965 – 1966	1970 - 1971	1975 – 1976	1980 – 1981	1985 – 1986	1990	1995 – 1996	2000 – 2001	2005 – 2006	2010	2013 - 2015
عدد الآبار	86	105	104	104	98	97	85	57	52	22	33
أعلى قيمة ملجم/لتر	6145	6303	7550	7490	7698	8486	8164	9256	7983	6990	5545
أقل قيمة ملجم/لتر	3300	2825	3534	3630	3607	3428	3678	3340	3234	4100	2236
المتوسط الحسابي ملجم/لتر	4367	4259	4753	4742	4943	4736	4973	5044	4965	5252	3267



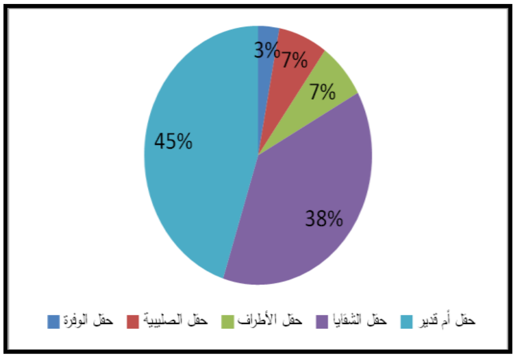
شكل (1): ظاهرة تداخل ماء البحر والمياه الجوفية المالحة مع خزانات المياه الجوفية العذبة (البنك الدولي، 2006).



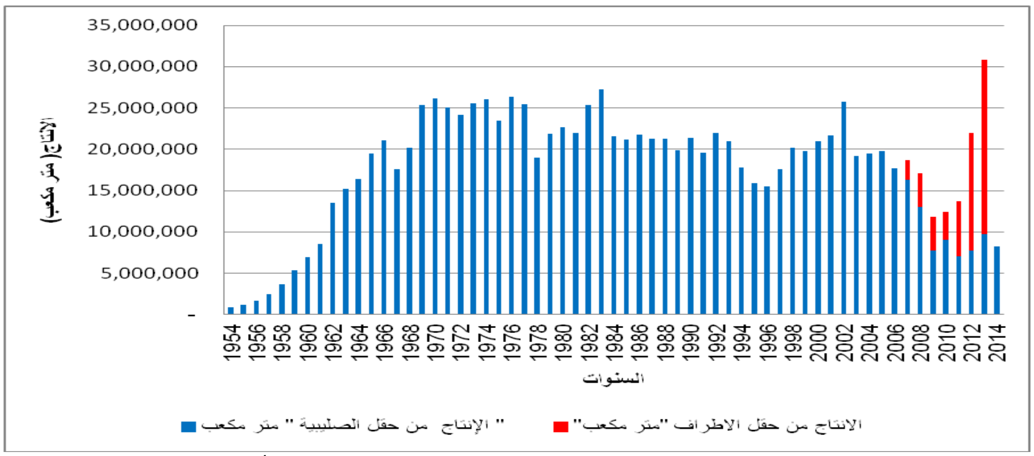
شكل (2): خطوط الملوحة في المياه الجوفية لمكمن الدمام مع موقع حقول أم العيش والروضتين والصليبية والشقايا وأم قدير والوفرة والعبدلية (Kwartengm,2002).



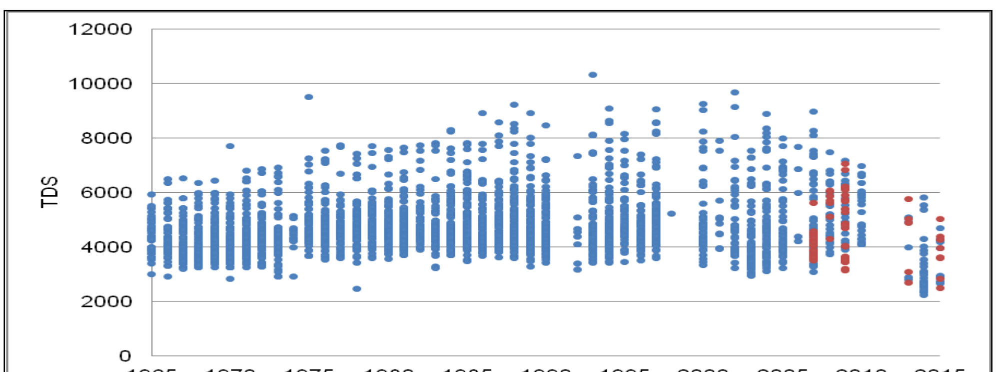
شكل (3): مواقع الحقول الرئيسية المنتجة
للمياه قليلة الملوحة في دولة الكويت



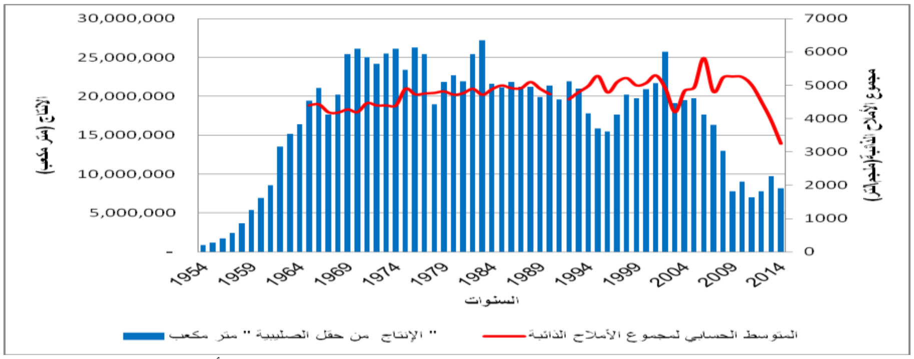
شكل (4): انتاج المياه قليلة الملوحة في دولة االكويت عام
2014 (مصدر البيانات وزارة الكهرباء والمياه، 2014)



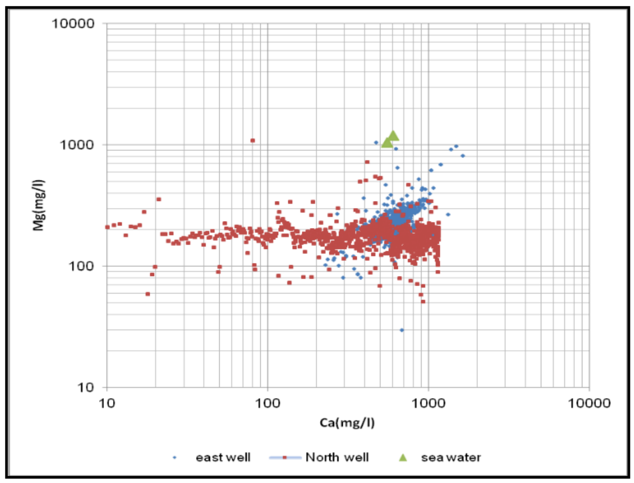
شكل (5): كمية الانتاج (متر مكعب) من حقل الصليبية من عام 1954 -2014 ومن حقل الأطراف من عام 2007-2013
(مصدر البيانات: وزارة الكهرباء والماء، 2014)



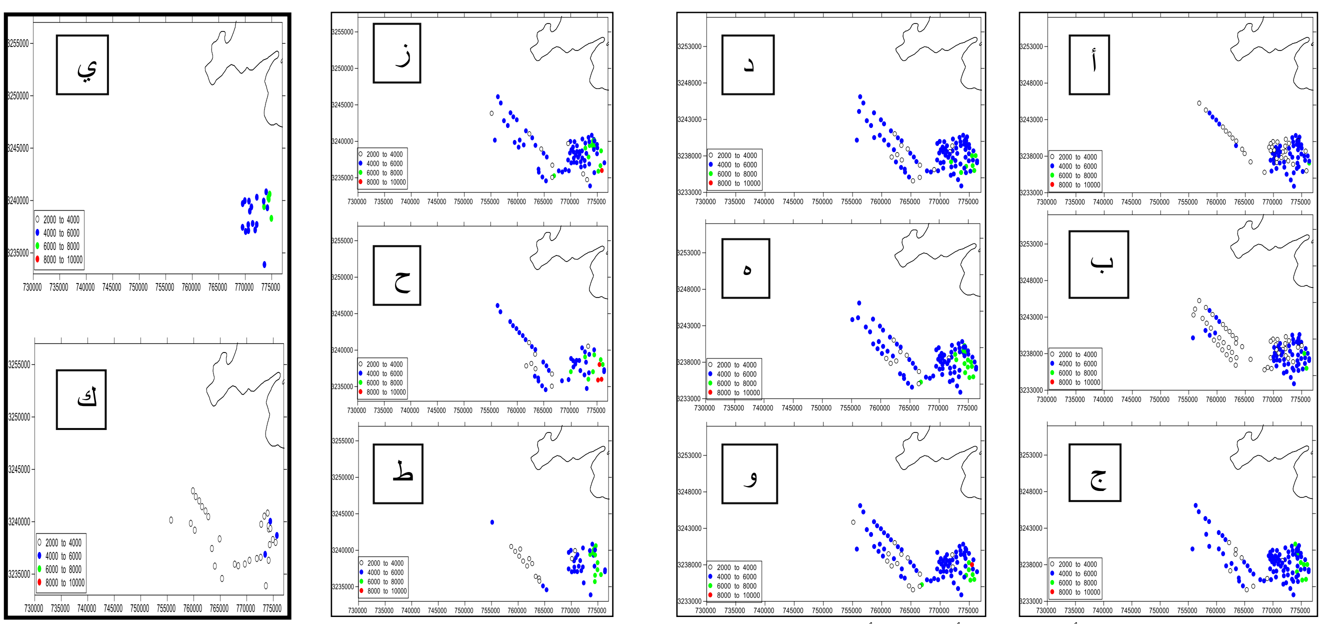
شكل (6): مجموع الأملاح الذائبة (TDS) ملجم/لتر في حقل الصليبية من عام 1965-2015 وحقل الأطراف من عام 2007-2014.



شكل (7): العلاقة بين كميات السحب (متر مكعب) والمتوسط الحسابي لمجموع الأملاح الذائبة (ملجم/لتر)



شكل (8): العلاقة بين الكالسيوم والمغنيسيوم لكل الآبار الشرقية والشمالية في حقل الصليبية من عام 1975- 2015 مع عينة من مياه بحر.



شكل (9): توزيع مجموع الأملاح الذائبة (أ) الفترة الأولى (1965-1966)- (ب) الفترة الثانية (1970-1971)- (ج) الفترة الثالثة (1975-1976)- (د) الفترة الرابعة (1980)- (هـ) الفترة الخامسة (1985-1986)- (و) الفترة السادسة (1990)- (ز) للفترة السابعة (1995-1996)- (ح) الفترة الثامنة (2000-2001)- (ط) الفترة التاسعة (2005-2006- (ي) الفترة العاشرة (2010)- (ك) الفترة الحادية عشر (2013-2015) في حقل الصليبية

Impacts of Anthropogenic Activities on the Groundwater Resources of Northern Kuwait

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Abstract
A study was carried out to understand the possible extent and intensity of anthropogenic activities, including damages to the oil wells caused from the 1991 Gulf War and subsequent military operations, and increased human activities on the natural environment of northern Kuwait and their consequences on the groundwater resources that exist in that area. The investigations on the effects of human activities on the groundwater were carried out along several lines. These included (i) examination of remotely sensed data (satellite images) to identify areas that had experienced significant anthropogenic activities, (ii) infiltration and penetration tests to assess the effects of these activities on vertical conductivity and the state of consolidation of soil respectively; (iii) measurement of rainfall to assess its quantity, intensity and variability; (iv) collection and chemical analysis of surface runoff samples to estimate the runoff volume and its chemical quality; (v) measurement of groundwater levels; (vi) and collection and chemical analysis of groundwater samples to evaluate the effects of rainfall and runoff on potentiometry and quality of groundwater. The recourse to computer modeling was taken in the estimation of recharge on a regional scale over the study area. The Soil and Water Assessment Tool (SWAT) model provided estimates of the various partitions (e.g., runoff, recharge, transmission losses, and evaporation) of the hydrologic cycle. A digital elevation model (DEM) was used to define the distribution of watersheds and stream networks, as well as geometric properties. This DEM was produced from satellite images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). This paper presents the main findings and conclusions of the study.

Keywords: Monitoring Wells, Measurements, Rainfall, Soil, Intensity, Assessment.

Introduction
Northern parts of Kuwait host significant reserves of fresh and brackish groundwater that are of strategic importance for the water-starved country. The damages to the oil wells caused from the 1991 Gulf War, subsequent military operations and increased human activities in these areas after the end of the military operations have affected and are continuing to affect the natural environment of the area. These in turn are expected to have adverse impacts on the groundwater reserves of this area. A study was carried out to understand the possible extent and intensity of these impacts on groundwater.

The study area has a general slope towards the northeast with two depressions, Raudhatain and Umm Al-Aish, breaking the general trend (Fig. 1). A large number of dry river channels ('wadis') terminate in these depressions and carry surface (and subsurface) runoff to these depressions whenever there are some high intensity rainfall events in this area (Al-Sulaimi and Mukhopadhyay, 2000). The depth to groundwater increases towards the northeast with closed contours under the depressions of Raudhatain and the Umm Al-Aish. The cones of depression at the southwestern part of the Raudhatain depression and in the Abdally Farm area, created due to the exploitation of groundwater in these areas, were found to be significant. Though on a regional scale, groundwater's total dissolved solids (TDS) increases towards the northeast; good quality (TDS $\leq$ 2000 mg/l) water exists in and around the Raudhatain and Umm Al-Aish depressions. Furthermore, the usable quality of water (5000 mg/l $\geq$ TDS $\geq$ 2000 mg/l) is present beyond the periphery of these two depressions, its geographic distribution suggesting recharge along the main wadi system that extends to the southwest from these depressions. The main recharge, however, takes place within the depressions as indicated by the presence of freshwater (TDS $\leq$ 2000 mg/l) there.

The investigations on the effects of human activities on the groundwater were carried out along several lines, which included the examination of remotely sensed data (satellite images) to identify areas that had experienced significant anthropogenic activities; infiltration and penetration tests to assess the effects of these activities on vertical conductivity and the state of consolidation of soil, respectively; measurement of rainfall to assess its quantity, intensity and variability; collection and chemical analysis of surface runoff samples to estimate the runoff volume and its chemical quality; measurement of groundwater levels; and collection and chemical analysis of groundwater samples to evaluate the effects of rainfall and runoff on potentiometry and quality of groundwater.

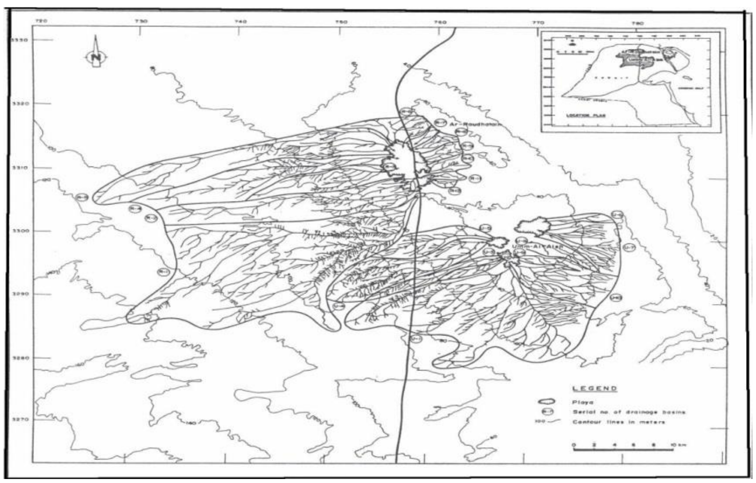

Fig. 1: Al-Raudhatain and Umm Al-Aish Depressions and the associated wadi system with catchment boundaries.

Field Investigations and Major Findings

One of the main activities in this study was measurement of groundwater levels using monitoring wells. The obtained results suggest that, with the correction for barometric pressure, water level variations with time become much more subdued, hence very little indication of rise in water level with rainfall incidents is observed in most of the wells. For ease of understanding and since recharge varies from point to point depending on the rainfall runoff volume passing through the point, surface water application for irrigation and other purposes, and local vertical hydraulic conductivity, the whole study area was divided into several zones, including topographic depressions, peripheral areas of topographic depressions, inter-wadi areas, wadis, and agricultural area of Abdally.

It was observed that at the centers of the depressions, high intensity rainfall was often associated with a sharp rise in water level. A gentler water level rise was also observed, possibly due to the long-term effect of slow percolation of rainfall runoff at the center of the depression. The effect of rainfall on groundwater level at the periphery of the depressions was found to be slight, even when rainfall intensity was relatively high. In the areas between the wadis, especially when the depth to water was more than 100 m, the effects of rainfall on the water levels was hardly significant, the order of changes being less than 0.05 cm. The shallow (depth < 20 m) groundwater in the Abdally Farm area displays sinusoidal change in level with season that may be related to both the infiltration of rainfall and increased return water from irrigation during winter.

All the monitoring wells drilled on the wadi bed were located in the upper reaches of the wadi system, and when depth to water was more than 100 m, the rainfall possibly had very little effect on the water levels. Lowering of water level, observed in some of the wells, could be related to the production from the Raudhatain Water Bottling Plant well that exploits the freshwater lens and other wells that supply water for military installations and for the exploration and production operations carried out by the Kuwait Oil Company (KOC) in this area. The decrease in electrical conductivity (EC) with the rise in water level in a few of the wells could be related to the infiltration of rainfall with lower salinity, whereas the opposite trend (increase in EC with the rise in water level) could be due to the higher load of salt collected from the soil in the infiltrating rainwater in the polluted areas. Increases in EC with time in some of the other wells were attributed to the lateral movement of higher salinity water due to the increased hydraulic gradient caused by groundwater production in the neighboring areas.

Infiltration and penetration tests were carried out at nine locations within the study area (Plate 1). In general, the infiltration rate increased with the penetration rate suggesting better permeability for soil that allowed higher penetration rate. It could further be observed that most of the low penetration rates (suggesting harder soil) and low infiltration rates (suggesting lower permeability) were associated with areas with mud tracks and animal dwellings, those impacted with oil pollution and those that had experienced military activities. Pristine soil, unaffected by any of the aforementioned activities, generally showed higher penetration and infiltration rates. The high infiltration rates appear to occur outside the depressions. The centers of the depressions are generally characterized by lower infiltration rates, possibly due to the accumulation of finer sediments present on the surface.

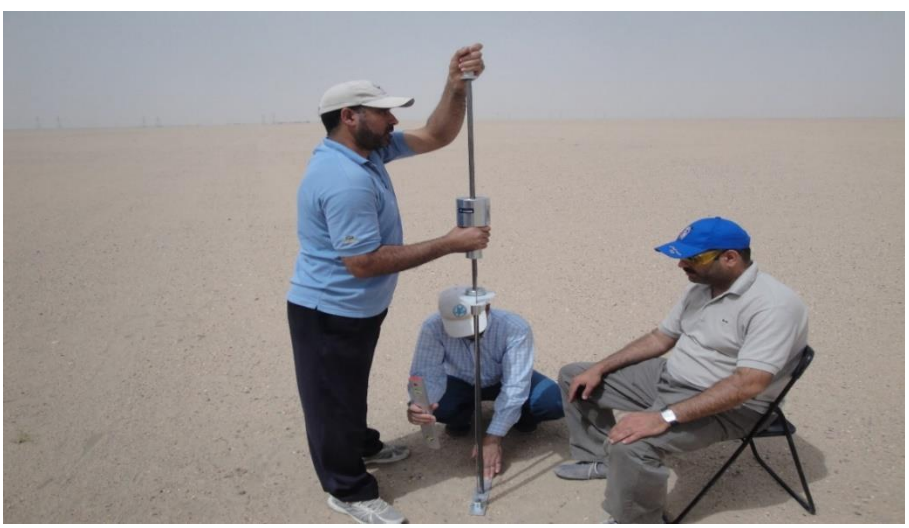

Plate 1: Dynamic cone penetrometer testing at an apparently undisturbed soil in the Al-Raudhatain depression

Soil samples were collected from the sites where penetration and infiltration tests were performed, and chemical analysis of the soil extracts was carried out. The soils from areas with no human activities were characterized by lower values of TDS, total organic carbon (TOC), sulfate, nitrate, and nitrite. Soil from the area with military activities was characterized by high TDS (> 2500 mg/l) and sulfate contents (> 1500 mg/l). Animal dwelling sites had the highest TOC value, followed by oil-impacted soil. TDS, sulfate, nitrate, and nitrite contents were significantly higher at the animal dwelling site and in the soils from mud tracks. Apart from high TOC, oil-impregnated soils had comparatively higher nitrate and nitrite contents. The high values of TDS, TOC, nitrate, and sulfate in the soils affected by various aforementioned human activities would be expected to contaminate the surface runoffs in these areas and should affect the groundwater quality when these runoffs infiltrate to the groundwater table.

From the results of analysis of the rainfall and runoff samples collected from the study area, not much correspondence between the chemical quality of the runoff and that of underlying groundwater was discernible. This was expected because recharge from the rainfall runoff was mainly confined to the two main depressions in the area and to a limited extent along the wadis. Lower values of TDS, TOC, and sulfate for both the runoff samples and the groundwater samples in the Raudhatain depression indicated possible recharge in this area. The higher values of these parameters in the runoff samples collected in the vicinity of the Umm Al-Aish depression suggested contaminations derived from the soils polluted by oil and salt from the seawater used for firefighting. The underlying groundwater was also locally enriched in these parameters suggesting recharge by the polluted runoff.

The concentrations of stable isotopes oxygen 18 (^{18}O) and deuterium (^{2}H) were determined for the monitoring wells. The inferences made from these data were as follows:

- Along the wadis, underlying groundwater had isotopic composition similar to that of the runoff water samples suggesting that these areas received recharge from rainfall.
- Groundwater in the Umm Al-Aish and Raudhatain depressions and on the southwestern slope of the Abdally depression had similar isotope concentrations as the runoff water samples nearby, supporting the hypothesis of recent recharge at these locations.
- In the inter-wadi areas and away from the depressions, the groundwater had isotopic characteristics (richer in oxygen-18 isotope) different from the recent runoff water samples, suggesting little interaction between the two types of water.

The recourse to computer modeling was taken in the estimation of recharge on a regional scale over the study area. The Soil and Water Assessment Tool (SWAT) model provided estimates of the various partitions (e.g., runoff, recharge, transmission losses, and evaporation) of the hydrologic cycle. A digital elevation model (DEM) was used to define the distribution of watersheds and stream networks, as well as geometric properties. This DEM was produced from satellite images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (Al-Dousari and Uddin, 2010). Geologic and soil maps, available from previous studies, were used for mapping the geology, soil, and land use types. Rainfall data were obtained from the Tropical Rainfall Measuring Mission (TRMM). The needed meteorological data were obtained from various internet sources. Infiltration rates obtained through field tests were used. Natural recharge in 2009 was estimated as 4.3% of the precipitation, and mean annual recharge for the decade 2000 to 2009 as 3.9% of the precipitation for both Northern (Raudhatain) and Central (Umm Al-Aish) catchments. The mean annual natural recharge was estimated at 18 x 10^6 m^3 and 13 x 10^6 m^3 for the Northern (Raudhatain) and Central (Umm Al-Aish) catchments respectively. Other researchers, using a similar methodology for the same catchments, obtained a figure of 5.6 and 3.6% for the period 1998 to 2006 for the Northern and Central catchments respectively, and indicated that conservative estimates of the annual recharge for the both investigated watersheds amounted to approximately 50 x 10^6 m^3. The modeled annual recharge volumes were low, of the order of 2.9 x 10^{-4} of the total amount of groundwater stored in the ground to a depth of 30 m or 0.007 of the total amount of groundwater with TDS < 1500 mg/l stored in this layer.

Twenty potential locations (size: 1 to 75 km^2) for freshwater lens development were identified in northern Kuwait, and continuous rainfall-runoff models (SWAT) were applied to provide a first-order estimation of the average annual recharge in the catchment (127 x 10^6 m^3) and freshwater lenses (8.17 x 10^6 m^3). Since there were no long-term rainfall data in the study area, the recharge modeling for the study area, Raudhatain and Umm Al-Aish catchments, was based on rainfall data of the Kuwait International Airport for the period 1965 to 2012. A general runoff and stream flow routing program (RORB), was used for estimating natural recharge from the total amount of annual rainfall (R) and (R-IL), where IL stands for initial loss estimated from the infiltration test results. Based on the infiltration tests, the study area was divided into six areas, which either shared similar recharge potential and/or were of specific interest for the purpose of this study. Both modeling runs used runoff coefficient (Rc) = 0.07, and the resulting mean annual recharge was 51,569,503 and 29,727,219 m^3 for the (R) and (R-IL) runs respectively. These volumes are in close agreement with those presented by earlier researchers.

Both precipitation and temperature in Kuwait show a positive (increasing) trend for the period 1962 to 2012. These two most important determinants of the climate have an opposite effect on the natural recharge. Provided that increases in precipitation follow an established rainfall intensity, frequency, and duration patterns, the net increase in precipitation leads to an increase of natural recharge. Increased temperatures, however, lead to increased evaporation and transmission losses, and in effect reduce the natural recharge. It is somewhat uncertain how the interplay of these two factors will determine the future scale of recharge in north Kuwait as the climate change takes hold.

An attempt was made for assessing the effects of climate change on groundwater recharge in the study area under different climate change scenarios (Kotwicki and Sulaimani, 2009). It was found that in the Arabian Peninsula, there were significant uncertainties on the percentage change of quantity of groundwater recharge and even the sign of change. As reported in literature, for 75% of all considered cases of soil, vegetation, and climate types in Australia, recharge elasticity varies between 2 and 4, indicating a 20 to 40% change in recharge for a 10% change in annual rainfall. Similar variability was expected in Kuwait as well.

In summary, in the study area, recharge from rainfall mainly takes place in the two depressions and to some extent, along the wadis. Human interferences like animal rearing, grazing, off-road driving, military activities and pollution from oil industry can consolidate the soil surface and reduce the recharge rate. Additionally, these activities pollute the soil with different types of contaminants that can be leached by the infiltrating runoff and carried to the groundwater. Both these consequences will have negative effects on the usable (both fresh and brackish) groundwater accumulations within the study area. Judicious control of human activities within this fragile area is, therefore, called for. The current study can provide the baseline data for monitoring the long-term effects of these activities (including those caused by the climate change) on the recharge rates and the groundwater quality, which will lead to the effective measures for protecting the valuable groundwater resource. Based on the observations made in this study, the wadis and the depression and their vicinities should be avoided as much as possible for carrying out any form of human activity that may cause soil pollution and reduction of soil permeability, as these are the areas where natural recharge to the groundwater mainly occurs. The effects of climate change on the runoff-recharge scenario in north Kuwait remain somewhat uncertain at present as, apart from the uncertainty about the extent and direction of the climate change in the study area, there are many other factors like geology, geomorphology, and changes in these aspects caused by human activities that will come into play in determining the end results. Long-term monitoring of both groundwater levels and quality will be required to assess the threat to groundwater reserves and to adopt appropriate mitigating actions.

Conclusion and Recommendations

In the study area, recharge from rainfall mainly takes place in the two depressions and to some extent, along the wadis. Human interferences like animal rearing and grazing, off-road driving, military activities, and pollution from oil industry can consolidate the soil surface and reduce the recharge rate. Additionally, these activities pollute the soil with different types of contaminants that can be leached by the infiltrating runoff and carried to the groundwater. Both these consequences will have negative effects on the usable (both fresh and brackish) groundwater accumulations within the study area. Judicious control of human activities within this fragile area is, therefore, called for.

The current study can provide the baseline data for monitoring the long-term effects of these activities (including those caused by the climate change) on the recharge rates and the groundwater quality, which will lead to the effective measures for protecting the valuable groundwater resource. Based on the observations made in this study, the wadis and the depressions and their vicinities should be avoided as much as possible for carrying out any form of human activity that may cause soil pollution and reduction of soil permeability, as these are the areas where natural recharge to the groundwater mainly occurs. The effects of climate change on the runoff-recharge scenario in North Kuwait remain somewhat uncertain at present as there are many factors like geology, geomorphology, and changes in these aspects caused by human activities that will come into play in determining the end results. The findings of this study are expected to have immense implications on the management of the groundwater reserves of northern Kuwait, which hosts the only substantial fresh groundwater body in the country in an attempt to minimize the adverse effects of human activities in northern Kuwait on the groundwater resources in order to safeguard the freshwater accumulations of northern Kuwait that have strategic importance in this water-starved country. Additionally, the findings of the study are expected to help in devising ways to improve natural recharge to the aquifers, thus improving both the usable groundwater volume available and its safe yield.

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Groundwater Level Monitoring of the Quaternary Aquifer at Al Ain City, United Arab Emirates (UAE) using Geophysical Methods

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Abstract
Groundwater monitoring is a main objective of this study. Geophysical methods have been used to manage the Quaternary groundwater aquifer and to follow the groundwater level fluctuations at the western part of Gabal Hafeet, Al Ain City, UAE. Seventeen Seismic Refraction profiles and three; Electrical Resistivity tomography (ERT) have been acquired. Results of this study indicate, three different zones, which are the unsaturated to partially saturated zone, in which depth ranges between 2 to 7 m. The second zone is the saturation zone reflecting water level range from 10 to 15 m deep or more. As well as, the third zone reflects the underlying weathering rocks. ERT profiles also confirm the water depths. Moreover, the available wells conclude the comparable depths obtained from the geophysical data analysis. Groundwater level monitoring of three successive years 2014, 2015 and 2016 shows that, water level rises from the range of 12 and 19 m to the range of 9.5 m and 13.5 m with much better water quality. It is worthy to mention that intensive rainfall of about 240 mm/h hit the region on March, 2016. Surface water infiltration plays a significant role in recharging the aquifer, and enhances the water quality.

Keywords: Seismic Refraction, ERT, Groundwater, Monitoring, Water Quality.

Introduction

Seismic Refraction has been adapted in this study to investigate the groundwater Quaternary aquifer in a pilot area nearby Jabal Hafit – Al-Ain city, southeast of the UAE (Figure 1). Groundwater level of the area is systemized. Measured water levels for the available wells were used as control points. The results of these measurements were used to confirm the assumption that the groundwater level can primarily be revealed by seismic refraction in the gravely-sands or silty clay areas. The groundwater level can be determined as a boundary of acoustic impedance by seismic refraction method (Galfi and Palos, 1970). Electrical Resistivity tomography technique is also acquired as another geophysical method, to confirm the results and investigate the study area, and to monitor the fluctuations of the groundwater level of the Quaternary along the study area. Since those methods are non-invasive and used to estimate the water accumulation and groundwater level changes. To achieve the main objectives of this study, twenty Seismic Refraction profiles and three Electrical Resistivity Tomography (ERT) profiles have been acquired at selected locations.

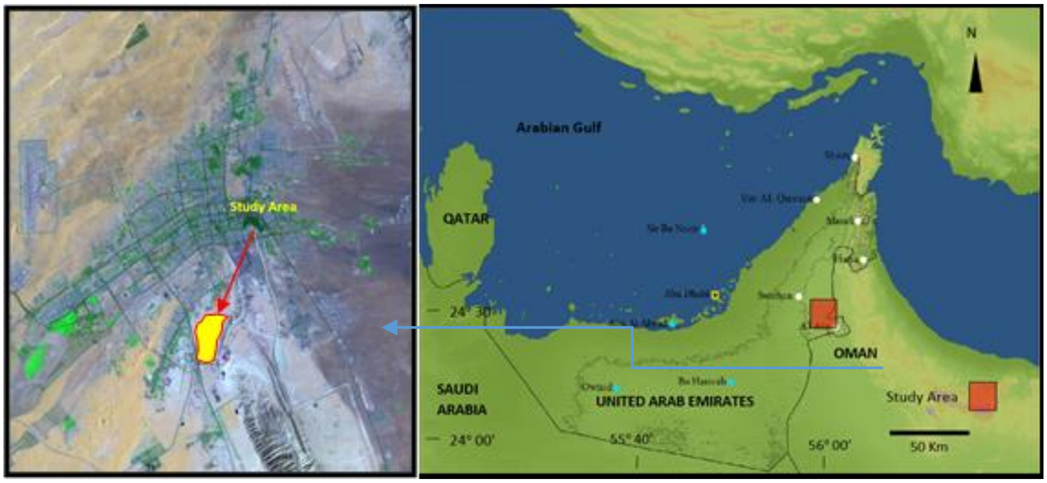

Figure 1: Location Maps showing the study area, Shot points and ERT

Geological Setting

The study area is situated in Al-Ain; in the eastern part of Abu Dhabi - UAE near the border with sultanate of Oman and at the western margin of the northern Oman Mountains (Figure 1). Although Al-Ain is located within an arid desert belt of the world and characterized by drainage net that formed as a result of the prevalence of humid climate during the Quaternary (Hunting Geology and Geophysics Limited, 1979); it is considered to be one of the largest and ancient oases of the Arabian Peninsula due to the fresh groundwater supply which is derived from the Oman Mountains to the east. The geomorphic units in Al-Ain area are classified as mountains, gravel plains, drainage basins, sand dunes, interdune areas and inland sabkhas. The main mountains in Al-Ain area are Jabal Hafit, Jabal Moundassah, Jabal Malaqet, Jabal Al-Oha and Jabal Rawdah. Jabal Hafit is considered as one of the most prominent features of the area, it is located to the southeast of Al-Ain city between latitudes 24° 00' and 24° 13' N and between Longitudes 55° 44' to 55° 49' E. It is a Tertiary anticlinal structure with approximately 29 km length and 5 km width and maximum elevation of about 1160 m above the sea level, plunging south-easterly in Oman and north-westerly in UAE (Hunting Geology and Geophysics Limited, 1979). It is bounded to the north by Al-Ain city, to the east by Al-Jaww plain, to the south east by Mazyad, to the south by Oman and to the west by Ain Al Faydah and Zakher. Jabal Hafit is an eroded anticline, with limbs dipping to the east and west. The overall morphology of the mountain gives it a “whaleback" appearance. The limestones and marls exposed in Jabal Hafit are considered of Lower, Middle and Upper Eocene age. To the east, it is bounded by Al-Jaww plain and Oman Mountains. The gravel plains occupy the area between the Oman Mountains to the east and sand dunes to the west. The gravel plains consist of alluvial sand and gravel transported by wades dissecting the Oman Mountains. The continuity of these plains is locally interrupted by sand dunes which covered about 75% of the total area of UAE (Embabi 1991). The stratigraphy of Al-Ain area comprises mainly of a sedimentary sequence ranging in age from the Cretaceous to the Quaternary (Hunting Geology and Geophysics Limited, 1979), [Hamdan & El-Deeb, 1990) – (Whittle & Alsharhan, 1994). Most of Al-Ain area is covered by Quaternary deposits that consist of near- surface and surface sediments of mixed alluvial and Aeolian origins, together with some much localized sabkhas.

Methodology

Twenty Seismic refraction profiles acquired, (Figure 2) and the extension of each profile was 120 m. forward and reverse shooting have been done with geophone interval of 10 meters, using the multi-channel Geode 3000 seismograph. An array of 12 geophones used and a sledge hammer energy source with 98 Joules of approximate energy of one shot. The accuracy of time measurement is about 10^{-4} sec. The direct and refracted waves are the most important (Murad *et al.*, 2010) (Gabr *et al*., 2012). The first arrival of the energy and its time measured at regular intervals by detectors from the data which plotted in time – distance graphs (Figure 2). As well as, three ERT profiles conducted using Wenner array for data acquisition (Figure 1). The resistivity measurements normally made by injecting current into the ground through two current electrodes (A and B) and measuring the resulting voltage difference at two potential electrodes (M and N). From the current (I), voltage (V) values, apparent resistivity (ρ_a) value is calculated, $\rho_a = K\,V/I$ Where K is the geometric factor, which depends on the arrangement of the four electrodes. Syscal Pro Resistivity meter with 96 channels used to acquire the profiles.

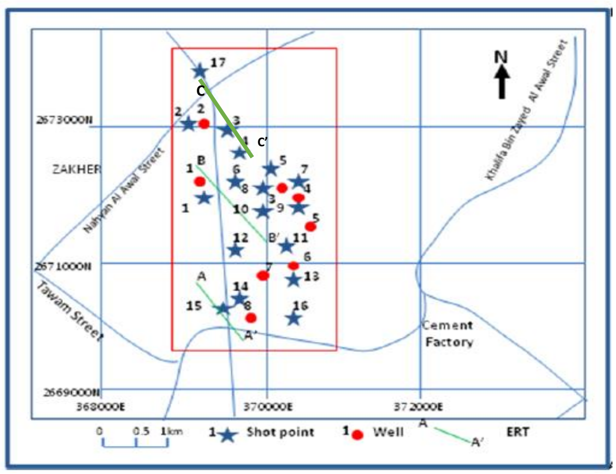

Figure 2: Location Map shows the study area, Shot points and ERT

Results and Discussions

The seismogram is the main result of the field work; it represents the analog recording of the received signals. The recorded seismic traces reflect the response of the subsurface interfaces. The most important first arrivals are the direct and refracted waves, received by the geophones. Some of these traces are shown as noisy or bad traces, even after applying filtering techniques during the processing stage which had been carried out to enhance signal/noise ratio. So, some of these bad or highly noisy traces are killed or deleted from some of the shot records. The first arrival picks are taken and tabulated, the time-depth graphs are plotted and the plotted points are best fitted to reflect the layers' interfaces and estimate the seismic velocities. The seismic velocities are calculated from the slope of the fitted lines on the time-distance curve (Figure 2). Two parameters are usually used to quantify the layer thickness. The first of these is referred to as the cross-over distance (Xc), which simply refers to the offset at which the head wave becomes the first arrival. The second commonly used parameter is called the zero-offset time (intercept time to). By measuring xc or to, in addition the seismic velocities of the first and second layers, the thickness of the layer (h) could be computed (Reynolds, 1997).

The elastic properties of the medium will be changed, when the pore volume is filled by water (Galfi & Palos, 1970). The groundwater level represents a change in the elastic properties in the "dry" bed above the groundwater contact. The velocity will be characteristic for the grains while in the "wet" bed below the water level, a velocity of about 1430 m/s to 1530 m/s with may be a little bit of change in the water velocity to be 1200 m/s to 1600 m/s is due to the expected conditions and characteristic of water. In case of fine –grained beds for example silt and clays, the adhesive water filling up a great part of the pore volume, give enough compression elasticity even to a "dry" bed, which reveals itself in the velocity of wave propagation. The practical experiences confirm that the velocity of wave propagation in both dry and wet clays is a value of about 1000 m/s (Galfi & Palos, 1970). Thus could expect minor change in groundwater level. If layers of sand underlay the groundwater level are interbedded with clay, the waves refracted from the water level and the boundary between sand and clay beds may interfere with one another. In case of clay interbedding occurs in the dry sand beds overlying the groundwater table, waves refracted from the sand-clay boundary may completely screen refraction arrivals from the groundwater level. Time-distance curves of selected shot records are shown in figure 2 as an example.

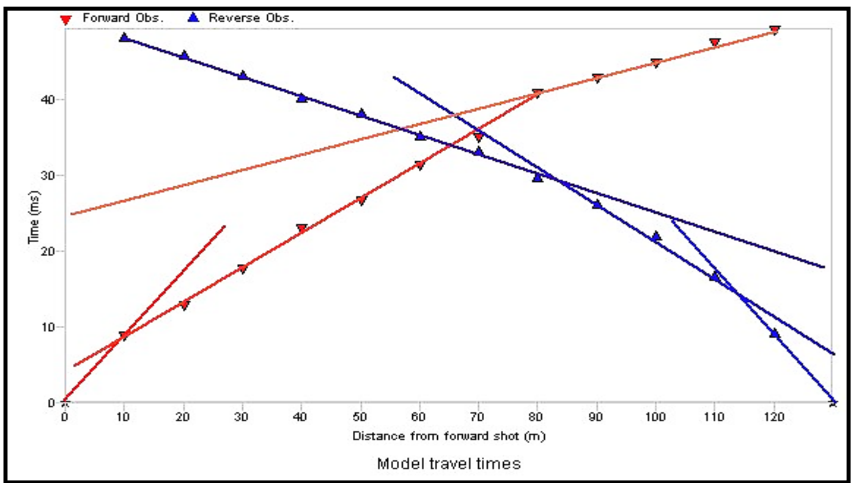

Figure 3: Time-Distance curve

Practically, the obtained results from the shot records and interpretation indicate that the minimum seismic velocity range of 251-1080 m/s was observed in the unsaturated weathered material above the water level. The saturation zone has a velocity in range of 1430-1600 m/s or a slightly higher, while in the underlying weathering rocks the range is from 1700 to 3860 m/s and more. This velocity range may represent the beds' interfaces. Refracting velocity at water level will be lowest when the water level is at the shallowest depth. The water level drops closer to the top of the permanently saturated zone, refracting velocities are observed to increase and only the permanent water level can be seen with refraction method. The distribution of the seismic refracting velocity of the water level in the study area is seen in Figures 4a & 4b).

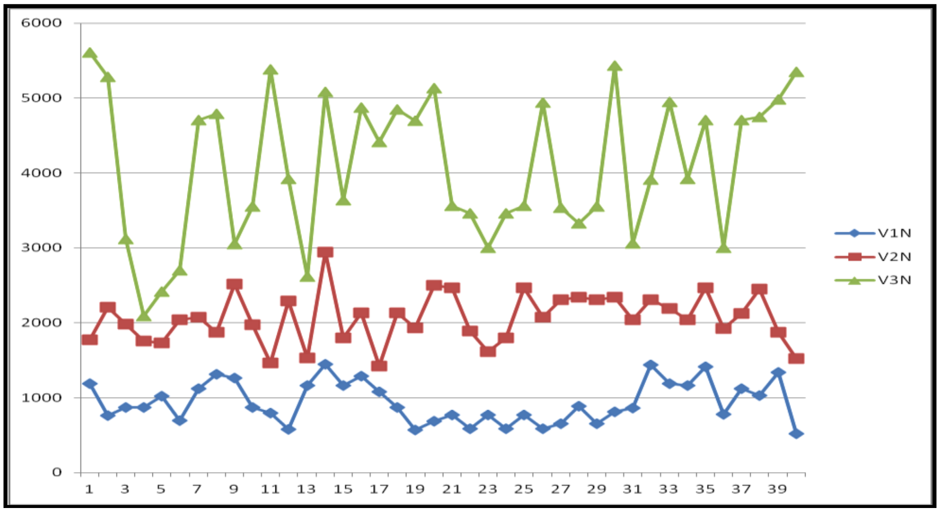

Figure 4a: Seismic velocities distribution in the study area

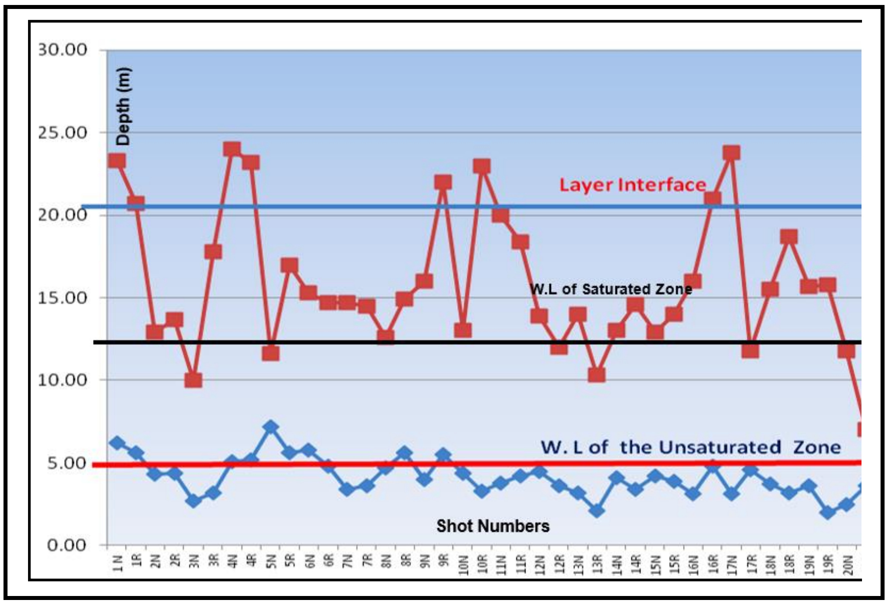

Figure 4b: Seismic refraction interfaces

Moreover, the groundwater level was measured using the electrical sounder periodically for successive years 2014, 2015 and 2016 and the monitoring of the available wells in the surrounding area indicate that, water level rises from the range of 12 and19 m to the range of 9.85 m and13.87m with much better water quality.

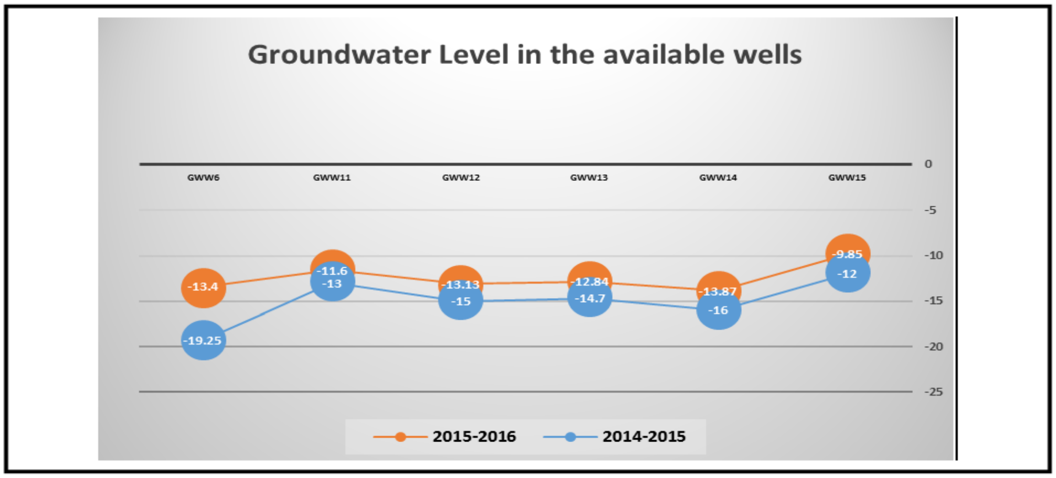

Figure 5: Groundwater Level monitoring in the available Wells in the surrounding area

The Groundwater level distribution maps which produced from the seismic refraction and the available drilled wells in the study area for the two successive years 2014-2015 and 2015-2016 (Figures 6 & 7) show that, the groundwater level fluctuation and the shallow water depths reach to about 2 m at specific sites as estimated from Seismic refraction analysis this may represent the perched water in the partially saturated zone, where the average water level is ranging from 7 to 10 m depth. Also the maps show water level rises in some localities rainfall rates and the aquifer recharge.

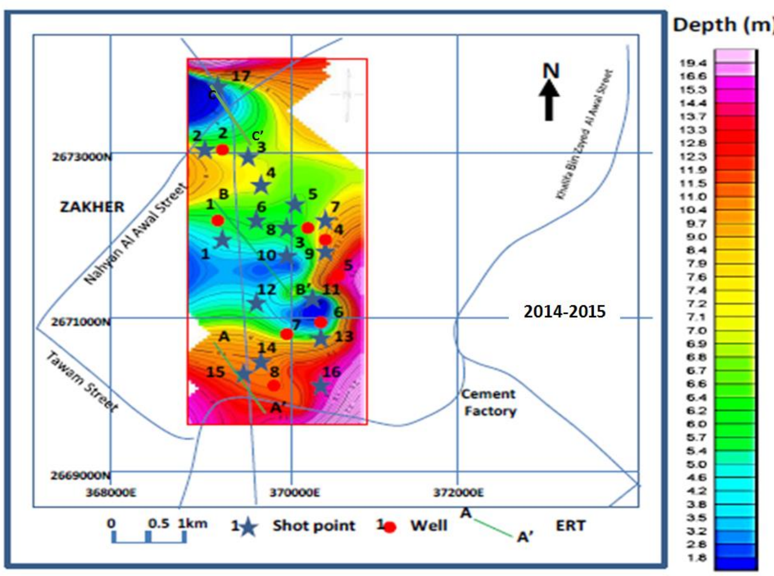

Figure 6: Seismic refraction water level map (2014-2015)

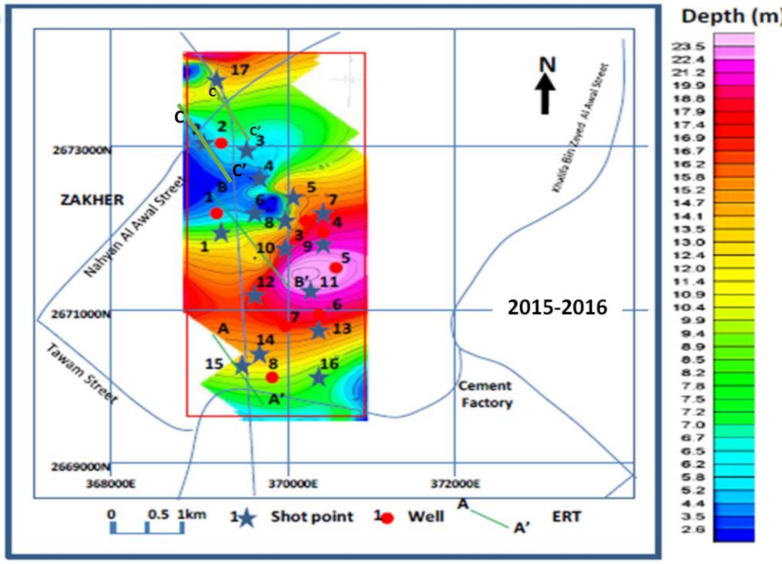

Figure 7: Seismic refraction water level map (2015-2016)

The ERT interpretation results show that, a surficial resistive layer of dry alluvium with resistivity of 700 Ω.m or more, then the apparent resistivity value is decreasing from 15 to <5 Ω.m; then resistivity increase with depth to about 300 Ω.m and more at certain localities. ERT profiles confirm groundwater depths that obtained from seismic refraction data analysis (Figures 8 & 9).

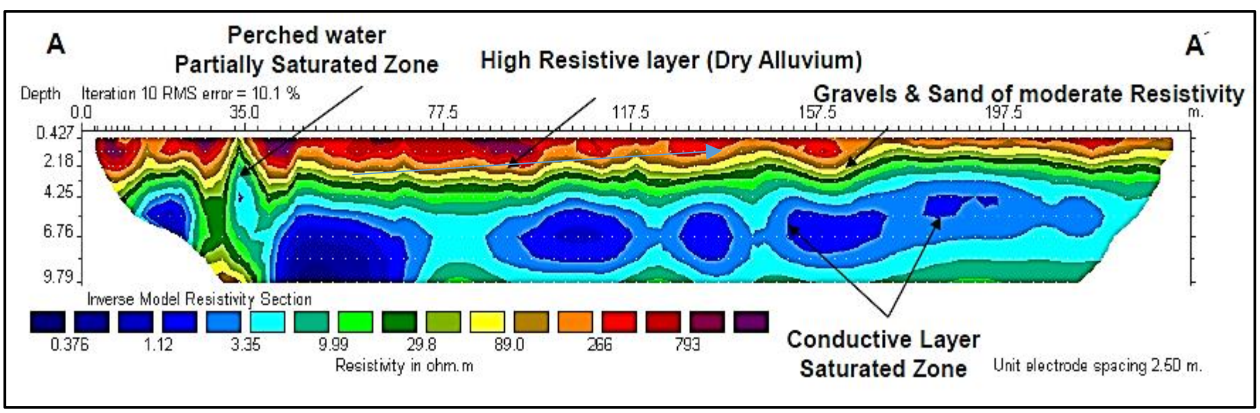

Figure 8: ERT profile along the study area

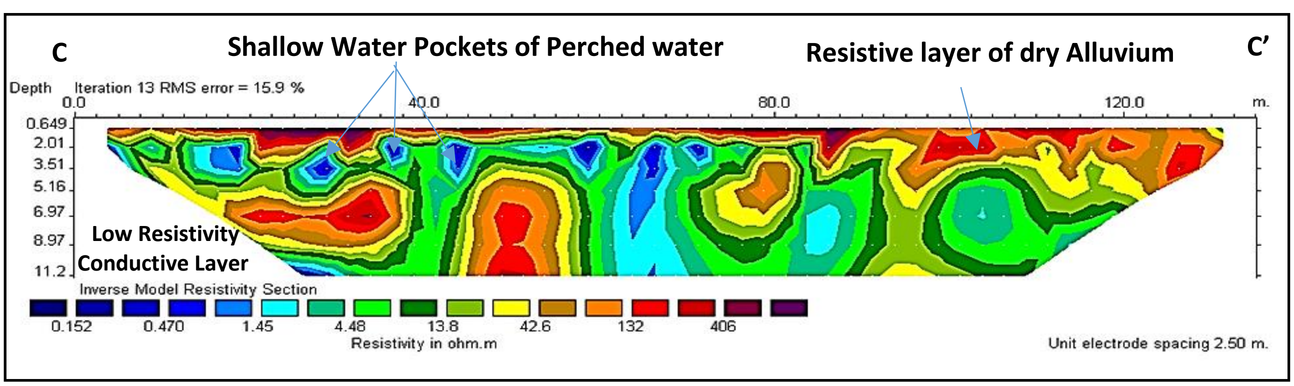

Figure 9: ERT profile along the study area

Conclusion

Seismic Refraction and ERT methods used to investigate the groundwater aquifer and water level at Al Ain city. Geophysical data interpretation and groundwater level measurements reveal that, the groundwater level indicated at some localities as perched water from 2 m and less than 4m, while the saturated zone shows depth range from 10 to 15 m or more, the obtained measurements in the saturated zone indicates seismic velocities ranges between 1430-1600 m/s, while at the top of the capillary fringe zone give rise to another response indicated by seismic velocity range between 251-1080 m/s. The resulted water level maps show general agreement and similarity between the measured wells map and the seismic refraction water level map. Some shallow depths are indicated which may reflect the surface of perched water zone. The resulted water level maps show general agreement and similarity between the measured wells map and the seismic refraction water level map. Some shallow depths are indicated which may reflect the surface of perched water zone. ERT profiles also confirm the previously estimated depths. Moreover, the groundwater level monitoring of the available wells in the surrounding area indicate that, water level rises from the range of 12 and19 m to the range of 9.85 m and13.87m with much better water quality. These results confirm the aquifer recharge and enhance the groundwater quality in which supporting the water sustainability. This study recommended that the monitoring of water level in the study area should be done periodically to protect the residential areas from any sudden rise in water level. Also, the expected damage due to sudden water storms should be avoided through implementation of surface engineering protection from the eastern side of the study area. This is due to the existence of the western limb of Jabal Hafit anticlinal fold.

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Vulnerability Assessment for Shared Aquifers, Case Study: Dammam Shared Groundwater Aquifer

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Abstract

Gulf countries have been experiencing different degrees of natural and anthropogenic water risk affecting the sustainability of their limited water resources and preservation of the ecosystem equilibrium. The fragile arid environment and its resiliency to cope with external natural and anthropogenic activities, including the expected impacts of climate change, present a major challenge to decision-makers who must achieve adequate, safe and dependable water and food supply in the future to improve human well-being in their societies, and to meet the requirements of future generations. It is expected that climate change will impose further stresses on the limited freshwater resources in Gulf countries and intensify their vulnerability. This is of particular concern for those countries relying on shared water resources, which in the absence of sharing agreements will increase tensions between riparian countries. In this study vulnerability assessment for shared Dammam aquifer is carried out using the vulnerability methodology (UNEP, 2009) to provide Vulnerability Index (VI). The study concluded that the issue of shared water resources should be given high priority by GCC countries to finalize water resources sharing agreements according to international water laws. Large water savings opportunities exist in the agricultural sector where most water wastage occurs. Savings are possible by increasing irrigation efficiency with the introduction of enhanced irrigation and agricultural techniques, reuse of treated wastewater, augmentation by agricultural drainage water, and the implementation of incentive/disincentive systems.

Keywords: Anthropogenic, Sustainability, Resources, Agriculture, Technology.

Groundwater Sustainability at Wadi Al Bih Dam, Ras El Khaimah, United Arab Emirates (UAE) using Geophysical methods

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Abstract
Seismic Refraction (SR) and Vertical Electrical Sounding (VES) are effective techniques used to investigate the groundwater accumulations at the dam site of Wadi Al Bih area, Ras El Khaimah, UAE. The survey designed to estimate the thickness of the shallower deposits and the subsurface lithological layering, predict the depth to the water level and expect the infiltration rate in the study area. Selected nine seismic refraction profiles carried out in the study area, in which forward and reverse shooting producing eighteen points of water level. As well as, six Vertical Electrical Soundings also acquired to confirm the results. The interpretation of the processed geophysical data indicates that, the estimated depth to the water level reaches to 4 - 5 m depth, seismic refraction shows three different ranges of seismic velocities and VES shows fresh water zones exist at shallow interval within 50 m depth. The water salinity may increase with depth due to interaction with fractured limestone and due to the seawater intrusion. This study also recommends artificial removal of the thin surficial muddy layer behind the dam, which ranges from 15 -20 cm thickness, this may enhance the infiltration rate and for better aquifer recharge from the accumulated rainfall surface water.

Keywords: Geophysical Methods, Seismic Refraction, ERT, Groundwater, Sustainability.

Introduction

Groundwater sustainability is a main objective in most of the countries of the arid regions, where the study area is located, which is Wadi El Bih Dam area, Ras El Khaimah, United Arab Emirates (UAE) (Figure 1) (Photo 1). The groundwater aquifer, water resources, infiltration rate and the recharge of the aquifer as well as the groundwater quality are very important points to be studied and investigated in this research work. Geophysical surveys designed and used to investigate the shallow groundwater aquifer behind the dam site, this also may contribute to assess the dam efficiency. Seismic Refraction (SR) and Vertical Electrical Sounding (VES) surveys designed to estimate the thickness of the shallow deposits, the subsurface lithological layering and to predict the depth to the water-bearing zone in the study area.

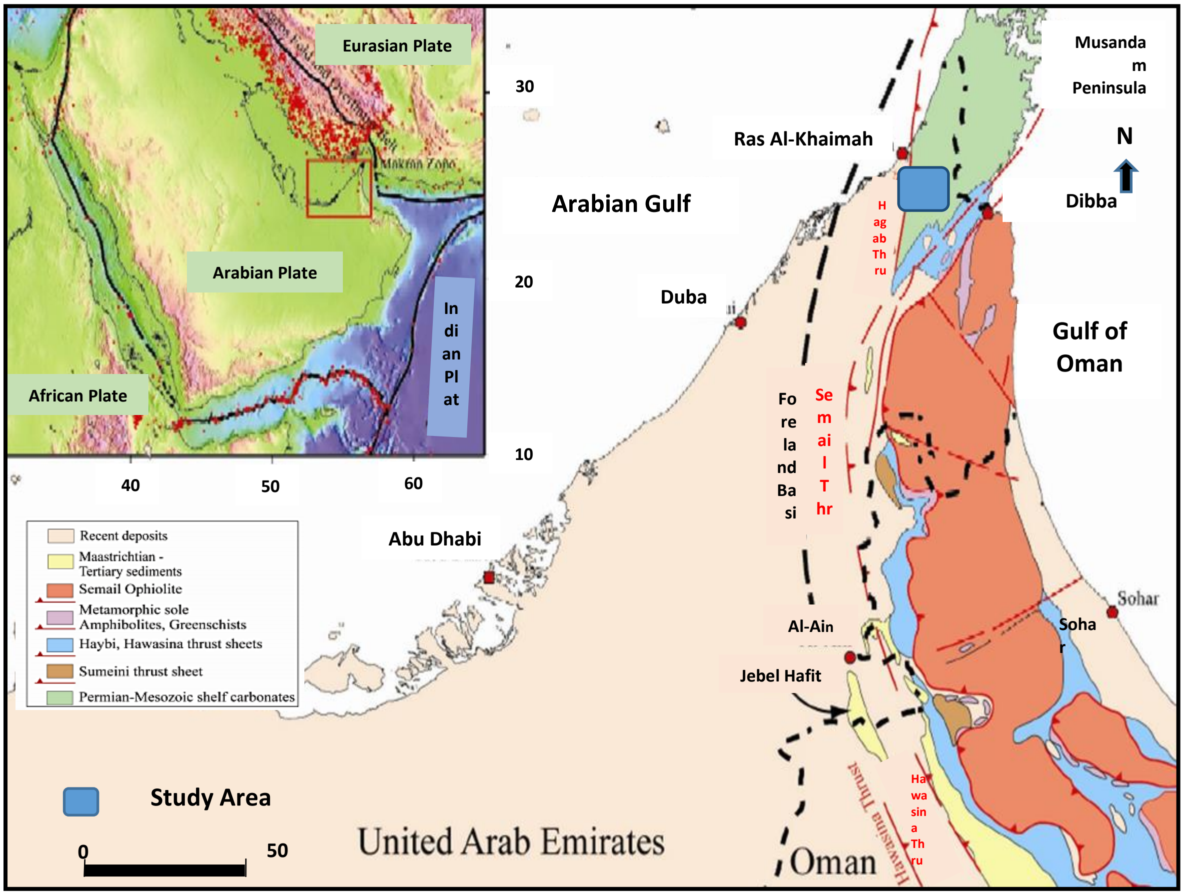

Figure 1: Location Map of the study area (Wadi El Bih, Ras Al Khaimah, UAE)


Photo 1: Wadi El Bih, Ras Al Khaimah, UAE

Methodology

Seismic Refraction is a good geophysical tool, used to investigate the underground water and the subsurface layering at the study area (Figure 1) (Photo 1). Depth to the bedrock and thickness of the shallow deposits as well as the depth to the groundwater level can be determined as boundaries of acoustic impedances by seismic refraction method (Galfi and Palos, 1970, Murad *et al.*, 2010). In the first part of the present work, our knowledge concerning the groundwater level and structure framework of the area and groundwater systemized. The measurements conducted on the bases of the considerations of the first part used to confirm the assumption that, in the gravels-sandy or silty clay areas the groundwater level revealed first by seismic refraction.

In the case of differing elastic properties, the groundwater level can be determined as a boundary of acoustic impedance by seismic refraction method. When the electric properties of near surface sand and clay beds investigated, a principal obstacle recognized in applying the method of resistivity measurement to problems of water exploration. Namely, the dissociated ions of adhesive water, being an electrolyte, in the case of both sand and clay give a relatively good electric conductivity even to the "dry" ground, which will not significantly have altered by the saturation of the pore volume by ground water. Not regarding several exceptional cases, the ground-water table does not behave, as an electric boundary and it cannot locate by the method of resistivity measurement. The possibilities of using the seismic refraction method are determined by the elastic properties of the near surface layers.

Seismic Refraction method uses seismic energy that returns to the surface after traveling through the ground along refracted ray paths. The first arrival of seismic energy to a detector offset from a seismic source always represents either a direct ray or a refracted ray. The seismic record section is the main result. Offset increases from right to left. Filled in all of the portions of the trace those are above zero with black. Plots of this type called variable area plots. This is done because it makes it much easier to correlate similar features in the ground motion from trace to trace. The direction of travel of the transmitted waves changed on entry into the new medium, and this change referred to as Refraction. By acquiring refraction seismic observations in two directions, we can immediately determine whether subsurface layers are dipping. If dipping layers are present, the travel-time curves obtained in the two directions are no longer mirror images of each other as in case of horizontal interface. This fact allows simple refraction surveys performed in which attention is concentrated solely on the first arrival (or onset) of seismic energy and time-distance, plots of the first arrivals interpreted to drive information on the depth to refracting interfaces. This simple approach does not always yield a full or accurate picture of the subsurface. In such circumstances, interpretations that are more complex may be applied. The method is normally used to locate refracting interfaces (Refractors) separating layers of different seismic velocities, but the method is also applicable in cases where velocity varies smoothly as a function of depth or laterally. The large difference in velocity between dry and wet sediments renders the water table a very effective refractor. Hence, refraction surveys find wide application in exploration programs for underground water applies in sedimentary sequences often employed in conjunction with electrical resistivity methods. There can be an ambiguity in interpretation of p-wave refraction data since layer depth with a velocity in excess of 1500 m/s could be either the water table, or a layer of more consolidated rock. Recording both P and S wave data overcomes this problem, since water table will affect the P-wave velocity but not that of the S-waves. Nine seismic refraction profiles as forward and reverse shooting have been acquired in the study area with 60 m profile length and geophone interval of mainly 5 meters (Figure 2); using the multi-channel Geode ES3000 seismograph with 12 geophones and sledge Hammer source equipment.

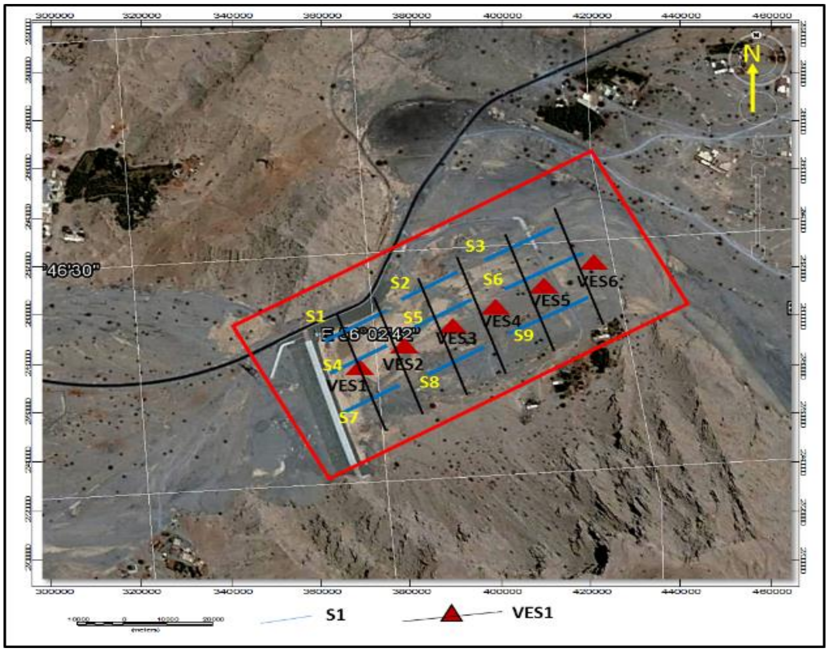

Figure 2: Satellite image shows seismic refraction profiles and VES locations

The accuracy of time measurement is about 10-4 sec. The seismogram is the main result of the fieldwork; Forward and reverse seismograms (Figures 3&4). It represents the analog recording of the received signals. The recorded seismic traces reflect the response of the subsurface interfaces. The most important first arrivals are the direct and refracted waves, received by the geophones, some of these traces may show as noisy or bad traces, even after applying filtering techniques during the processing stage that are usually carried out to enhance S/N ratio. So, some of these bad or highly noisy traces are killed or deleted from some of the shot records. The first arrival picks tabulated, the time-depth graphs plotted and best fitted to reflect the layers interfaces and estimate the seismic velocities (Figure 5). The seismic velocities calculated from the slope of the fitted lines on the time-distance curves. Two parameters used to quantify the layer thickness and dependence in where the head wave becomes the first arrival. The first of these referred to as the crossover distance, X_c

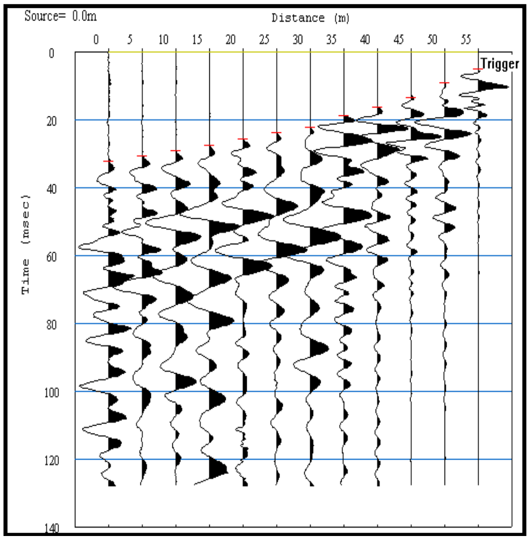

Figure 3: F- shooting seismogram

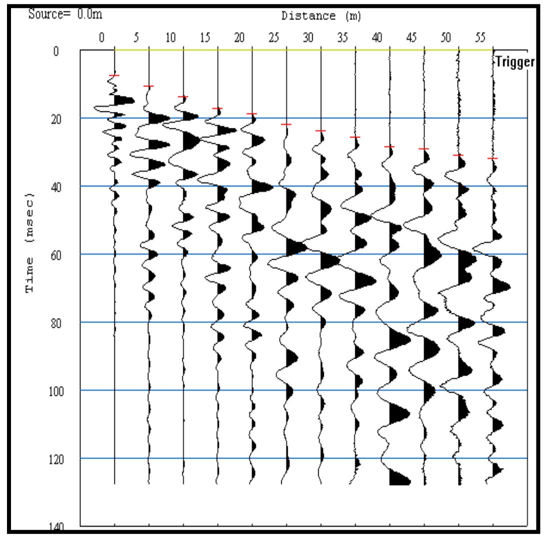

Figure 4: R- shooting seismogram

The crossover distance simply refers to the offset at which the head wave becomes the first arrival. The second which is commonly used parameter called the zero-offset time (intercept time), t_o. By measuring X_c or t_o, the thickness of the layer, Depth (Z) can be calculated using the corresponding equation.

$$Z_1 = t_o V_2 V_1 / 2(V_2^2 - V_1^2)^{1/2} \quad \text{..} \quad \mathbf{(1)}$$

$$Z_1 = X_c/2 \ (V_2 - V_1 / V_2 + V_1)^{1/2} \quad \text{..} \quad \mathbf{(2)}$$

$$Z_2 = 1/2 \{ t_{i2} - [2h_1 (V_3^2 - V_1^2)^{1/2}] / V_3 V_1 \} \ V_3 V_2 / (V_3^2 - V_2^2)^{1/2} \quad \text{...................} \quad \mathbf{(3)}$$

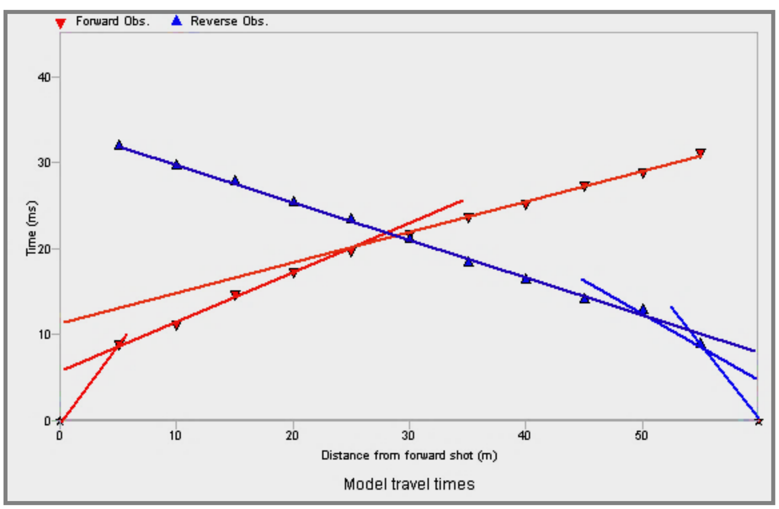

Figure 5: Time-Distance curve

The electrical methods in general include different techniques and instruments depending on the nature of the method used in prospecting. Some of these methods make use of natural currents and others depend on the injection of artificial currents into the earth. For more details about these different techniques refer to Musset and Khan, 2000; Reynolds, 1997, Telfored *et al.,* 1990, Parasnis, 1986; Robinson and Courth, 1988, and Dobrin, 1976.

The resistivity measurements made by injecting current into the ground through two current electrodes (A and B) and measuring the resulting voltage difference at two potential electrodes (M and N). From the current (I), voltage (V) values, apparent resistivity value is calculated, from the current intensity (I) and voltage (V). An apparent resistivity (ρ_a) value is calculated.

ρ_a = K V /I………………………… (4)

Where, K is the geometric factor, which depends on the arrangement of the four electrodes.

The calculated resistivity value is not the true resistivity of the subsurface, but an apparent value, which is the resistivity of a homogeneous ground that will give the same resistance value for the same electrode arrangement. The relationship between the apparent resistivity and the true resistivity is a complex one. To determine the true subsurface resistivity an inversion of the measured apparent resistivity values using a computer program. The larger electrode spacing, will be the deeper the ground disturbance which can be detected.
The classical resistivity survey techniques are the VES and profiling. In VES, the center of the electrode array remains fixed, but the spacing between the electrodes increased to obtain more information about the deeper sections of the subsurface.

Six Vertical Electrical Soundings (VES) using Wenner array were carried out with electrode separations up to AB = 150 m (Figure 2). This separation could penetrate the ground layers to a depth more than 50 m. The field apparent resistivity values collected by using resistivity meter (Sting R & IP). The obtained values were analyzed using the computer software. VES profiles were plotted electrode spacing versus apparent resistivity, reflecting the change of resistivity vertically and estimating depths of investigation. (Figure 6)

Results
Seismic Refraction and VES results indicate four different lithological intervals; these are, topmost mudstone layer with about $\cong$ 0.2 m thickness, this surficial layer may cause surface water accumulation and slowing the infiltration rate to recharge the aquifer. Underlained by gravel layer of loose, coarse, and permeable alluvial gravels of carbonate origin reaches to about 6 m and extends to 15 to 20 m depth underlined by layer of transitional fractured limestone reaches to 40-50 m, then dense compacted bedrock of limestone extended to 100 m and below (Figure 7). The interpretation of the geophysical data indicates that, the estimated depth to the water level reaches to 4 - 6 m depth. The VES results evidenced that; water salinity may increase with depth due to interaction with fractured limestone. To enhance the infiltration rate and for better recharge of the aquifer from the rainfall, accumulated surface water recommended to artificially removing the very thin surficial muddy layer that ranges from 15 -20 cm thickness.

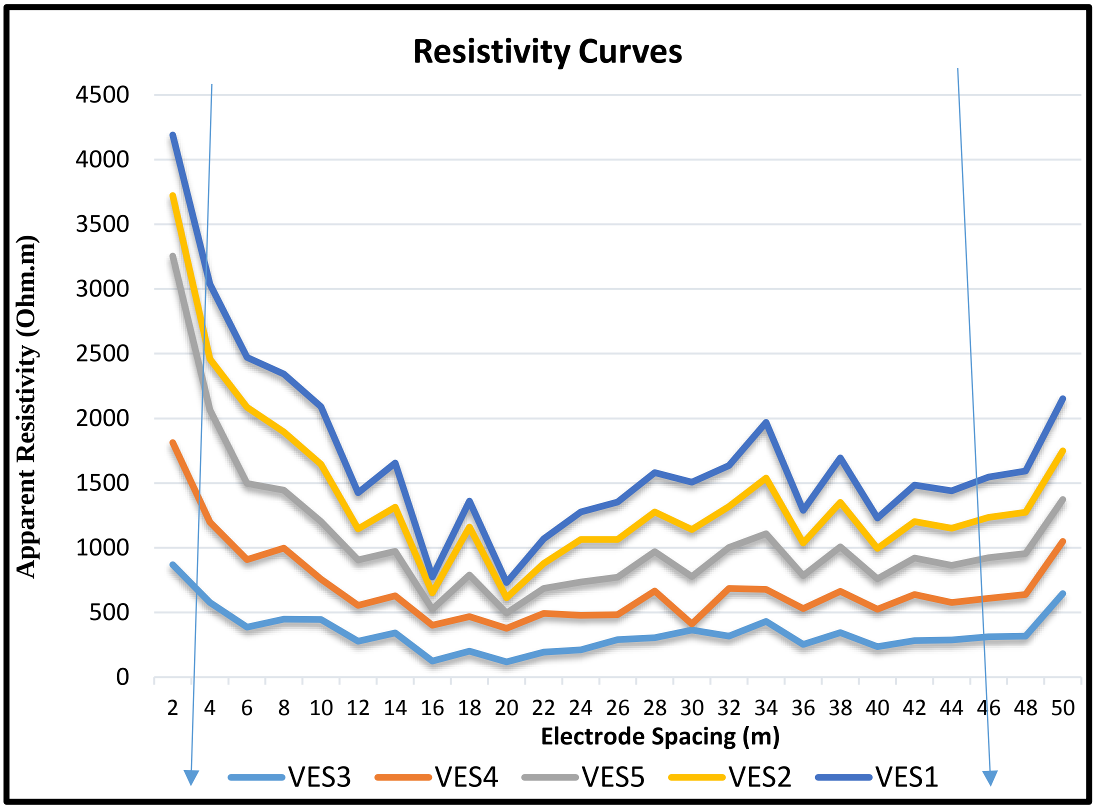

Figure 6: The interpretation of the VES data indicates that, the estimated depth to the water level reaches to 4 - 6 m depth with higher resistivity indicates fresh water acumulation. The VES results evidenced that, water salinity may increase with depth due to interaction with fractured limestone.

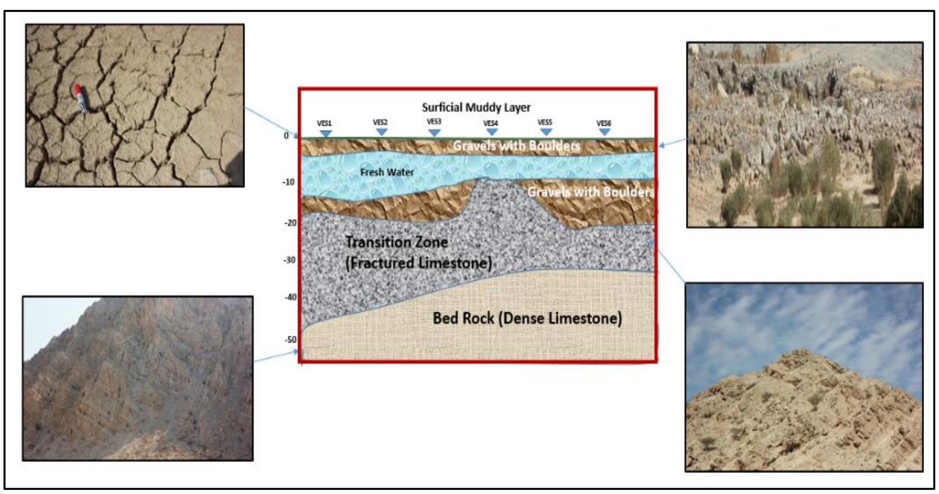

Figure 7: Cross-section of the study area through Vertical Electrical Soundings

Conclusion

The expected outcomes of this research project indicate that, the vertical and horizontal seismic velocity variations, as well as detecting qualitatively and quantitatively the depth of the layers interfaces and estimate the water level which ranges between 4 to 6 m. Moreover, the VES survey reflects the vertical electrical resistivity distribution, representing the lithological succession to 50 m depth and the probable water saturation zone, which confirms the groundwater depth and the existence of fresh water at shallow interval. This study confirms the dam efficiency and recommends artificial removal of the thin surficial muddy layer which ranges from 15 -20 cm thickness, to enhance the infiltration rate and for better recharge of the aquifer from the surface water and sustain the groundwater resources.

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Investigations of Upper Most Soil Zone Characterizations and Its Impact on Recharging the Shallow Groundwater Aquifer in Arid Region: A Case Study on Wadi Al Bih Dam, Ras Al Khaimah, Northern Emirates, United Arab Emirates (UAE)

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Abstract
The movement of surface water through the upper most soil layers (infiltration) encompasses the key element of the hydrologic cycle, where it characterizes the pathway of contribution to the groundwater. Infiltration experiments are performed in the field to measure the infiltration rates of the soil layers and the corresponding hydraulic conductivity. The infiltration rate is the constant rate at which water can move into the soil and the hydraulic conductivity can emphasize the fluency rate of water movement through it. Therefore, site characterization is one of the substantial task for water harvesting and collection especially in arid region like United Arab Emirates (UAE). The Wadi Al Bih dam lies in the downstream of one of the largest valleys, which were initially formed, with watershed area along the Oman mountains summits in Ras Al-Khaimah Emirate. The dam plays important role to halt the flash floods and contribute infiltration process to recharge the shallow aquifer. This study aims to measure the infiltration rate of soil in upstream and downstream of the Wadi Al Bih dam and highlight the relationships between soil properties, infiltration rates, hydraulic conductivities and the dams' ability to stop and harvest the surface water. This will certainly provide insight of downward water movement and its' pathway to the shallow groundwater aquifer. The results reveal that average infiltration rate varies from 9.9 to 31.5 cm/h and average hydraulic conductivity ranges between 31 and 142 cm/s, which reflect the variability of soil nature in the dam area. The surface soil on both sides of the dam reservoir exhibits different soil types; poorly graded sand with gravel and poorly graded sand. Soil dominated by large grain size will contribute high infiltration rate and hydraulic conductivity. However, the clay layer of about 50-100 cm thick, which covers only upstream reservoir near dam structure, causes reducing the water seepage downward to aquifer. As a result, such investigations will provide a useful information how far the soil characterization controls the surface water penetration into shallow groundwater aquifer.

Keywords: Soil Characterization, Infiltration Rate, Hydraulic Conductivity, Shallow Aquifer, Wadi Al Bih.

Introduction

The study area is located in the northeastern part of the United Arab Emirates (UAE) at the downstream of Wadi Al Bih (Fig.1). The proper assessment and management of water resources in the UAE would certainly contribute to water conservation, enhancement of the quality of available water and restoration of the depleted groundwater resources in the various aquifers. Groundwater is the principal natural water resource in the UAE with the clastic bearing formations which represented by the Quaternary shallow groundwater aquifer, particularly in the contact areas between UAE and Sultanate of Oman. This shallow clastic aquifer is supplied by groundwater recharge from the rainfall in the watershed areas along the summit of Oman

Mountains. The Wadi Al Bih represents one of the main Quaternary clastics depositional system in Ras Al Khaimah emirate that harvest most of surface water which comes from these high mountains of Oman during heavy rainfall events. Therefore, the Wadi Al Bih may become a large surface reservoir of water that either penetrates into the subsurface or creates indigenous surface lakes and wadi runoff.

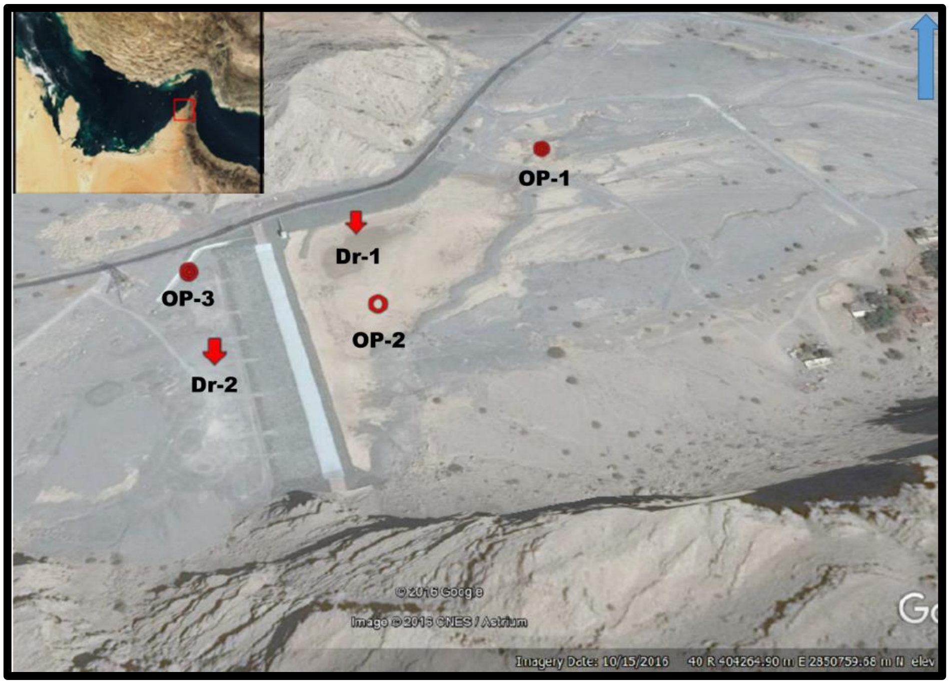

Fig.1: Location map of the study area (Wadi Al Bih dam, Ras Al Khaimah, UAE).

Evolved from its principal assignment and concern to improve and sustain the water resources in the country, the Ministry of Agriculture and Fisheries (MAF) has constructed a large number of dams across the main wadies to harvest the rainwater, protect the environmental system and recharge the aquifers. However, the Wadi Al Bih dam represent one of these major constructed dams in the study area. Efforts are focused on evaluating the effects of storm-related flush flooding and extent of recharge to groundwater in the dam reservoir area where groundwater from the Wadi Al Bih aquifer is used mainly for human consumption, farming and development purposes. Accordingly, evidence about the infiltration capacity of the dam surface reservoir and characters of the top clastic layers become vital for the water stability approximation. These data are inappropriately mislaid and the current work with field and laboratory investigations aims to find out such information on the upper part of the aquifer system.

Regional Geology, Climate and Hydrogeology

The geomorphic features have a main role in flow and improvement of both surface and groundwater. The geology controls the characteristics and patterns of the storage layers, stratigraphic sequences and structural zones of hydrogeological systems. Such factors would greatly effect surface water runoff from rainfall events, infiltration rates, storage capacity, and groundwater table fluctuation in the system.

The area is characterized by the predominance of geomorphologic features such as mountains, gravel plains, and drainage basins in addition to the occurrence of major and minor dams along the area to harvest the rainwater, protect the environmental system and recharge the aquifers. The infiltration rate of the upper layer of the soil would determine, to a high extent, the capability of the system to be rejuvenated from rainfall happenings. The Wadi Al Bih contains extensive network of tributaries covering a surface area of 483 km^2. It reflects the biggest drainage basin in the UAE and represents one of the most important aquifers in the northern part of the UAE. The area of Wadi Al Bih covered with thin soil and rare vegetation zones.

The Wadi Al Bih drainage basin described by a rugged topography with steep slopes and its catchment area underlain by limestone. The basin is in intermediate size and the degree of flush hazards is high [1]. The minimum and maximum elevation is 65 and 2087 m above mean sea level (amsl) respectively.

The geology of the area composed of Permian to Mesozoic shallow-water, carbonates that are exposed in a couple of west-verging thrust sheets (Fig. 2). Glennie et al. (1974) found that these rocks are part of the Arabian shelf deposits and were thrusted due to the obduction of the Semail ophiolite during the Late Cretaceous [2]. A later tectonic phase, related to the folding of the Zagros Mountains, resulted in thrust culmination during the mid-Tertiary and eventually in the formation of the Musandam Mountains and the peninsula [3].

Paleogeographically, these Permian and Mesozoic sediments were deposited on a shelf located between the Arabian shield in the SW and the Tethys Ocean in the NE. The whole sedimentary succession exceeds 3,000 m in thickness and shows less tectonic overprint than age equivalent sequences in the Oman Mountains [3]. The Upper Permian and Triassic strata reach approximately 1,700 m in thickness. Permian deposits are mainly outcropping in two structures, the Hagab and Yabana anticlines, in the Wadi Al Bih area as well as on the eastern shore of the peninsula in Omani Musandam [4]. Triassic and younger Mesozoic rocks are found throughout the area and have been encountered in several offshore wells [5].

The UAE has arid climate and is located in the eastern part of the Arabian Peninsula. In summer, temperature may reach up to 48°C and seldom rainfall. In winter, lowest temperature is recorded around 14°C. The average temperature exhibits fluctuations across the country as well as over time [6-8]. The average monthly rainfall pattern varies widely through the year and over 80% of the annual rainfall take place during the winter. The average annual rainfall over the period 1970-2001 was roughly 120 mm/year. Over the whole year, rainfall decreases from mountain areas to desert and coastal areas [6-7, 9-10].

The targeted area gets little rainfall In general, but some seasonal sudden water storms occur and cause flooding in the region. Rainfall and temperature were irregular according to the available data from 1977 to 2014. Rainfall mainly occurred in winter (from November to March) averaging 120 mm/year [9]. Temperature was fluctuated over the period and reached its high value in summer [9-11]. According to the data; the maximum rainfall (381 mm/year) and the minimum rainfall (14 mm/year) were recorded in 1982 and in 1985, and the maximum and minimum temperatures were 28.8 °C and 14 °C in 2010 and in 1992 at Ras Al Khaimah Airport. The annual mean temperature was 27.7°C (Fig. 3).

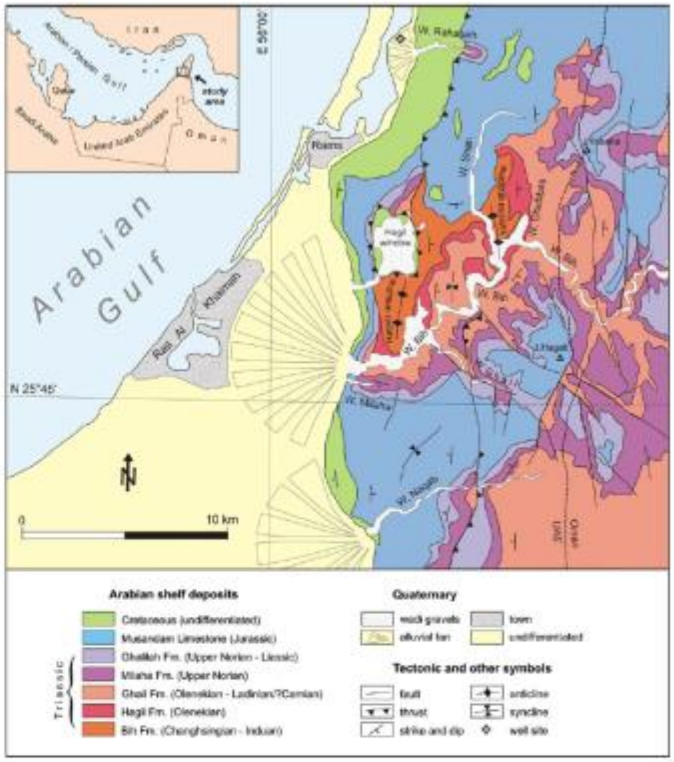

Fig. 2: Geological map of the study area [3].

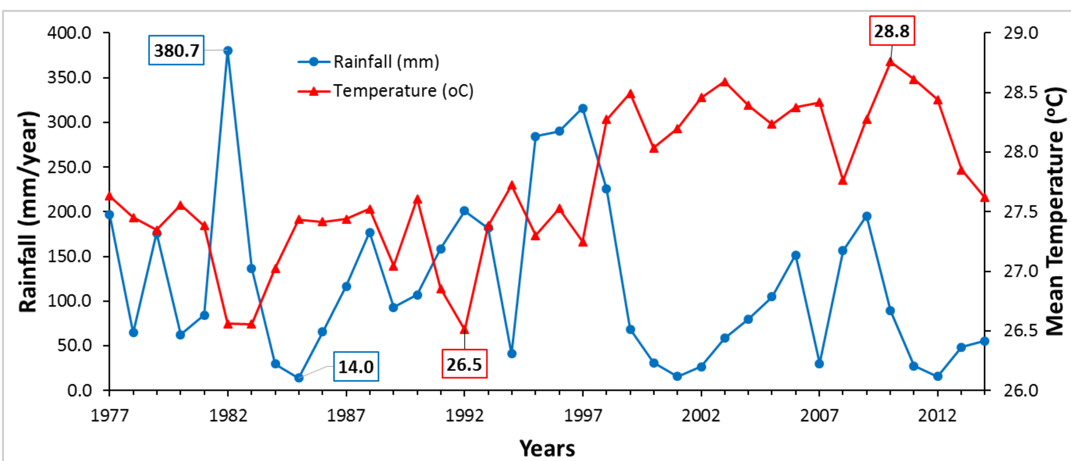

Fig. 3: Rainfall and mean temperature of the Ras Al Khaimah emirates from 1977 to 2014 [4-5]

The main groundwater aquifers in UAE are classified into limestone aquifer, fractured ophiolite rocks, gravel aquifers and west and sand dune aquifers (Fig. 4). The largest reserve of fresh groundwater in the UAE occurs in the gravel alluvial deposits extending along the western side of Oman Mountains starting from Ras Al Khaimah to Al Ain. The sand dune aquifer covers about 74% of the total area of the UAE. It receives most of its recharge from the western side of the mountain, whereas the Arabian Gulf and Gulf of Oman are the main discharge area [12].

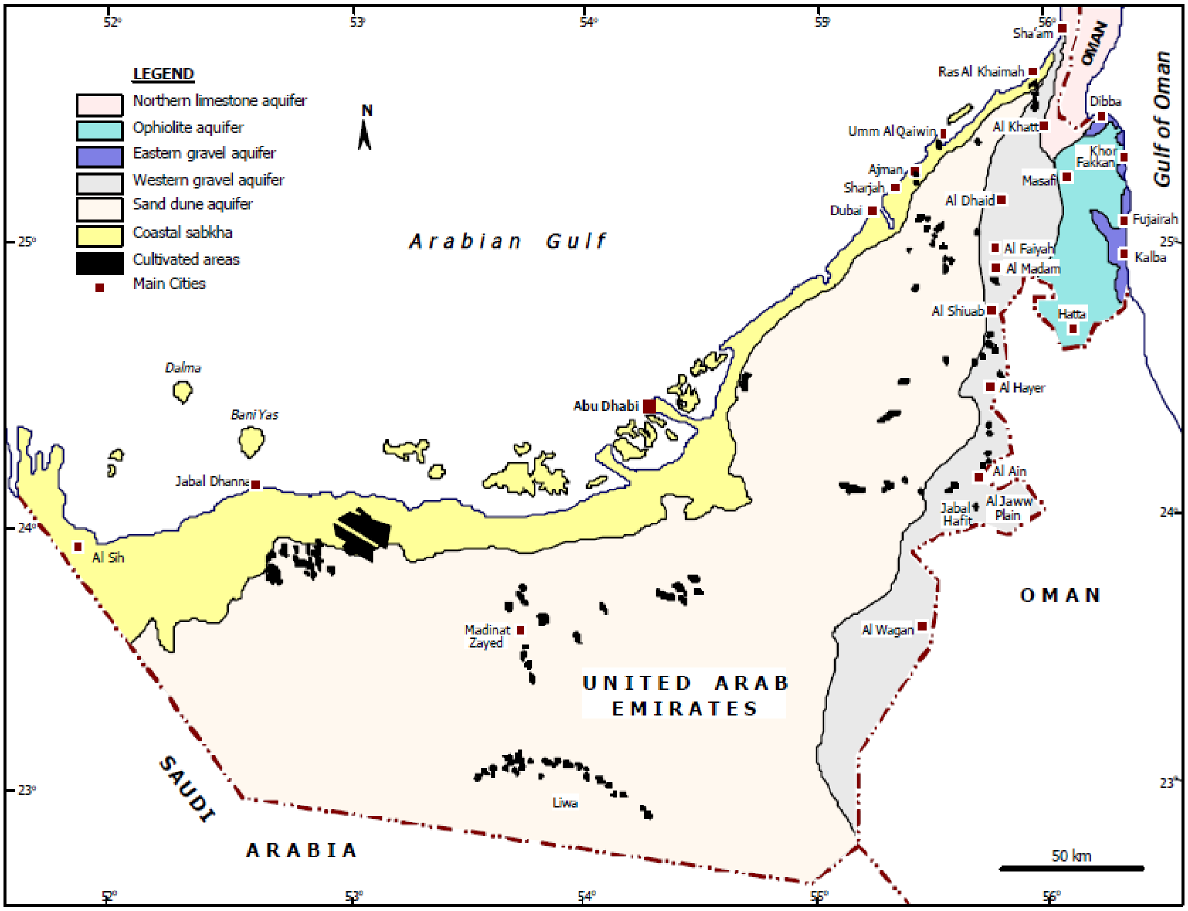

Fig. 4: Main aquifers in the United Arab Emirates [12]

The aquifer in the study area is classified based on the lithological composition into the upper gravel and the lower limestone units consequently. The first unit composed from loose, coarse, and high permeable alluvial gravels originated from carbonate, while the second one consists of fractured limestone which underlain the gravel deposits. Electrowatt (1981) indicated that the gravel deposits of the Wadi might have a good ability to carry water with small storage volume. Most of the natural recharge to the aquifer systems is received at the heads of alluvial fans by infiltration form Wadi's flows originated in the mountain zone [13].

The recharge to the Wadi Al Bih aquifer occurs from a catchment of average elevation of 1,050 m asml [11]. Groundwater in the study area flows from the upper segment in the northeast to the lower segment in the southwest.

In most arid regions, the amount of recharge would be in the order of 2% to 10% from the total volume of annual precipitation. However, this amount could be significantly increased through the proper implementation of water harvesting schemes including the construction of retention and detention dams across the main Wadies [15]. The vertical hydraulic conductivity of the alluvial gravel decreases from 10 m/day at the unconfined and un-cemented upper aquifer to 0.1 m/day in the middle semi-confined and semi-cemented aquifer [13]. The lateral hydraulic conductivity of the upper unconfined aquifer ranges from 32 to 67 m/day, which can serve as channels for sideward transport of surface water [16].

Materials and Methods of Study

Five sites were selected for performing two double ring infiltration tests and three open pit tests on both upstream and downstream of dam (Fig. 1). The site selection was done depending on coverage of the sediment compositional and textural variability, recharge orientation and accessibility. Three of them (one double ring and two open pits) carried out in the dam upstream and two (one double ring and open pit) were conducted in the dam downstream. Increment infiltration rate measurements were performed based on ASTM standards [17] using double ring device of 30 cm diameter (inner ring) and 60 cm (outer ring) (Fig. 5a) while the open pit infiltration test were done manually by recoding the elapsed time and the total depth of water seepage inside the pit (Fig. 5b). In double ring tests, water level in the outer and inner rings was automatically maintained at a constant head using two floating siphons. Maintaining a constant head in the outer ring was not as critical as maintaining constant head in the inner ring to measure the infiltration rates. This is because the purpose of the outer ring head (the annular space between the two rings) is to reduce the leakage of water outward under the inner ring area however, the flow rate (cm^3) was taken in consideration for calculating the increment infiltration along the test duration time. In the field, cumulative infiltration rates and time were recorded for each double ring tests, which generally continued for about 4-6 hours. The infiltration rate becomes constant when the saturated infiltration rate for the particular sediment has been reached. Sediment information for each site was obtained from field description as well as laboratory sieve analysis of eleven sediment samples were collected from all the tested locations (Fig. 5c). Finally, field data of each test was graphically represented in order to visualize sediment behavior with respect to the infiltration rate.

Results and Discussions

The inner ring readings of the fieldwork were used to calculate the infiltration rates and exhibits values ranging between 3.9 to 25 cm/hr while the recorded infiltration test results from the open pits reveal values vary from 2.5 to 67.3 cm/hr in the upstream and downstream of the Wadi Al Bih dam. The overall tests including double ring and open pit average results ranges between 9.9 to 46.2 cm/hr as shown in Table 1. The infiltration capacity at the tested sites also displays a reversible trending of increase and decrease on both sides of the dam with respect to the increment infiltration rate versus elapsed time in hours, which was of higher values in the downstream side (Dr-2) and lower in the upstream part (Dr-1) as illustrated by Fig. 6a. Furthermore, the open pit (OP-1 and 3) infiltration results have the identical response whereas, the OP-1 reflects higher values and OP-2 and 3 show lower ones as represented in Fig. 6b. The average values of hydraulic conductivity indicate low value (31 cm/s) at upstream site for Dr-1 and OP-2 and 3 while high value (142 cm/s) are acquired at the downstream site for Dr-2 and OP-1 as shown Table 1.

Fig. 5: a) Open pit test b) double ring test and c) soil sampling after test

Table 1: Infiltration rate and hydraulic conductivity values

Location	Test ID	IR (cm/hr)	K (cm/s)
Upstream	Dr-1	3.9	11
	OP-3	2.5	74
	OP-2	23.3	7
		Average values	
		9.9	31
Downstream	Dr-2	25	277
	OP-1	67.3	6
		Average values	
		46.2	142

Results of the textural analysis (sieving technique) showed variability in the grain sizes dominated by poorly graded sand with gravel in all test sites including double ring and open pit sites except the location of OP-1 that exhibits poorly graded sand as shown in Fig. 7a-b. These variations in the texture of the deposits are apparently belongs to the lithological constituents of the source material and to the geomorphological conditions Fig 8a-b.

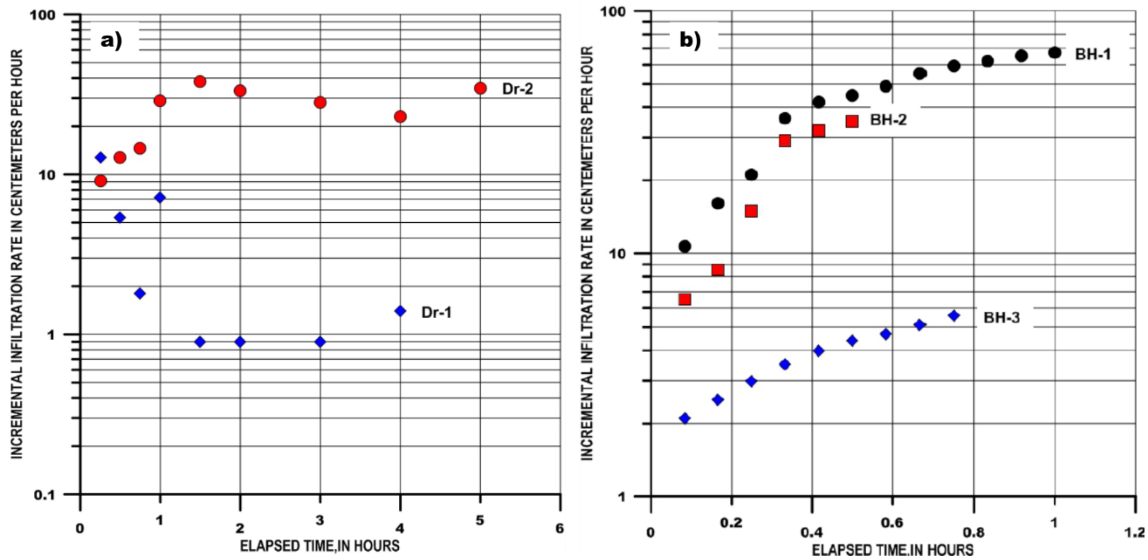

Fig. 6: Observed infiltration rate versus time in hours for a) double ring b) open pit tests

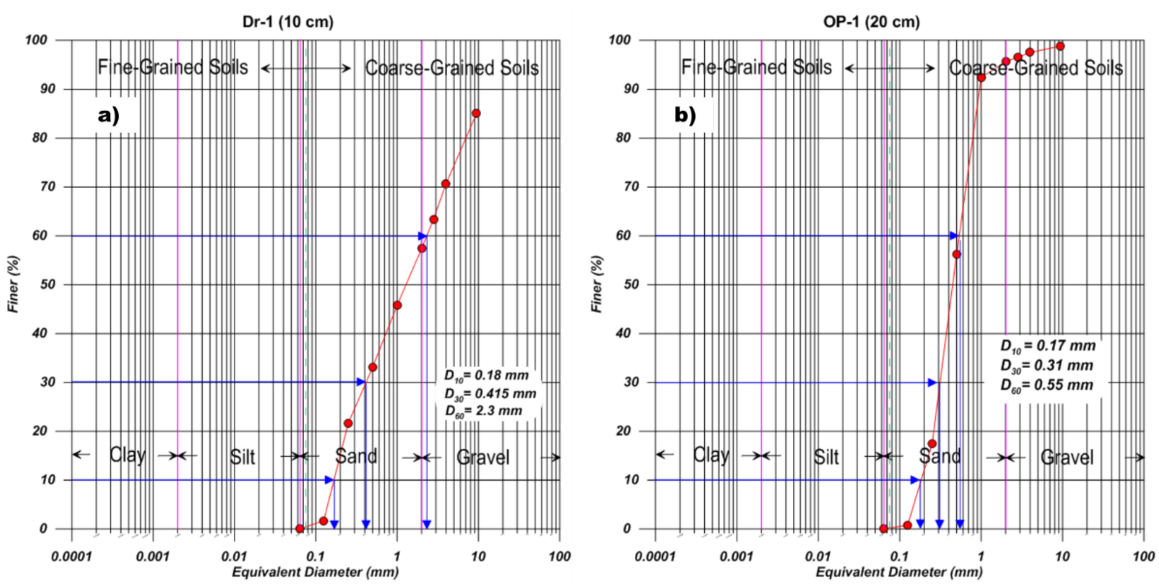

Fig. 7: Sieve analysis plots a) Dr-1 b) OP-1

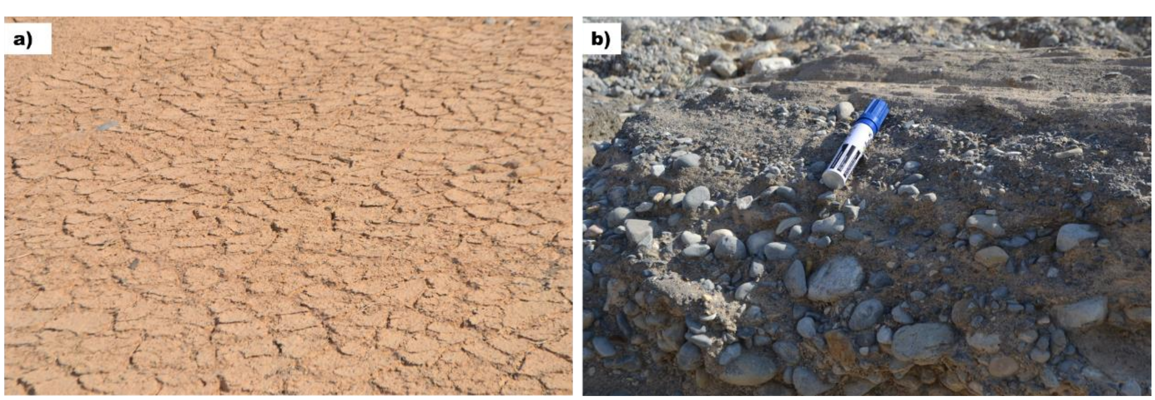

Fig. 8: Soil texture variation in upstream a) nearby b) far away from the dam

Conclusion and Recommendations

The top most zone of soil features are clearly observed in the study area and have a vital role in the processes of surface water infiltration or perching as shown in Figs.10 and 11in both sides of the dam. However, the coarse-grained nature of the sediments and the mud cover in the dam reservoir (upstream) pushing up the water seepage in some zones and perching the water for sometimes in the other areas. In addition, the increase of the infiltration rate and hydraulic conductivity in the downstream site compared with the upstream site may be attributed to the coarse texture of the sediments, and the dryness conditions which make the soil to absorb more water and increase the seepage under the water rock interaction and dissolving the cement and the matrix materials that present in the pore spaces. In the contrary, despite the largest reservoir area in the upstream and the coarser habit of soil textures (gravels, boulders and cobbles, etc.) the results reveal low values of infiltration rates and hydraulic conductivity parameters. This could be explained by the mud cover impact on the upper most soil zone whereas this clayey soil can be dissolved and melt in the rainfall water and moves down ward to decrease the hydraulic conductivity and infiltration capacity rather than in some areas specially close to the dam which has relatively thick cover prevent completely the water movement downward into the shallow aquifer.

Accordingly, it is recommended to remove periodically the mud cover from the area closed to the upstream dam wall to make the area usually active and ready to transmit the collected rainfall water immediately to the subsurface and recharging the shallow aquifer. By this way, the sustainability of the shallow groundwater aquifer in the area will be preserving good water quality and big quantity to safe the water user from any sudden shortage or scarcity in the region.

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Artificial Recharge: Mitidja Plain in Northern Algeria

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Abstract
The Mitidja plain is the largest sub-coastal plain of Algeria. It is located in the hinterland of Algiers that stretches over the territories of the capital city, Boumerdes, Tipaza and Blida. It covers an area of 1,450 km2 from, on a-100 km long with a width varying from 8 to 18 km. To be more precise, it is located north of Blida Atlas (1,620 m, Chréa peak), which protects it from the Saharan influence. In recent years, the recharge by rainfall has decreased because of drought. Furthermore, growth in needs of population, industry and agriculture has required increased pumping, which can lead to an unbalance of the groundwater. However, a generalized decreases in of the static level ranging up to more than 30 m in some areas. To avoid such a situation and for a more rational use of capacities of Mitidja groundwater, management by mathematical method becomes necessary. Within the scope of this work, we thought it was useful to present management scenarios based on a mathematical model: A.S.M "Aquifer Simulation Model". After a presentation of the overall operation of the geohydrologic system, use of the mathematical model based on the finite-difference method in steady state improves knowledge of hydraulic characteristics of the groundwater and the tendency of a complete water balance. Model calibration allowed checking the results reliability regarding the geometry and limits of the groundwater the hydrodynamic parameters thereof (estimation of permeability coefficient and storage coefficient). Second simulation in non-steady state (model operating) allowed determining the impact of flow rates taken from climatic trends on pieatic evolution of the groundwater. With this aim in view, with a currency of 1,460 days (4 years), operating scenarios were considered.

Keywords: Artificial Recharge, Modeling, Scenario, Mitija, Algeria.

1. Introduction

Algeria experienced several major droughts during the last century, in the 40s and 70s (Meddi and Hubert, 2003; Meddi Meddi H. and M., 2009; Meddi *et al.*, 2009; Taibi *et al.*, 2013). Space scale, intensity and major & perceptible impact which is the decrease of water resources that are the basis of agricultural yields, characterized the most recent drought. Water deficiency in recent decades has negatively affected agricultural production as well as surface and underground reserves of water resources. For Mitidja plain, the prolonged drought which led to sheet overdraft, produced a widespread decline in the static level up to more than 40 m in Larbaâ region, and more than 30 m in Blida region and a decline in drillings performance at the rate of 50%. Also, the lowering of water tables made salt-water encroachment easier in the eastern part of the groundwater. Most aquifers are currently being overdrafted, and this can only get worse in the future with the new needs. Drought and overdraft contribute to water quality degradation. It should also be reported that the natural recharge by rainfall (54% in 1970 and only 41% in 1980 for Mitija sheet (Meddi 1988) and wadi-sheet exchanges are no longer able to maintain the balance of overdrafted aquifers through drillings and wells. Artificial recharge for aquifers, from surface water or treated wastewater, became a very widespread practice in the world. The same recharge helps replenish sheets reserves, especially those affected by overdraft following the example of the Algerian aquifers. Mitija hydrogeological potentialities bring out a significant sheet the available resources of which are estimated at 500 hm^3. This sheet consists of two sets of groundwater reservoirs: the Astien and the alluvium of Quaternary. The second reservoir, by far the largest one, represents a-295 hm^3 inflow per year, i.e.; 60% of the overall volume (Loucif, 2003). Through this work, we want to prove feasibility of the artificial recharge for Mitidja sheet in its Southeast part, by enlarging on some digital simulation-based- scenarios. In these scenarios, different inputs and outputs will be tested to bring out the best possible scheme to increase groundwater reserves, through the use of surface water in the years to come. Many infiltration basins have existed in the past in the region, but were abandoned. With this new project, we will examine the development of the best scenario to perform, in order to meet the project's objectives, i.e.; maintaining the balance and restoring Mitija sheet.

2. Mitidja Plain Identification

2.1. Geographical position

Mitidja plain is the largest sub-coastal plain of Algeria. It is located in Algiers hinterland that stretches over territories of the capital, Boumerdes, Tipaza and Blida. It covers an area of 1,450 km^2 from Boudouaou wadi (Boumerdes) to the east up to Menacer basin (Tipaza) to the west, on a-100 km long with a width ranging from 8 to 18 km. It is a depression elongated from west to east, and it curves inwards Blida west-southwest and east-north-east direction up to El Hamiz wadi and the sea. It is directed in a parallel to the coastal topography. It is gently sloping towards the Sahel and the sea. The mean elevation is 100 m. As shown in Figure 1, we can define some elements that demarcate Mitidja plain:

- Atlas piedmonts in South.
- Sahel ripple in North.

Fig. 1: Mitija Plain's general geographical position

2.2. General outline of the climate

Mitidja plain is located North of Blida Atlas (1,620 m Chréa peak), which protects it from the Saharan influence. It is, by virtue of its geographical position, subject to the Mediterranean climatic regimen influence. Plain Mitidja is subject to a regional coastal subhumid climate that characterizes all coastal plains. Climate becomes more and more continental further away from the coast, and a marked drop in temperatures is recorded. Rainfall values in the region ranges from 184 mm to 1,211 mm, focused on a rainy period from October to February. Mean interannual rainfall in Mitija plain are irregularly distributed. Mitija plain pluviometry over a-33 year period (1971-2004), presents a great irregularity in annual means over the study period, a decrease from 1980 could be linked to the drought that affected the region and a decrease in the mean annual rainfall flows from east to west.

2.3. Geology and hydrogeology

Mitija geology was the subject of several studies based on major work of Glangeaud (1935); Ayme *et al.* (1952). Mitidja plain is one of Algeria's Neogene basins. According to Glangeaud (1935), the same plain is a rift zone between two highlands of mesozoic fields with the release of eruptive rocks that line the plain perimeter. It is the seat of a continuous bottom subsidence marked by Pliocene-Quaternary fillings, located north of Tell domain (Takorabt, 2011). Mitija basin formation was controlled by the rigid substratum subsidence between the East & West and Northeast & Southwest orientated faults. Its history dates back to the Eocene, while its structural units formation takes shape by the end of the Astien. Miocene, Pliocene and Quaternary's deposits react as a flexible overburden during the basin subsidence (Glangeaud, 1932). Mitidja Basin is a sedimentary postnappe basin (consisting of Pliocene-Quaternary lands) and also a synclinal oriented in the Northeast and Southwest direction with an asymmetrical bottom standing on a Plaisancian marly substratum, of Miocene age or sometimes Cretaceous (Takorabt, 2011).

2.4 Water Resources

According to the ABH (Hydrographical Basins Agency, 2000) for Algiers region, Mitija groundwater resources of is 328 $Hm^{3,}$ including key fields that catch the sheet: Mazafran I and II, Chebli, Barraki, Haouch Felit and Hamiz). Surface water is stored in dams currently in existence in the plain: Hamiz dam with a storage capacity of 15.6 hm^3, Boukhordène dam with a storage capacity of 90 hm^3 and Bou Roumi dam with a storage capacity of 200 hm^3.

3. Artificial recharge for Mitidja plain

The recharge induced in Mitija region has been in existence for colonial times. Seven infiltration basins were realized in Haouch LeGros region southeast of Boufarik (Fig. 2). Through this device, the sheet is fed by run-off water from Blida Atlas piedmont during the rainy season. Recently, the National Water Resources Agency (ANRH) has launched a pilot project to supply artificially Mitidja sheet in Bougara municipality (Fig 2).

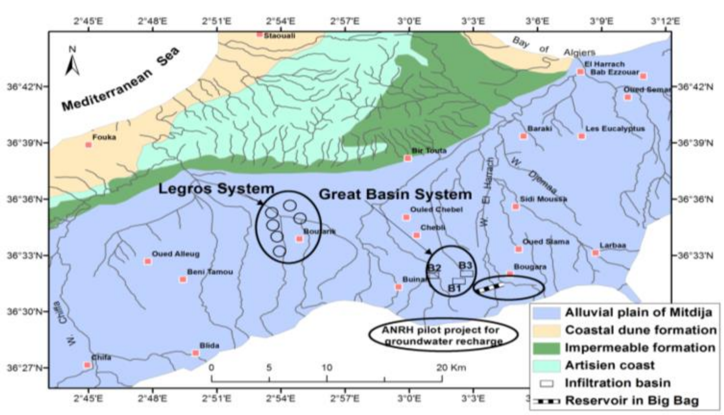

Fig. 2: Geographic situation of the various recharge systems currently in existence in Mitidja (ANRH, 2012)

The recharge device consists of four basins (ANRH, 2012), including a large settling basin with 50x50x3m dimensions and three infiltration basins with 30x15x3m dimension (Fig. 3). These basins are gravity-fed through a concrete canal with 80 meters length from El Harrach wadi (Cf. Fig.16). To assess reliability of this artificial recharge device, thirty (30) static water supplies (wells and boreholes) make up the sheet's fluctuations monitoring network in the experimental site region (ANRH, 2012). The first estimates of artificial recharge on the experimental site for the months of March and April 2005, give a volume at the rate of 17,280 m³ / day and 1,036,762 m³ during the two months. These induced infiltrations led to the groundwater levels recoveries ranging from 3.05 to 13.64 meters. These results show the efficiency of the procedure for artificial sheet recharge to recharge groundwater fields affected by the drought which is raging in the region since 1975 and groundwater overdraft (drinking water and irrigation). These encouraging experimental results have led us to develop this work through mathematical simulations (*artificial recharge modeling).* The simulations focused on five possible scenarios using the existing infiltration basins and existing drillings as means for recharging the sheet in order to bring out the best experimental device that will produce the best results in terms of sheet recovery for the medium and long term.

View of the large settling basin (50x50x3m) (ANRH, 2012)

View of the two infiltration basins (30x15x3m) (ANRH, 2012)

Fig. 3: Settling basin and two infiltration basins of the experimental project to supply artificially Mitidja sheet in Bougara municipality (ANRH, 2012)

3.1. Artificial recharge method for Mitidja sheet

The evolution of Mitidja aquifer system piezometry shows a continuous drop since 1980. During the 1980-2000 period, one noted a significant and continuing drop in the sheet level. It is at the rate of 30 meters in some places of the sheet, while for the period from 2000 to 2012, a stabilization of the sheet level was recorded. The drop in the piezometric level for the period 1980-2000, in catchworks is due to several phenomena, among others: long drought period, seasonal and annual fluctuations of rainfall and intensive pumpings in industrial and agriculture areas.

Stabilizing the sheet level for the period 2000-2012 is in direct connection with: the increase in annual rainfall after the year 2000 and the pilot project of artificial sheet recharge on Hammam

Melouane wadi bank from 2005. ANRH's figures (Fig. 4) show the evolution of piezometric level downstream from infiltration basins. Static sheet levels measured in 2005 (date for commissioning) at three piezometers located downstream from the basins, give depths between 35 and 41 meters but after removing the basins' feeder channel , levels fell to values ranging between 54 and 68 m in 2010.

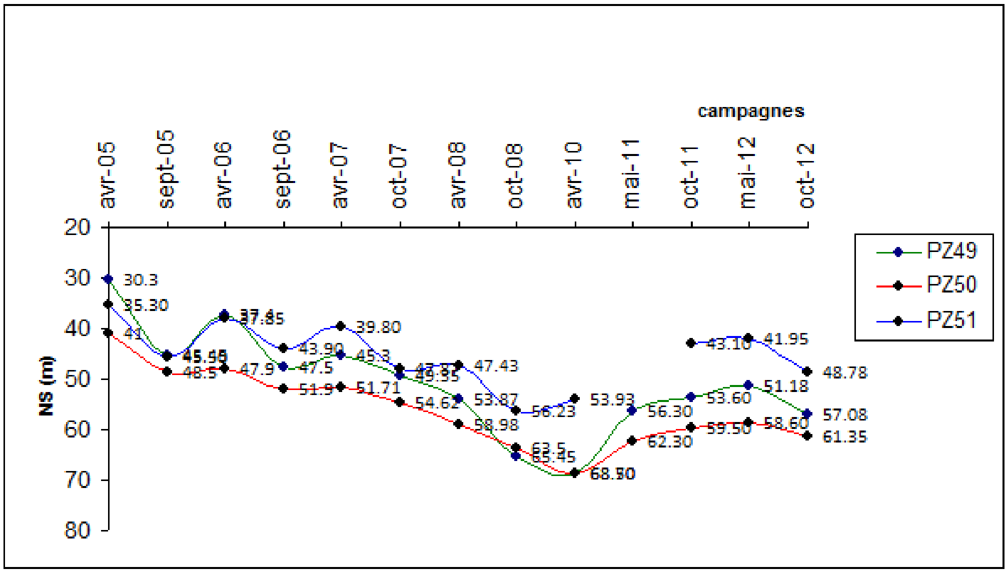

Fig. 4: Piezometric level development downstream from the infiltration basins (Period: 2005-2012)

<u>*In brief*,</u> this project of recharge through infiltration basins has produced good results. Currently, these basins are at a standstill because of to the wady's water diversion to the new Douéra dam. This fact might further increase the sheet lowering.

3.2. Modeling the experimental area of Mitidja artificial sheet recharge

The modeling's objectives are the monitoring and surveillance of the piezometric condition in the experimental area before and after the use of artificial recharge technique and the risks that may be caused and the searching for a better solution through the scenarios proposed.

3.3. Presentation of the structure modeled

a. General idea of the system currently in existence in the pilot project

The pilot project for Mitija sheet recharge includes:

<u>1st experience (ANRH):</u> on the upper El Harrach wadi bank, there are:

- ✓ One (01) fines particles setting basin (50 m x 46 m x 3 m).
- ✓ Three (03) basins intended for water infiltration (31 m x 15 m x 3 m). These basins are supplied by water intake channel from the wadi. The project also includes piezometres realized downstream to follow up the recharge effect on groundwater level.

2nd experience (Blida Water Resources Directorate): located 3 km in north-west of ANRH's site. These basins are large-sized (50 to 100 m length and 30-50 m width) and are fed by irrigation canals dating from 1827 and conveying Hammam Melouane wadi water.
At present, five (05) basins were realized in the region between Bouinan and Bougara and which recharge the sheet with high flows:

- Basin 1: with an infiltration flow ranging from 40 to 70 l/second.
- Basin 2: with a flow of 306 l/second (gauging dated March 14th, 2005).
- The other basins receive from 20 to 40 l/second.
- A large settling basin prior to its finalization had an inflow of 986 l/second.

The pilot project for sheet recharge is located on El Harrach wadi bank that is the object to be modeled. This bank corresponds to the stretch of the permeable formation for the eastern Mitija region. It is located in the area between Bouinan and Bougara towns. We consider the aquifer in this region as "monolayer" with free surface flow, two-dimensional in the whole field and low hydraulic gradient. Under such conditions, we used a two-dimensional flow model, i.e.; A.S.M model (Aquifer Simulation Model) developed by W. & R. Rausch Kinzelbach (Heidelberg / Stuttgart) in 1992, 5.0 E.

The model program will solve the model "n" equations, in the form of a matrix of "n" lines and "n" columns. The topographic base, used as a reference for the model, is obtained by scanning the water-level map (Cf.Fig.) of Mitija sheet (October survey, 2012, drawn up by ANRH). The study area has, thus, been divided into a set of square meshes, of 500 m square, distributed as a follow-on from a matrix of 17 lines and 10 columns.
The boundary conditions are defined as all hydrodynamic conditions, flows or potentials permanent or variable, imposed within an aquifer system. Their definitions require the quantitative system description.

- Geologic boundaries: Characteristics and positions of the study area were prepared from the information collected during the region's hydrogeologic synthesis.
- Bed-rock: Mitidja alluvial aquifer stands on the impermeable marls of the Plaisancian. The bed-rock represents an impervious boundary, without exchange by leakage with the aquifer, deeper.

In the project zone, morphology of this surface was interpolated to obtain an elevation for each mesh of the model.
Hanging side: across the study area, modeled alluvial sheet is considered to be free. As a result, the aquifer's hanging side boundary corresponds to the soil surface and doesn't matter in the model, at least as the modeled piezometry does not reach the soil surface.
Impervious boundaries: conditions for imposed flow will be expressed in terms of net recharge: a direct rainfall infiltration recharge (homogenized recharge at each mesh) and an infiltration recharge from El Harrach wadi.

b. First scenario
With the existing catchworks and their current rates, without infiltration basins inflow, we performed a simulation over a-four (04) year period. Based on the current values of inputs and outputs, the histogram representing the sheet's water balance after 4 years of operation shows that the sheet keeps roughly the same current values. Drought risk still remains. Graphic

representation of the piezometric evolution over time (Fig. 5) shows a slight lowering (0.35 to 0.76 m) in the two piezometers of the downstream part (PZ 01 and PZ 02) and a significant lowering (1.80 m) in the upstream part (PZ 03) during the four years.

c. Second scenario

In this case, the region is supposed to be subjected to a drought. This situation forces us to increase the sheet's operating flow with 35% (from 1.20 m^3 / second to 1.62 m^3 / second) and reduce inflows entering the sheet by 15% (from 2.21 m^3 / second to 1.88 m^3 / second). Infiltration basins are still at a standstill. For this second scenario, over 4 years of operating in such a situation, the balance drawn up for the sheet will be showing a shortfall with a **negative** "surplus" **: - 0.34 m^3 / second.** In actual fact, the lowering is indicated by a very significant drop in hydrostatic depths at the three gauging piezometers. Thus, a significant depression of the sheet (ranging from 6.54 m to 16.43 m in 20 years, depending on location) is recorded for the three gauging piezometers (Fig. 6).

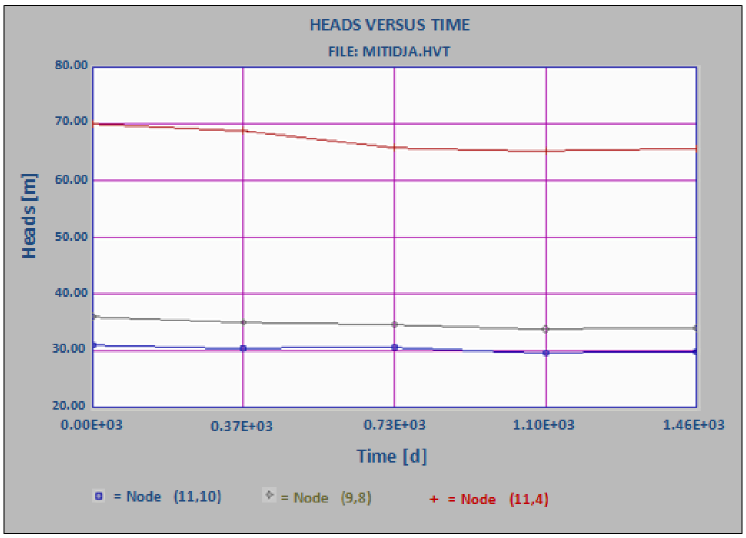

Fig. 5: Time-dependant piezometry in the case of the first scenario

d. Third scenario

The objective of this scenario is to see the effect of infiltration basins on the sheet lowering in this pilot project. For this, we keep the same current operating flow of (1.20 m^3/ second) and we relaunch infiltration basins activity with an infiltration rate of **0.22 m^3 / second.** The simulation for this scenario over a-four (04) year period, leads to interesting results. In this case, the sheet' water balance shows a trend towards a balanced regimen, with a surplus of **0.61 m^3 / second.** The results of such a scenario in terms of piezometry show:

- In the southern part, piezometer PZ 03 shows a piezometric increase during the first year by 3.15 m, then a decrease not to exceed 0.65 m in four years.
- However, in the north, piezometric fluctuations are more marked (they vary from 2.0 m at PZ 011 and 1.05 m at PZ 02), Fig. 7.

This scenario improves the sheet situation, but does not meet the population's growing requirements of the region.

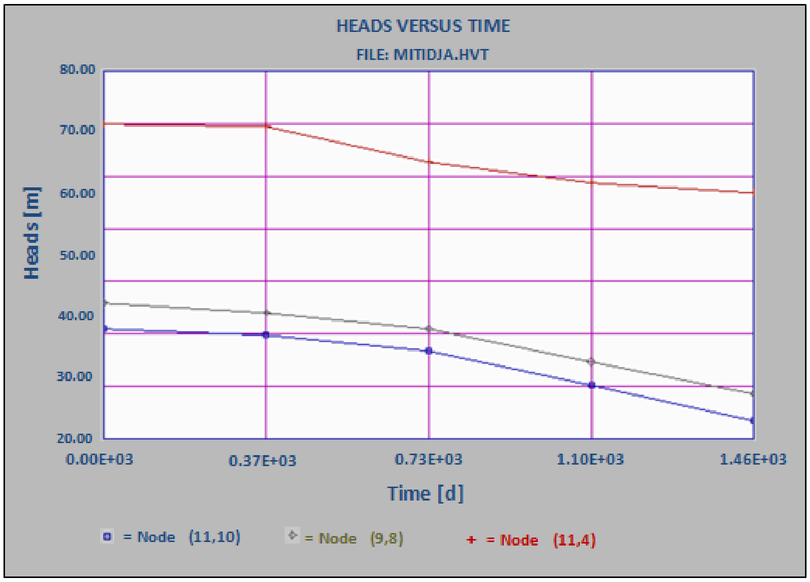

Fig. 6: Time-dependant piezometry in the case of the second scenario

f. Fourth scenario

In this case, we increase by 1.20 m^3 / second to **1.50 m^3 / second** the sheet's operating flow due to the growing water resources demand. The additional 0.30 m^3 / are distributed on wells and boreholes of the study area. The infiltration basins are in service **(0.22 m^3 / second)** for this scenario. The fourth scenario shows that, over four years of operation, the sheet regime is not showing a shortfall but notes a smaller underground water reserve: 0.11 m^3 / second.
This fourth scenario shows that, over four years of operation, the sheet regime is not showing a shortfall but records smaller underground water reserve: 0.11 m^3 / second. Following the hydrostatic variations recorded during the four years in the observation points of the study area (Fig. 8). We observe:

- In northern part, a small piezometric rise (first year of simulation) after a sheet level stabilization. The rise in the two piezometers is at the rate of 1.13 m in PZ 01 and 0.71 m in PZ 02.
- In the southern part, the piezometer PZ 03 shows a piezometric stability then a lowering at the rate of 0.45 m over four years.

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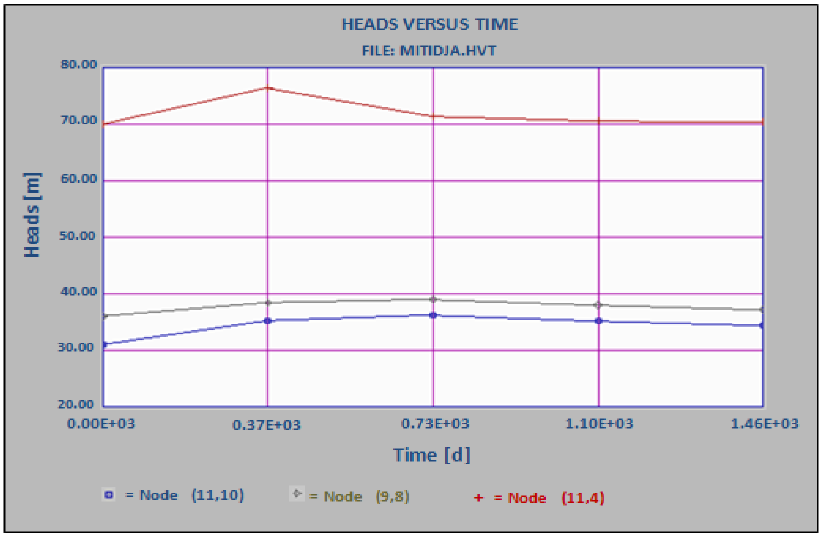

Fig. 7: Time-dependent piezometry in the case of the third scenario

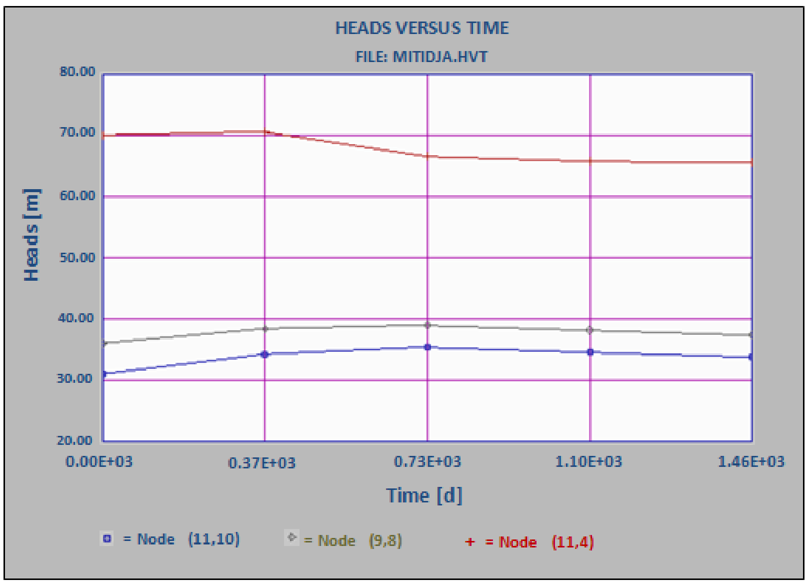

Fig. 8: Time-dependent piezometry in the case of the fourth scenario

g. Fifth scenario

For this scenario, we propose the folowing solution:

- Keep the same recharge device through the current infiltration basin (0.22 m^3/second).
- Adding a new site (infiltration basins in the median part of the study area) with a flow rate of 0.25 m^3/second.
- Using three drillings already existing in the downstream part with a flow rate of 0.15 m^3/second. These drillings are used for a dual purpose: supply and extraction.

The ensuing diagram shows a best result than the precedent one.

Pour this scenario, a trend towards a very balanced regime (surplus is: 1.01m^3/second).

Pizometric values in the three gauging piezometers produce satisfying results as regards the rise in the piezometric level. This rise varies between 14.70 and 29.50 m.
Pizometric values in the three gauging piezometers (Fig. 9), Pizometric values in the three gauging piezometers on the piezometric level rise at the study area. This rise varies between 14.70 and 29.50 m.

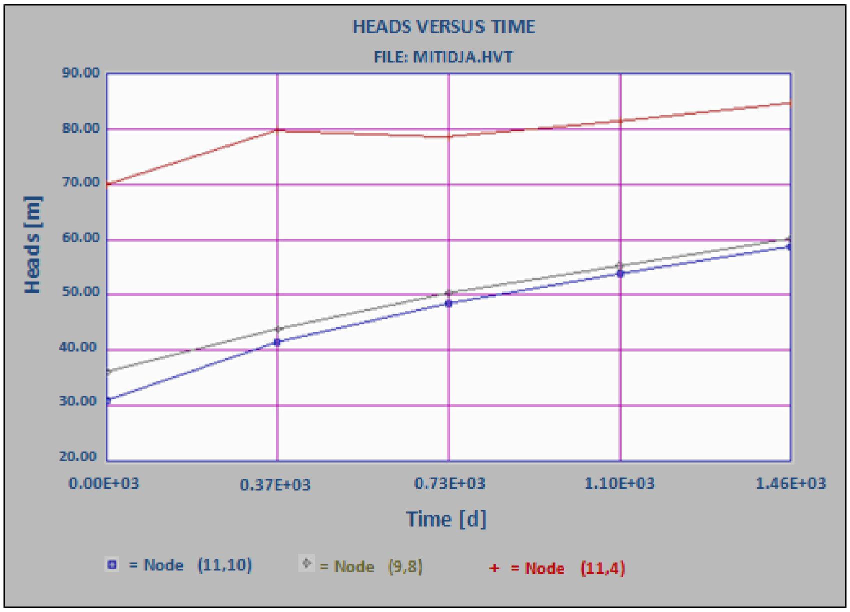

Fig. 9: Time-dependant piezometry in the case of the fifth scenario

4. Conclusion

The vulnerability of Mitija sheet water became a reality with the lowerings in the static level not to exceed 30 m in some places. This evolution is mainly due to the decrease in recorded atmospheric inflows since the mid-1970s and the excessive use of ground water to cover the water demands for drinking water supply and those of agriculture. Both demands have risen in recent years because of population growth and irrigation areas development. Therefore, an induced inflow to the replenishment of water underground reserves has become an imperative. This inflow can be done through artificial recharge of the sheet as it has been proven by the scenario 5. For the latter, piezometric values, within the three observation piezometers, produce satisfactory results in terms of piezometric level rise. This rise varies between 14.70 and 29.50 m.

By way of consequence, the artificial recharge system has demonstrated its efficiency in water resources development. This water storage strategy is more efficient and less expensive. However, this operation comes up against varying problems related to turbidity, pollution and temperature. Turbidity causes clogging of the injection structures or the filter medium of the infiltration basin, which requires a pre-treatment before use. The surface pollution is likely to cause a deterioration in groundwater quality (a thorough monitoring of water quality is therefore essential). In addition, an imbalance of thermal control may be established, especially when it is about direct inject into the sheet. El Harrach wadi water, in its upper course, is of good physicochemical quality and can, therefore, be used in infiltration or injection supply system through boreholes, without this water might raise problems.

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Aquifer Storage and Recovery in Wadi Ham, United Arab Emirates

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Abstract
During low water demand periods, the surplus of desalinated water might be used as a sources for groundwater recharge. As a result, the quality of the groundwater will be enhanced and the injected water can be recovered. This paper investigates the possibility of storage and recovery of desalinated water in the brackish aquifer of Wadi Ham, United Arab Emirates. To that end, the geological and hydrogeological parameters of Wadi Ham are defined and a three-dimensional numerical model is used to simulate the injection of desalinated water and the development of the freshwater mound in the brackish groundwater environment. The freshwater is stored in the system for a specified period of time and then pumped back through the same injection well. The efficiency of the system is calculated as the ratio between the volume of water recovered with a salinity of 700 ppm or less and the volume of the injected desalinated water. The development and recession of the water mound is presented. Results indicated that careful attention should be devoted to injection and recovery rates and the storage duration to achieve a good performance of the system.

Keywords: Aquifer Storage and Recovery, Numerical Model, Wadi Ham, Recovery Efficiency.

Introduction

The lack of fresh water resources constitutes one of the major obstacles against the sustainable development in the UAE. Groundwater contributes by more than 50% of the water budget of UAE (MOEW, 2010). However, the groundwater recharge is limited to the infiltration during intermittent flood flow in dry wadi channels due to the sporadic and infrequent rainfall in the area.

Techniques of artificial aquifer recharge have been used all over the world for over 200 years mainly to protect against water shortages in many arid and semiarid countries (Carling and Gustafsson 1998). Masciopinto (2006) studied artificial recharge of a coastal aquifer in southern Italy. He showed that artificial recharge stabilized the normal situation while improving chemical quality of the water. After the recharge, the saltwater/freshwater interface had receded by 2 km. In Tunisia, artificial recharge is used in the Teboulba coastal aquifer as it suffers the deleterious effects of uncontrolled exploitation and deterioration of water quality. The water quality was improved in the Teboulba aquifer during artificial recharge operations by water from the Nebhana dam (Bouri and Dhia 2010).

A relatively new and rapidly-spreading practice in artificial recharge is the use of aquifer storage and recovery (ASR) wells (Pyne 1995; Sheng 2005). ASR is an effective strategy for water resources management and has been widely used in many saline aquifers (Chunhui *et al*. 2011). To achieve a high efficiency, ASR is usually practiced through continuous cycles of injection and recovery over an extend period of time. The broad based knowledge of local geology, hydrogeology, water quality, water demand and variability, and water availability is important for the success of an ASR schemes (Pyne 2005). The recovery efficiency is controlled by a wide variety of factors including ambient hydraulic gradient, aquifer permeability, porosity, heterogeneity, thickness, and confinement, ambient groundwater density and quality, injected water density and quality, and ASR operation (Merritt 1985, Missimer *et al.* 2002). Pavelic *et al.* (2002) stated that recovery efficiency may vary enormously between ASR schemes due to a range of hydrogeological and operational factors. The range of optimum transmissivity is depending on desired pumping rates and recovery efficiencies (Missimer *et al.*, 2002).

Groundwater flow models were also used to assess the impact of hydrogeologic and operational parameters/factors on recovery efficiency of ASR systems (Christopher and Mary 2006). Many of the authorities in UAE including the Environmental Agency of Abu Dhabi and Sharjah Electricity and Water Authority are considering the implementation of large scale ASR projects. Few pilot projects have already been completed in Abu Dhabi and Sharjah Emirates. The growing requirement of water in various consumption sectors in the coastal region of Kalbha and Fujairah is met by withdrawing large quantities of groundwater from Wadi Ham aquifer. Over the last two decades, groundwater levels have declined significantly, causing a severe seawater intrusion problem. Many wells have been dried up and several farms have been abandoned during the last two decades. The growing importance of the topic emphasized the need to study the state of the knowledge in relation to aquifer storage and recovery systems. This paper investigates the possibility of storage and recovery of high quality desalinated water in the brackish aquifer of Wadi Ham, Fujairah Emirate.

Hydrogeological Settings

The UAE lies in the south eastern part of the Arabian Peninsula between latitudes 22^0 40’ and 26^0 00’ North and longitudes 51^0 00’ and 56^0 00’ East. It is bounded from the north by the Arabian Gulf, on the east by the Sultanate of Oman and the Gulf of Oman and on the south and west by the Kingdom of Saudi Arabia. The major part of the land is covered by desert and remaining part is characterized by the geomorphologic features include mountains, gravel plains, sand dunes, coastal zones and drainage basins (Al Hammadi, 2003).

Wadi Ham rises in the mountains approximately at 1000 m above mean sea level immediately south and south east of the Masafi and draining south eastwards into the Gulf of Oman between Fujairah and Kalbha. The catchment lies between the city of Fujairah on the Oman Gulf to the east and the town of Masafi located on the divide of the Masafi mountain series. The total catchment area is 192 km^2. The upper portion is characterized by narrow valleys and steep slopes leading to distinct channels down to the wadi floor of coarse alluvial gravel sand boulders and steep flanks along the surrounding peaks. The number and the depth of channels decrease towards the coast. Wadi Ham valley floor is a flat-gravelly plain with triangular shape broadening to the sea and draining the surrounding mountains.

The catchment area of wadi Ham is mostly dry throughout the year but the occasional intense rainfall can lead to short duration flash floods. The aridity nature of catchment is threatened by the lack of renewable freshwater resources. Average annual rainfall in the catchment is around 130 mm/year, however, rainfall varies between 10 and 530 mm/year (Sherif *et al.* 2009). The rainfall records in the study area over the last 14 years have shown that the average annual rainfall dropped to less than 70 mm. The recorded average annual rainfall in UAE is around 110 mm (Sherif *et al*. 2011).

Wadi Ham is composed of two aquifers; namely the main Quaternary aquifer which is composed of Wadi gravels and the fractured Ophiolite aquifer. Gravels are unconsolidated with higher permeability at the ground surface and becoming cemented and consolidated as the depth increases. These gravels could be subdivided into recent gravels, being slightly silty sand gravel with some cobbles; young gravels, which are silty sandy gravels with many cobbles and boulders; and old gravels, which are silty sandy gravels with many cobbles and boulders (Electrowatt 1981). Values of the hydraulic conductivity of the unconsolidated gravels tend to be high, typically from 6 to 17 m/day and in the range 0.086-0.86 m/day for the cemented lower layers (Electrowatt, 1981 and ENTEC, 1996). The unconsolidated gravels primary porosity is very high when compared to the cemented gravels. The storage coefficients typically range from 0.001 to 0.003 (Electrowatt 1981, ESCWA, 1997). The saturated thickness various between 10 and 40 m and the transmissivity varies between 100 and 200 m^2/d. In the vicinity of the shoreline, the saturated thickness varies between 50 and 100 m and the transmissivity value ranges between 1000 and 10,000 m^2/d. The hydraulic conductivity ranges between 2 and 250 m/d (IWACO, 1986).

Development of the Numerical Model

The study domain of Wadi Ham aquifer comprises an area of 117.81 km^2 with a length of 11.9 km east to west and a length of 9.9 km north to south (Fujairah to Kalbha). The study area and the aquifer boundaries were delineated. The model domain includes the Gulf of Oman and the ophiolite sequence rock out crops. The ophiolite outcrops are separated as inactive or no flow area. The study area is divided into a mesh including 11781 square cells of 100 m by 100 m. The net area of the aquifer is only 64.94 km^2 covered by 6494 active cells.

The area occupied by the Gulf of Oman in the model domain was considered as a constant head boundary cells with a sea level head (0.0 m) for the modeling period. The model area of lower plains of Wadi Ham composed of recent Pleistocene wadi gravels. This layer is underlain by the impermeable consolidated rocks of the Semail formation (Ophiolitic sequence). Based on this, a one-layer model of Wadi gravel and sand is considered. Aquifer parameters are identified through comprehensive study conducted in the eastern coast of UAE (Sherif et al., 2006 and Sherif et al. 2012).

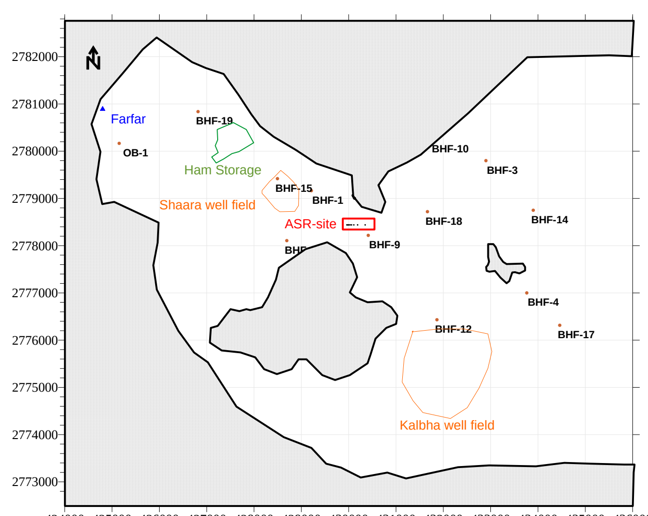

Fig. 1: The study domain

Recharge from rainfall as well as the ponding area of Ham dam is considered. Rainfall daily data was collected from the nearby Farfar gauge station. The rainfall (m/day) was assigned to all active cells in the modeled area. Recharge due to ponding (m/day) was assigned for the storage area. Monthly groundwater levels for 16 observation wells in Wadi Ham area were collected over a period of sixteen years. Initial head values were obtained through the steady state simulation and from available data of groundwater levels within the study domain when the aquifer was in a steady state conditions in the early eighties. Two well fields (Fig. 1) in the study area are in operation for the domestic and agricultural water supply. The first one is Shaara well field, 2 km downstream of Wadi Ham dam. The second field is Kalbha well field with 60 wells which has been in operation since 1995.

Flow Model

All the simulations were conducted in three dimensional fields using MODFLOW. The model was calibrated over a five-year period from January 1989 to December 1993. The groundwater levels obtained for December 1988 of all observation wells were considered as initial head values. Model calibration was performed by changing aquifer parameters, recharge and discharge factors to ensure that the calculated heads at observation wells are reasonably matching field measurements. Figure 2a shows comparison between all temporal and spatial records of water levels in all observation wells during the calibration period with the corresponding simulated groundwater levels. It is evident from this figure that model results are in good agreement with observed groundwater levels considering groundwater abstractions and recharge from rainfall events. Calibrated distributions of the specific yield, hydraulic conductivity and recharge factors of rainfall and reservoir ponding were kept constant and used in model verification.

Model verification was carried out over duration of sixteen years starting from January 1994 to December 2010. Similar to the calibration period, rainfall and reservoir data are assigned to all active cells the model area. The calibrated distributions of specific yield and hydraulic conductivity were used with the new pumping rates. Simulated hydrographs over the verification period were compared with the observed field hydrograph for the same observation wells that were used in the calibration process. The observed field groundwater levels versus simulated levels for all observation wells at different times are presented in Figure 2b. A good matching between the observed and simulated values over the verification period was observed. The statistical values (Table 1) indicate that the observed and calculated values are within the acceptable range.

Table 1: Comparison of observed and calculated statistical parameter

Parameter	Calibration period			Validation period		
	Observed (m)	Calculated (m)	Difference (m)	Observed (m)	Calculated (m)	Difference (m)
Min	-3.181	-2.936	0.245	-2.771	-2.531	0.240
Max	50.856	48.399	2.457	64.106	61.363	2.743
Mean	11.897	12.608	0.711	13.425	13.852	0.427
STDEV	14.703	14.675	0.028	15.743	15.767	0.024

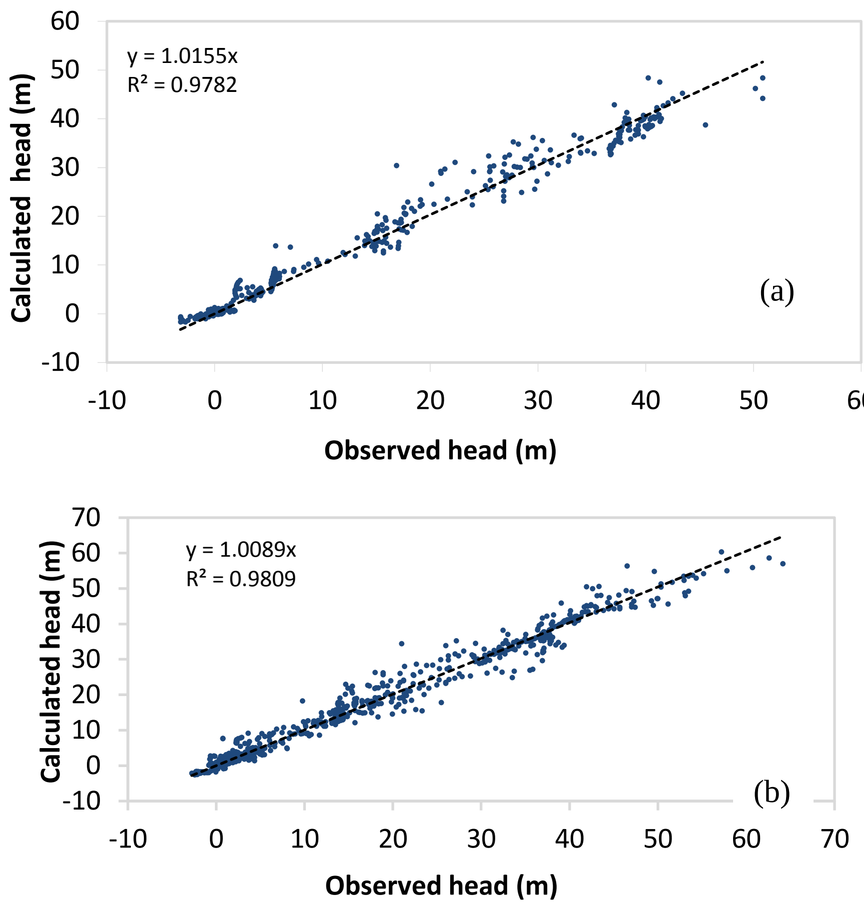

Fig. 2: Fitting of observed and calculated water level: a-calibration period and b-validation period

Transport model

A solute transport model was developed to assess the variation of salinity concentration due to the injection of desalinated water and its recovery from the ASR well. The calibrated flow model was used to simulate the salinity levels of the groundwater aquifer and its variation in time and space. The simulations were carried out using MT3DMS module.

The longitudinal dispersivity for each grid cell was set 20m. The ratio of horizontal to longitudinal dispersivity of the layer was 0.1 and the ratio of vertical to longitudinal dispersivity of the layer 0.01. For the transport model, the boundary conditions describe the exchange of solute mass between the model and external system. The constant boundary condition acts as a contaminant source providing solute mass to the model domain in the form of known concentration for a relatively long period of time. Cells representing the Gulf of Oman in the study domain were considered of constant concentration with a salinity of 35,000 mg/l. Because the extinction depth was assumed 2 m, the evapotranspiration from the water table was found negligible. Therefore, the concentration accompanying the evapotranspiration flux was also neglected. Point source boundary condition specifies the concentration of each species entering or leaving the model through flow boundary conditions specified in the flow model. A freshwater concentration was assumed where there is a freshwater influx through the main wadis.

These simulated concentrations were compared with the limited observed data available in the study. The observed field salinity levels versus simulated levels for some of the observation wells are presented in Figure 3. A reasonable agreement between the observed and simulated concentration values was obtained.

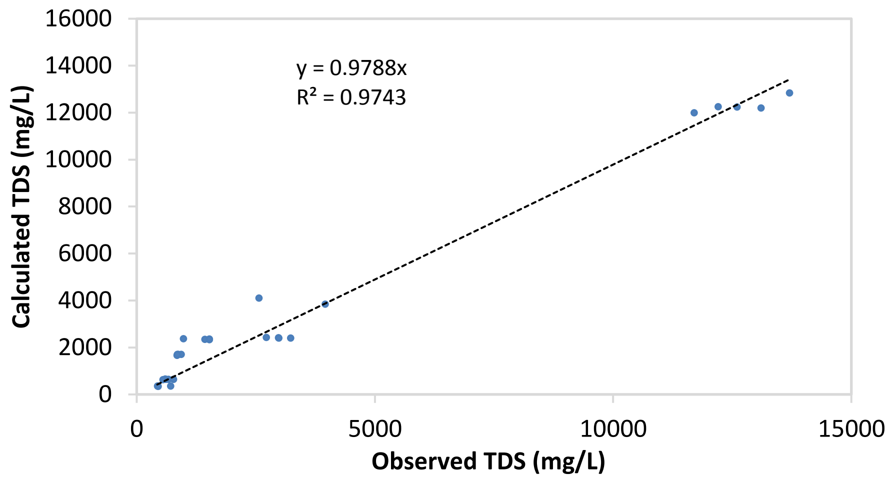

Fig. 3: Fitting of observed and calculated salinity level for validation period

Simulations and Discussions

Proposed ASR site was located in an area with minimum variations in groundwater and concentration levels. The TDS in the selected area ranges between 800 and 1500 mg/l. The location of the proposed ASR site is presented in Figure 4. The ASR system consists of 8 wells within the range of 600 m in the east-west direction. ASR is basically considered as an injection/recovery well and 7 more wells as an observation wells. The distance between the wells varied between 10 m and 160 m. The grid was refined to 20 m by 20 m in the vicinity of ASR site. The simulation was conducted in a dry period with almost no variations in heads and concentration levels. The input concentration of the injected (desalinated) water was set as 140 mg/l and the injection program was based on the pumping schedule of the well.

The implementation of the ASR numerical exercise took place during the period January 01, 2002 to December 31, 2002. Injection and recovery periods were selected as 60 days with variable storage period and discharge levels for well ASR. The variation in water table during the normal and the ASR periods is shown in Figure 5 for 30 days of storage and with discharge rate of 500 m^3/day. The water table variation is observed minimum during the normal phase of the system and equally dynamic during the ASR period. Obviously, ASR is more active as it is considered as pumping and recovery well in this case. Figure 6 shows the variation of water table during the injection (60 days), storage (30 days) and recovery (60 days) phase for the well ASR. The increase in water table was about 8.0m at the end of 60 days of injection and lowering of water table is about 11.0m at the end of recovery period.

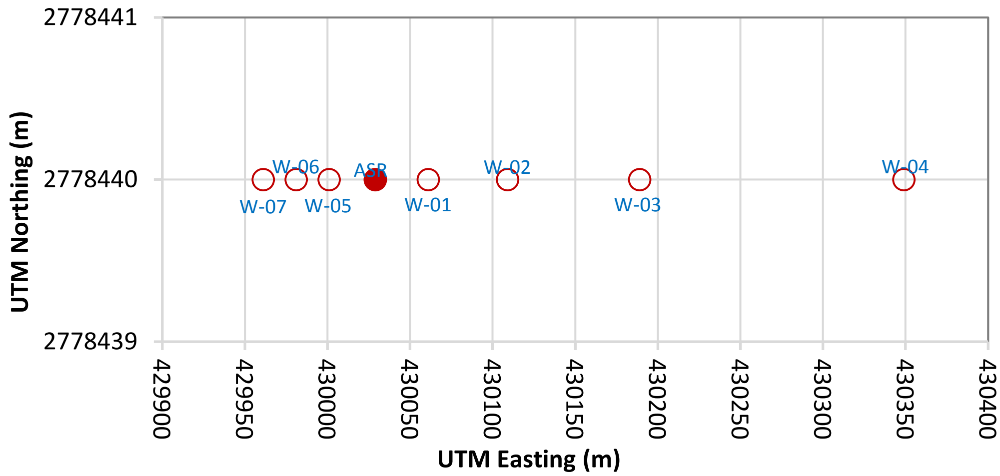

Fig. 4: The proposed ASR system

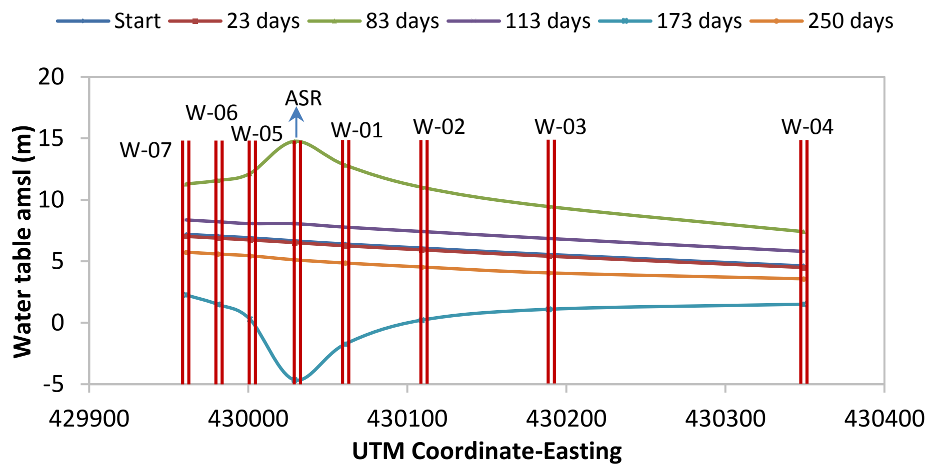

Fig. 5: Water table profile at different simulation time

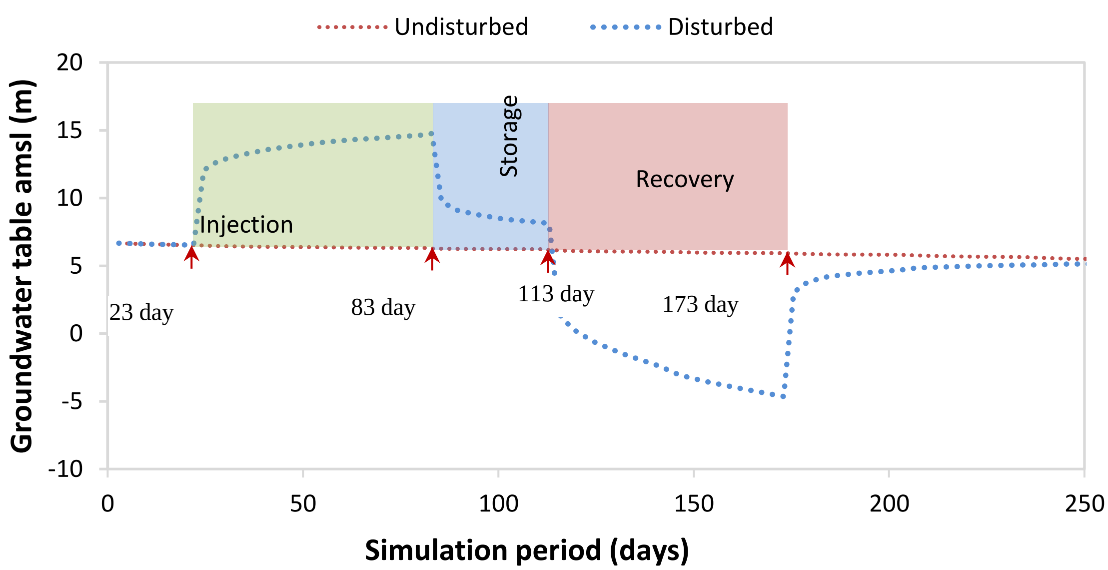

Fig. 6: Variation of water table during the disturbed and undisturbed phases for ASR well

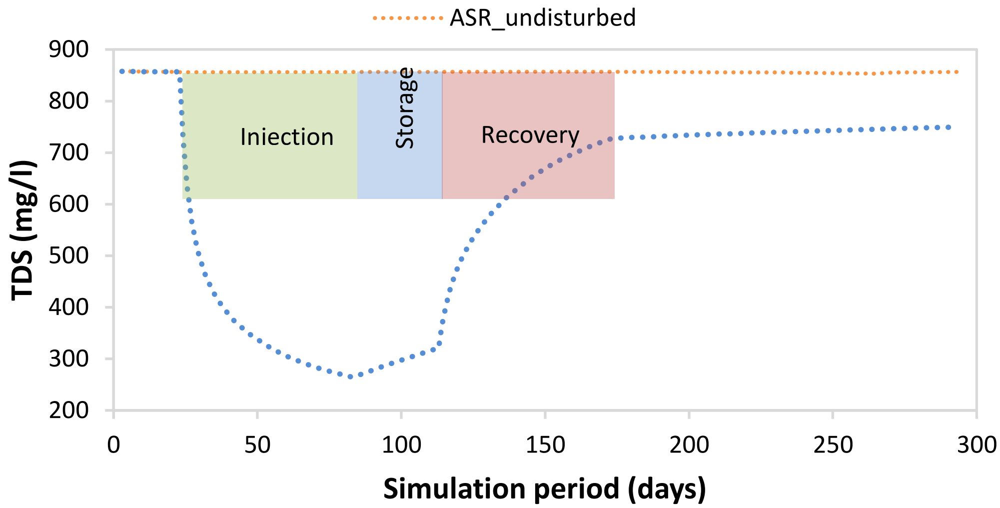

Fig. 7: Variation of salinity level during the undisturbed and disturbed conditions of ASR well

It was also observed that the initial two days of injection as well as recovery has shown maximum variation in water table level. However, after the initial two days, variations stabilize and rate of change becomes steady during the remaining phase of injection and recovery. A sharp decline of water level was observed in the initial 20 days of storage period and becomes steady decrease for the remaining period.

The variation in water quality during the normal and the ASR periods is shown in Figure 7 with injected desalinated water of 140 mg/L. The observed quality variation is minimal during the normal phase of the system and large variation during the ASR period. Predictably, ASR is more proactive as it is considered as pumping and recovery well. The Fig. 8 shows the variation of water quality during the injection (60 days), storage (30 days) and recovery (60 days) phase for the well ASR. The water quality was lowered to about 265 mg/l at the end of 60 days of injection and steadily increasing to 321 mg/l at the end of storage period. At the end of recovery period, salinity level raises to 730 mg/l. It was also observed that the initial two days of injection has shown maximum variation in water quality levels. However, after the initial two days, the rate of variation becomes steady during rest of the recovery phase. The quality level is not reaching initial level even after the recovery period of 60 days. It was also observed that changes in TDS levels become marginal after the recovery phase.

The ASR_01 was selected as an injection and recovery well for the simulation with 60 days of injection and recovery period. Initially, 30 days of storage considered for discharges 400m^3/day, 500m^3/day, 600m^3/day and 700m^3/day. The recovery days were cut-off when threshold quality level 700 mg/l was reached. Efficiencies were estimated for 45, 60, 75, 90, 105 and 120 days of storage periods. The efficiency was drawn against storage period (Figure 8). Presumably, shorter duration of storage has higher efficiency than the higher storage periods. However, consistent efficiency was observed in the case of recovery discharge level 500m^3/day. It also shows that between 40 and 50 days of storage has moderate efficiency level (70-78%). The higher rate of decrease in efficiency recorded after 50 days of storage period. The variation of efficiency against recovery rate was established and presented in the Figure 9. The discharge level of 500m^3/day has better efficiency level when compared to other recovery discharge level. These figures also establish that lower storage period has better efficiency than the higher storage period.

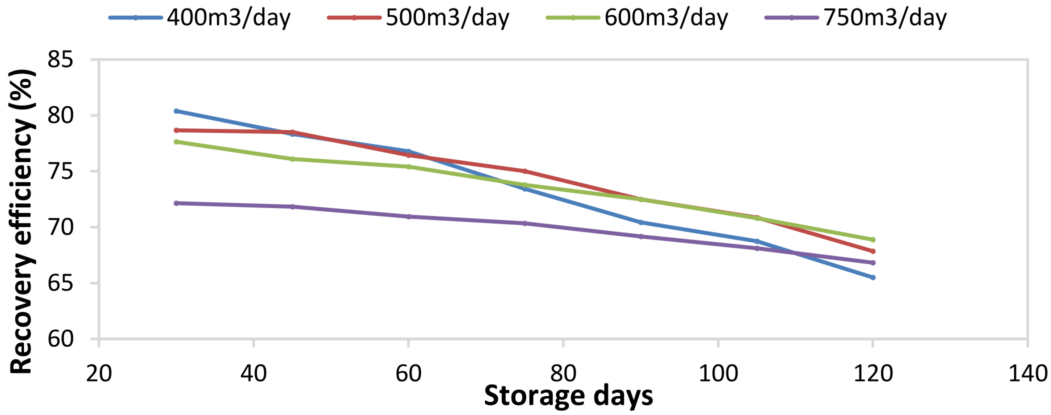

Fig. 8: Efficiency against storage duration

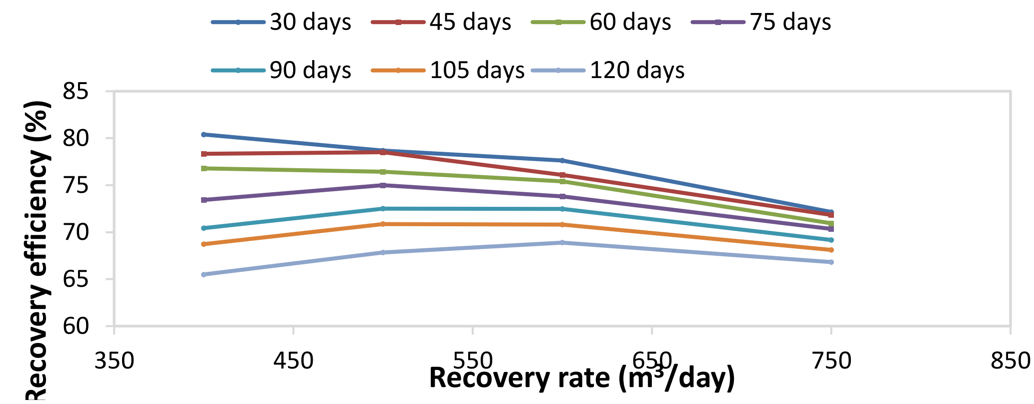

Fig. 9: Efficiency against recovery rate

Conclusion

A three dimensional model has been developed to simulate the aquifer storage in recovery in the area of Wadi Ham, UAE. The model was calibrated and validated using available records of groundwater levels and salinities. Different scenarios and durations of injection and recovery are investigated to identify the best scenario which would allow for optimum recovery of the injected water. A higher recovery efficiency was achieved for the discharge rate of 500m^3/day with 45 days of storage period. Injection and recovery rates between 500m^3/day and 600m^3/day provided better efficiency among other pumping rates. The Results indicated that careful attention should be devoted to injection and recovery rates and storage durations to achieve a high performance of the ASR system. The developed model may be used to for the further simulation of injection and recovery rated and durations, storage period and location of ASR wells for a better management of ASR systems.

Acknowledgment

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Feasibility of Using Treated Wastewater in Groundwater Aquifer Recharge in Abu Dhabi Emirate, UAE

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Abstract
With a population of over 1,300,000, the rapidly growing Abu Dhabi Emirate faces an increasing need for reusing its tertiary Treated Sewage Effluent (TSE) due to increasing demand for water supplies in different development sectors. In Abu Dhabi Emirate, the annual production of treated wastewater is about 285 million m^3 in 2014 which is about 8% of the total Emirate water balance. Only about 55% of the treated wastewater is reused in wetlands, landscaping, and recreation areas due to the capacity of distribution system after treatment. Recently, a new emirate strategy for assessing the alternative options for reusing the treated wastewater was developed including irrigation of agriculture crops and aquifer recharge. Irrigating agricultural crops with recycled wastewater has been practiced in arid and semi-arid regions and is rapidly getting popular in the countries of the Arab Region. Reuse of treated wastewater involves several types of risks: Health, Environmental, Economic and Strategic. It is difficult to measure these risks. The lack of specific criteria and guidelines governing the artificial recharge of groundwater with treated wastewater and the aquifer systems hydraulic parameters in the areas near the treatment plants are currently hampering the implementation of large-scale groundwater recharge projects with treated wastewater. Groundwater recharge with treated wastewater presents a wide spectrum of technical and health challenges that must be carefully evaluated. This paper presents assessing the feasibility of reusing treated wastewater in aquifer recharge including aquifer suitability, risks, pretreatment requirements, environmental factors, purpose of groundwater recharge, sources of treated wastewater, recharge methods, location and economic parameters. All these criteria will be studied and revised, to illustrate the potential of aquifer recharge with treated wastewater and develop a comprehensive and protective regulatory program.

Keywords: ASR, TSE, Treated Waste Water, Water Quality, Geochemistry, Groundwater Management.

1. Introduction

Depletion of freshwater supplies for potable and irrigation uses is a major challenge in GCC countries as well as other arid region countries. For centuries, GCC countries were relied upon shallow groundwater resources to supply potable and irrigation water demands. Anthropogenic impacts, including over pumping, deterioration and contamination, have combined to deplete or render unusable the groundwater in shallow alluvial aquifers within the region. In GCC countries agriculture irrigation water use is about 75% of the total water use with generally small contribution of agriculture production to the national economy (less than 2%). Due to the arid nature of the climate, there are quite limited options available to supply the necessary freshwater to maintain the growing demands. One of these options is the reuse of treated wastewater. Wastewater reuse has drawn increasing attention worldwide as an integral part of water resources management. Such a move is driven by two major forces: scarcity of freshwater resources and heightened environmental concerns. Meanwhile, economic considerations are also becoming increasingly important amid the introduction of market-based mechanisms in environmental and water resources management. Reclaimed wastewater from municipalities and industries has been used as an additional source of water supply in many parts of the world, especially in areas where water resources are scarce and population and economic growth is rapid. The situation in Abu Dhabi is a typical case in point. Reclaimed wastewater can be used for many purposes, including agricultural irrigation, groundwater recharge, car washing, toilet flushing, urban lawn watering and recreational amenities, road cleaning, etc. Of all the users of reclaimed wastewater, public gardens irrigation has been by far the major user in many areas in Abu Dhabi Emirate where wastewater is reused. This is mainly because of the large water use in irrigation, relatively low quality requirement, and relatively low cost of infrastructure for the irrigation water supply. Reclaiming and reusing the wastewater is not a new concept. The practice can be traced back to several centuries ago. In the scientific literature, there are a large number of studies on wastewater treatment from technological and engineering aspects. Concerns on health impacts of using reclaimed wastewater, especially for irrigation and groundwater recharge have also drawn an increasing attention in the last decade. However, studies of the economic viability and institutions of wastewater reuse have been few. Treated domestic effluent is a valuable extra water source that can be reused for diverse purposes, primarily for agriculture production, aquatic life preservation, and aquifer recharge. Groundwater enrichment with effluent is maintained primarily via Soil Aquifer Treatment (SAT) (Quanrud *et al.*, 2003). Advanced wastewater treatment is required in order to maintain adequate levels of sustainable agriculture production, decelerated salinization processes of the ground waters and to prevent long range adverse effects of gradual environmental pollution (Rebhun 2004). Complying with these challenging goals can be attained mostly by implementing the membrane technology (Lopez *et al.*, 2003).

Abu Dhabi Emirate is an arid region where the average annual rainfall is less than 100mm. The water resources components found within the Emirate are traditional or conventional resources (rainfall, springs, wadis, sabkhas, lakes, ponds and groundwater) and non-traditional or unconventional resources (desalinated water and treated wastewater). Groundwater occurs in the Emirate as either consolidated or unconsolidated surficial deposit aquifers or as bedrock/structural aquifers and contributes 63.6% to the total water demand, followed by desalinated water (29.2%) and treated wastewater (7.2%). Groundwater supply is decreasing and the imbalance between supply and demand is being filled by ever increasing amounts of desalinated water (EAD, 2009a). Although wastewater reclamation and reuse has been recognized as a promising strategy to alleviating water scarcity and reducing the impacts on the environment, the actual reuse of treated wastewater is rather limited. In Abu Dhabi Emirate only 60% of the total treated quantities are reused and the rest are discharged to environment (RSB, 2009). Increasing the reused volumes will relief the pressure in using costly desalinated water and the over-abstracted brackish groundwater.

Aquifer storage and recovery (ASR) using treated sewage effluent (TSE) appears to be a viable option of both storing and improving the quality of water. Conventional surface disposal of wastewater can cause significant deterioration in surface water quality. Direct disposal of TSE into rivers and drains often leads to eutrophication due to the presence of contaminants, such as nitrate and phosphate (Horne and Goldman, 1994). A common indicator of eutrophication is increased phytoplankton density resulting in green turbid and foul-smelling water. After such a bloom, the algal biomass is broken down both chemically and biologically, resulting in greater chemical and biological oxygen demands (COD, BOD). Alleviating such a situation requires a reduction in water-borne nitrate, phosphate and pathogenic bacteria in the river or drain water.

ASR was defined by Pyne (1995) as “the storage of water in a suitable aquifer through a well during times when water is available, and the recovery of the water from the same well during times when it is needed.” This definition has been found to be unsatisfactory in that the operational requirement for injection and recovery to be performed using the same well is overly restrictive. The essential, defining feature of ASR is that it involves the injection, storage, and recovery of the same or similar quality water with perhaps some mixing with regional groundwater. An alternative modified definition of ASR that captures the essence of the technology is “the storage of water in a suitable aquifer through a well during times when water is available, and the recovery of the same or similar quality water using a well during times when it is needed.”

The above definition recognizes that there are distinctly different types of ASR systems that vary in how they achieve useful storage of water (Maliva, *et al.*, 2006 and Maliva, 2008). The injection of water into physical storage-type ASR systems actually increases the amount of water physically present in the aquifer, as manifested by an increase in aquifer water levels or pressure. For physically bounded ASR systems, injection and recovery could be performed at separate locations. Chemically bounded ASR systems store freshwater by displacing poorer quality (usually saline) water. A third type of ASR system, which is referred to as interface management systems, uses the injection of freshwater to prevent or reverse the migration of the interface with poorer-quality water. It has been known since the 1940's that the fecal coliform standards are not protective of public health from illness and death associated with the use of domestic water supplies. However, it was not until the Milwaukee epidemic that regulatory agencies took the necessary action to begin to provide for greater public health and environmental protection than that achieved through the fecal coliform standard for both the epidemic and endemic waterborne pathogen problems associated with domestic water supplies. Lee (1993) has developed a comprehensive review of the waterborne pathogen issues associated with domestic water supplies and reclaimed wastewaters. This review should be consulted for further background information on the issues discussed herein with respect to the hazards that the use of the inadequately disinfected reclaimed domestic wastewaters that meet fecal coliform standards represent to those who consume or otherwise have contact with these waters or areas where they have been applied.

Haas et al. (1993) reported based on a risk assessment analysis of viruses in drinking water that the U.S. population lifetime risk of death from exposure to waterborne viruses in domestic water supplies is as high as 1 in 20. In the same perspective, typically the US EPA and state regulatory agencies regulate chemical constituents in drinking water, such as non-carcinogens, so that there is zero risk associated with the use of the water. For carcinogens, a risk level of 1 in 1,000,000 is used. It is apparent that the waterborne pathogens in treated water supplies and, for that matter, reclaimed wastewaters are occurring at far greater risks than are allowed for regulated chemical constituents present in treated domestic water supplies.

A more extensive discussion of this topic area, particularly as it relates to groundwater recharge, is provided by Jones-Lee (1995). These review papers contain extensive references to the literature pertinent to evaluating the public health and environmental threats that residual pathogenic organisms and hazardous and otherwise deleterious chemicals in secondarily treated domestic wastewaters represent to the use of these wastewaters for ornamental shrubbery and golf course irrigation in a reclaimed domestic wastewater reuse project. They also contain information that should be considered in evaluating the hazard that residual pathogens in secondarily treated domestic wastewaters that are recharged to an aquifer represent to those who utilize these waters for domestic purposes. Further, Jones-Lee (1995) discuss the significant potential liability that those who develop reclaimed wastewater reuse projects with only minimal treatment of the wastewater before reuse where aquifer soil treatment is used to remove residual pathogens and hazardous and otherwise deleterious chemicals can be incurring because of the potential for the aquifer to accumulate hazardous or deleterious chemicals in the area where treatment occurs to a sufficient extent so that these areas will become future Superfund sites that will ultimately have to be remediated. The aquifer treatment process does not necessarily convert all hazardous or deleterious chemicals present in secondarily treated wastewaters to benign substances that represent no threat to future users of the aquifer. It is now becoming well-known, as discussed by Lee and Jones-Lee (1995), through the work being conducted through the Orange County Water District and Stanford University (Fujita et al., 1995 and Ding et al., 1995) that there are a number of organic chemical constituents that are present in domestic wastewaters that are recharged to an aquifer that are being transported in the groundwater to recovery wells with little or no degradation.

2. Treated Wastewater Production in Abu Dhabi

2.1 Present Status

Abu Dhabi has treated domestic and municipal wastewater in centralized treatment facilities since 1973. The Emirate has continued with its development of excellent wastewater treatment facilities. There are now 32 wastewater treatment plants, split equally between the Western and Eastern regions as shown in Figure (1). Combined, they produce about 332.25 million m^3/yr as shown in Table (1). Zakher (Al Ain) and Al Mafraq (Abu Dhabi) plants produce 94% of all treated effluent, which is mostly used for irrigation of parks, gardens and other recreation amenity areas. The main wastewater treatment plant serving the Abu Dhabi city is Al Mafraq plant with a maximum design capacity of 260,000 m^3/day. The main sewage treatment plant serving Al Ain City is Zakhir plant with a maximum capacity of 54,000 m^3/day. The plant is currently operating at peaks of 120,000 m^3/d, which increases a risk of deterioration in the quality of effluent and sludge produced, as well as the risk of by-pass influent to the percolation area at the rear of the treatment plant. The other STPs are quite small, but because of remote urban expansion, some are now over-loaded and are presently being prepared for upgrading.

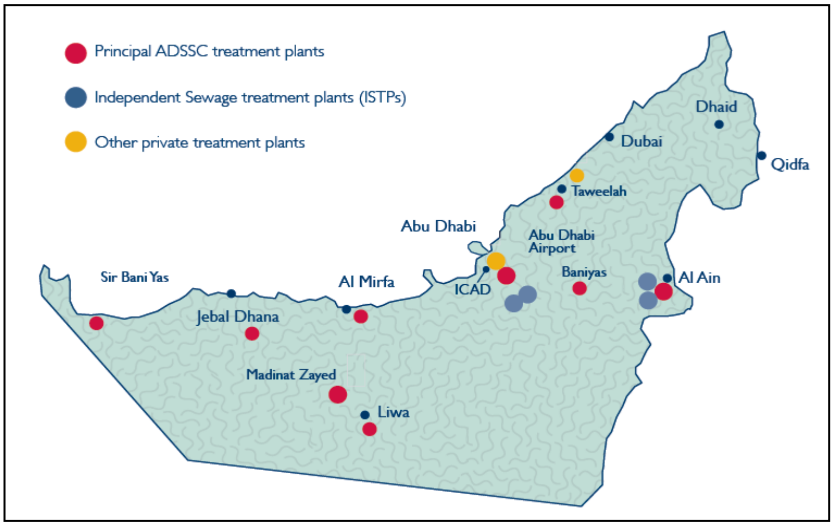


Figure 1: General location of Abu Dhabi main wastewater treatment facilities

Table 1: Present wastewater facilities in Abu Dhabi Emirate (2015).

Region	STPCC ID	STPCC	Average Daily Recycled Water Produced (Ml/day)	Average Daily Recycled Water Discharged to Reuse Systems Onsite (in Ml/day)	Average Daily Recycled Water Discharged to Reuse Systems Offsite (Ml/day)	Average Daily Recycled Water Discharged to the Environment (Ml/day)
Abu Dhabi Island & Mainland	STP1	Al Ghantout WwTW	0.578	0.036	0.524	0.018
	STP2	Al Khatim WwTW	0.654	0.223	0.431	0.000
	STP3	Yas Island	8.161	0.000	8.161	0.000
	STP4	Masdar	0.224	0.000	0.224	0.000
	ADSTP1	Al Wathba 1 WwTW	242.898	3.467	235.010	410.529
		Al Wathba 2 WwTW	229.949	0.358		
		Mafraq WwTW	188.855	10.569		
	STP37	ICAD	14.933	0.000	0.000	14.933
	STP38	Saadiyat	3.209	0	3.209	0
Al Ain & Remote Areas	STP8	Al Saad WwTW	82.219	0.790	78.897	2.532
	STP9	Sieh Hamer (Saih Al'lhamah)WwTW	90.775	0.389	88.179	2.207
	STP11	Al Arrad WwTW	0.056	0.000	0.000	0.056
	STP12	Al Dhahirah WwTW	0.116	0.005	0.000	0.111
	STP13	Al Faqah WwTW	0.658	0.008	0.484	0.164
	STP14	Al Hayer WwTW	1.665	0.000	1.141	0.503
	STP15	Al Khazna WwTW	0.974	0.071	0.903	0.000
	STP16	Al Quoa WwTW	2.196	0.086	1.238	0.873
	STP17	Al Rawada Gate WwTW	0.012	0.000	0.012	0.000
	STP18	Al Wagan WwTW	1.751	0.188	0.989	0.574
	STP19	Bukarriyah WwTW	0.234	0.102	0.000	0.172
	STP20	Remah WwTW	0.612	0.035	0.564	0.014
	STP21	Seih Gharaba WwTW	0.156	0.030	0.003	0.125
	STP22	Shuwaib WwTW	1.133	0.005	1.128	0.000
	STP23	Sweihan WwTW	1.007	0.000	0.847	0.033
	STP24	Wadi Fili WwTW	1.566	0.199	0.652	0.715
Western Region 1	STP25	Mirfa WwTW	7.756	0.682	4.974	2.100
	STP26	Mirfa Canning Factory WwTW	0.218	0.218	0.000	0.000
	STP27	Bainuna WwTW	0.928	0.928	0.000	0.000
	STP28	Madinat Zayed WwTW	12.411	1.048	6.578	4.786
	STP29	Liwa WwTW	1.204	1.008	0.194	0.002
	STP30	Abu Abyat Island WWTW (5 Biofilters)	0.209	0.000	0.209	0.000
	STP31	Sir Baniyass Island WWTW (8 Biofilters)	0.379	0.000	0.379	0.000
Western Region 2	STP32	Ghuweifat WwTW	0.432	0.043	0.348	0.040
	STP33	Ghayathi WwTW	5.807	0.623	5.179	0.005
	STP34	Delma WwTW	0.887	0.222	0.665	0.000
	STP35	Baaya Sila WwTW	3.491	0.229	3.223	0.039
	STP36	Baaya Sila Power Station WwTW	0.013	0.000	0.013	0.000
	STP39	Ruwais	1.938	0.000	1.938	0.000

Source: ADSSC, 2015

Due to the increasing number and size of developmental and industrial projects planned in the emirate of Abu Dhabi, the production of the row wastewater increased by about 10% annually. The main treatment plants are currently heavily overloaded, leading to the generation of low quality treated effluent. Furthermore, the overload could result in disposal of raw sewage in the marine environment and/or desert. During emergency situations in the sewage treatment plant, more than 25% of the raw sewage inflow is diverted to the marine environment creating environmental crisis to marine quality and ecology. The Discharge point of excess treated effluent and over flow line is located at the Musaffah Industrial Area south channel. Out of the total produced daily treated wastewater with about 910,299 m^3 only 467,870 m^3 are reused for landscaping and amenity plantation and reactional areas and about 441,428 m^3 are discharged daily to environment as shown in Table (2). This means that about 54% of the tertiary treated wastewater produced in Abu Dhabi is not utilized as shown in Figure (2).

Table 2: Wastewater production, reuse and discharge to environment in Abu Dhabi Emirate (2015).

Region	**Daily Production (m^3)**	**Daily Reuse (m^3)**	**Daily Discharge to Environment (m^3)**
Abu Dhabi	689,461	262,212	427,249
Eastern Region	185,166	176,957	8,208
Western Region	35,672	28,701	6,971
Total	**910,299**	**467,870**	441,428

Source: *ADSSC, 2015*

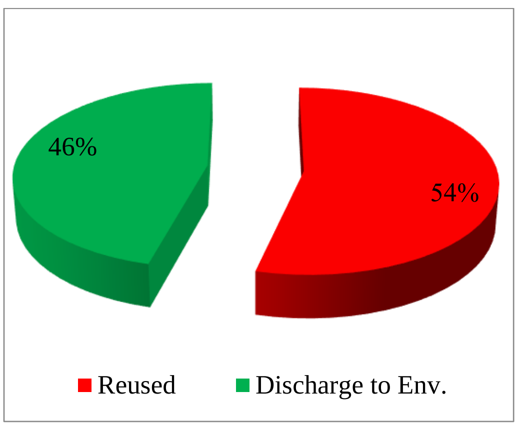


Figure 2: Treated wastewater utilization and discharge to environment

2.2 Future Predicted Treated Wastewater Production

The annual increase in TSE production ranges between 8% and 12% with an average of about 10%. This means with the assumption that the increase in the production will continue business as usual; the total produced TSE in 2030 will be about 1,435 million cubic meters as shown in Figure (3).

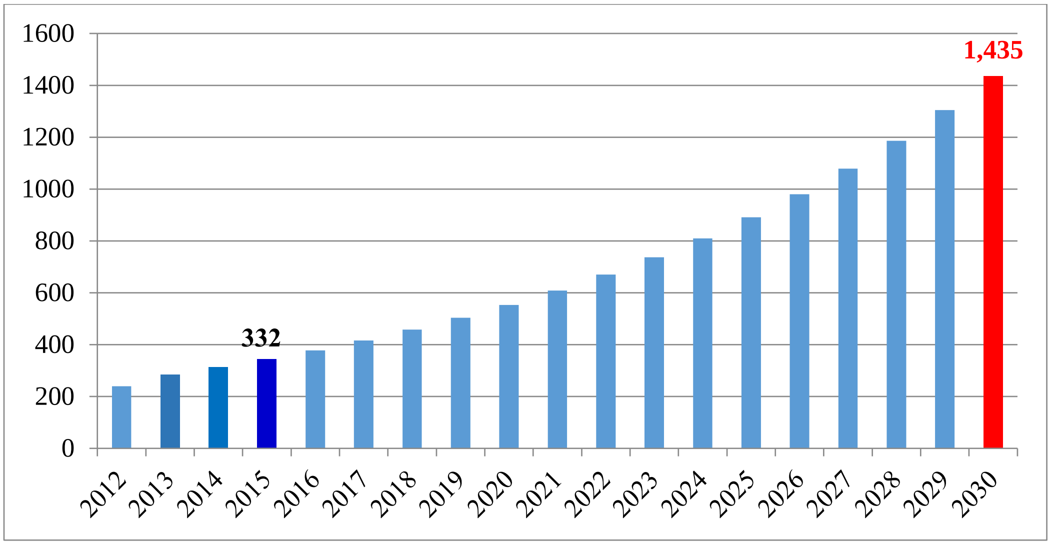


Figure 3: Predicted increase in the treated wastewater production (2012-2030)

3. Treated Wastewater Reuse Options

Six key factors with gradual importance contribute to the success of a water reuse project: economic, financial, regulatory, psychological, organizational and technical factors as shown in Figure (4). The economic, financial and psychological factors depend on two main groups of parameters: (1) the internal motivation of the local water agencies and authorities to rapidly establish a meaningful economic analysis and a rigorous financial plan and to gain public acceptance and (2) external non-controlled parameters such as slow and heavy institutional decision-making process, politicians' subjectivity, stakeholders' personality.

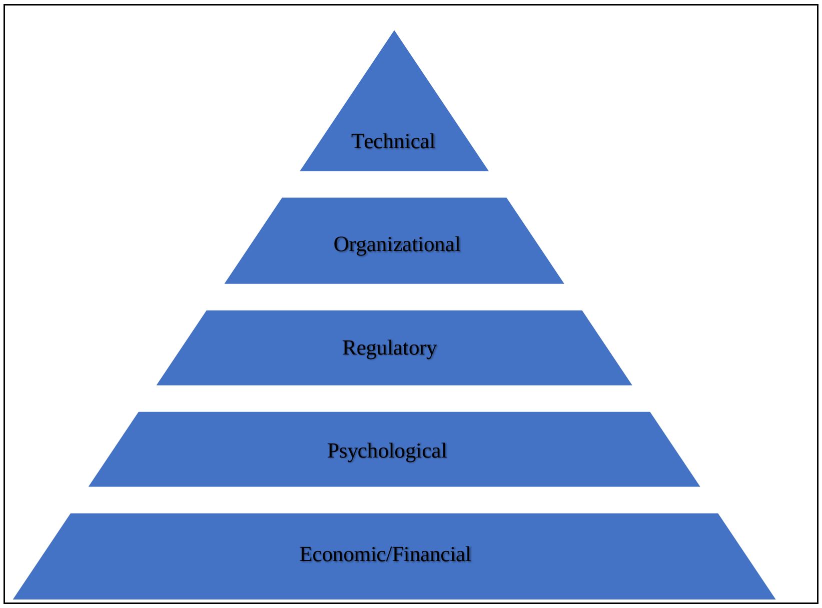


Figure 4: Main key factors for successful wastewater reuse

Three potential options of reusing the discharged treated wastewater are available in Abu Dhabi emirate. These options include: (1) the direct reuse for irrigation in the nearing agriculture farms, forests, landscaping and amenity plantations; (2) injection of the treated wastewater into the groundwater aquifers where brackish-water aquifers are available to refresh these aquifers for future potential use of prevent seawater intrusion; (3) industrial and district cooling use in the Abu Dhabi city. For the first and second options, the conveyance of treated wastewater to the demand centers or to the nearest aquifer system will be via the construction of the main transmission pipelines with subsequent storage facilities. In some agriculture use for food production additional treatment facilities will be required to improve the quality and satisfy the end users. In the aquifer recharge option additional infrastructure including injection systems (wells or basins) to inject the water in the underlying aquifer system and recovery pumping wells for utilizing the injected wastewater.

3.1 Reuse for Irrigation

Irrigation water use accounts for the largest share of water consumption in Abu Dhabi Emirate, with up to 85% of the total water demand. This includes irrigation water for farms, forests, landscaping and amenity plantations. At present, only 27,000 m^3/day used in farms and the remaining are used in forests, landscaping and amenity plantations. Irrigation wastewater reuse especially for food production to increase the emirate food security and food self-sufficient ratio was and is becoming a key element in the integrated water management policies of the emirate. A plan was developed to reach zero level discharge of treated wastewater to environment by 2020. To start the implementation of this plan, two projects were recommended: (1) replacement of irrigation water (mainly desalination) for farms and forests along Dubai road with a daily capacity of 125,000 cubic meters as shown in Figure (5); (2) replacement of irrigation water (mainly groundwater) for farms and forests along Al Ain road with a daily capacity of 240,000 cubic meters as shown in Figure (6).

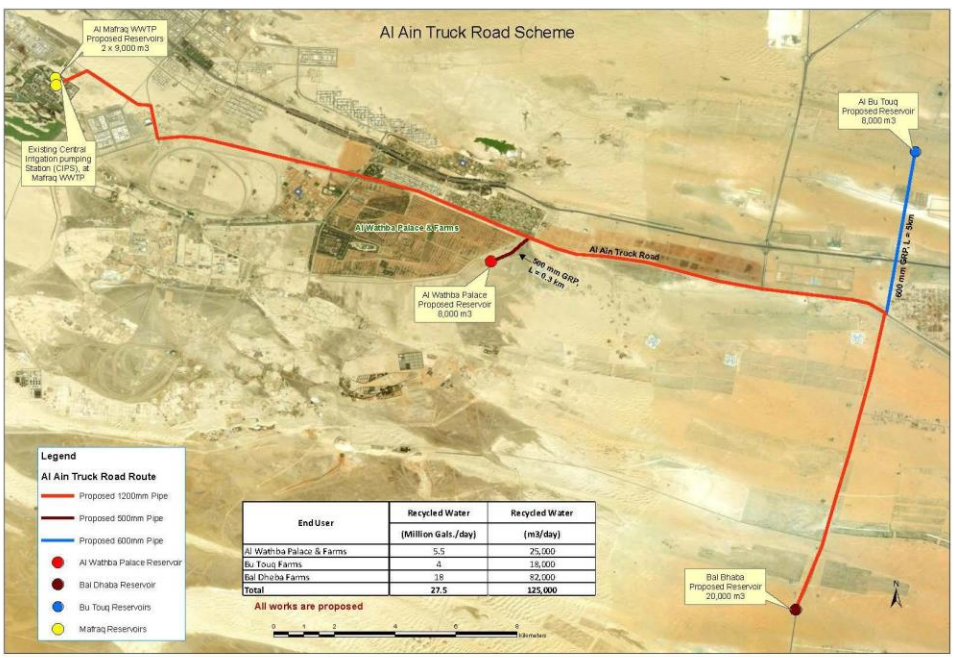
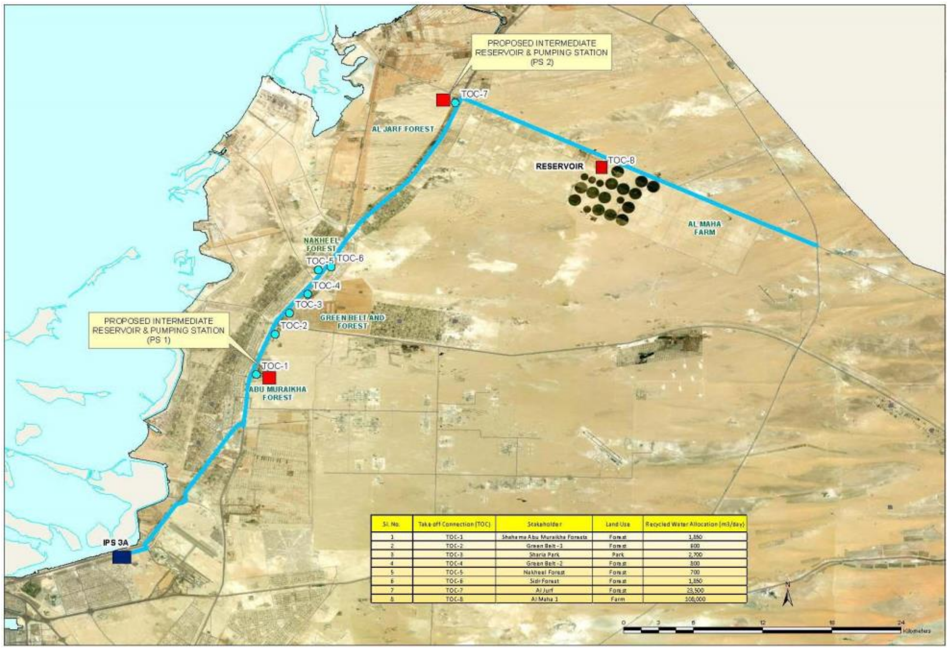


Figure 5: Reuse of wastewater in irrigation along Dubai Road (project 1)



Sl. No.	Take off Connection (TOC)	Stakeholder	Land Use	Recycled Water Allocation (m3/day)
1	TOC-1	Shaheema Abu Muraikha Forests	Forest	1,350
2	TOC-2	Green Belt - 1	Forest	600
3	TOC-3	Sharia Park	Park	2,700
4	TOC-4	Green Belt - 2	Forest	300
5	TOC-5	Nakheel Forest	Forest	700
6	TOC-6	Sidr Forest	Forest	1,350
7	TOC-7	Al Jurf	Forest	23,500
8	TOC-8	Al Maha 1	Farm	106,000

Figure 6: Reuse of wastewater in irrigation along Al Ain Road (project 2)

Before reusing treated wastewater for irrigation in agriculture sector, a thorough analysis was undertaken from economic, technical and environmental perspectives. In this regard the comprehensive costs and benefits of such wastewater reuse should be evaluated. Conventional cost benefit analysis quite often fails to quantify and monetize externalities associated with wastewater reuse. Hence, environmental valuation techniques and other related tools should be employed to guide decision-making. Moreover, the economic effects of wastewater irrigation need to be evaluated not only from the social, economic, and ecological standpoint, but also from the sustainable development perspective.

3.2 Reuse for Aquifer Recharge

Recharging aquifers with treated wastewater will benefits from the soil aquifer treatment (SAT). SAT is a geopurification system where partially treated wastewater artificially recharges the aquifers and is then withdrawn for future use. By recharging through unsaturated soil layers, the effluent achieves additional purification before it is mixed with the natural groundwater. In water scarce areas, treated effluent becomes a considerable resource for improved groundwater sources. One of the recommended options is to reuse the treated wastewater in Abu Dhabi to recharge the groundwater aquifer systems either to improve the groundwater quality in the coastal zones or to be recovered for irrigation purposes.

In Abu Dhabi unconsolidated aquifers are the most common and productive aquifers and comprise both recent sand dunes and alluvial deposits of varying age. Collectively, the deposits comprise the surficial aquifers of Abu Dhabi Emirate or alternatively, the shallow, unconfined aquifer. The following units of the shallow aquifer have been mapped as shown in Figure (7):

- SA_L Quaternary aquifer/ aquitard units directly underlain by the Lower Fars Formation as a basal unit (regional aquiclude).
- SA_U Quaternary sand and gravel aquifer underlain by the Upper Fars Formation as a basal unit.

- *SA_S* Coastal and inland sabkhas.
- *SA_M* Quaternary sand and gravel aquifer underlain by tectonically emplaced dark Marlstones and shales as main basal unit.

Recent studies indicated that the shallow aquifer comprises all permeable layers that are hydraulically connected and exhibit a hydraulic head that is defined by the water table for any given point. The upper aquifer comprises the upper part to the shallow aquifer which is generally hydraulically more active when yielding groundwater to a fully penetrating well. The lower part of the shallow aquifer can therefore often be considered as an aquitard. Treated wastewater can be injected to the upper shallow quaternary aquifer part. Two types of recharging system can be sued either injection wells or recharge basins. The feasibility studies done at Liwa are indicating that recharge basins is more technically viable and economically feasible in Abu Dhabi emirate. One of the main challenges facing the reuse of treated wastewater in aquifer recharge in Abu Dhabi is the groundwater salinity. Most of the groundwater quality within the shallow aquifer system calcified as brackish, saline or even hyper saline as shown in Figure (8). The recovery ratio is defined as volume of pumped recharge water over volume of recharge water (Bear and Jacobs, 1965; Bear, 1979). It was also called molecule for molecule recovery (Reese, 2002), which usually result in a lower estimate of recoverability of recharge water due to ignoring mixing of stored and native waters (Pyne, 2005). The conventional recovery efficiency is defined as the percentage of the water volume stored in an operating cycle that is subsequently recovered in the same cycle while meeting a target water quality criterion, for example potable water quality, in the recovered water (Reese, 2002, Pyne, 2005; Lowry and Anderson, 2006). In this definition, the mixing between recharge water and native groundwater is allowed and accounted for depending on how the targeted water quality criterion is set. It may result in a higher estimate of recoverability for the stored water by replacing non-recoverable stored water with native water or stored water from previous cycle during the recovery.

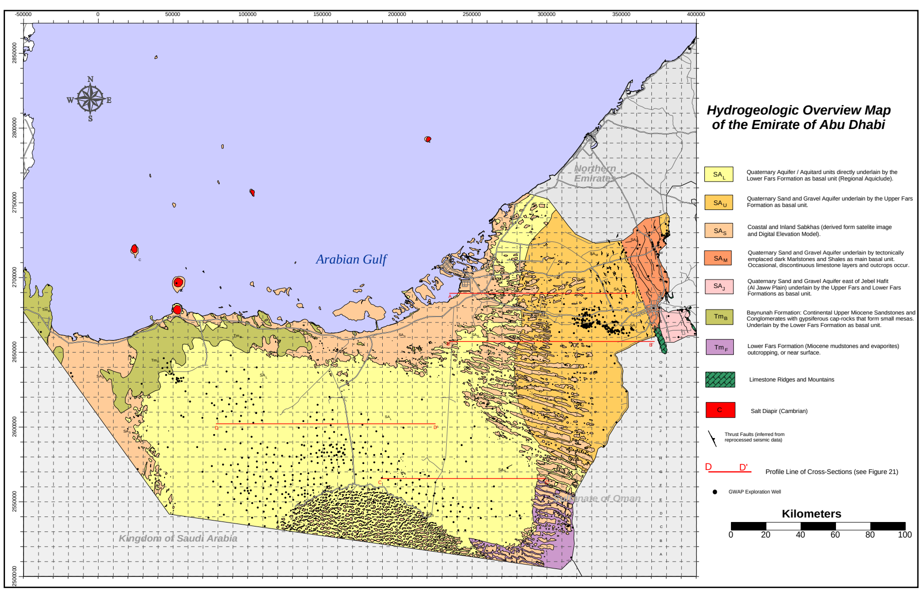


Figure 7: Hydrogeological map of Abu Dhabi Emirate

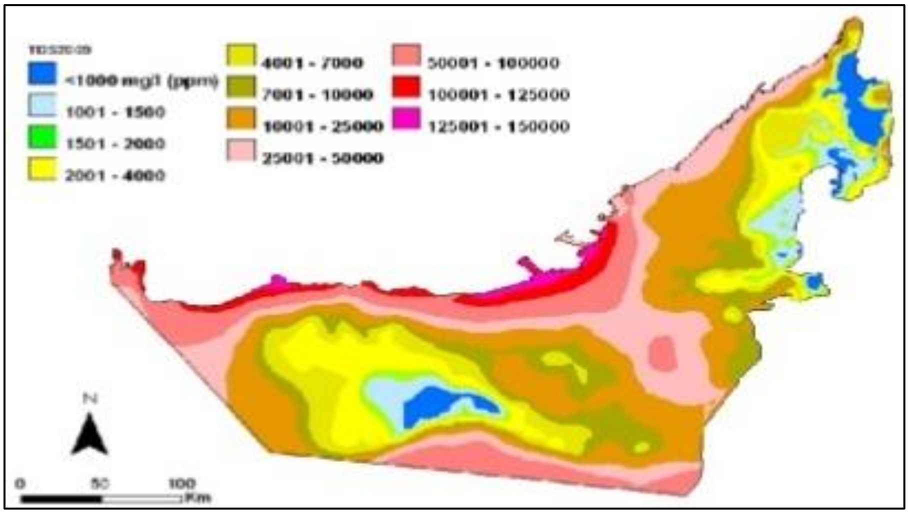


Figure 8: Groundwater salinity map for Abu Dhabi Emirate (2015)

3.3 Reuse for Industrial and District Cooling

The industrial and district cooling demands are very limited with a capacity of 25,000 m^3/day. So covering these demands will not be enough to utilize all discharged treated wastewater to the environment. So, partially these demands can be covered with no impacts on the other two alternatives/options. Three factors are affecting the reuse of treated wastewater in industrial sector and district cooling including quantities, quality, regulations and the feasibility. Additional treatment facilities maybe needed which will be additional cost and affect the feasibility.

4. Cost Benefit Analysis

4.1 Estimation of Wastewater Treatment Costs

There is no published figure or estimation for the cost of wastewater treatment in Abu Dhabi at present. So, wastewater treatment costs have been estimated from the literature for government investment in the treatment sector. The results indicating that the cost per unit treated wastewater ranges between 3 to 5 AED due to many factors affecting this cost.

4.2 Estimation of Conveyance Costs

The cost of conveyance is based on design and construction of the pipelines using a standard diameter high-density polyethylene pipe (HDPE). The two pipelines diameters considered are 1200 mm. The strength grade of the HDPE pipe is 16 BAR PE 100. It is assumed that a pumping station will be required for each 40 km of pipeline for Al Ain road project. For Dubai road project there is no need for pumping as the existing pumping station will be enough The average elevation change in Al Ain road project is estimated to be about 70 m and head losses due to pipe friction limit the overall head loss to no greater than 120 m.

4.3 Estimation of Injection and Groundwater Monitoring Costs

For aquifer recharge option, four 10 recharge basin were estimated with a daily injection capacity of about 45,000 m^3/day. Recovery wellfields were designed for utilizing the injected water for various purposes later as shown in Figure (9). Also, groundwater monitoring system is needed to collect the information on the injected plume movement into horizontal and vertical direction as well as the interaction with native groundwater quality as shown in Figure (10).

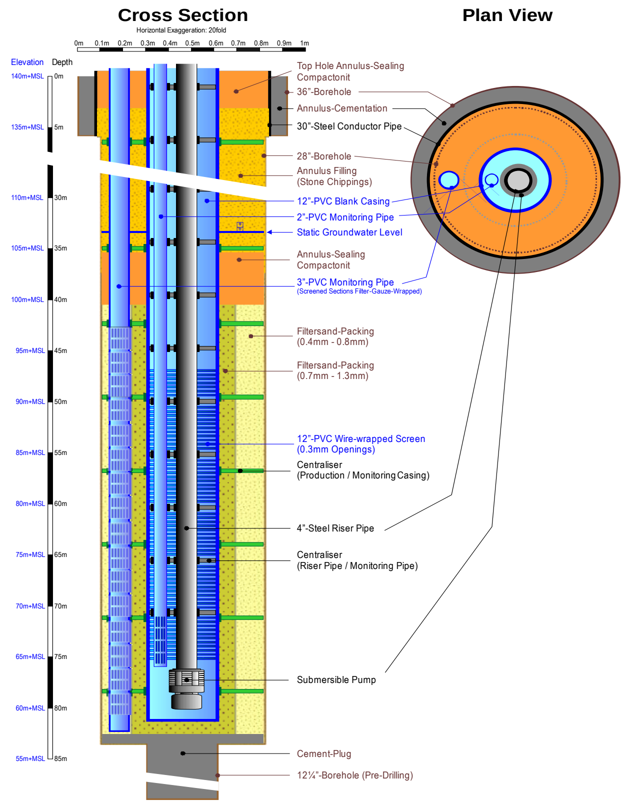


Figure 9: Typical design of recovery wells

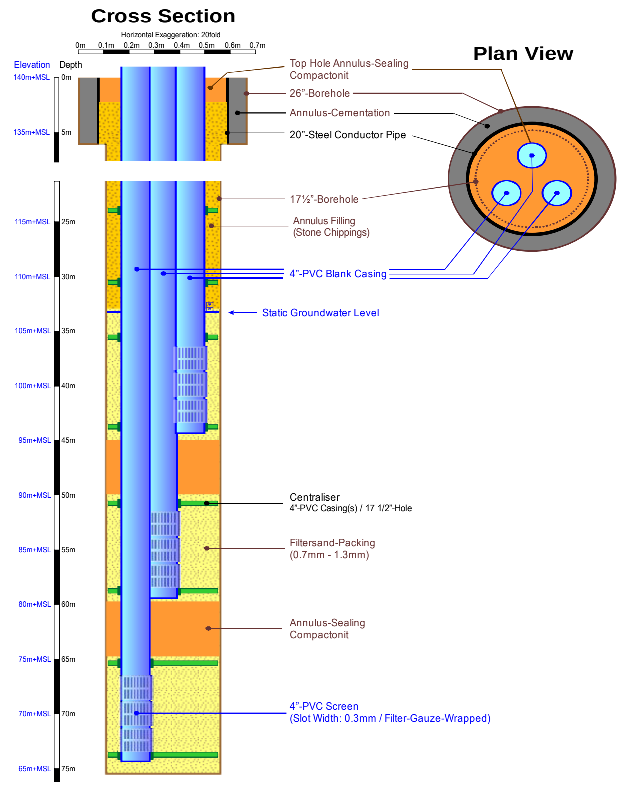


Figure 10: Typical design of monitoring wells

5. Results and Discussion

A five step cost-benefit analysis was applied to different options for reusing treated wastewater in Abu Dhabi:

Step 1: Select and evaluate the water re-use options/alternatives

Step 2: Estimate the internal costs;

Step 3: Estimate the externalized costs;

Step 4: Implement the cost-benefit analysis;

Step 5: Implement an economic sensitivity analysis.

These steps were used to assess the case of Abu Dhabi recommend projects and options including direct reuse for irrigation versus groundwater aquifers recharge. The results of this cost benefits analysis indicated that the treated wastewater reuse would have a range of positive economic and environmental impacts. For the direct use in irrigation uses, the market value for tertiary treated wastewater is set between \$0.65 and \$1.1 /m^3 without pumping and between \$0.95 and \$1.31 /m^3 with pumping while the estimated operation and maintenance cost for producing and transmission of the wastewater to the demand centers is about \$0.16/m^3 without pumping and \$0.16/m^3 with pumping. Reusing treated wastewater will reduce nutrient concentration which may detriment agricultural crops fertilization, although the negative economic impact figures vary from different studies between \$-0.07/m^3 and \$0.01/m^3. The reuse will help to replace daily use of desalinated water of about 125,000 m^3. The cost of the cubic meter of desalinated water is about 10.3 AED and in Al Ain Road it wil save using brackish groundwater and the Capex and Opex for more than 1000 groundwater wells.

Aquifer recharge system with treated wastewater is inexpensive, efficient for pathogen removal, and is not highly technical to operate. Most of the cost associated with an SAT is for pumping the water from the recovery wells, which is usually $20-50 USD per m^3. In terms of reductions, SAT systems typically remove all BOD, TSS, and pathogenic organisms from the waste and tend to treat wastewater to a standard that would generally allow unrestricted irrigation. The biggest advantage of aquifer recharge with treated wastewater is that it breaks the pipe-topipe connection of directly reusing treated wastewater from a treatment plant. This is a positive attribute for those cultures where water reuse is taboo.

Treated wastewater can successfully replace potable desalinated water in district energy/power applications. However the present demands will not cover the available non-utilized and discharged treated wastewater. So their demands can be covered without impact on the other alternatives. Treated wastewater analyses over extended time frames indicated that the quality is suitable and no additional treatment is needed. The critical parameters of the treated wastewater include Cl, PO_4, NH_3, TOC, and TSS. There are some factors which should be taken into consideration for this option including design, materials, chemical, and the operational. Monitoring and control systems should be added.

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Using Groundwater Flow Model (MODFLOW) As a Management Tool for Targeted Sub-Basins in Sana'a Basin

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Abstract
The numerical modelling (MODFLOW) has emerged as an effective tool for managing groundwater resources and predicting future responses, especially when dealing with complex aquifers systems and heterogeneous formations. MODFLOW model has been used herein as a management tool for the targeted sub- basins (Wadi Bani Hawat sub-basin, Wadi Dhahr & Al-Ghayl sub-basin, Wadi Hamdan & As Sabrah sub-basin, Wadi Ghayman sub-basin); the most important groundwater resources for domestic and agricultural sectors in Sana'a basin. Groundwater extraction from this basin already exceeded the safe yield of the aquifer, a sharp drop in the water table, and a dry out of most wells. Currently, more than 13000 wells including governmental, private and unauthorized wells are operating within the basin boundary. A conceptual model was designed according to the actual groundwater dynamic flow system in the 2010 Hydrosult Sana'a Basin Model. Also, the governing partial parabolic differential equation was defined, including the vertical conductivity flow between the aquifers. Total groundwater abstraction values were compiled after filtering the available data, including the 2015 NWRA-SB wells inventory data. These data were documented in a database and stored in soft copy (excel form). In this study, three simulations of groundwater development scenarios were distinguished. The first scenario is applied for evaluation of the present status and till 2025. The second and the third scenarios are focused on the effect of water augmentation i.e. decrease the present rate of groundwater abstraction to 30% and 50% respectively, with considering the highly intervention of IWRM structure of Sana'a basin on the on-going activities related to change land use, change crop pattern, value chain, marketing, modern irrigation techniques, water harvesting techniques, etc. Scenario 3 gives a remarkable improvement of the water resources system in the four sub-basins within a reasonable period (in the year 2025), thus, it will keep the water resources sustainability. It is recommended that irrigation systems should be improved with the usage of harvesting water methods to reduce the losses and increase the groundwater recharge respectively in the targeted four sub-basins.

Keywords: Groundwater Flow Model, MODFLOW, Management Scenarios, Sana'a Basin, Targeted Sub-Basins.

1. Introduction

The Sana'a basin (SB) relies to a large extent on groundwater for both irrigation and urban water supply. Historically, water supplies were obtained from dug wells and ghayls, tapping the unconsolidated Quaternary deposits in the plain. Borehole construction and the introduction of pumps began in the 1960s and increased rapidly from the mid-1970s onwards. This enabled deeper aquifers to be exploited for irrigation and municipal supplies. Groundwater development has been largely uncontrolled. With groundwater levels' lowering often more than five meters a year, the risk of complete depletion of groundwater resources is eminent in many locations. For that reason government decided that it should become the manager of the ground water resources as to ensure that at least sufficient water will be available for drinking water in the foreseeable future. The National Water Resources Authority (NWRA) was created to fulfill the role of water manager and seven branches have been established including one for the SB. The local communities have to play an important role as local partner of the NWRA to achieve sustainable use of the water resources.

The water resources situation in the SB is critical in the sense that the annual abstraction is 300 million m^3 and the recharge 100 million m^3 only. The requirement for drinking water equals the volume of annual recharge consequently the ground water resources is depleted at an annual rate of 200 million m^3. It is estimated that at this rate the main aquifer presently used will be dried out in about 15 years.

Since 1972, many studies have been carried out by different organizations and institutions, covering geological, hydrological, and hydrogeological investigations. Sources of data and information were compiled mainly from the output of these surveys (Russian 1982, SAWAS 1993, NWAS 2000, 2004, WEC 2002, NWRA 2004, 2005, 2006, GAF, 2007, and NWRA-SB Monitoring Network information).

In addition, a groundwater MODFLOW model of the SB was initially prepared by SAWAS, the Netherlands institute for Applied Geosciences in 1996, and then, by Hydrosult in 2010. The study presented herein used MODFLOW to construct a groundwater flow model for the targeted sub-basins using 2010 Hydrosult model and the NWRA-SB 2015 wells inventory data as input. This model was then used as a management tool for assessing the current situation and forecasting future responses to assumed coming events of main four targeted sub-basin in Sana'a basin. Three different future pumping scenarios have been considered.

2. Description of the Targeted Sub-Basins

The Sana'a Basin is an inter-mountain plain located in the central Yemen highlands. Yemen covers a total area of approximately 536,000 square kilometers, and consists of 22 governorates including the four targeted sub-basins (Wadi Bani Hawat sub-basin no. 9, Wadi Dhahr & Al-Ghayl sub-basin no. 14, Wadi Hamdan & As Sabrah sub-basin no. 15, Wadi Ghayman sub-basin no. 19), see Figure (1). The plain has an elevation of about 2,200 m above sea level (asl), but is surrounded to the west, south and east by mountains rising to more than 3,000 m asl. The basin has an area of some 3,200 km^2 and forms the upper part of the catchment of Wadi al Kharid, a sub-catchment of the Wadi al Jawf. The climate is semi-arid, with an average annual rainfall of 235 mm at Sana'a. In 1995, the population of the city was estimated to be about one million and reached to 2.08 million in 2004. Groundwater is abstracted from four main aquifers across the basin: alluvium (mostly in the Central zone), volcanics (most dominant in the southern and south western zones, sandstones (currently exploited in the Bani Hushaish, Hamdan, and Nihm areas but also found throughout most of the Musayreka hydrologicl unit in significantly deeper horizons), and lime stones (in the Wadi al Kharid hydrological unit, i.e the northwestern and northeastern groundwater zones).

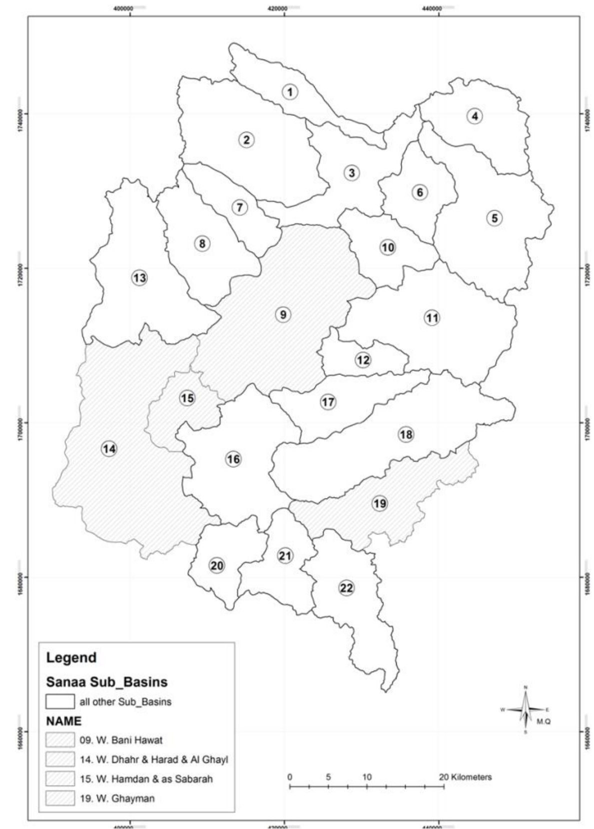

Figure (1): Location of the Four Targeted Sub-Basins

Table (1) presents relevant data and the expected depletion rate at the end of 2025 for the four targeted sub-basins, it shows a deficit in water resources in the four targeted sub-basins and provide a first in the challenge of water resources management in particular for the Bani Hawat sub-basin.

Table (1): Relevant Data for Four Targeted Sub-Basins

No.	Sub-basin	Total area (^10^4 m^2)	Irrigated area **(^10^4 m^2)**	Recharge (Mm^3/year)	Present depletion (Mm^3/year)	Depletion rate in 2025 (Mm^3/year)
9	Bani Hawat	32,703	4,825	5.6	61	40
14	Dhahr & Al-Ghayl	36,083	1,297	7.1	16	11
15	Hamdan & As Sabarah	6,350	788	0.8	7	5
19	Ghayman	14,334	533	1.2	4	2
Total area for 4 sub-basins		89,470	7,443	14.7	88	58

3. Conceptual Model

Different maps and data were imported from Hydrosult Modflow that was run on 2010, the steps of running the model was established to determine the flow system and the hydraulic connection between the different aquifers in order to determine the partial differential equation governing the dynamic of groundwater flows in the four sub-basins.

Groundwater dynamic flow system and layered aquifer simulation

The groundwater flow systems are defined according to the conditions of the dynamic flow of each unit. The sub-basins are sub-divided into 3 layers as shown on Table (2).

Layered aquifer simulation

First simulated layer

The Tertiary and Quaternary Volcanic Groups are bounded in the easterly and westerly directions by the Constant Head Boundary (CHB), which is located at the water divide boundary. The value of constant head is variable along the different cells, but it has a constant value for each cell for each stress period during the running of the model. These values can be adjusted during the unsteady state calibration run according to the quantity of flow to be considered for the basin to balance with the total inflow and outflow from the basin. The north direction of this layer is bounded by the GHB, representing the groundwater flow connected with the Amran Limestone formations. The flux across the boundary is calculated with a given boundary head value. The drain cells are assigned at the first layer, where the infiltration of seepage occurs from sewage water under Sana'a city. Also, the location of the fault-line directed south-north just a few kilometers west of Sana'a city is represented by a low value of conductivity in both simulated layers.

Second simulated layer

The second simulated layer is bounded from all directions (north, east, and west) by GHB conditions, representing the flow into or out of a cell from an external source, or at the internal hydrogeological boundary.

Table (2): Water Flow Systems

No.	Sub-basin	Water Flow Systems		
		One Layered Aquifer	Two Layered Aquifer	Three Layered Aquifer
9	W. Bani Hawat	Alluvium Sandstone	Alluvium Volcanic Alluvium Sandstone	Alluvium Volcanic Sandstone
14	W. Dhahr & Al-Ghayl	-	Volcanic Sandstone	-
15	W. Hamdan & As Sabarah	-	Volcanic Sandstone	-
19	W. Ghaymen	-	Volcanic Sandstone	-

4. Model Input

Bounday domain

The model domain covers the dimensions of the selected region with defined co-ordinates:

X min = 386,500 - X max = 460,000 Y min = 1,663,500 - Y max = 1,749,000

Grid network

MODFLOW is used for defining the applied 2010 Hydrosult grid network for modeling and simulation studies. The boundary of SB and the boundary of the simulated model was imported to MODFLOW model for 4 targeted sub-basins. The area has been adjusted to cover the entire each sub-basin boundary region of approximately 895 square kilometers. The complete model area was assigned as active cells.

Constant head boundary conditions (CHB)

The area included in the groundwater model is bounded by the watershed boundary of the four targeted sub basins. CHB is applied to fix the head value in a selected grid cell regardless of the flow system conditions in the surrounding grid cells. In the southern and western parts of sub basins no. 14, and in the eastern and southern parts of sub basin no. 19, the Volcanic Group is characterized by a water-divide hydraulic effect. The constant head value is variable along the different cells for first layer, but it has a constant value for each cell at each time period.

General head boundary conditions (GHB)

In the case of the four sub-basins model, GHB is applied at the nodes where there are hydraulic contacts between the different layers. It is applied at the adjacent second layers (Cretaceous Sandstone formations for 4 targeted the boundary of sub-basins with Tertiary Volcanic Group on the some places of western boundary of sub-basin no. 9).

Closed boundary condition (no-flow boundary)

This boundary has been simulated in this model by inactive cells; the outside the model domain. Also, in the first and second layers, the internal boundaries with other sub-basins for the four targeted sub-basins model is considered a no-flow boundary except the southern boundary in the sub-basin no. 9, the eastern boundary in the sub-basin no. 15, and the western boundary in the sub-basin no. 19 where the urbanization areas, are considered in-flow or out-flow. The hydraulic parameters of the Amran Limestone (kx, ky, and kz) are assigned a very low value. Thus, the complex of the different formations lies over an almost impervious bed of Amran limestone formations.

Recharge boundary conditions (RCH)

Average groundwater recharge of the targeted four sub-basins were determined based on 2010 Hydrosult ModFlow, that value for each sub-basin was estimated from reservoir, catchment runoff and direct rainfall, and return flow from demand sites. The value of recharge depends on many factors, including surface topography, soil cover material, and predominant land use and vegetation type. It applied to the uppermost active wet layer of the model for each vertical column of grid cell with constant value with respect to the time factor. The model can simulate variable values of recharge rate considering the effect of aridity and climate change.

Wells

By reviewing the different studies, the values of total yearly pumping were adjusted to conform to the projected water balance for the targeted sub-basins. The transient period is considered at the end of year 2015.Excel files were developed and imported according to the MODFLOW Software forms includes: well name, X co-ordinate, Y co-ordinate, screen ID, top elevation of screen, bottom elevation of screen, screen radius, casing radius, and stop time when pumping rate is appreciable**.**

Head observation wells

The head observation well data required by MODFLOW format includes: well name, X co-ordinate, Y co-ordinate, screen I.D., screen elevation. These data were applied for the simulation in the transient calibration run.

Hydraulic parameters

Pumping test data were compiled from past studies carried out by NWSA and SWEP, and were evaluated and re-analyzed within Hydrosult, 2010. The conductivity parameter includes Kx, Ky &Kz (was considered to be 10% of the value of Kx). The values of the storage coefficient and specific yield are computed mainly from analyses of pumping tests plus the general values obtained from the Na'aman model (2004) were introduced as initial values for unsteady state or non-equilibrium flow. The same procedure as that applied for the conductivity coefficient for the steady state calibration was applied for the transient calibration for the values of the specific yield and the storage coefficient.

5. Model Run Setting

Time steps

The steady state run was mainly to calibrate the aquifer conductivity parameter and its variation for both the first and second simulated layers in the targeted sub-basins. In the early seventies, the basin was not affected by heavy pumping and over-exploitation. In 1972, Italconsult and in 2002, WEC made surveys of the water resources in SB. The available data, compiled by 2010 Hydrosult MODFLOW can be considered as the basic available data for the steady state calibration. The unsteady state calibration run covered the period from 2010 to 2015 according to the 2010 wells inventory carried by NWRA-SB. Computation for the time step is considered as 365 days (one year).

Layer type setting

The type for each of the three simulated layers has been defined as follows:

- The first simulated layer (Alluvium and Volcanic) defined as unconfined
- The second layer, mainly Sandstone, defined as confined and unconfined ;
- The method of Log-arithmetic mean inter-block transmissivity (value 20), is assigned as the numeric engine to be applied in the visual MODFLOW.
- The third layer is the Limestone and defined as Confined

5. Steady State Calibration Run

The steady state run was performed for year 2015, which is considered as the base year. Computation of the steady state calibration run can be summarized by the following main outputs:

- Initial head values for the transient models,
- Initial values for the invariable time hydraulic conductivity parameters (Kx, Ky, Kz),
- Water balance at the start period (2015).

Different runs (trial and error) were carried out to adjust the water budget components and to minimize the difference between computed and recorded head at the observation points. In SB, the total head difference (calculated and /measured) is about 1,000 m (from 1,800 to 2,800 masl). If a value of 5% of the ratio of error to the total head difference is acceptable, then errors up to 50 m are acceptable (Foppen 2004). Therefore, the output of the calibrated steady state run can be completely accepted. In four sub-basins model, the head difference is shown on Figure (2). It shows the precision of fit of observed heads in the aquifer and the calculated heads, where most of the data points intersect the 45-degree line on the graph.

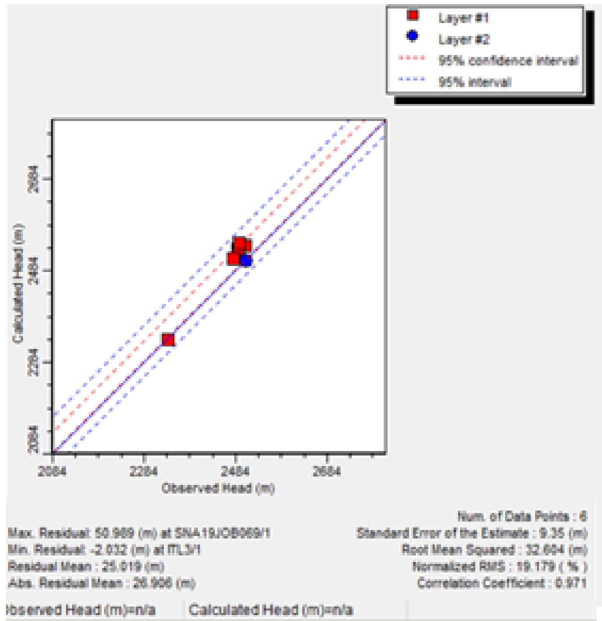

Figure (2): Scatter Graph of Calculated versus Observed Head *(*Steady-State Calibration Output*)*

Sensitivity analysis

The sensitivity analyses were carried out by running the model with the conductivity coefficient changed by 20%. The effect on the calculated groundwater in each aquifer is recorded. It was found, from the results of the sensitivity analyses, that there are three categories of sensitivities, defined as follows:

- Low sensitivity, where the change in levels does not exceed one meter in the aquifers. This is encountered where the following wells are located: ITL9, ITL10, ITL13, and ITL14. These wells are mainly located in Quaternary Alluvium and in some parts of the Quaternary Volcanics.
- Medium sensitivity, where the change in levels ranges from one to two meters in the aquifers. There is not encountered well in this category form the targeted sub basins. If it is found well mainly located in the Tertiary Volcanics.
- Very sensitive, where the change in levels exceeds two meters. This is encountered to wells: ITL2, ITL3, and ITL5. These wells are mainly located in the Tawilah Sandstone. The same sensitivity was observed for changes of anisotropy values.

Accordingly, the calibrated values for the hydraulic parameters can be accepted and can be applied for the modeling simulation procedures.

Calibrated flow balance graph

The outputs of the four targeted sub-basins steady state calibrated run for each of the defined budget zones were carried out. Verification was carried out for some values; total abstraction and total recharge were confirmed with their input values and the percentage of discrepancy between the total IN and OUT for the whole targeted sub-basins do not exceed - 0.01.

Calibrated hydraulic conductivity

Horizontal and vertical conductivity values were calibrated for the different water-bearing formations of the first and second simulated layers. The hydraulic parameters vary from cell to cell according to the calibrated water level in the cell with respect to the measured one. Figures

(3) & (4) show the areal distribution of the horizontal hydraulic conductivity parameter in first and second Layers while the legend in Table (3).

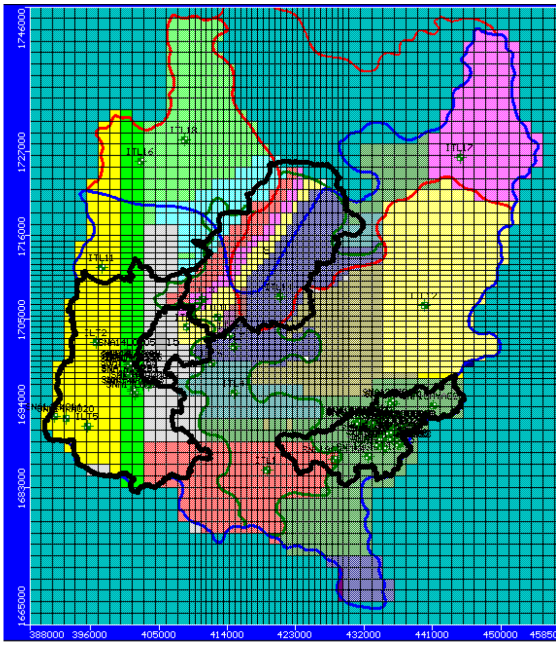

Figure (3): Steady State Calibrated Conductivity Parameters Distributions in First Layer

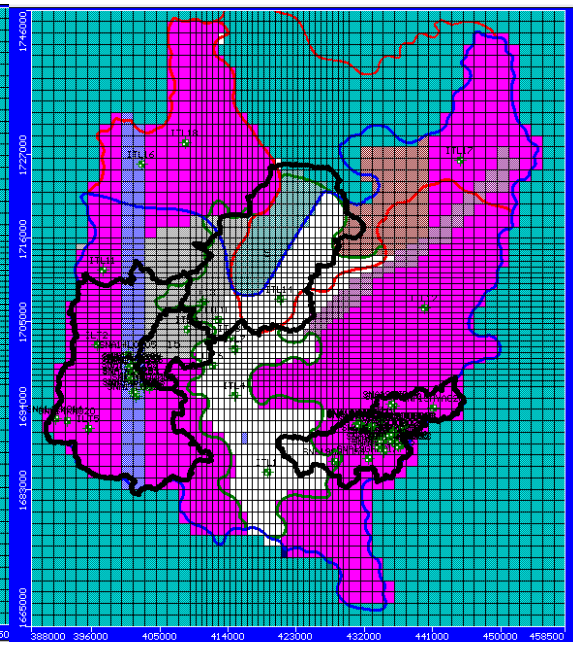

Figure (4): Steady State Calibrated Conductivity Parameters Distributions in Second Layers

Table (3): Calibrated Conductivity Values Legend

Zone	Kx [m/d]	Ky [m/d]	Kz [m/d]	Active	Distribution Array
1	1	1	1	☑	☑
2	0.02	0.01	2E-7	☑	☑
3	0.021	0.01	2E-7	☑	☑
4	0.021	0.01	1E-7	☑	☑
5	1	1	1	☑	☑
6	1	1	1	☑	☑
7	1	1	1	☑	☑
8	1	1	1	☑	☑
9	1	1	1	☑	☑
10	1	1	1	☑	☑
11	0.005	0.005	0.0027	☑	☑
12	10	10	1	☐	☑
13	0.02	0.01	0.002	☑	☑
14	0.2	0.1	0.002	☑	☑
15	0.05	0.05	0.005	☑	☐
16	10	5	0.04	☑	☐
17	1	0.05	0.0008	☑	☐
18	0.05	0.02	4E-6	☑	☐
19	0.2	0.1	5E-6	☑	☐
20	0.2	0.1	5E-7	☑	☐
21	0.002	0.001	5E-5	☑	☐
22	0.09	0.06	0.04	☑	☐
23	0.2	0.1	5E-5	☑	☐
24	0.09	0.06	0.04	☑	☐
25	1	1	0.1	☑	☐
26	5	5	0.4	☑	☐
27	1	1	0.04	☑	☐
28	10	10	1	☑	☐
29	10	10	1	☑	☐
30	15	15	1.5	☑	☐
31	2	2	0.2	☑	☐
32	5	5	0.5	☑	☐
33	5	5	5	☐	☐
34	0.2	0.1	0.002	☐	☐
35	0.0045	0.0045	2.7E-6	☐	☐
36	0.02	0.01	0.0002	☑	☐
37	1	1	0.001	☑	☐
38	0.0002	0.0001	0.002	☑	☐
39	0.02	0.01	0.0002	☑	☐
40	1	1	0.001	☑	☐
41	0.0002	0.0001	0.002	☑	☐
42	0.001	0.001	0.0005	☑	☐
43	0.07	0.07	0.007	☑	☐
44	0.001	0.001	0.0001	☐	☐

6. Transient (Un-Steady State) Calibration Run

Information about the pumped wells was prepared in MODFLOW form. Table (4) shows the location and details of the observation wells regarding to the targeted sub-basin. With the defined parameters, automatic generation of time steps takes place and the time steps are dynamically determined during the iterations by cutting the time step size when convergence becomes difficult, and increasing it when the difficulty passes as shown on Table (5). The transient run was carried out for 12 periods starting from the base year 2015 to the year 2025. Each period covered time steps (28 or 30 or 31 upon the days of month) (as the time multiplier is taken to a value of 1.20), see Table (5). The results of year 2015 were shown in detail for the steady state calibration run. The water balance components for the budget zone outputs were selected to demonstrate the rate of variation of the hydrogeological conditions of the basin in the last 14 years. The water balance was computed cell-by-cell for each defined budget zone for transient state flow. The percentage of discrepancy between the total IN and OUT in each zone budget output is in the range of (-0.04% to -0.02%).

Table (4): Head Observation Wells (Transient Calibration)

Sub-basin no.	Sub-basin	Well name	X_Coordinate (m)	Y_Coordinate (m)	Screen elevation (m)
9	Bani Hawat	ITL10	412700	1705300	2110
		ITL13	410620	1707625	2175
		ITL14	420860	1707950	2140
14	Dhahr & Al-Ghayl	ITL2	396709.68	1701929	2350
		ITL5	395664.52	1690954.8	2170
15	Hamdan & As Sabarah	ITL9	408600	1704000	2200
19	Ghayman	ITL3	434335	1692170	1920

Table (5): Adaptive Time-Stepping for Transient Flow

Year	Period	Start [day]	Stop [day]	Time Steps	Multiplier
1992	1	0	1095	31	1.2
1995	2	1095	2190	28	1.2
1998	3	2190	3285	31	1.2
2001	4	3285	4380	30	1.2
2004	5	4380	5110	31	1.2
2006	6	5110	6570	30	1.2
2010	7	6570	7665	31	1.2
2013	8	7665	8760	31	1.2
2016	9	8760	9855	30	1.2
2019	10	9855	10950	31	1.2
2022	11	10950	12045	30	1.2
2025	12	12045	13140	31	1.2

7. Model Predictions

Model predictions have been carried out to evaluate the expected response of any 155.05 Mm^3development plan that could be carried out to improve the groundwater system of the basin. The development plan can be emphasized on increasing the groundwater recharge and on decreasing and controlling the water consumptions for the different uses as follows: The first scenario is applied for evaluation of the present status. The second scenario is focused on the effect of water augmentation i.e. decrease the present rate of groundwater abstraction to 30% and considering the same till 2025 with the highly intervention of IWRM structure of SB on the on-going activities related to (change land use, change crop pattern, value chain, marketing, modern irrigation techniques, water harvesting techniques, etc…). The third scenario is focused on the effect of water augmentation i.e. decrease the present rate of groundwater abstraction to 50% considering an efficient intervention of IWRM structure and provide the necessary fund for the above on-going activities.

For the evaluation of first scenario, the pumped water inside the modeled area only is of about 227.2 Mm^3/year (WEC, 2002). Estimation of the JICA project was considered for 2005, at a value of 232.3 Mm^3/year and considered the same value until 2015. Also NWRA-SB wells inventory were applied for year 2015, the annual rate of pumping in the four targeted sub-basin was at a value 221.5 Mm^3. This rate of pumping in the four sub-basins has been considered the same value until 2025. The model was running for the adaptive time-stepping as shown in the above Table (5). The Simulation results for the year 2025 evaluate complete water balance components for each of sub-basin budget zones ,water table elevation contour map was constructed (see Figure 5) and the over-exploitation areas, where the groundwater level has dropped dramatically, and the water formations have dried in these locations (Figure 6) for layer 1, and (Figure 7) for layer 2.

The simulation results of the first scenario show that three over-exploitation areas in the first simulated layer will be developed. One area is at the sub-basin no. 09 of an area of about 160 km^2, another one at the sub-basin no. 14 of about 43 km^2, and the last area is at the sub-basin no. 15 of an area of about 19 km^2. In addition, it is expected that two over-exploitation areas will develop in the second simulated layer. Simulation results of the second scenario, in which the annual rate of pumping in the four targeted sub-basin will be 155.05 Mm^3/year if rate decrease to 30% and still the same to 2025 together with efficient intervention related to (change land use, change crop pattern, value chain, marketing, modern irrigation techniques, water harvesting techniques, etc) evaluate complete water balance components for each of sub-basin budget zones ,water table elevation contour map was constructed (Figure 8) and the over-exploitation areas, where the groundwater level has dropped dramatically, and the water formations have dried in these locations (Figure 9) for layer 1, and (Figure 10) for layer 2. Comparing the over-exploitation areas for the two simulated layers, (Figure 9 and Figure 10) for Scenario2, with the over-exploitation areas (Figure 6 & Figure 7) for Scenario 1, demonstrates a somewhat limited improvement in the groundwater system for the Basins no. 09, 14, and 15. For the first simulated layer, the water system is improved by about 14%, and for the second layer it is improved by about 92%.

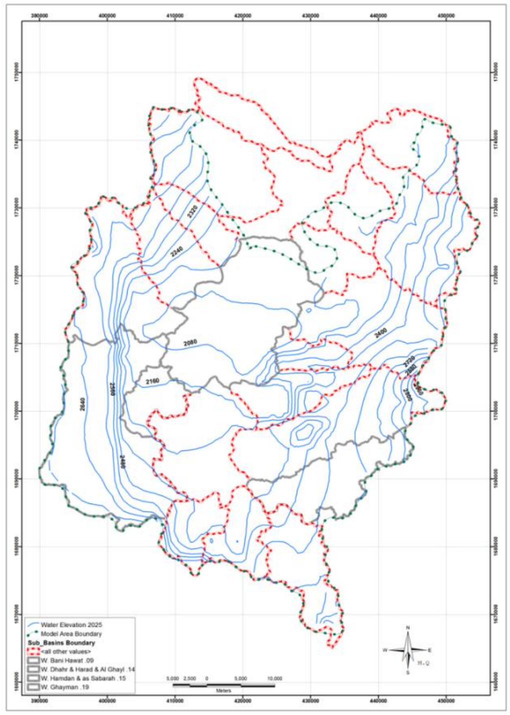

Figure (5): Water Table Elevation Contour Map for the year 2025 (Scenario 1)

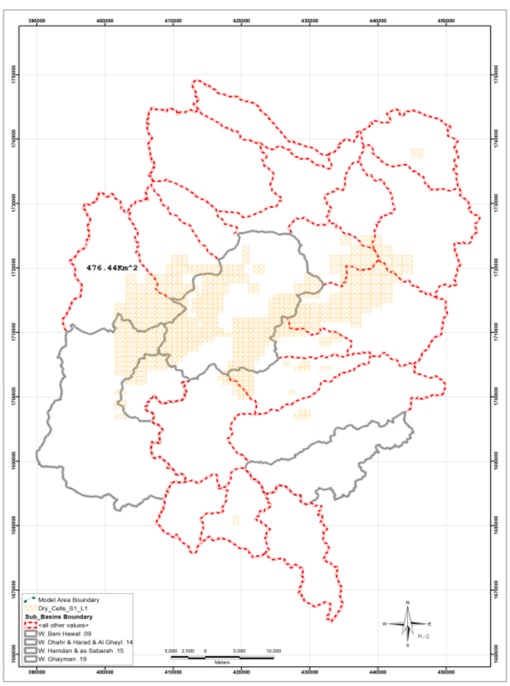

Figure (6): Expected Over-Exploitation Area in in First Layer for the Year 2025 (Scenario1)

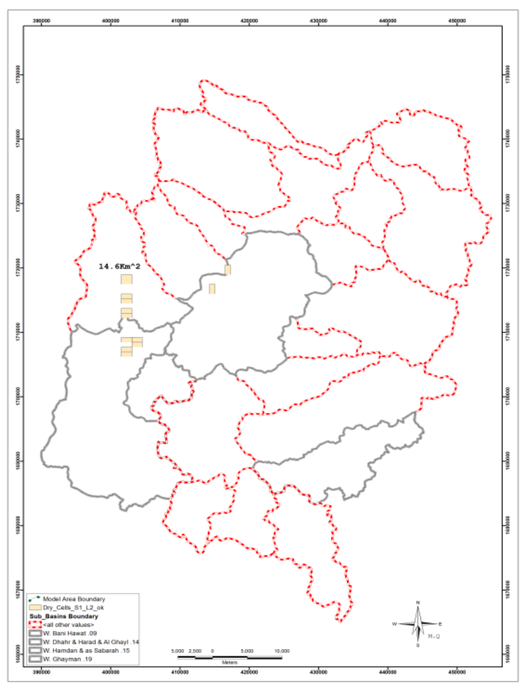

Figure (7): Expected Over-Exploitation Area in Second Layer for the Year 2025 (Scenario1)

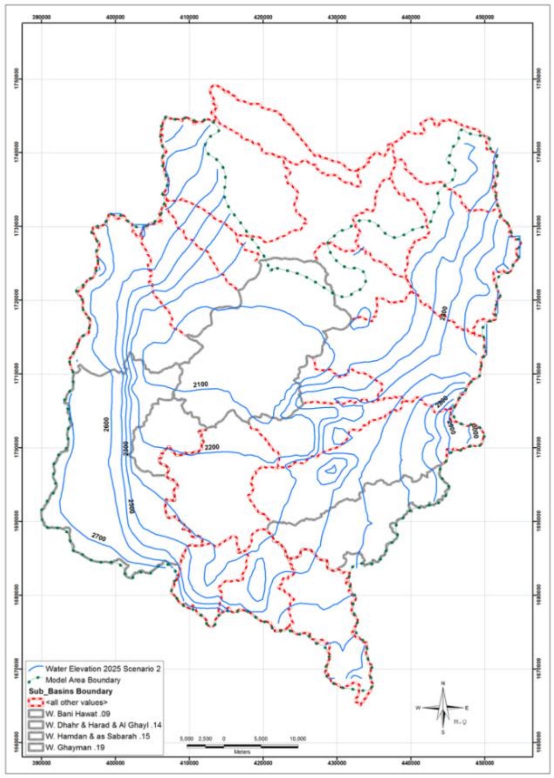

Figure (8): Water Table Elevation Contour Map for the year 2025 (Scenario 2)

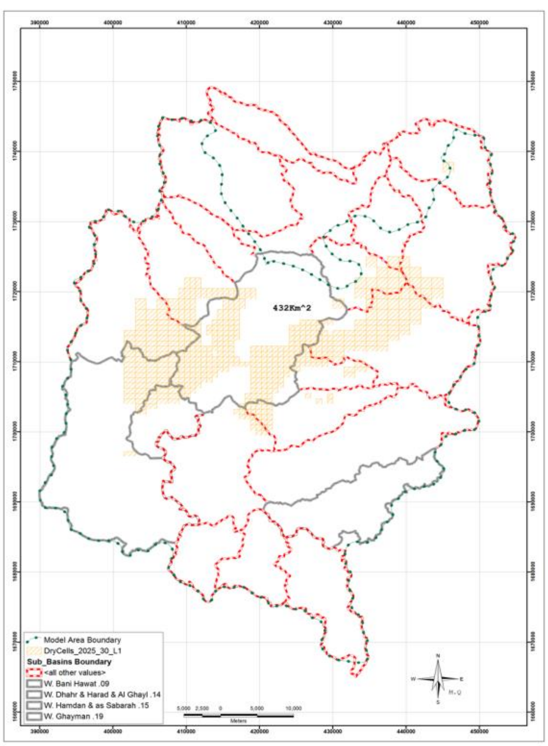

Figure (9): Expected Over-Exploitation Area in in First Layer for the Year 2025 (Scenario2)

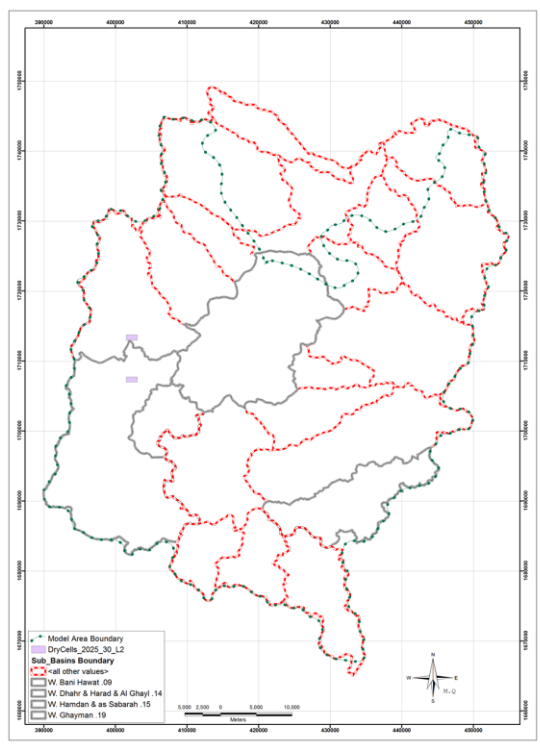

Figure (10): Expected Over-Exploitation Area in Second Layer for the Year 2025 (Scenario2)

Simulation results of the third scenario, in which the annual rate of pumping in the four targeted sub-basin will be 110.75 Mm^3/year if rate decrease to 50% and still the same to 2025 together with efficient intervention related to (change land use, change crop pattern, value chain, marketing, modern irrigation techniques, water harvesting techniques, etc) evaluate complete water balance components for each of sub-basin budget zones ,water table elevation contour map was constructed (see Figure 11) and the over-exploitation areas, where the groundwater level has dropped dramatically, and the water formations have dried in these locations (Figure 12) for layer 1. Comparing the over-exploitation areas for the first simulated layer, (Figure 12) for scenario 3, with the over-exploitation areas (Figure 6 and Figure 7) for scenario 1, demonstrates a somewhat limited improvement in the groundwater system for the Basins no. 09, 14, and 15. For the first simulated layer, the water system is improved by about 20%, and for the second layer it is improved by 100%.

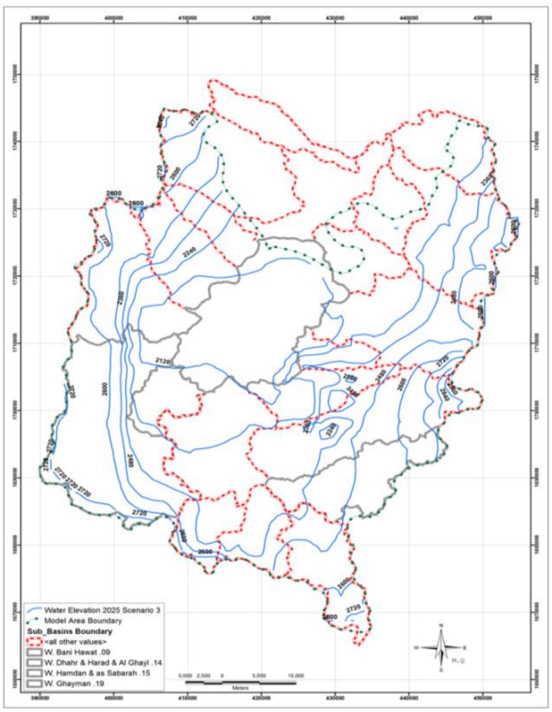

Figure (11): Water Table Elevation Contour Map for the Year 2025 (Scenario 3)

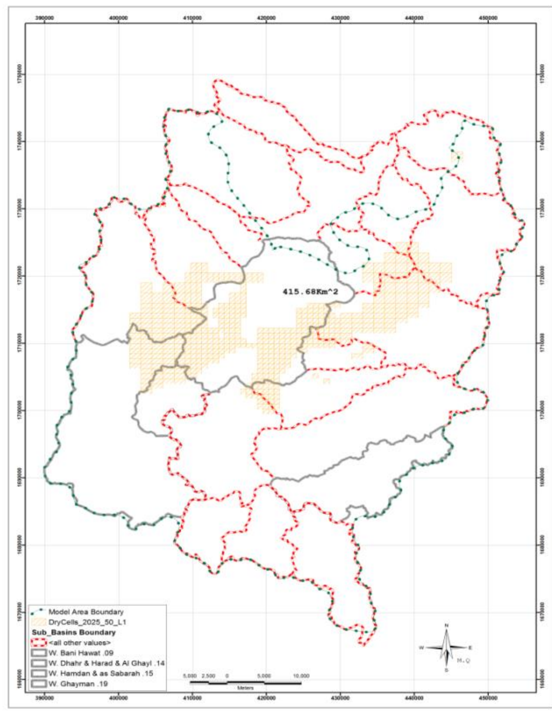

Figure (12): Expected Over-Exploitation Area in First Layer for the Year 2025 (Scenario3)

8. Conclusions

With reference to the output of scenario 1, the following conclusions can be derived;

- The over-exploitation areas in the first layer have decreased by more than 20%, where these areas were in Scenario 1 of about 222 km^2, and by applying Scenario 3; these areas covered only an area of 178 km^2.
- The over-exploitation areas in the second layer were computed for Scenario 1 of about 13.5 km^2, and this area has vanished and disappeared completely.

With reference to the output of Scenario 2, the following conclusions can be derived;

- The over-exploitation areas in the first layer have decreased by more than 14%, where these areas were in Scenario 1 of about 222 km^2, and by applying scenario 2; these areas covered only an area of 190 km^2.

- The over-exploitation areas in the second layer were computed for scenario 1 of about 13.5 km^2, where in Scenario 2 the exploitation-areas have about 1.1 km^2.

Table (6) illustrates the impact of applying the various scenarios. It should be noted that most advantage is gained through applying scenarios 2 & 3.

Table (6): Evaluation of the Results of the Proposed Scenarios in the Targeted Sub-Basins

Scenarios	Predicted Over-Exploitation Areas (Km^2)		Water Potentiality Improvement (%)	
	1st Simulating Layer	2nd Simulating Layer	1st Simulating Layer	2nd Simulating Layer
Scenario 1	222	13.5	---	---
Scenario 2	190	1.1	14	92
Scenario 3	178	---	20	100

As shown above, Scenario 3 gives a remarkable improvement of the Water Resources System in the four sub-basins by a rate of more 20%, within a reasonable period (in the year 2025). Thus, it will keep the water resources sustainability.

9. Recommendation

- It is recommended that irrigation systems be improved and that losses in transport and distribution of irrigation networks be reduced.
- Different methods can be applied to increase the Groundwater Recharge, whether from Reservoir, Catchment Runoff, or Return Flow from demand sites. The available potential to use water-harvesting methods in Four Sub-basins is very encouraging.
- Continuous monitoring, coupled with a computerised GIS database, is a powerful tool with which proper planning can be updated. Geographic Information Systems have to be applied extensively to enable various methods of storage, treatment and linkage of data and the projection of such in maps by international or national geographic coordinates.
- Periodical accurate measurements of water level and pumped water quantities are required to ensure that there are no discrepancies between measured values during exploitation of groundwater and values predicted by the model. So use of the mathematical model technique is not only for planning, but also for follow-up and management processes. Thus the four sub-basins should enact water laws that regulate the utilisation of water within the available resources, protect them against deterioration, assign responsibilities and competence to the administrative bodies and regulate relations between these bodies

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SESSION 3: CLIMATE CHANGE AND WATER RESOURCES

Keynote

Water Futures under a Changing Climate for the GCC Countries

Rachael McDonnell, Karim Bergaoui, Makram Belhaj Fraj, and Rashyd Zaaboul

Abstract
Water managers, farmers and those living in rural areas will relate how they are experiencing today the impacts of a drier, hotter and more extreme climate in the Gulf region. Yet there is little published research and analysis of these changes and their impacts. The results of two recent projects undertaken by the Climate Change Modeling and Adaptation Section at ICBA will be presented. The modelling work highlights likely future conditions whilst the accompanying vulnerability assessment looks at those people/sectors most vulnerable. Many water and farming systems have been identified as being at risk to drought and recent events.

Work at ICBA has focused on generating new insight through improved climate data to support the adaptation planning actions of decision-makers. This has involved various modelling exercises. To begin with historical baseline data sets were established which characterized precipitation and temperature trends using existing gridded global data sets such as CRU1 and ERA-Interim2 for the last 30 years. Then dynamical downscaling modeling of various global General Circulation Models (GCMs) which were identified as best representing MENA region's climate. The resulting data sets were used to analyses the dynamics of future climate conditions during key periods in the growing season and the water budget. The key findings of this work will be presented.

Increasing droughts were identified as a particular area of concern with these extreme events affecting all countries, with agriculture and water resources being particularly vulnerable during these times. In the Arab Gulf countries there is little discussion of droughts as the impacts of the increased aridity and heat are largely offset by more irrigation. This means more groundwater resources in particular are used to counter the decrease in soil moisture and increases in evapotranspiration. There has been little analysis of changes in crop yields during these times, with production often coming at a high price on non-renewable so precious water reserves. The countries of the Gulf do not have in place drought management systems so there is little if any planning of how to offset the negative impacts of these events. Preliminary analysis of downscaled climate change data suggests these extended periods of dry days will increase and that temperatures will rise. The length, timing and severity of the drought are important determinants on the subsequent impacts. Using both field and satellite measured climate data for many decades, baseline the Evaporative Stress Index conditions will be established for the 12 months of the year from an energy balance modeling and then drought anomalies. Irrigation and potential evapotranspiration anomalies will be generated to identify the characteristics of the events and the increased need of water for irrigation during the drought episodes.

1 The University of East Anglia's CRU (Climate Research Unit) gridded global climate data sets
2 The European Center for Midrange Weather Forecasting's ERA-interim (Ecmwf Re Analysis) gridded data sets up to present

For climate change adaptation, there are key areas to be managed in Gulf water systems – the nature and magnitude of demand and supply system. Managing groundwater systems, – the strategic reserve in all Gulf countries - is vital. There are a number of areas that require increased focus so that the aquifers are protected for the future. There is a need to examine existing governance and policy systems to ensure they are fit for purpose. There is also need for water accounting and enhanced water productivity to be part of everyday management. Economic analysis of climate change impacts and droughts in particular, are needed so that long and short term changes in the cost of ground water use and alternate supplies such as wastewater and desalinated seawater are considered.

Keywords: Climate Change, Adaptation, Downscaling Modeling, Agriculture, Water Resources.

Keynote

Impacts of Climate Change on Coastal Aquifers in Northern Oman

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Abstract
This paper evaluates numerically, the effects of climate change (precipitation, temperature, and sea level rise (SLR)) on two selected coastal aquifers in North of Oman: (1) Jamma aquifer which is mainly used for irrigation and (2) Samail Lower catchment aquifer (SLC) which is mainly used for domestic water supply. SLC aquifer is considered as a strategic reserve for domestic water supply and hence of great economic value. Unlike Jamma aquifer, SLC maintains positive gradient seaward direction as the aquifer is currently protected and managed. The water dynamics in both aquifers are studied under the different RCP scenarios for years 2050 and 2070 according to IPCC. Results show that the salinized area in Jamma site, considering the intruded distance of the 1500 ppm iso-concentric line (m), will increase from 21.9 km^2 (base case "2015") to 28.9 Km^2 (2050) and to 30.3 Km^2 (2070). This implies that a further 32 % of agricultural land will be salinized by year 2050 and about 38.5 % by year 2070. This effect is significant given the narrow agricultural strip area it covers which is also shared with other land uses as urban and industrial uses. The SLC aquifer will experience an increase of saline water intrusion by 6-8 times of that for the base case for year 2050 scenarios and 8-13 times for year 2070. This is obvious as the hydraulic gradient increases at the coastal boundary due to SLR. However, seawater intrusion is not an issue in the SLC aquifer as it currently maintains a positive hydraulic gradient seaward direction. This acts as a barrier against further incursion of salt water landward direction. This is reflected in the water budget under all RCPs scenarios showing large volume of pristine water flowing out through the coastal boundary (4 times that inflowing to the aquifer). The main conclusion is that the impact of the climate change is happening at rapid pace during the next few years to come (15 years). This necessitates urgent implementation of mitigation actions, before the farming community at large (along with other users) be severely affected and corrective measures become infeasible. SLR was found to be the main factor that significantly affects the coastal aquifers. This is because the change in rainfall rate for north of Oman is small and the effect of evapotranspiration is low given the high extinction depth (deep water table). The extent of the effect of climate change on aquifers is site specific. Stressed aquifers are highly vulnerable and severely affected. Mitigation and adaptation measures must be planned first for more vulnerable aquifers. Although, the aquifer systems that currently maintains a positive hydraulic gradient seaward direction (like SLC in this study) is not significantly affected by the climate change, but improper development and management of those systems would definitely shift them to be more vulnerable to adverse effects by climate change.

Keywords: Climate Change, Groundwater Resources, Sea Level Rise, Coastal Aquifer.

Introduction

Arid and semi-arid regions rely mainly on groundwater resources, especially where surface water is scarce. The demand for groundwater for municipal, agricultural, and industrial uses has grown steadily during the past decades. These limited resources face many threats including over abstraction, contamination, mismanagement, etc. Moreover, climate change is considered also one of the greatest challenges facing the world which is predicted to adversely affect the water resources (Parry *et al.,* 2007). According to the IPCC Fifth Assessment Report on Climate Change (IPCC, 2013) global mean temperatures will continue to rise over the 21st century under all of the RCPs (Representative Concentration Pathway's scenarios). Through improper land use, overutilization of water, and deterioration of green canopy; human activities can accelerate climate change (Collischonn *et al.,* 2001). Climate change (in terms of temperature and precipitation) influences the hydrological systems, in terms of evaporation, rainfall patterns, sea level rise (SLR) and recharge to groundwater aquifers. Recently, impacts of climate change on groundwater resources attracted the attention of many researchers (e.g., Earman and Dettinger, 2011). SLR is considered as the main factor significantly affecting coastal aquifers especially in areas like Oman where the water table depth reaches in average 10-15 m below ground surface.

In most countries, coastal areas have high ecological value, economically very important, and typically densely populated compared with inland zones (McGranahan *et al.,* 2007). The effect of climate change on groundwater resources is related to the recharge rate and interaction between the surface water and groundwater (Loaiciga, 2003). Therefore, it is believed that groundwater is indirectly and slowly influenced by climate change compared with surface water resources. Reviewing the literature reveals that many studies talked about the effect of climate change on groundwater recharge and groundwater level fluctuation (e.g., Anderson and Emanuel, 2008; Perez-Valdivia *et al.,* 2012). Reduction in groundwater recharge (due to decrease in precipitation) will deplete the coastal aquifer storage due to continuous exploitation of the resource and hence accelerate seawater intrusion. The Intergovernmental Panel on Climate Change (IPCC, 2013) predicts that by 2100, global warming will lead to a SLR of 0.11 – 0.88 m. Another study by Pfeffer *et al.* (2008) showed that sea level may rise by 0.8 to 2.0 m by 2100. The average rate of SLR over the 20th century was 1.7 ± 0.3 mm/ year from analysis of tide-1869 gauge data (Church and White, 2006). However, the rate has increased in recent years. From 1993 to 2003, the average rate of SLR was approximately 3.1 mm/ year with approximately half of that rate coming from thermal expansion (IPCC, 2007). Sea level is presently rising at a rate of 3.4– 3.5 mm/ year based on satellite-based sea-surface altimetry, tide gauges, and global gravity measurements (Cazenave *et al.,* 2009). By the end of the 21st century there are clear consequences depending on which scenario is followed, with SLR ranging from 0.57 to 1.10 m by 2100. The maximum rate of SLR by 2100 reaches 17 mm/year for the RCP 8.5 scenario.

Danielopol *et al.* (2003) concluded that coastal aquifers in arid and semi-arid regions will suffer from negative impacts of climate change, especially due to changes in the recharge pattern and to seawater encroachment due to the rising seawater level. The latter, compounding the level of stress the aquifer is experiencing (Hydraulic gradients), where shallow coastal aquifers are at greatest risk (Kumar *et al.,* 2012). SLR may change (reverse) the hydraulic gradient that may exacerbate seawater intrusion. Recently, there has been an increasing interest in evaluating the extent of seawater intrusion in response to SLR (e.g., Werner *et al.,* 2013). The literature review reported a number of case studies about the effect of climate change on coastal aquifers (e.g., Sherif and Singh, 1999; Carneiro *et al.,* 2010; Ferguson and Gleeson, 2012; Michael *et al.,* 2013;

Green and MacQuarrie, 2014; Garner *et al.*, 2015; Lemieux *et al.*, 2015). Sherif and Singh (1999) investigated the possible effect of climate change on seawater intrusion in two different coastal aquifers (Nile Delta aquifer in Egypt and Madras aquifer in India). The results show that a 0.5 m rise in the Mediterranean Sea level will cause additional intrusion of 9.0 km in the Nile Delta aquifer. The same SLR in the Bay of Bengal (Madras aquifer) will cause an additional intrusion of 0.4 km. As a conclusion, the Nile Delta aquifer is more endangered under the conditions of climate change and the selected SLR. Additional pumping will cause serious environmental effects in the case of the Nile Delta aquifer. Carneiro *et al.*, (2010) simulated effects of SLR and changes in recharge to the quantity and quality of groundwater on a coastal Saïdia aquifer in Morocco under three IPCC scenarios up to year 2099. The simulated results show that the freshwater volume reduced by 50 - 60 % with respect to the base condition, due to the decline in recharge and the reduction in inflows from neighboring aquifers via the cross flow. The vulnerability of coastal aquifers to groundwater use and climate change have been studied by Ferguson and Gleeson (2012). The results found that coastal aquifers are more vulnerable to groundwater extraction than to predict SLR under different cases of hydrogeologic conditions and population densities. Only aquifers with very low hydraulic gradients (seaward direction) are more vulnerable to SLR.

Green and MacQuarrie (2014) investigated the relative importance of projected SLR, recharge, and pumping rates scenarios on seawater intrusion in a coastal aquifer located in Richibucto region of New Brunswick, Atlantic Canada, using a three-dimensional numerical model. These scenarios were simulated for the period from 2001 to 2100, based on a net decline in groundwater recharge (40–85 mm/year), a net SLR (0.93–1.86 m) and an increase in abstraction rate by a factor of (2.3 times) for 2100. As a result, the effect of the SLR had the least impact on seawater intrusion into shallow and intermediate depths (less than 60 m below sea level) along the transition zone. The effect of decreasing recharge was most important at shallow to intermediate depths, while the impact of increased abstraction rates was most significant at the extraction depth and at the vicinity of the active wells.

Luoma and Okkonen (2014) assessed the impact of climate change on groundwater resources in a shallow, unconfined, low-lying coastal aquifer in Hanko, southern Finland, using the UZF1 package coupled with MODFLOW model to simulate flow from the unsaturated zone through the aquifer. The results indicated fluctuations in the recharge pattern over the period 2071–2100, with recharge occurring earlier in winter and spring. As a result, the hydraulic gradient will be reversed over parts of the aquifer due to SLR (i.e., low-laying zones or depressions elevations will be becomes below sea level after SLR), compromising groundwater quality due to seawater intrusion. This, together with increased groundwater recharge during some seasons, will result in shallow water table problem that may consequently contributes to appearance of out-seeps in the low-lying area.

Garner *et al.*, (2015) studied impacts of sea level rise and climate change on coastal plant species in the central California coast and suggested that SLR represents a higher risk, while the risk from climate changes (in terms of precipitation and temperature) is lesser known, but there is a cumulative effect from both. Lemieux *et al.*, (2015) investigated the individual and combined impacts of SLR, decreased groundwater recharge and coastal erosion on the position of the freshwater–saltwater interface of the Magdalen Islands, Québec, Canada. The results showed that SLR was the most significant parameter, followed by decreasing groundwater recharge and coastal erosion. While, the simulation results of these impacts together showed that over a 28-year period, the freshwater-saltwater interface migrates inland over a distance of 37 m and rises by 6.5 m near the coast to 3.1 m further inland. Murali and Kumar (2015) generated scenarios for two different rates of SLR 1 and 2 m in the vicinity of Cochin, India. The losses of urban areas were estimated at 43 km^2 and 187 km^2 for the 1 and 2 m SLR, respectively, which is alarming information for the most densely populated state of India. The results obtained point that SLR scenarios will bring deep effects on the land use and land cover classes. Also, it makes reduction in coastal drainage gradients that may increase flooding attributable to rainstorms, which could promote seawater intrusion into coastal aquifers and force water tables to rise. Reviewing the literature shows that the effect of climate change on groundwater resources is site specific based on geological and hydrological settings along with the level of development of the aquifer. Hence, vulnerability of key aquifers in different countries (especially arid and semiarid areas) to different climate change scenarios must be assessed and well-studied to better suggest/recommend the suitable mitigation approaches for each case.

Substantial uncertainty persists about the impacts of climate change on mean precipitation from general circulation models (GCMs) (Bates *et al.*, 2008), but there is much greater consensus on changes in precipitation and temperature extremes, which are projected to increase with intensification of the global hydrological system (Allan and Soden, 2008; IPCC, 2011). Longer droughts may be interspersed with more frequent and intense rainfall events. These changes in climate may affect groundwater initially and primarily through changes in irrigation demand, in addition to changes in recharge and discharge. A global analysis of the effects of climate change on irrigation demand suggests that two thirds of the irrigated area in 1995 will be subjected to increased water requirements for irrigation by 2070 (Döll, 2002). Projected increases in irrigation demand in southern Europe will serve to stress limited groundwater resources further (Falloon and Betts, 2010).

Since early 1970, the Al-Batinah costal aquifer has seen intensively developed for irrigation purposes. Al-Batinah area represents about 50% of the total agricultural land in Oman (Oman Salinity Strategy 2012). Groundwater is the only source of supply for farming activities, i.e., agriculture is the main consumer of available water resources in the country (MRMWR 2005). It is necessary to assess the effects of climate change on this important coastal aquifer. Unlike Jamma aquifer, SLC aquifer is mainly used for domestic water supply as detailed below. Irrigation water constitutes around 15 % of the total abstracted volume (21000 m^3/day). The aquifer is considered as a strategic reserve for domestic water supply. Unlike Jamma aquifer, SLC maintains positive gradient seaward direction as the aquifer currently unstressed by abstraction. SLC is of great economic value (Zekri *et al.*, 2014) as well as of paramount importance for urban water supply. Thus, the threats the aquifer would face due to climate change is explored and presented below.

Objective

The aim of this study is to evaluate numerically, the impact of climate change on two selected coastal aquifers of different hydrological conditions in North of Oman: Jamma aquifer (South Al-Batinah area), 150 km East of Jamma site, and Samail Lower catchment (SLC), Al-Seeb area.

Approach
MODFLOW 2005 (Harbaugh, 2005) was used to solve the governing flow equation using the Geometric Multi-grid (GMG) solver. Modeling setup for Jamma aquifer readers are referred to MECA 2015 for more details in model setup. For SLC aquifer are detailed in Ebrahim et al. (2015) and Al-Maktoumi et al. (2016).

Description of Jamma Aquifer
Jamma aquifer is located on the southeast Batinah coast of Oman and covers an area of about 295 km^2 (Fig. 1 a) forming an important alluvium aquifer (Al Barwani and Helmi, 2006). The study area is characterized by warm winters with low humidity and very hot and humid summers along with low and irregular rainfall. The average rainfall in the area is about 60 mm/year with higher rate (reaching 140 mm/year) recorded in the mountains area (upstream part of the catchment-southern boundary of the study area) (Weyhenmeyer *et al.*, 2002). The average air temperature is 28.5°C. Dry climatic condition prevails with high rate of evapotranspiration (ET is 2400 mm/year (MWR, 1996). In the study area, the ET is 4.5 mm/day (1644 mm/year).

The aquifer is utilized by about 1037 unmonitored irrigation wells clustered along a coastal strip of 5 km width (Fig. 1c). The vast majority of the wells are shallow dug wells and penetrate only up to the quaternary alluvium layer with a total abstracted volume of about 89 Mm^3/year (based on the water resources Ministry survey and estimate) with an average abstraction rate for each well is 235 m^3/day. Groundwater level in the study area is monitored by MRMWR via 7 observation wells (Fig. 1b). The cropped land in the study area is about 1090 hectares, of which 80% is irrigated by flood irrigation system whereas the remaining 20% adapted modern irrigation systems.

The unregulated abstraction of water from the aquifer and unmanaged irrigation practices along with the drought condition stressed the aquifer far beyond the safe yield. Consequently, seawater intrusion becomes a serious problem in the area. A simplified geological map of the Jamma study area is obtained and presented in Fig. 1b (Lakey *et al.*, 1995). There are two distinct geomorphological zones, (Fig. 1c): The first zone (southern part) is mountainous/ piedmont upper catchments dominated by Samail Nappes, and Hawasinah and Hajar Super Group (HSG) sedimentary rocks. The second (northern part, Jamma area) is alluvial fans and a plain that extends through the central and lower reaches of the catchment to the coast. The coast is fringed by beach dunes and Sabkha deposits.

The aquifer is modeled as two units, layer 1 (Quaternary Alluvium with low clay content) and layer 2 (Tertiary alluvium or as named regionally “Upper Fars formation”- more compacted and characterized by lower hydraulic conductivity and porosity) (A- A^- in Fig 1b). The thickness of layer 1 ranges between 81-222 m (amsl) and for layer 2 between 195 – 429 m (amsl).

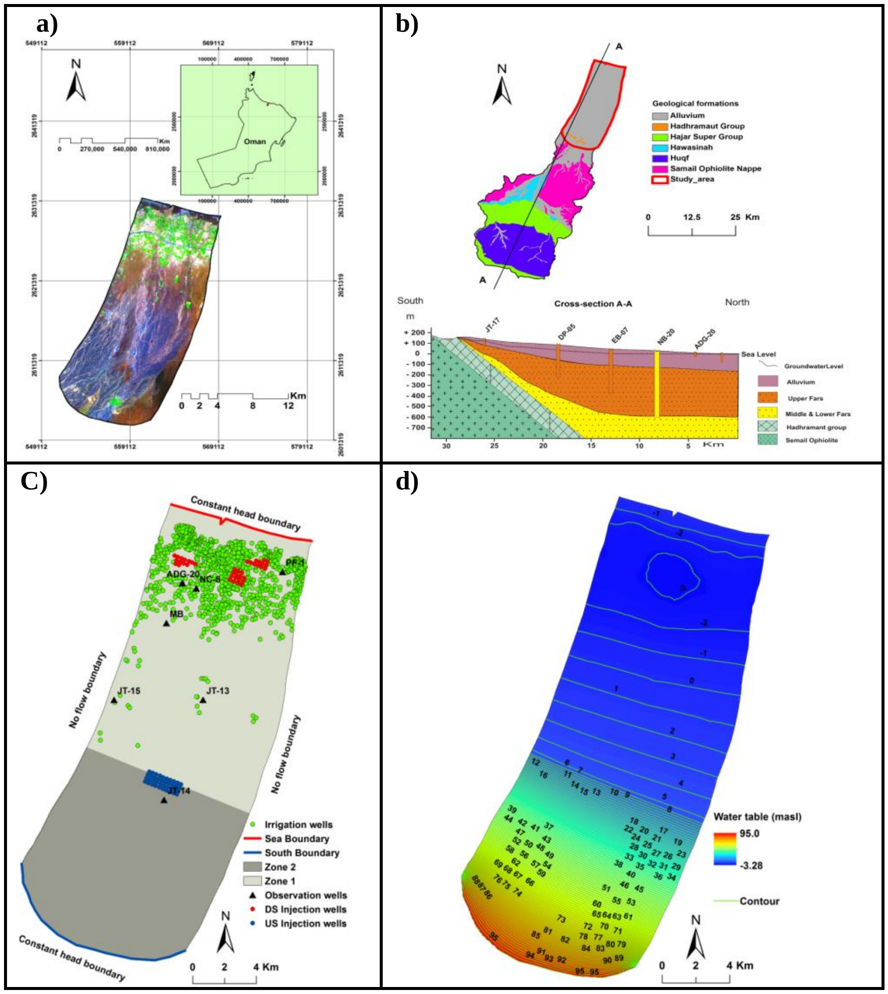

Figure 1: Location and characteristics of the Jamma study area

Numerical model setup for Jamma aquifer

MODFLOW-2005 code (Harbaugh, 2005) withy ModelMuse (Winston, 2009) as a graphical user interface (GUI) was used to simulate groundwater flow. The study area was discretized by 952 rows and 610 columns (with cell size of 30m x 30m), and 2 layers with a total number of 1,161,440 cells of which 655,390 are active. Constant head boundaries are assigned to the coastal line (head = 0) and the south boundary to account for the deep percolation from the mountainous area that receives higher amount of the rainfall (140 mm/year) and considered as the header tank for the coastal area (Fig. 1c), whereas no flow boundaries were assigned to east and west boundaries of the model domain as they represent a regional flow lines. The direct recharge from rainfall at the coastal plain was assumed to be 20 % (3.29E-05 m/day) of the average rainfall (Lakey et al., 1995). The evapotranspiration of 4.5 mm/day is assigned with an extinction depth of 12 m. Processing of the pumping test data divided the modeled area into two zones: lower conductive material in the upper part of the model area and a downstream zone of higher conductivity (Fig. 1c). Seawater concentrations (TDS) of Oman Sea range from 40,000 to 48,000 ppm (Greenlee et al., 2009). In this study, the coastal line represents a constant concentration boundary (TDS of 40,000 ppm) with a dispersion coefficient of 200 m^2/day. The simulation period is 20 years with 244 stress periods (of 30 days length). Sensitivity analysis was carried out using UCODE 2005 (Poeter et al., 2005) with the help of ModelMate (Banta, 2011). The steady state condition was calibrated using data of year 2005 from 7 piezometers (locations shown in Fig. 1c). The calibrated hydraulic conductivities of zone1 and zone 2 are 35, 8, 20 and 0.3 m/day for layer1 and layer 2 respectively; and the direct recharge from the rainfall is 1.80247E-06 m/day. Results of the calibrated groundwater model show a correlation factor of 0.96. The mean error is -0.04 m, the mean absolute error is 0.9 m, and the root mean square error is 1.17 m, which shows that the model performs satisfactorily.

Description of SLC Aquifer

Several papers (e.g., Al-Lawati 1997; Kacimov et al. 2010; Abdalla and Al-Abri 2013; Ebrahim 2013; Al-Saqri et al. 2015; Zekri et al. 2014, 2015) have presented detailed discussions concerning the geological and hydrogeological properties of the SLC aquifer, therefore, only a brief discussion is provided below.

The study area consists of the coastal plain of the Wadi Samail catchment and covers an area of approximately 59 km^2 (Fig. 2). From the north, the study area is bounded by the Oman Sea and by Wadi Samail catchment from the south, Wadi Taww from the west and the Wadi Rusayl from the east. In addition to irrigation water, the aquifer has been an important source of potable water supply to major cities in Muscat governorate throughout the last three decades. Currently, the aquifer is considered a strategic reserve.

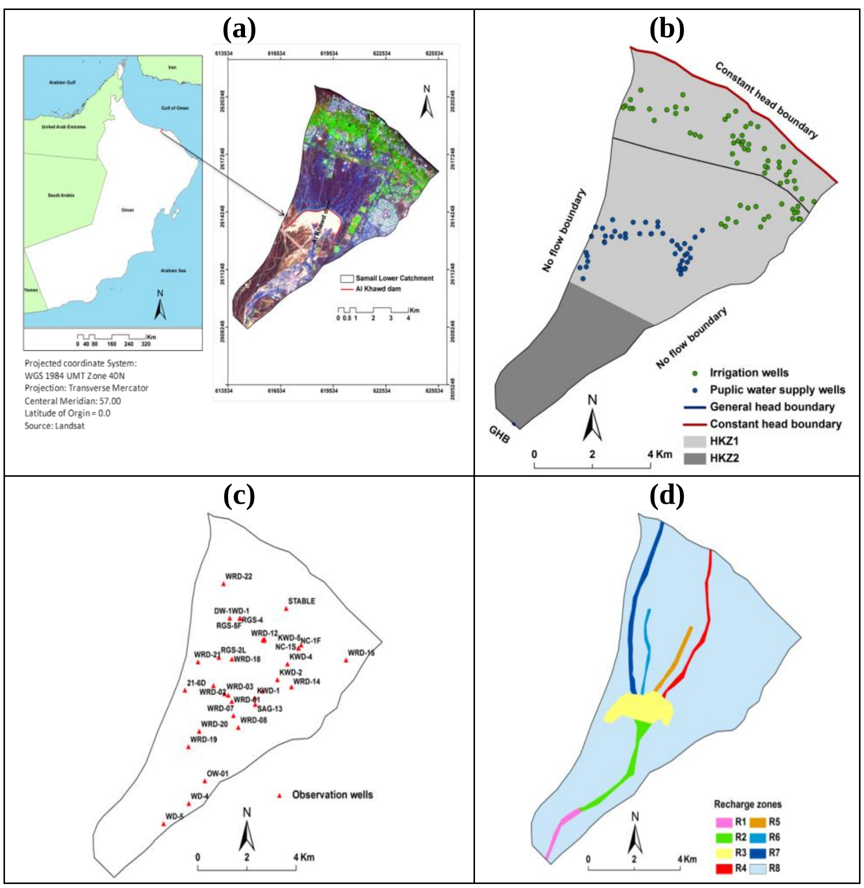

Figure 2: (a) Location and characteristics of the SLC study area, (b) the boundary conditions, locations of public and irrigation wells and zones of different hydraulic conductivities and (c) the location of observation wells (upper panel) and (d) recharge zones *(Al-Maktoumi et al., 2016)*

Al Khawd recharge dam was constructed in March 1985 in the SLC approximately 7 km from the coastal line (Fig. 2) (Kacimov et al. 2010; Abdalla and Al-Abri 2011). Over years and because of reduction of abstraction for domestic supply (as government shifted to desalination water in the area) and dam functionality, the aquifer storage recovered and the hydraulic gradient maintained seaward direction, hence mitigating seawater intrusion observed during the stressful period the aquifer experienced.

Geologically, the SLC mainly consists of Quaternary alluvial deposits, which form extensive terraces and alluvial fans made from recent and ancient alluvium units. The former makes up approximately 70% of the total alluvial deposits and thickens towards the coast. Hydrologically, the aquifer is modeled as two primary units. Details of modeling conceptualization, setup, and calibration, are presented in Al-Maktoumi et al., (2016).

Climate change scenarios

The climate change and its variability are recognized as one of the most serious challenges facing the world (Parry et al., 2007). The SLR is an important component of climate change for coastal areas. In most countries, coastal areas have high ecological value and economic importance, and typically are more densely populated than inland areas (Mc GRANAHAN et al., 2007). SLR may change the hydraulic gradient between land and sea and may exacerbate seawater intrusion (Werner et al., 2013). The impact of SLR on seawater intrusion has been explored extensively through national- or global-scale assessments (Ferguson and Gleeson, 2012; Michael et al., 2013). According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Reference: IPCC, 2013), the climate change (ET and precipitation, and AR5 global mean sea level increase) projections of Representative Concentration Pathways (RCPs) for years 2050 and 2070 are presented in Table 1 for the two selected sites.

Table 1: Reference Evapotranspiration (ET_0), Precipitation, and SLR projections based on the RCPs for 2050 and 2070 for the selected sites.

	ET0		Precipitation		SLR	
	2050	2070	2050	2070	2050	2070
	mm/day		mm/year		m	
Jamma site						
RCP2.6	7.15	7.15	81	83	0.24	0.4
RCP4.5	7.34	7.33	76	73	0.26	0.47
RCP6.0	7.50	7.57	81	83	0.25	0.48
RCP8.5	7.85	7.92	93	84	0.30	0.63
SLC site						
RCP2.6	7.15	7.15	80	91	0.24	0.4
RCP4.5	7.34	7.33	82	77	0.26	0.47
RCP6.0	7.5	7.57	87	90	0.25	0.48
RCP8.5	7.85	7.92	98	88	0.3	0.63

Note: The ET_0, precipitation, and SLR of the current case are 4.5 mm/day, 60 mm/year and 0.0 m respectively for Jamma site and 5 mm/day, 80 mm/year and 0 m respectively for SLC.

Results and Discussion

The simulated results of the different RCPs for both years 2050 and 2070 are discussed based on water budget, average change in groundwater table, and heads distribution. The water balance of the base case "year 2015" and RCPs at 2050 and 2070 with the change in groundwater level with respect to the base case are presented in Table 2 (a, b, c, and d).

Table 2: Water balance of the current case and the simulated RCPs for the two sites and years 2050 and 2070

a) Jamma - 2050

	Abstractions	Inflow from the sea	Inflow from the south	ET	Direct recharge	Average change in water table (RCPs -current)
	(m^3/day)					(m)
Current case	243,695	171,702	79,288	7,829	534	-
RCP2.6	243,695	178,884	79,238	13,748	721	0.10
RCP4.5	243,695	179,499	79,246	14,227	679	0.11
RCP6.0	243,695	179,646	79,239	14,465	721	0.11
RCP8.5	243,695	180,859	79,213	15,460	828	0.13

b) Jamma - 2070

	Abstractions	Inflow from the sea	Inflow from the south	ET	Direct recharge	Average change in water table (RCPs -current)
	(m^3/day)					(m)
Current case	243,695	171,702	79,288	7,829	534	-
RCP2.6	243,695	180,135	79,186	14783	739	0.20
RCP4.5	243,695	181,331	79,193	15,609	650	0.23
RCP6.0	243,695	181,859	79,174	16,177	739	0.24
RCP8.5	243,695	184,295	79,147	18,016	748	0.32

c) SLC - 2050

	Abstraction rate	Inflow from the sea	Outflow to the sea	Inflow from the south	ET	Direct recharge	Average change in water table
	(m^3/day)						(m)
Current case	21,343	413	12,837	887	9,069	41,944	
RCP2.6	21,343	2,460	10,253	905	13,375	41,944	0.06
RCP4.5	21,343	2,708	10,094	906	13,773	41,956	0.06
RCP6.0	21,343	2,793	10,069	906	13,927	41,986	0.05
RCP8.5	21,343	3,322	9,744	907	14,775	42,051	0.07

d) SLC - 2070

	Abstraction rate	**Inflow from the sea**	**Outflow to the sea**	**Inflow from the south**	**ET**	**Direct recharge**	**Average change in water table**
	(m^3/day)						(m)
Current case	21,343	413	12,837	887	9,069	41,944	
RCP2.6	21,343	3,136	9,812	902	14,528	42,009	0.18
RCP4.5	21,343	3,646	9,430	905	15,273	41,926	0.20
RCP6.0	21,343	3,913	9,313	905	15,731	42,003	0.20
RCP8.5	21,343	5,017	8,598	907	17,419	41,991	0.27

The water balance of the current case model (2015) and RCPs at years 2050 and 2070 with the change in groundwater level with respect to the current model for the Jamma aquifer show that the inflow from the sea boundary, ET0, direct recharge, and change in average water table increase with respect to the current case. Considering 2050 simulations, the results show that the discharged water via evaporation increased by 75% (RCP 2.6) and reaches 97% for RCP 8.5 scenario. In average, the groundwater level for the entire modeled area is found to increase by 10 cm (RCP 2.6) while reaching 13 cm for RCP8.5. This could be attributed to the existing depression in the water table which is filled up by the saline water due to SLR. The SLR increases the aquifer storage and balances out the increased discharge by ET but with saline water (more deterioration in aquifer-water quality). This is reflected on the rapid rise in the inflow from the sea for all RCPs with small differences between them. The impact of climate change is getting worse for year 2070 as the problem is dynamic. The volume of water lost by evaporation increases by 130% (considering RCP 8.5) with respect to the current case (2015) which is associated to the rise in water table.

To illustrate more the effect of SLR on the saline water intrusion interface, the solute transport is simulated using MT3DMS code. The 1500 (mg/l) iso-concentric line was considered. In this study, a constant concentration boundary (TDS of 40,000 ppm) is assigned along the coastal boundary and across the vertical depth of the modeled aquifer. The intruded distance of the saline water interface for the 1500 ppm iso-concentric line and the salinized agriculture land (km^2) for the base case and all RCPs scenarios at 2050 and 2070 were analyzed. The results show that the 1500 ppm iso-concentric line ingress further landward direction to the point of 3120 m from the coastal boundary for the RCPs of year 2050 (was at the point 2370 m for the base case – increased by 750 m) and advancing further by 160 m for RCPs of year 2070. Consequently, the salinized area based on intruded distance of the 1500 ppm iso-concentric line (m) increases from 21.9 km^2 (current case) to 28.9 km^2 (RCPs 2050) and to 30.3 km^2 (RCPs 2070). As that, a total of about 7.0 km^2 more of agricultural land will become unsuitable for agricultural production by year 2050 and about 9 km^2 for year 2070. This effect is significant provided the narrow agricultural strip in Al-Batinah area that is also shared with other land uses as commercial and housing industry. Considering SLR for year 2070, the 1500 ppm line will ingress inland by nearly 1 km with respect to the current case (year 2015) which will result in more deterioration of farming land. The water quality deterioration and land salinization in Jamma aquifer (South Al-Batinah area) are found to take place rapidly during the first 15 years (2015- 2030). The land deterioration due to salinity is found to occur at a rate of 30 m/year (considering the 2015 as a reference measurement). These results suggests that the managerial/mitigation actions should take place at early stage (first years) otherwise mitigation scenarios would not be effective and the aquifer restoration would be difficult if not impossible. Decision-makers should act from now, in order to reduce the risk-associated with climate change- that is threatening the aquifer and consequently the community in the 15 years to come.

For SLC, the rainfall rate will increase by a couple of millimeters for all RCPs, while significant increase in SLR and ET will occur (see table 2-c&d). These stresses result in an increase of saline water intrusion by 6-8 times for year 2050 scenarios and 8-13 times for year 2070 in comparison with the current case. This is obvious as the hydraulic gradient increases at the coastal boundary due to SLR. Regardless this increase in seawater inflow in the SLC aquifer, seawater intrusion is not an issue as the aquifer currently maintains a positive hydraulic gradient seaward direction. This gradient forms a barrier against further incursion of salt water. This is illustrated in the water balance data as under all RCPs scenarios, large volume of the pristine water flowing across the coastal boundary (3 to 4 times that inflowing to the aquifer). Unlike the stressed situation in Jamma aquifer, the inflowing saline water basically circulated back to the sea within a narrow mixing zone.

The effect of climate change on recharge is insignificant as the change in rainfall rate is in the order of 7 mm for year 2050 simulations and 20 mm for the year 2070. The SLR -as expected- acted as a hydraulic barrier that imposed resistance to the natural flow seaward direction. As a consequence, the outflow to the sea decreases with different fractions depending on the RCPs for both years 2050 and 2070. However, the outflow to the sea is still strong enough to combat the seawater intrusion regardless the SLR. However, if the aquifer is stressed beyond the safe yield, most likely the adverse impact of the climate change on the aquifer will be more significant. Mitigation policies should be set according to the plans of further development to the aquifer.

More detailed results are presented in MECA (2015).

Conclusion

The results of this study found that the extent of the climate change effect on coastal aquifers is a site specific. More developed aquifers (stressed aquifers) are highly vulnerable and severely affected. Aquifers need to be categorized in different groups to plan the mitigation tasks accordingly (reduction of abstraction rate, implementation of managed aquifer recharge using Treated wastewater, etc). For the studied coastal aquifers in Northern Oman, the impact of the climate change is occurring at a rapid rate during the first few years to come. This necessitates the implementation of mitigation actions as early as possible. Otherwise, late implementation will be less effective in mitigating the affected aquifers and will definitely affects the farming community in large along with other purposes. SLR found to be the main factor that significantly affects the coastal aquifers. This is because the change in rainfall rate as per the RCPs scenarios for North of Oman is small and the effect on ET is small due to high extinction depth. Although currently some coastal aquifer systems maintain a positive hydraulic gradient seaward direction (e.g., SLC), will not be affected significantly by the climate change. However, mismanagement of those systems would definitely shift them to be more vulnerable to adverse effects of climate change.

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Precipitation Monitoring and Future Precipitation Assessment under Climate Change

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Abstract
Our contribution addresses new concepts and methods for high resolution precipitation information, their application in the Near East and their potential future implementation in the Gulf region. For now-casting precipitation, we present a novel precipitation sensing technique based on the analysis of commercial microwave link networks (CML) as they are operated by cellphone companies worldwide. For the analysis of expected future precipitation and water availability we present specifically adapted meteorological and hydrological model chains allowing to achieve distributed information on expected future water availability. In the first part, the novel CML based technique is explained. It is especially suitable in poorly gauged areas with very local, often extreme precipitation events. In arid areas it can help not only to access the precipitation amount but also can play a key role in flood warning and disaster management systems. The contribution presents the rationale behind this technique and discusses application results obtained both in Germany, but also in the Wadi Faria, Palestine. In the second part, assessment of expected future precipitation amount and precipitation characteristics in the Near East based on available regional dynamical climate change downscaling experiments is given. The contribution discusses the principle of coupled modeling, i.e. dynamical downscaling and subsequent hydrological modeling. We focus on the derivation of expected climate change for the Near East and the Upper Jordan river catchment, such as shifts in frequency and intensity of extreme climatic events, specifically droughts and floods, and corresponding changes in surface- and subsurface water availability. Our results demonstrate that a significant reduction of water availability has to be expected with clear impacts on wealth and economy. The example presented for the Near East will show the potential of the methods and stress the necessities for similar assessments for the Gulf region.

Keywords: Precipitation, Remote Sensing, Microwave Links, Climate, Hydrology, Coupled Modeling.

Introduction

Water management is crucial for life, in particular in semi-arid regions. Reliable management can, however, only be carried out if robust observations and skilled forecast models are available. The declining number of operational rain gauges (Lorenz and Kunstmann, 2012) decreases the quality of the traditional rainfall observations, though. Furthermore, high resolution models have to be applied in order to resolve regional and local hydrometeorological effects, in particular in complex terrain.

We show that commercial microwave link (CML) networks can be a suitable choice for rainfall observation. We further introduce our recent high resolution modelling results and approaches for the improvement of current and future water management in the Middle East.

Precipitation observation using commercial microwave link networks

The fact that rainfall significantly attenuates microwave radiation in the frequency range above 10 GHz was already observed in the early twentieth century when rain showers disturbed the first microwave based communication experiments. Rain induced attenuation is hence mainly regarded as an unwanted disturbance. However, the other way round, a measurement of this attenuation can be used to derive a robust estimate of the path-integrated rain rate along the propagation path. With the large existing and growing networks of CMLs, which form the backhaul of the cell phone networks worldwide, the necessary attenuation measurements can be carried out in many regions of the world, often even where traditional rain gauge and weather radar data is not available.

A further advantage, in contrast to weather radars with their problematic *Z-R* relation, is the relation between attenuation A in dB/km and rain rate R in mm/h, which has only a weak dependence on the drop size distribution (DSD), as can be seen in Figure 1.

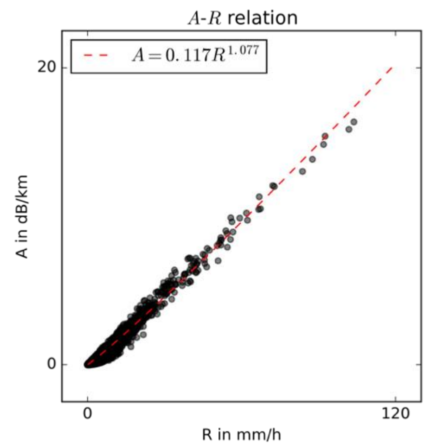

Fig. 1: Relation between rain rate *R* and attenuation *A* at 30 GHz. The black dots show the calculated values for minutely DSD data measured by a optical Disdrometer of the course of one year. The dashed red line shows the power law fit for the *A-R* relation.

The relation between attenuation A in dB/km and rain rate R in mm/h can be approximated very well by a simple power law of the form:

$$A = aR^b \tag{1}$$

Where a and b are constants depending mainly on frequency and polarization and slightly on the DSD. Figure 2 shows the values of a and b for the typical range of frequencies used in CML networks. With the values of b close to 1 in the relevant frequency range, equation (1) is linear, which prevents the introduction of errors when relating the two path averaged, but spatially heterogeneous, quantities A and R.

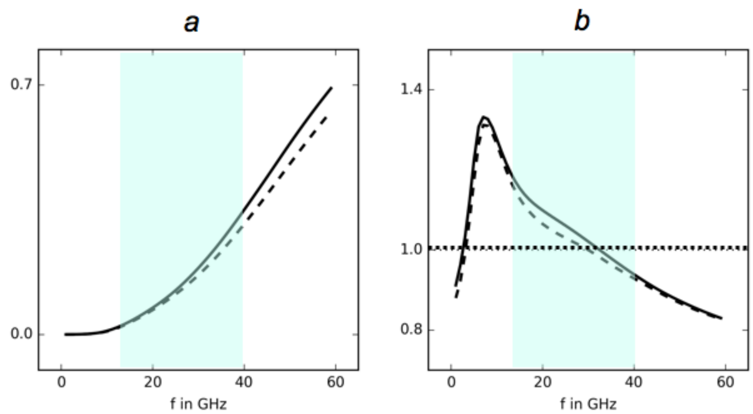

Fig. 2: Parameters *a* and *b* for the *A*-*R* power law relation. The solid line shows the values for horizontal, the dashed line for vertical polarization. The dotted line indicates *b*=1, where the *A*-*R* power law relation is linear. The area, shaded in light blue, is the frequency range typically used in CML networks.

Since the first studies on the usage of CML attenuation data for the derivation of rainfall information (Messer *et al.*, 2006), this technique was applied in several countries and numerous methods for the necessary processing of the attenuation data have been published (Schleiss and Berne, 2010, Chwala et al. 2012, Overeem et al., 2013, Doumounia, et al., 2014).

In Germany, the Karlsruhe Institute of Technology (KIT) in cooperation with Ericsson, acquires CML attenuation data in real-time (Chwala *et al.*, 2016), currently covering half of the area of Germany with a selection of 3000 CMLs. Data is continuously archived and processed. New methods for processing and validation are developed focusing on improving robustness and real-time capabilities. Figure 3 shows an example of a validation of the CML-derived rainfall fields for a smaller region in southern Germany, showing very good skill of the CML method.

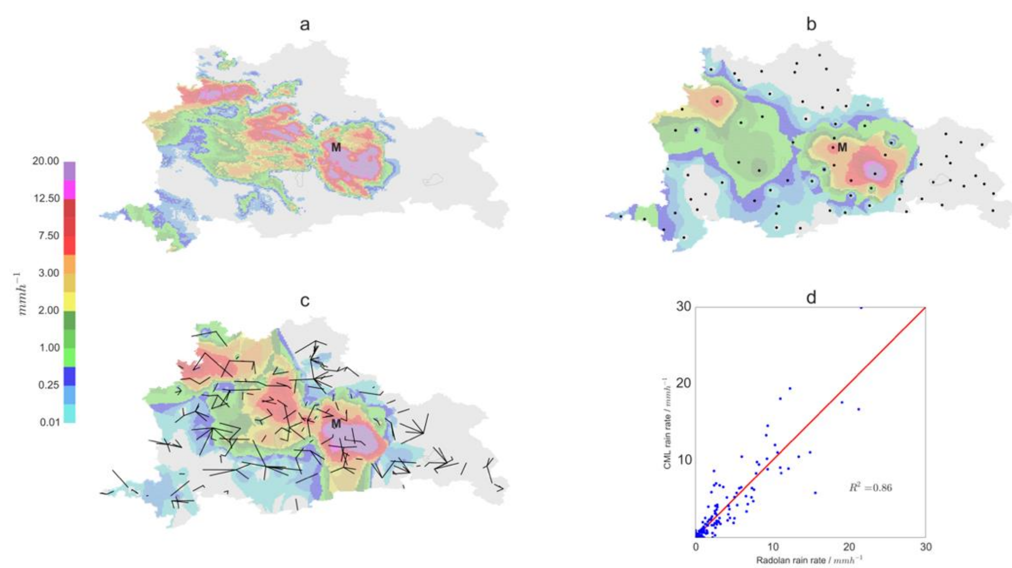

Fig. 3: Comparison between hourly rain rates maps for 04:00 UTC, June 8, 2015, derived from (a) weather radar, (b) rain gauge and (c) CML data for southern Bavaria (a part of southern Germany). The location of the city of Munich is indicated by the letter *M*. The scatter plot (d) show the comparison between CML rain rates vs. the weather radar data averaged along the respective CML.

Within the DFG funded project IMAP, KIT and An-Najah National University (Palestine), in cooperation with the local cell phone provider Jawwal, are analyzing CML data for the Wadi Faria, which leads from Nablus to the east to the Jordan river valley. The Wadi shows a strong rainfall gradient, with approximately 600 mm per year in the mountainous region around Nablus, to less than 200 mm per year in the lower part in the east of the catchment. A first analysis of the CML data for the rainy season 2015/2016 can be seen in Figure 4. It shows that the CML close to the two reference gauges agrees very well with them, and that the other CMLs capture the rainfall gradient very well.

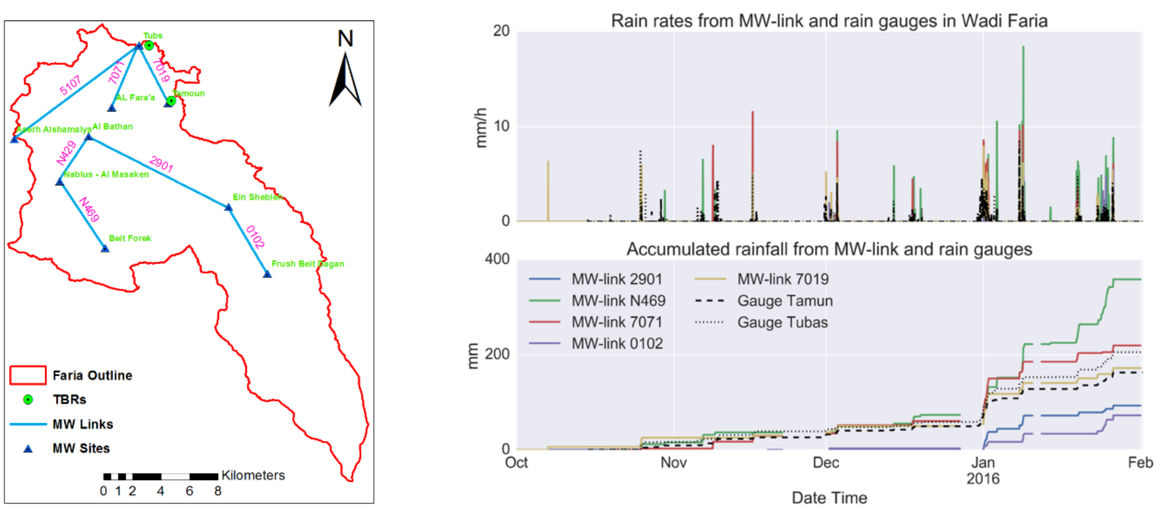

Fig. 4: Comparison of rainfall observations from rain gauges and CMLs in the Wadi Faria, located east of Nablus (Palestine). Left: A map of the Wadi Faria including the location of the rain gauges and CMLs. Right: Time series of rain rate data from CML and rain gauges. The two gauges (dashed and dotted line) are placed close to the CML 7019 (yellow line). The other CMLs are located in the upper and lower part of the catchment and capture the local strong rainfall gradient (from Nablus down to the Jordan River) very well.

Current research focuses on integrating the CML-derived rainfall information into hydrological simulations to improve the flash-flood modeling and forecasting in the Wadi Faria. As a next major step the data acquisition will be expanded to include a larger number of CMLs in Palestine.

Expected future changes in precipitation amount and characteristic for the Near East
Managing water availability is not only important on a short temporal scale of days, weeks and month, but also on longer climatic scales, to be able to develop required mitigation strategies in time. This is in particular true for semi-arid regions which could be affected most by the projected global warming. Hence, it is not only important to have reliable rainfall observations. Robust forecasts of the future changes of water availability are also of utmost importance. However, the spatial resolution of global climate models is often not high enough, to accurately describe important regional effects. This problem can be overcome by dynamically downscaling global climate model (GCM) data using regional climate models (RCMs) for a certain region.

We have investigated the expected future development for the western part of the Middle East using the RCM MM5, driven by two different global climate models, ECHAM5 and HadCM3 using the A1B emission scenario (Smiatek *et al*., 2011). Figure 5 gives and overview of the study region. The spatial resolution of the nested dynamic downscaling approach was 18.6 km, and transient runs were performed for the period 1960–2099.

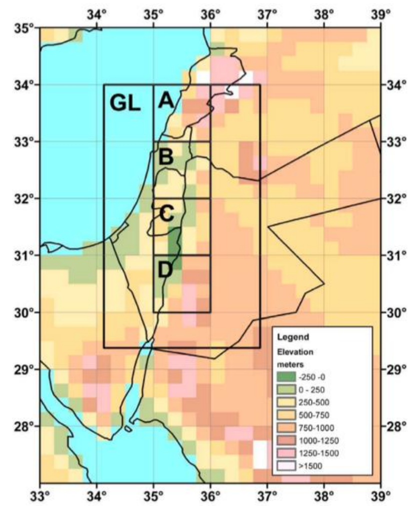

Fig. 5: Study region, with different focus regions (only region GL is relevant for this publication) and topography from a gridded data set with raster size 0.25°. Source: Smiatek et al., 2011

The investigated statistics include mean precipitation, frequency and intensity of wet days and strong precipitation events, as well as mean temperature and heat wave duration index. The results show that the models satisfactorily reproduce the mean temperature and precipitation patterns. The comparison with the observational reference for the period 1961–1990, see Figure 6, reveals a bias in the annual mean precipitation ranging from −20% to +17%, with an ensemble mean of −3%.

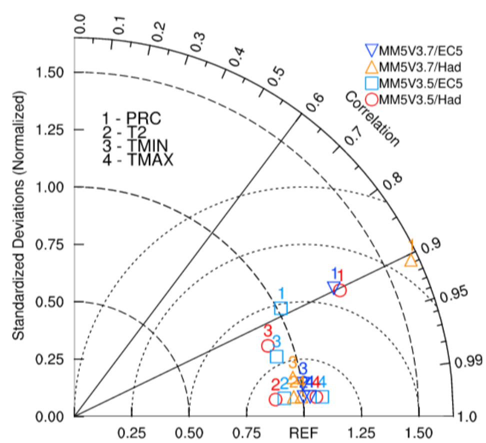

Fig. 6: Annual mean (1961–1991) spatial correlation between modeled data and the observational reference in the investigation area GL. Abbreviations are as follows: PRC, precipitation; T2M, mean2 m temperature; TN, minimum temperature; TX, maximum temperature. The reference for precipitation and temperature are the Global Change and Hydrological Cycle (GLOWA) data and the E-OBSV3 data set, respectively. Source: Smiatek *et al.*, 2011

The models show limitations in reproducing the precipitation seasonality. All models underestimate the wet day frequency and show differences in the strong precipitation events. The simulations of the future climate signal indicate an ensemble mean increase of the annual mean temperature of approximately 2.1 K in the period 2031–2060, and 3.7 K for the period 2070–2099 related to the 1961–1991 mean. In the same periods, the annual mean precipitation is simulated to decrease by approximately −11.5% and −20%, respectively (see Figure 7), which means a reduction of expected water availability in the Jordan River region. All models show an increase of the heat wave duration index. A significant elevation dependence is present in the simulated future climate signal on both temperature and precipitation. The simulations show an increased coefficient of variation in annual precipitation, indicating that larger inter annual precipitation variability can be expected in the future (Smiatek *et al.*, 2011).

For a more detailed hydrometeorological analysis a high resolution non-hydrostatic atmospheric model coupled with a respective hydrological model approach is required. So far, mostly one-way coupled approaches have been realized (e.g. Smiatek *et al.*, 2014). The WRF-Hydro coupling architecture now allows to combine both a distributed hydrological modeling system (Noah Distributed Hydrological System, NDHMS) and an atmospheric model (WRF) in a fully coupled manner (Arnault *et al.*, 2016; Senatore *et al.*, 2016). This will allow for more detailed hydrological process descriptions that account for the linkage between water- and energy fluxes both in the subsurface but also to the atmospheric boundary layer.

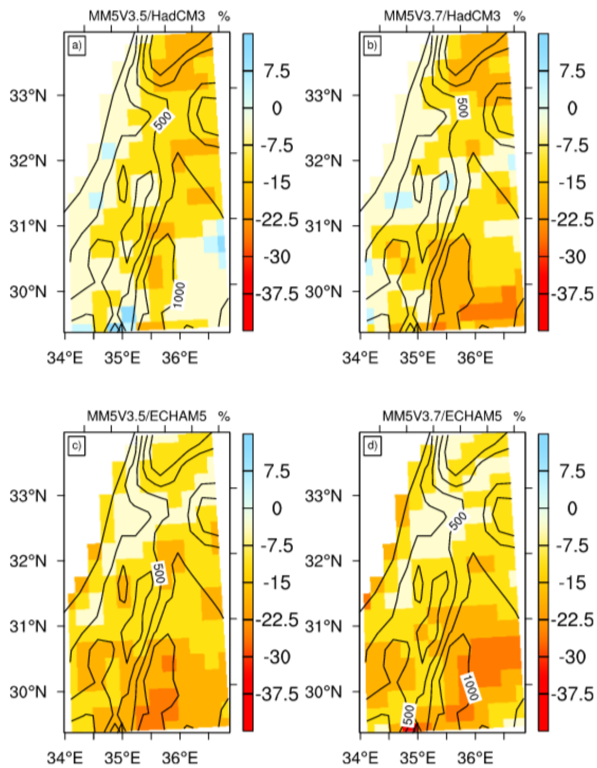

Fig. 7: Difference between the annual mean precipitation in the A1B scenario (2031–2060) and reference (1961–1990) simulations: (a) mm5v3.5had, (b) mm5v3.7had, (c) mm5v3.5ec5, and (d) mm5v3.7ec5. Units are percentages of the present values. Elevation contours are from model topography. Contour spacing is 250 m. Source: Smiatek et al., 2011

To validate and extend the hydrological capabilities of WRF-Hydro in semi-arid regions (Givati et al., 2016), we run it for the Wadi Faria (Palestine), where we also investigate the usage of CMLs for precipitation observation (see Figure 4). Our first results, shown in Figure 8, are still limited by the uncertainties of the very few rain gauge observations that are used to drive the model. Nevertheless, the model performance is already reasonable.

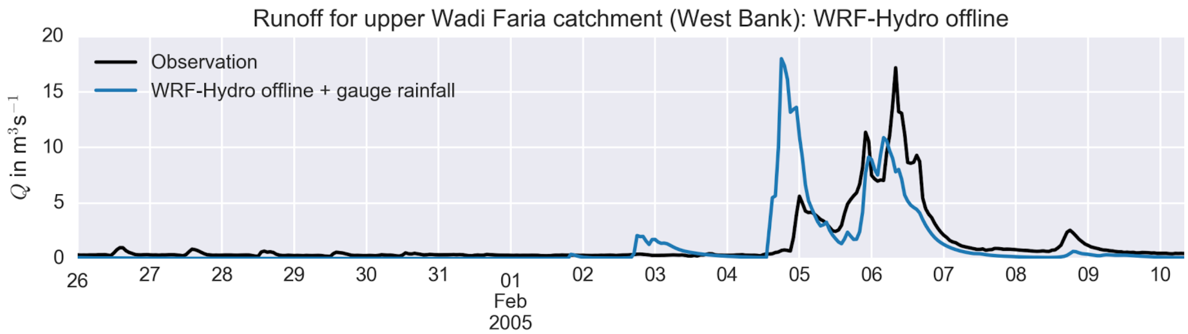

Fig. 8: Results of the offline WRF-Hydro hydrological model for the upper Faria catchment using rain gauge data

With our forthcoming intensive rain gauge instrumentation for the rainy season 2016/2017 we will build the foundation for more elaborate model validation. Based on this we will work on extending WRF-Hydro with functionalities for channel-loss and overbank flow, to better represent the fast precipitation-runoff processes in steep and rocky terrain, like in Wadi Faria. This will lead towards a more elaborate representation of terrestrial hydrologic processes and thereby improve the fully coupled model systems.

Conclusion

Both, the use of CMLs for precipitation (or stream flow) nowcasting and the application of high resolution regional climate- and coupled model systems (like WRF-Hydro) are highly beneficial scientific tools for supporting decision making in water management. This is in particular true in semi-arid and arid environments like the Gulf region, where the predicted increase of water scarcity demands improved management and mitigation strategies. Our examples presented for the Near East show the potential of the methods and stress the necessities for similar assessments for the Gulf region.

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Assessment of Water Resources Vulnerability to Environmental and Climate Changes in the Mountains of Oman

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Abstract
Al Jabal Al Akhdar, in the northern Oman Mountains, has experienced rapid socio-economic development and related land use changes over the last decades, exerting pressures and have direct impacts on increasing demands for water resources and therefore their deterioration in the area. Climate change and its consequences present one of the most important threats to water resources and their vulnerability in this fragile region. The objective of this paper is to assess water resources vulnerability to climate change in this mountainous region. Vulnerability assessment was carried out using guidelines prepared by United Nations Environment Programme (UNEP) and Peking University to evaluate four components of the water resource system: water resources stress, water development pressure, ecological health, and management capacity. The results showed that the calculated vulnerability index (VI) was high, indicating water resources stress. The dominant category was management capacity and the dominant parameter was ecosystem deterioration, both driving the vulnerability on water resources. This study will support policy and decision makers in evaluating options to modify existing policies and develop long-term strategic plans and effective policies for climate change mitigation and adaptation measures and for sustainable use and management of water resources in the region.

Keywords: Vulnerability Index; Water Resources Stress; Ecological Health; Management Capacity; Climate Change; Al Jabal Al Akhdar; Oman.

1. Introduction

Water resources are being degraded as a result of multiple interacting pressures [1], particularly environmental and climate changes. The Fourthand Fifth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC) played a major role in framing understanding of likely impacts of climate change on human society and natural systems, making it clear that “water is in the eye of the climate management storm” [2–4]. Different possible threats resulting from anthropogenic climate change include temperature increases, shifts of climate zones, sea level rise, droughts, floods, and other extreme weather events [5]. The Earth’s surface temperature has increased by about 0.5°C during the last two decades, and a rise with similar amplitude is expected up to 2025, with direct effects on the global hydrological cycle, impacting water availability and demand [2–4]. Negative impacts on water availability and on the health of freshwater ecosystems will have negative consequences for social and ecological systems and their processes [6]. For example, with an approximately 2°C global-mean temperature rise, around 59% of the world’s population would be exposed to irrigation water shortage [7].

The net effects of climate change can be translated into increases in the vulnerability of water resources systems, because of their limited adaptive capacity [8]. Therefore, there is a need to assess the vulnerability of water resources in order to enhance management capacity and adapt measures to cope with climate change impact for sustainable water resources use and management.

Most water-stressed arid countries are vulnerable to the potential adverse impacts of climate change; particularly increases in temperatures, less and more erratic precipitation, drought and desertification.This is especially true in arid mountain regions, particularly Al Jabal Al Akhdar where a unique set of water management practices has enabled the development and survival, over centuries, of an agro-pastoral oasis social-ecological system [9]. This study was conducted to assess the vulnerability of water resources of Al Jabal Al Akhdar to environmental and climate changes, since no vulnerability assessments have been previously conducted in Oman or in this fragile mountain ecosystem.

2. The Study Area

Al Jabal Al Akhdar (Green Mountain) is located in the central part of the northern western Al-Hajar Mountains of the Sultanate of Oman (Figure 1), in the highest portion of 1500 to 3000 m above sea level. Historically, water availability has connected the agro-pastoral system and dictated the bounds of agricultural development and the human development [9]. The area is also of particular cultural significance for Omani people for its location, topography, agricultural terraces, biodiversity and climate.

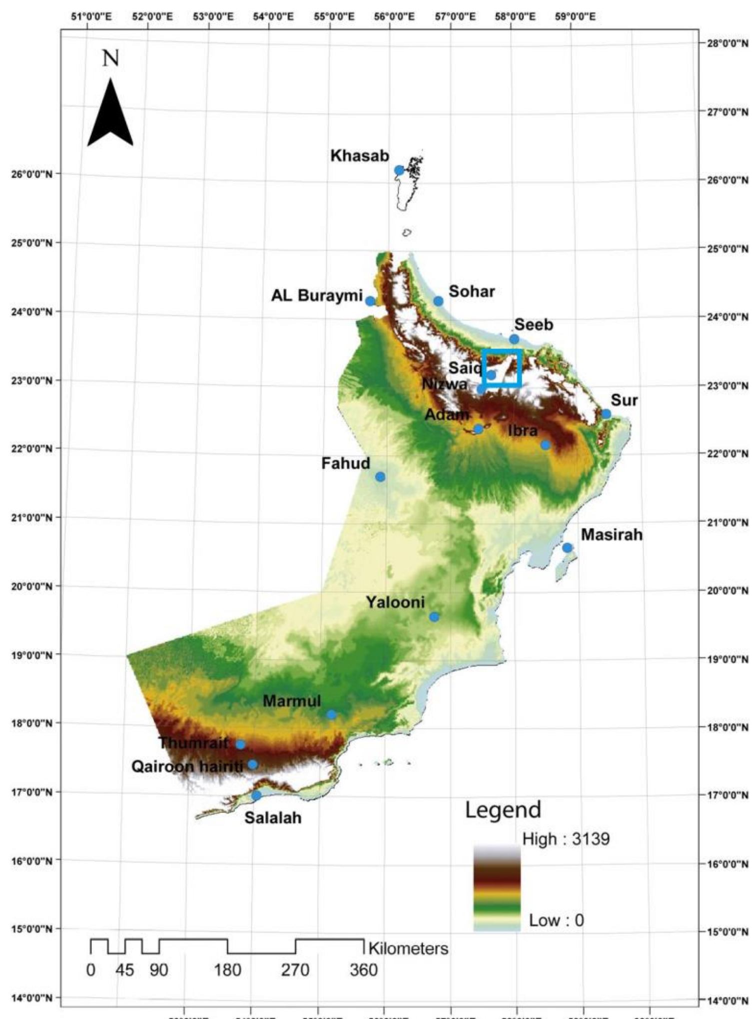

Figure 1: Oman map showing the location of Al Jabal Al Akhdar (in blue rectangle)

Because of its altitude, temperatures in the mountain are some 10 to 12°C lower than in the coastal plains. In general, mean monthly temperatures drop during winter to below 0°C and rise in summer to around 22°C. Rainfall is highly variable and irregular with an annual mean of about 250–400 mm [10] and is the main source of freshwater.
Agriculture is the main economic activity, although the sector does not contribute much to the national economy (only 3.7% ofthe total Oman GDP), it is the main dominant water consumer in Oman including the study area (more than 92% of the total available water) [11]. The area produces a variety of fruits, particularly pomegranates and roses (grown for the extraction of rose water).

Livestock husbandry is also an important part of the agriculture in the area, for food and income through the sale of fibre (goat and sheep hair), and provides a source of manure for the cultivation of crops. Goats are the main livestock in local communities, representing more than 80% of the total animal units [9]. Due to its relatively cool weather, especially during summer, and the construction of asphalted access road up to the mountain in 2006, followed by the construction of hotels, many tourists visit the area, mainly to see natural landscapes and agricultural terraces and to camp.

Natural freshwater resources in Al Jabal AlAkhdar are of three types: groundwater (wells), lotic resources (natural springs and *aflaj*) and lentic resources (man-made dams) [9]. Groundwater is accessed via wells, which are the main local source of water for drinking and domestic purposes (municipal, commercial). *Aflaj* are surface and/or underground channels fed by groundwater or a spring, or streams, built to provide water to the farming communities. Dams are artificial structures which are constructed to harvest rainy water.

Al Jabal Al Akhdar has limited and highly variable water supplies: the most significant parameters influencing freshwater availability are the amount and frequency of rainfall. According to the climate change projection for the country [12], the variability of rainfall is expected to further increase, adding more uncertainty and complication to the planning and management of water resources. Together, the anthropogenic activities and climate change have affected the availability of water resources, and if these trends continue, the area's ecosystems and residence's households will be further affected [9]. Vulnerability assessment of water resources to environmental and climate changes is therefore essential to inform sustainable water resources management in the area.

3. Methodology

The methodological guidelines for "Vulnerability Assessment of Freshwater Resources to Environmental Change", developed by United Nations Environment Programme (UNEP) and Peking University [8] were used to assess the vulnerability of water resources of Al Jabal Al Akhdar to environmental and climate changes. According to the guidelines, the vulnerability of water resources can be assessed from two perspectives: the main threats to water resources and their development and utilization dynamics; and the region's challenges in coping with these threats. The threats can be assessed in terms of resource stresses (RS), development pressure (DP), ecological health (EH) and management capacity (MC).Thus, the vulnerability index (VI) of the water resources can be expressed as: $VI = f(RS, DP, EH, MC)$ [8].

Each component of VI has several parameters: RS = f [water stress (RSs) and water variation (RSv)]; DP = f [water exploitation (DPs) and safe drinking water inaccessibility (DPd)]; EH = f [water pollution (EHp) and ecosystem deterioration (EHe)]; MC = f [water use inefficiency (MCe), improved sanitation inaccessibility (MCs), and conflict management capacity (MCg)]. In accordance with the vulnerability assessment guidelines, a number of governing equations were applied to estimate these parameters and VI (Table 1).

The vulnerability index (VI) was finally estimated based on the four categories using the equation in Table 1. VI provides an estimated value ranging from zero (non-vulnerable) to one (most vulnerable) to determine the severity of the stress being experienced by the water resources of the study area. A high VI value shows high resource stresses, development pressures and ecological health, and low management capacities.

Table 1: Equations used for calculation of all categories and parameters of vulnerability index of water resources in the study area.

Category	**Parameter**	**Equation**	**Description**
Resource Stress (RS)	RS_s	$RS_s = (1000 - R)/1000$	R: Total renewable water resources per capita (m^3/person/year)
	RS_v	$RS_v = CV/0.3$ $CV = S/\mu$	CV: Coefficient of variation μ: Mean rainfall (mm) S: Standard deviation
Development Pressures (DP)	DP_s	$DP_s = WRs/WR$	WRs: Total water demands WR: Total renewable water resources
	DP_d	$DP_d = P_d/P$	P_d: Population without access to improved drinking water sources P: Total population of the area
Ecological Health (EH)	EH_p	$EH_p = (WW/WR)/0.1$	WW: Total untreated wastewater WR: Total renewable water resources
	EH_e	$EH_e = A_d/A$	A_d: Land area without vegetation coverage A: Total area of the country
Management Capacity (MC)	MCe	$MC_e = (WE_{wm} - WE)/WE_{wm}$	WE: GDP value produced from 1 m^3 of water WE_{wm}: Mean WE of West Asia countries
	MC_s	$MC_s = P_d/P$	P_d: Population without access to improved sanitation P: Total population of the area
	MC_g	MC_g = parameter matrix	Matrix scoring criteria
$VI = \sum_{i=1}^{n}\left[\left(\sum_{j=1}^{m_i} x_{ij} * w_{ij}\right) * w_i\right]$			n: number of parameter category m_i: number of parameters in $i$thcategory X_{ij}: value of jth parameter in $i$thcategory W_{ij}: Weight given to jth parameter in ith category W_i: Weight given to ith category

4. Results and Discussion

4.1. Resource Stresses

4.1.1. Water Stress Parameter

The calculation of water stress for Oman, including the study area, shows a critical water stress (RS_s = 0.58) (Table 2) based on the estimated total renewable water resources per capita of 422.5 m^3/person/year [13]. The increase in population and rapid socioeconomic development in Al Jabal Al Akhdar exert pressures on water resources: domestic water consumption increased from 150,000 m^3 in 2001 to 580,000 m^3 in 2012; an annual increase of 35% per year [14]. Much of this increase may be due to the burgeoning tourist industry. For 1985, 1995, and 2005, the calculated RSs for Oman were 0.0, 0.30, and 0.36 based on the estimated per capita renewable water resources of 1029.35, 697.76 and 635.84 m3/person/year, respectively [14].

Table 2: Calculated Vulnerability Index with various categories and parameters for the water resources of the study area.

Category	**Resource Stress**		**Development Pressure**		**Ecological Health**		**Management Capacity**		
Parameter	RSs	RS_v	DP_s	DP_d	EH_p	EH_e	MC_e	MC_s	MC_g
Calculated	0.580	0.330	0.210	0.000	0.140	0.940	1.000	0.000	0.950
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.290	0.165	0.105	0.000	0.070	0.470	0.330	0.000	0.314
Component Total	0.4550		0.1050		0.5400		0.6435		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	**0.1138**		**0.0263**		**0.1350**		**0.1609**		
Overall Score	**0.436 (High)**								

Water Stress (RS_s); Water Variation (RS_v); Water Exploitation (DP_s); Safe Drinking Water Inaccessibility (DP_d); Water Pollution (EH_p); Ecosystem Deterioration (EH_e); Water Use Inefficiency (MC_e); Improved Sanitation Inaccessibility (MC_s); Conflict Management Capacity (MC_g).

4.1.2. Water Variation Parameter

Rainfall amount and availability are the dominant factors in the supply of water resources in the study area. Analysis of rainfall data records from 1979 to 2012 resulted in a water variation parameter (RS_v) of 0.33, based on the estimated CV of 0.10, indicating low rainfall variability. The methodology guidelines [8] designate a set of rainfall variation values for the coefficient of variation as CV= 0.3 or as a CV>0.3. When CV is > 0.3, RS_v is assigned a highest value of 1, indicating large rainfall variation in time and space; a CV less than 0.3 reflects low variability. However, the study area experienced increasing temperatures over the same period (Figure 2). Minimum, mean and maximum temperatures increased at rates of 0.79, 0.27and 0.15°C per decade, respectively. Analysis of rainfall data showed a reduction in water availability, with a general decrease in total rainfall from 1979 to 2012 (Figure 2). Over this period, the average rainfall was 296.7 mm; the highest total was in 1997 (901 mm) and annual rainfall decreased subsequently to 202.8 mm in 2012, with an overall decrease in total rainfall at a rate of -9.42 mm per decade; indicating that the area isvulnerable to climate change as it is an arid mountain region. Projection of future climate in Oman using the IPCC A1B scenario shows an increase intemperature and a decrease in rainfall over the coming decades [12].

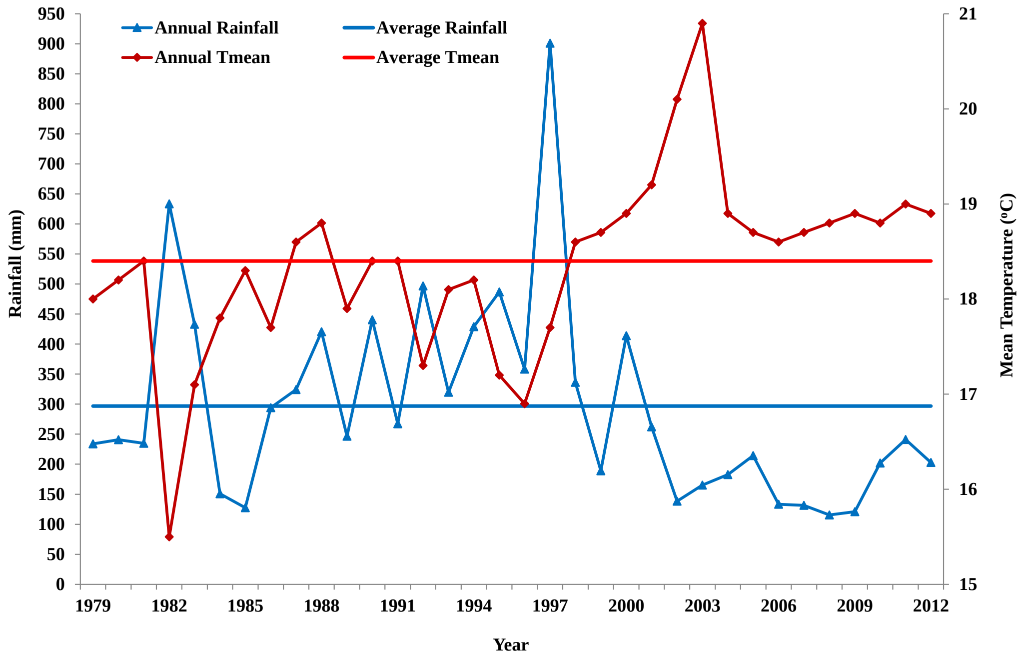

Figure 2: Trends in mean air temperature (Tmean) and annual rainfall in Saiq Meteorology Station (World Meteorological Organization (WMO) Index: 41254, Universal Transverse Mercator (UTM) coordinates Latitude: 23 04 28.33 N, Longitude: 57 38 46.63 E, Elevation: 1986 m) from 1979 to 2012(Data source: [10])

4.2. Water Development Pressures

4.2.1. Water Exploitation Parameter

The assessment of water development pressures indicated that the study area suffers from critical conditions in the development of water resources as determined by the water exploitation parameter (DP_s = 0.21) based on total water demands of 14 Million m^3/year and the available total water resources of 66 Million m^3/year [11] (Table 2), resulting in water shortages for domestic and agricultural purposes. There have been increases in the total population and socioeconomic development as well as increases in construction and commercial activities including hotels, and therefore water consumption by different sectors, causing an imbalance between supply and demand in the absence of the implementation of any conservation and management practices.

4.2.2. Safe Drinking Water Inaccessibility Parameter

The calculated safe drinking water inaccessibility parameter (DP_d) was zero since the fundamental needs of the population for water to live are met. There is sufficient infrastructure for providing drinking water throughout the study area; all people have access to safe drinking water. Thegovernment supplies drinking water to all households via groundwater wells, and a piped desalinated water project is in progress, to increase the availability of drinking water in the area.

4.3. Ecological Health

4.3.1. Water Pollution Parameter

The estimated water pollution parameter value was (EH_p= 0.14) (Table 2) based on the total untreated wastewater of 945,250 m^3/year [15] and the total available water resources of 66 Million m^3/year, given that the urban water usage is 1.1 Million m^3/year [11]. The analysis indicates low water pollution risks, which may be attributed to investments in wastewater treatment facilities: the government has established three wastewater treatment plants in the area with tertiary treatment levels and some sewerage systems,and all modern houses and other establishments have septic tanks.

4.3.2. Ecosystem Deterioration Parameter

EH_e was calculated as 0.94, based on the evaluation report of the land degradation and desertification in Arab Region [16] including Oman, as there is no available data on ecosystem deterioration for Al Jabal Al Akhdar. There are some indications of ecosystem deterioration in the study area due to decreased rainfall over the last three decades and therefore a decline of groundwater levels and the drying up of most aflaj [9]. The world map of the status of human-induced soil degradation [17] shows that the primary factor contributing to soil degradation in the Al-Hajar Mountains is loss of top soil through water erosion, with 25%–50% of the area affected by a moderate degree of degradation.

4.4. Management Capacity

4.4.1. Water Use Inefficiency Parameter

This parameter was not calculated for the study area since it is based on the country scale and cannot be estimated at a regional scale. In Al Jabal Al Akhdar, farmers still use a traditional method of irrigation by flooding, with no application of modern irrigation technology or investments in improving irrigation infrastructure systems. Based on water assessment survey [9] and UNEP report [14] on this situation, MC_e for the study area was estimated as 1, representing high water use inefficiency. This indicates unsustainable water resources management practices in the absence of a comprehensive water sector plan and strategy, leading to reduced water availability and increased vulnerability.

4.4.2. Improved Sanitation Inaccessibility Parameter

The entire population of the study area has access to sanitation facilities, such as sewer systems, septic tanks and wastewater treatment plants ($MCs = 0$) (Table 2), indicating adequate management regarding livelihood improvement through government investment in sanitation infrastructure. The availability of this infrastructure reduces pollution levels and preserves water resources, complemented by the implementation of policies and measures which may reduce the vulnerability of water resources to climate changes.

4.4.3. Conflict Management Capacity Parameter

The study area has no competition over water utilization with the neighboring regions. However, there is competition over water utilization between different sectors (agriculture and domestic). Agriculture is the dominant water consumer, with no application of conservation mechanisms and proper management capacity. There is also an increase in the domestic water consumption from groundwater wells, due to an increase in population and number of hotels and commercial activities, and there is no clear strategy for the development of the area [9]. Therefore, the assessment of MC_g showed a high vulnerability situation in regard to conflict management capacity ($MC_g = 0.95$) since this parameter takes into consideration the interrelation of different categories including institutional, agreement, communication and implementation capacity.

4.5. Vulnerability Index

Based on the available data, the calculated VI is 0.436, in the range of 0.4-0.7 which is classified as high based on the reference sheet for the interpretation of VI [10], indicating that the water resources of Al Jabal Al Akhdar are highly vulnerable and experiencing high stresses. Ecosystem deterioration is the dominant parameter, contributing 27% (Figure 3a). The area has also been experiencing a high degree of water use inefficiency, conflict management capacity and water stress representing 19%, 18% and 17%, respectively (Figure 3a), influencing the overall vulnerability on water resources. Comparison of the share of the different category groups to the final VI showed that the management capacity contributes most to the water resources vulnerability and is the dominant category (37%), followed by ecological health with 31% and water resources stress with 26% (Figure 3b).

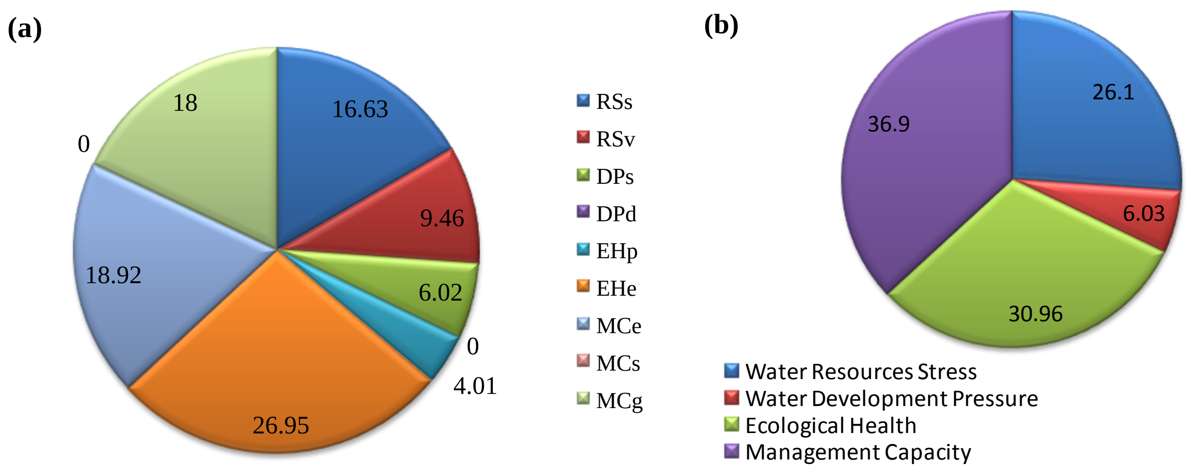

Figure 3: (a) Percentage of the weighted parameters for Vulnerability Index; (b) Share of the percentage of the weighted categories to the final Vulnerability Index for the study area. Water Stress (RS_s); Water Variation (RS_v); Water Exploitation (DP_s); Safe Drinking Water Inaccessibility (DP_d); Water Pollution (EH_p); Ecosystem Deterioration (EH_e); Water Use Inefficiency (MC_e); Improved Sanitation Inaccessibility (MC_s); Conflict Management Capacity (MC_g)

5. Conclusion and Recommendations

This is the first comprehensive vulnerability assessment of water resources in Al Jabal Al Akhdar, or Oman. The vulnerability assessment indicated high VI (0.436). Ecosystem deterioration is the dominant parameter contributing 27% to the vulnerability index. The water resources of the area have also been experiencing a high degree of water use inefficiency, conflict management capacity and water stress, influencing the overall vulnerability index by 19%, 18% and 17%, respectively. Management capacity is the dominant category, representing 37% of the category groups, driving the vulnerability of the water resources, which are also highly influenced by the ecological health (31%) and water resources stress (26%). These could be used as indicators for the vulnerability of water resources to environmental and climate changes in the study area.

There is a clear need for policies to mitigate the pressures on water resources which make them more vulnerable. Additional effort is needed to improve irrigation water use efficiency, conservation technologies, rainwater harvesting, and reuse of treated wastewater and grey water to relieve some of the agricultural pressures on water resources. There is also an urgent need for mitigation and adaptation to climate change impacts since the region is expected to face further increases in temperatures and decreases in rainfall over the coming decades.

The major contribution of ecosystem deterioration to the overall index suggests that, in order to sustain the ecological health of the area, more efforts are needed to conserve and rehabilitate vegetation cover and implement best practices for land use management. More investments are also required to expand sewer networks and the effective use of wastewater treatment facilities. Full coordination, integration and awareness on water management should be strongly connected to planning and policies at all levels and across all sectors.

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Groundwater Numerical Simulation of Hawasinah Catchment in North Batinah Region, Sultanate of Oman

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Abstract
The groundwater within the Hawasinah catchment area has been developed, up to date, to provide agricultural, industrial and domestic supplies. Over the last decade, the area faced drought which has been reflected on groundwater levels in the area. Furthermore, there are instances when groundwater level has been reduced below the sea level causing quality deterioration by sea water intrusion. Therefore, there is a need for a scientific analysis to evaluate ground water resources and apply groundwater modeling to understand and study the flow system and key parameters. The main objective of this work is to provide an understanding of the groundwater resources flow dynamics using a numerical simulation. The groundwater flow model was constructed based on data from Ministry of Regional Municipality and Water Resources and simulations were carried out using a pre- and a post-processor (GMS) is used to interface with MODFLOW GMS for the year1988. It is found that the main source of recharge to the Hawasinah Catchment area is through direct recharge from rainfall as well as wadi flow it is estimated by about 20 x 10^6 m^3/year from both rainfall, wadi flow plus return flow of irrigation water not included; The total amount of current abstraction is about 97.28 x 10^6 m^3/year; The hydraulic conductivity of the aquifer system attains a moderately wide range from 10 to 35 m/day for the alluvium and its 0.9 for upper Fars. The groundwater abstraction mainly carried out through private wells drilled. The hydraulic parameters were derived from pumping tests conducted on a few governmental wells existing in the area. Also few target observation wells were collected for calibration of the model.

Keywords: Groundwater Modeling, GMS, MODFLOW, Hydraulic Conductivity, Recharge.

Introduction
The basic requirement in groundwater evaluation, development and management is to apply groundwater modeling techniques. Numerical modeling has been initiated to understand and analyses the groundwater flow system and to evaluate its water balance. In order to build the model, geological, hydrological and hydrogeological data were collected and analyzed. The modeling work described herein was undertaken to advance the understanding groundwater flow in Hawasinah catchment. This study exhibits evaluation of the groundwater aquifer system of the Hawasinah catchment including geology, hydrology, hydrogeology, and modeling techniques. The report also describes the application of the groundwater flow model MODFLOW with respect to simulating the aquifer system behavior. It shows the groundwater potential in the area. The results of the simulation for calibration and verification are presented.

Objectives
- Review previous studies and investigation carried out on the area of the catchment.
- Present geology and hydrogeology analysis comprising the availability and development potential of groundwater resources;

- Simulate and develop model using The MODFLOW and the modeling code will be used which is internationally recognized and verified.

Study area

The Hawasinah catchment area lies in the north-western part of Oman (Fig.1). It includes three wadi basins which occupy an area of approximately 2,011 km^2, namely Wadis Shafan, Hawasinah, and Mashin, the total study area covers approximately 4,483 km^2 which represents the extension of the aquifer system underlying a part of the Hawasinah catchment.

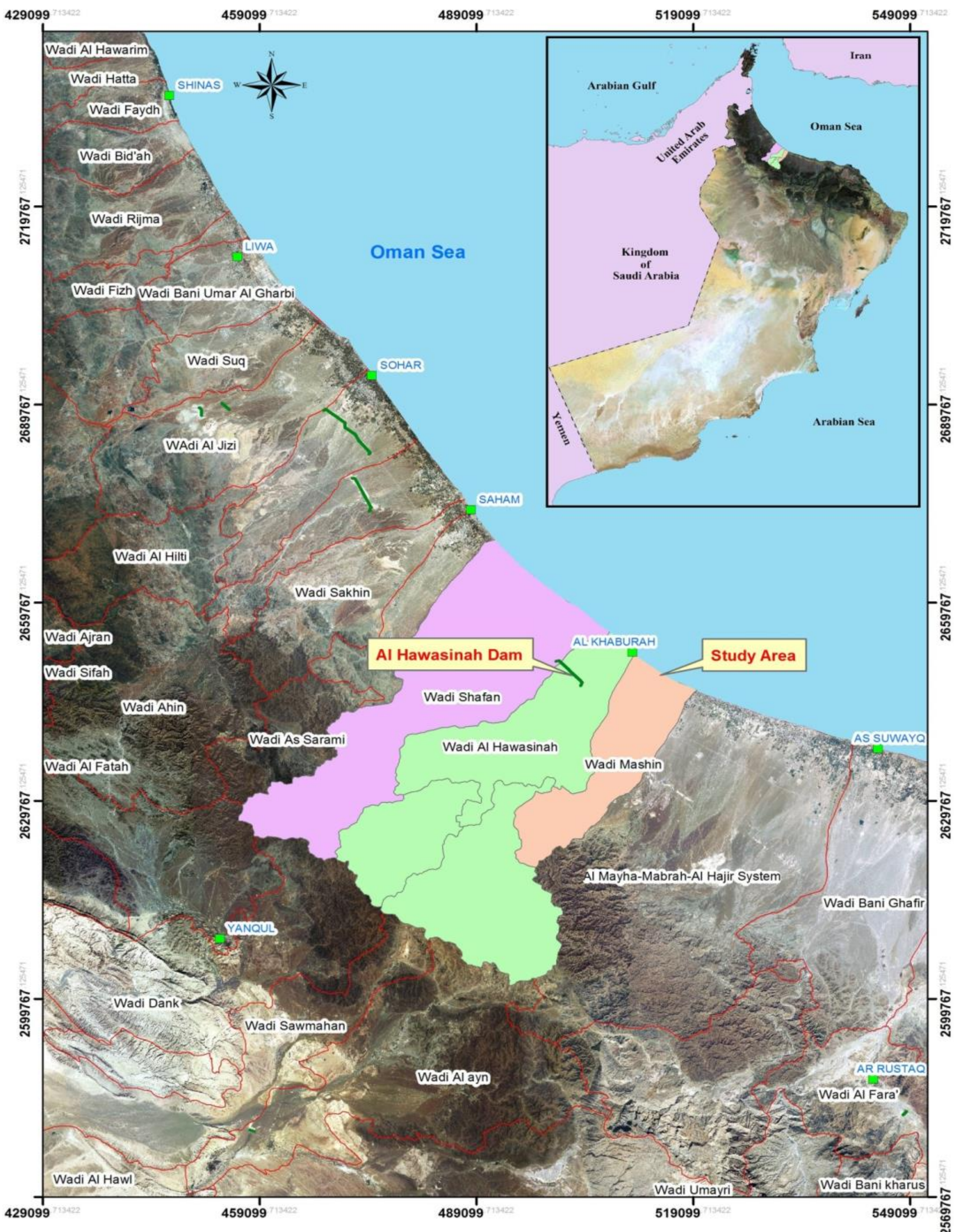

Fig.1: Location

Data compilation

Geology

The Hawasinah Catchment area consists of different geologic units of varying hydrogeological significance. Due to uplift and erosion processes, most of the geologic units are exposed forming an anticline structure in the south of the area. The geologic units can be summarized from oldest to youngest (Fig2) as follows:

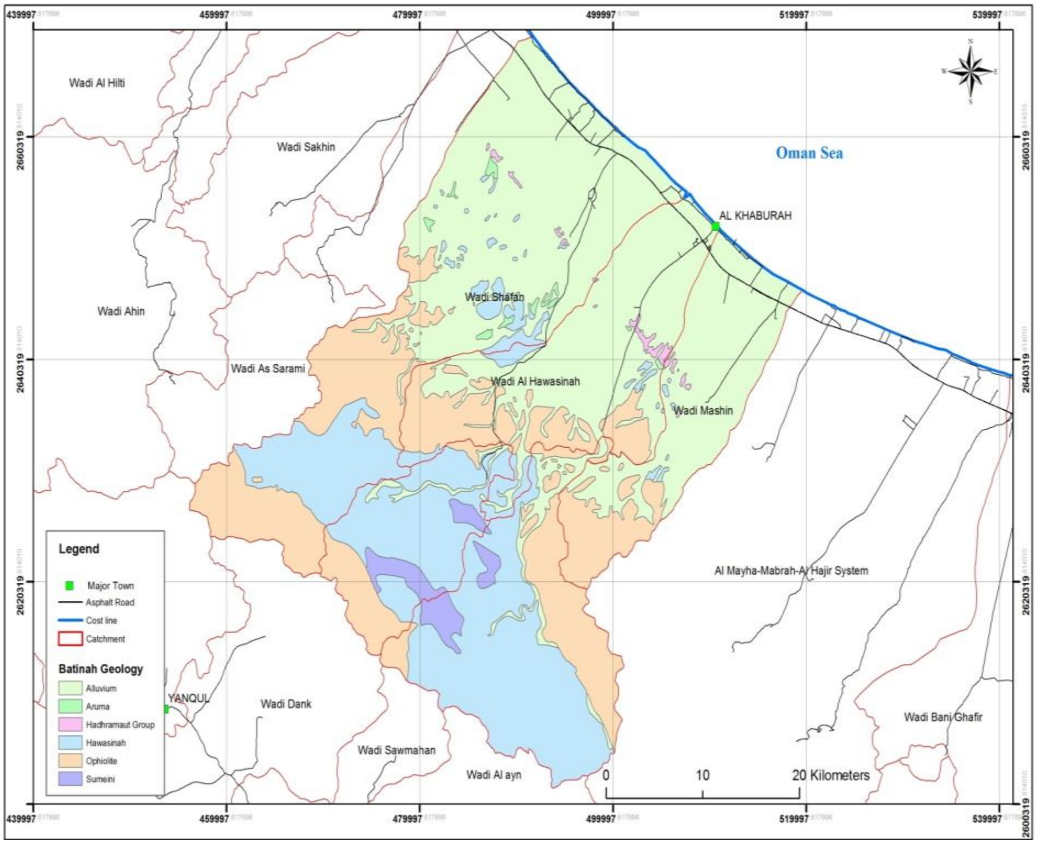

Fig.2: Geologic map

Hydrology-Recharge

Table 1: Estimated recharge of three catchments (20.4 M m^3/year) based on a study made by MacDonald (2010)

catchment	MacDonald(2010)
Shafan East (lower)	4
Hawasinah North(lower)	11.7
Mashin(lower)	4.7

Hydrogeology

The study area mainly consists of Tertiary to Quaternary alluvial deposits. Alluvial deposits may be more than 100 m thick (MacDonald, 1992).

Aquifer characteristics

The results of pumping tests conducted on some boreholes existed in the area (Table.3 and Table.4) showed that the transmissivity (T) value ranges from36 to 5621 m^2/day. The average T value of alluvium and upper Fars is 640 and 281 m^2/day respectively. The value of hydraulic conductivity (K) ranges between 0.9 and 243.3 m/day. It was noticed that the K value is highly changed. The very low conductivity is due to the high content of clay or silt in addition to the well-developed cementation process. Extensive cementation may locally transfer an alluvial channel into a hydraulic barrier, bringing groundwater to the surface. The average storativity (S) value of aquifer system from available two values is 2.8×10^{-4} and the average specific yield (Sy) 1.7

Table 2: Estimated K and S parameters (GRC, 2006)

Well Name	Easting	Northing	T (m^2/day)	K (m/day)	S	Sy
SH-1	491038	2653082	93	2.3	-	-
SH-2	494261	2656288	920	26.4	2.8×10^{-4}	0.017
SH-3	495901	2659009	1,209	22	-	-
SHTW-1	494301	2656162	853	24.5	-	-
NB-15	510453	2642155	81	0.9	2.8×10^{-4}	

Table 3: Aquifer Hydraulic parameters (After MacDonald, 1992)

Borehole	Transmissivity m^2/day	K m/day	Specific capacity m^2/day	Storage coefficient	Specific yield
WS1-25	1210	100.8	984	-	-
HA-1	5621	243.3	2246	-	-
HA-2	3600	51.4	-	-	-
HA-3	1603	25.6	2160	0.0075	0.015
HATW-1	36	1.3	77.76	-	-

Groundwater abstraction

- The average abstraction was 15.167 Mm^3/year withdrawn from alluvium unit in 1982.
- The total amount of recharge to the aquifer is 20.4 Mm^3/year, but the total present abstraction is 97.28 Mm^3/day.
- 93.96 Mm3/day used for agriculture and 0.422 M m3/day for urban uses.
- The total input to the catchment through direct flow from the rainfall, wadi flow and urban flow.

Aquifer potentiometry

The water level measurements done in 1982 (Table 4) have been used to calibrate a steady state model of the area.

Table 4: The water level measurements done in 1982

Well Name	x	y	Head (m.asl
Mohamed Mosallam	494300.00	2662300.00	0.1
AD-35	496900.00	2659600.00	1.5
AS-2	500900.00	2658300.00	0.90
Khawr Al Milh	502100.00	2657900.00	1.00
AlKhaldi garage	502200.00	2657500.00	1.50
WSI-25	506000.00	2649000.00	2.00
JT-34	501950.00	2645048.00	5.80
Mohamed Shamis	491790.00	2665272.00	7.00

Groundwater modeling

In this study a pre- and a post-processor (GMS) is used to interface with MODFLOW.

GMS stands for Groundwater Modeling System and is developed by the Environmental Modeling Research Laboratory of Brigham Young University (EMRL, 2004). Figure (3) shows the conceptual mode l of the study area. The catchment area is conceptualized to have a constant head at the north boundary in contact with the sea water, while the other three boundaries as no flow boundaries. The east and west no flow boundaries represent groundwater flow directions/divides, while the southern no flow boundary represent the bedrock outcrop.

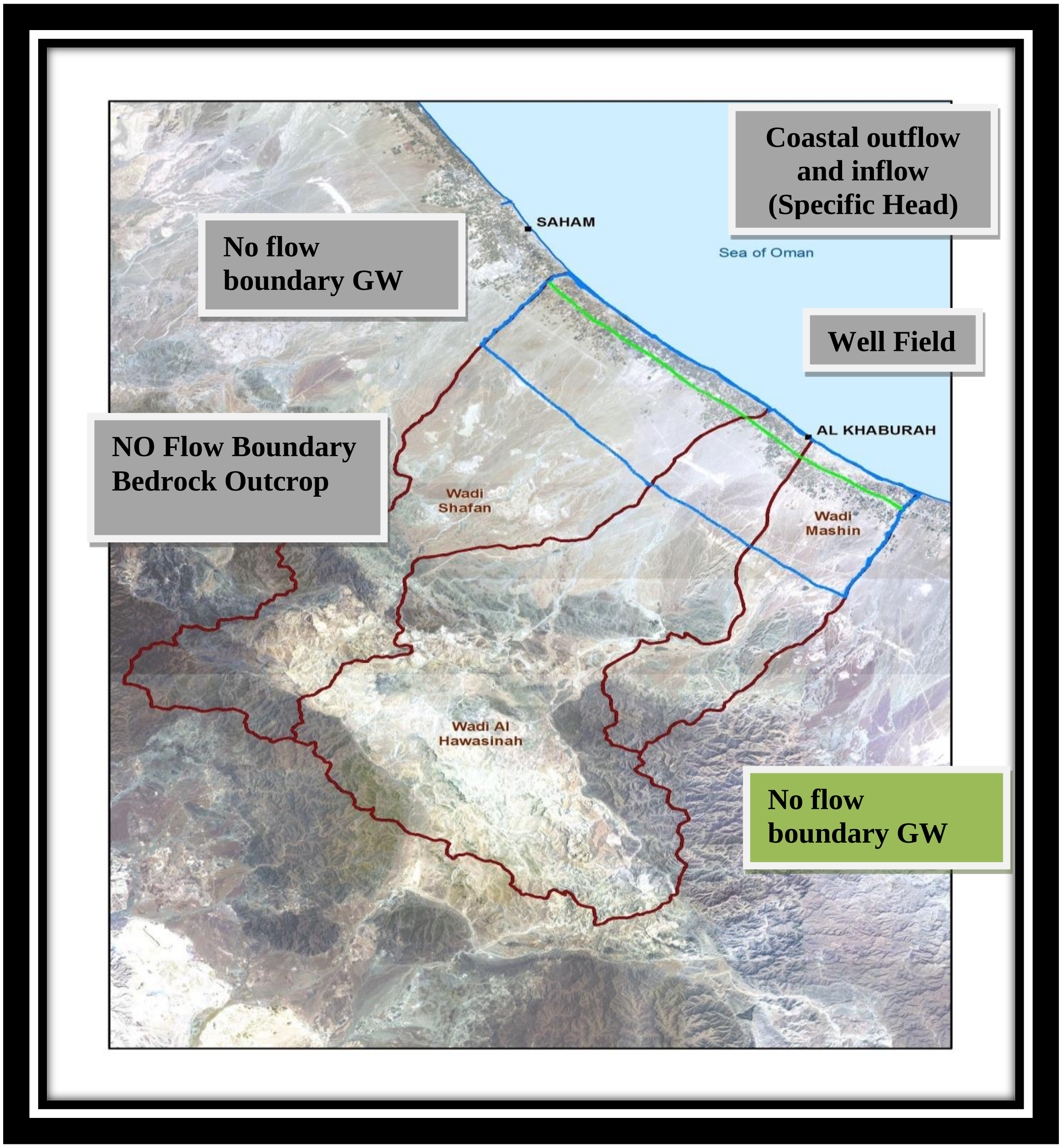

Fig. 3: Conceptual model of the lower wadi Alhawasinah

The water level recorded in 2006 was below sea level in most of the areas located near the coastal settlements. It was reported that the water level is generally parallel to the coast and ranged between -8.3 and +65.47 m.asl (fig .4)

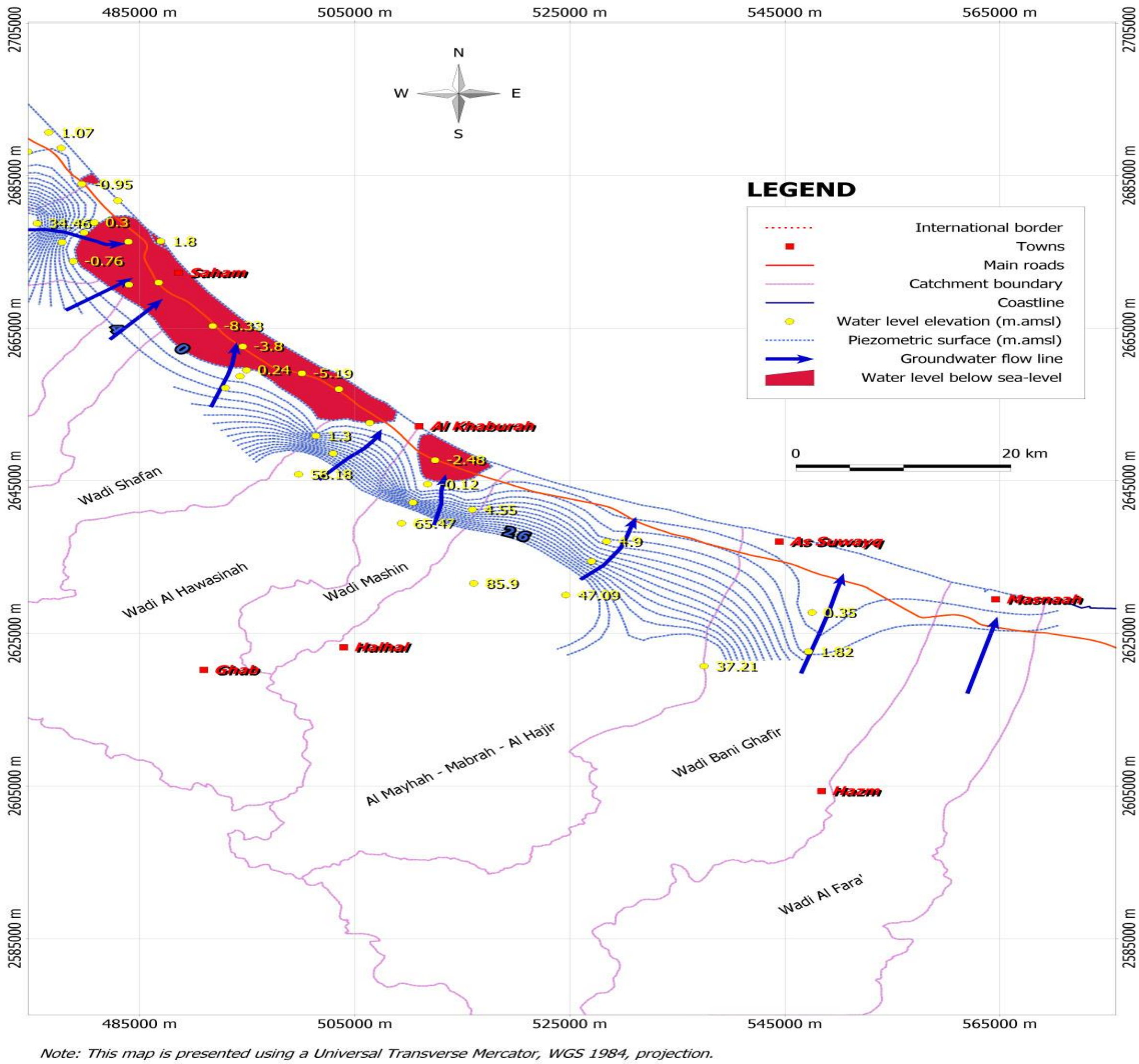

Fig. 4: Composite potentiometric level (October 2005 to June 2006) (After GRC, 2006)

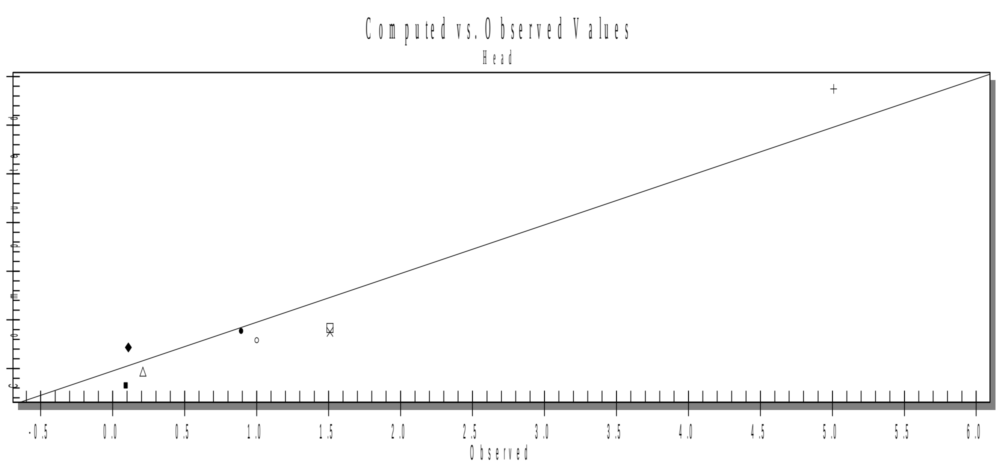

Figure 5: Computed Head vs. observed values

Calibration Results

The hydraulic conductivity values, obtained from pumping test data ranged between 5 m/day and 50 m/day and have been introduced to the model as initial values. Figure.6 show the spatially optimum distributed hydraulic conductivity values obtained during the calibration procedures. The value of K has ranged between 10 m/day and 35 m/day for the alluvium and the upper Fars unit attains a value of K 0.9 m/day. Figure. 10 shows that high hydraulic conductivity zones exist in middle area near the coast at Al-Khaborah city, while the low conductivity zones exist along the south western area. It can be concluded that the high hydraulic conductivity zones decreased by about 5 m\ day along the southwestern and increased by 5 m/day at the high conductivity zone However, it should be noted that this calibration is rather local because most of the data points exist basically in the central area.

Figure 10 shows that high hydraulic conductivity zones exist in middle area near the coast at Al-Khaborah city, while the low conductivity zones exist along the south western area. It can be concluded that the high hydraulic conductivity zones decreased by about 5 m/day along the southwestern and increased by 5 m\ day at the high conductivity zone However, it should be noted that this calibration is rather local because most of the data points exist basically in the central area.

Figures 10, 11 show calibrated head of alluvium. The head ranged from 10 m.asl at the southwest of the study area to zero level along the coast. The head was above sea level (0.1m) at wadi Mashin southeast of the Al Khabourah town near the coast. Also Figures.11 show calibrated head of upper Fars. Groundwater flow was thus from southwest to northeast. It was noticed that the hydraulic gradient was almost symmetrical all over the study area, drying model occurs because of its relatively shallow depth and its proximity to the most southwest boundary margins of the model.

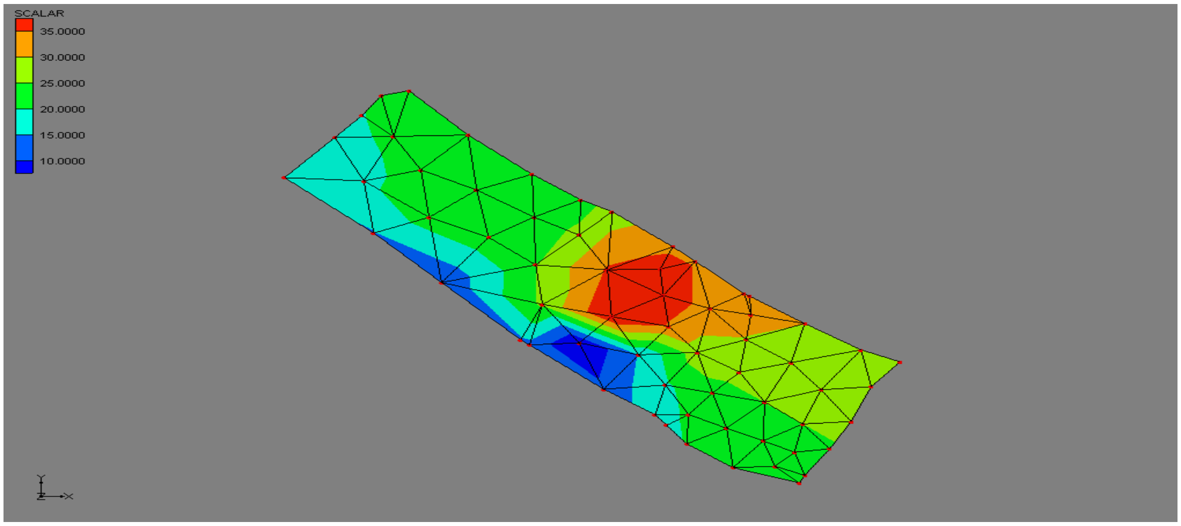

Figure 6: Calibrated hydraulic conductivity of alluvium (m/day)

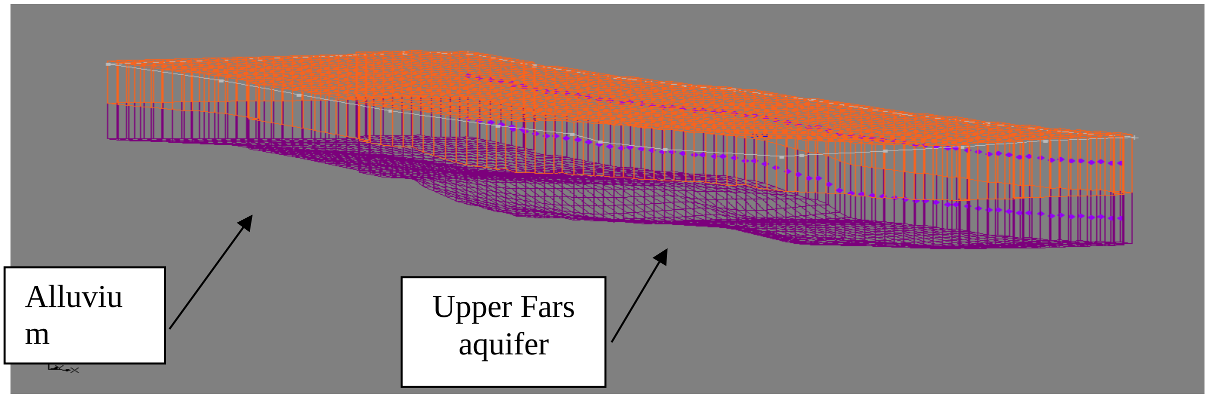

Figure 7: Cross-sectional area of the alluvium and upper fars aquifers

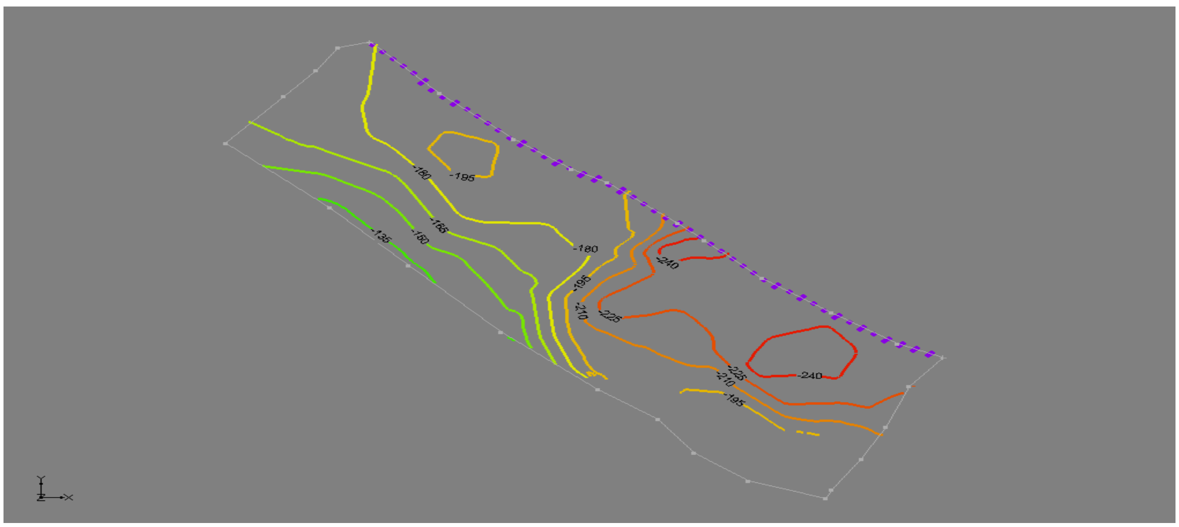
Figure 8: Top of aquifer system

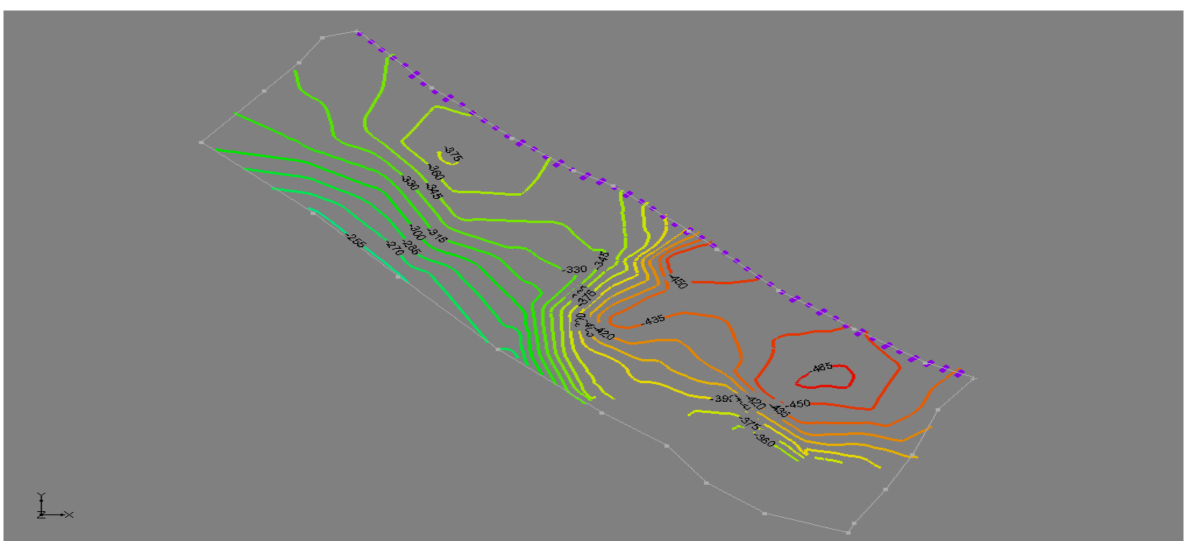
Figure 9: Bottom of aquifer system

Finally, the inferred flow balance from the steady state model is shown in Table 5. It shows a localized salt water intrusion of 7.6x 10^5 and 3.15 x 10^6 m^3/year to the alluvium and upper Fars respectively. Such water intrusion occurs at the two areas listed earlier where groundwater level declined below sea level. The last item shown in the table is an internal flow from alluvium to upper Fars and vice versa. The model estimates it as 2.8 x 10^5 m^3/year and 3.7 x 10^5 m^3/year respectively.

Table 5: Flow balance for the steady-state model m3\day

Component	*inflow*	*internal flow*	*outflow*
inflow from the Gulf (alluvium)	2108		
inflow from the Gulf (u. Fars)	874.87		
recharge (alluvium)			
recharge (u. Fars)			
flow from alluvium to u. Fars		7664.5	
flow from u. Fars to alluvium		10015.5	
abstraction (alluvium)			41128
abstraction (u. Fars)			0.0
outflow to the Gulf (alluvium)			6031.5
outflow to the Gulf (u. Fars)			3225.79

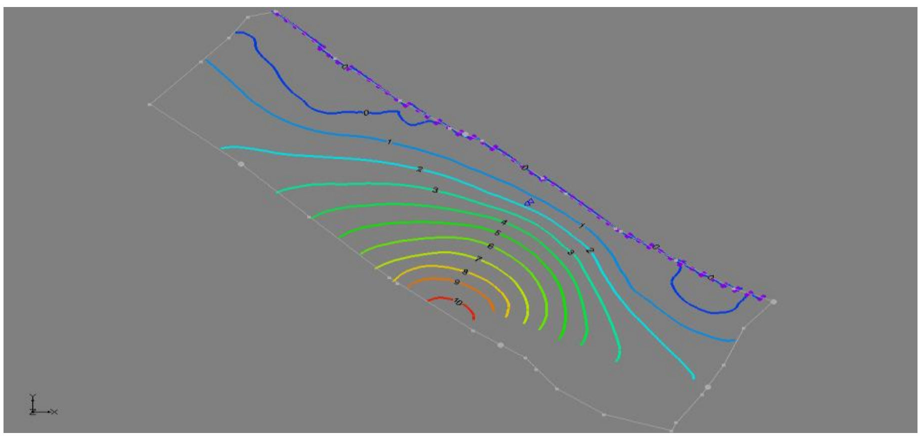

Fig. 10: Calibrated head of alluvium (m)

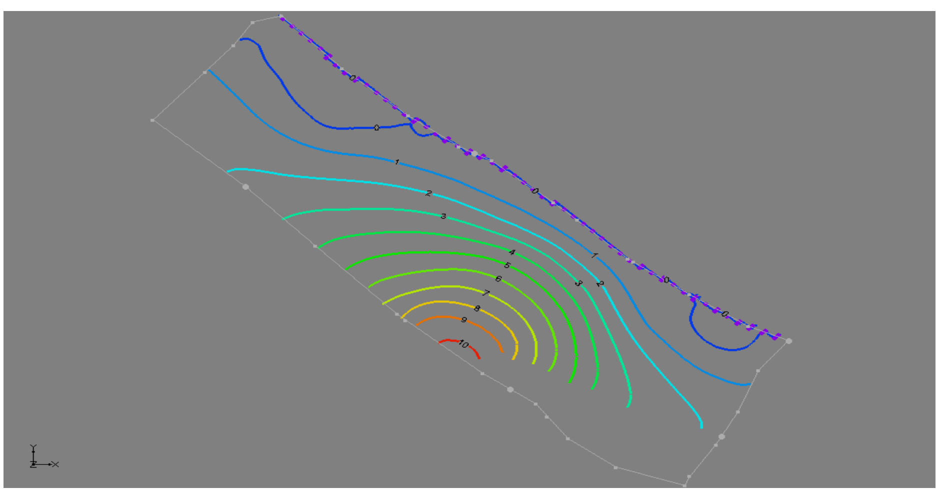

Fig. 11: Calibrated head of upper Fars (m)

Conclusion and Recommendation

The Hawasinah Catchment promising a good area in development activities especially agricultural purposes. Groundwater within this area has been extensively used to meet the water demand. Numerical model has been developed for the Hawasinah Catchment area to investigate the flow system and to evaluate the hydrologic parameters. A layered aquifer system has been defined consisting of two units' namely alluvium and Neogene's upper Fars.

The most important conclusions can be stated as follows:

- The main source of recharge to the Hawasinah Catchment area is through direct recharge from rainfall as well as wadi flow, it is estimated by about 20 x 10^6 m^3/year from both rainfall, wadi flow plus return flow of irrigation water not included;
- The total amount of current abstraction is about 97.28 x 10^6 m^3/year;
- The hydraulic conductivity of the aquifer system attains a moderately wide range from 10 to 35 m/day for the alluvium and its 0.9 for upper Fars
- The Head of water range between -0.3 to 6.5 m
- Inflow from the Oman Gulf is about 6,031 m^3/day to the alluvium and about 3,225 m^3/day to the upper Fars.
- A localized salt water intrusion of 7.5 and 3 Mm^3/year to the alluvium and upper Fars respectively
- The abstraction from wells were 15 Mm3/year

The most important Recommendation can be stated as follow:

- More work required for aquifer geometry
- Additional data of hydraulic parameters are required
- Modeling work needed in the transient state to see the effect of aquifer behavior on the long term.
- Set prediction development scenarios the effect of abstraction on the groundwater level
- Model work on water quality needed to see the effect of development on groundwater quality

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Predicting Daily Storage Volume in 16 October Dam Using Artificial Neural Networks (in Arabic)
التنبّؤ بحجم التخزين اليومي في بحيرة سد 16 تشرين باستخدام الشبكات العصبيّة الاصطناعيّة

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الملخص
لقد أثرت التغيّرات المناخيّة بشكل كبير على الهطولات المطريّة من ناحية الشدّة والتوزّع المكاني والزماني، الأمر الذي أثر بشكل مباشر على قيم تدفقات الأنهار وحجوم تخزين البحيرات التي تتغذى منها. لذلك تهدف هذه الدراسة إلى ايجاد نموذج للتنبّؤ الدقيق بحجوم التخزين في بحيرة 16 تشرين في محافظة اللاذقية في الجمهوريّة العربيّة السوريّة باستخدام أسلوب الشبكات العصبيّة الاصطناعيّة، والذي يستخدم كنظام إنذار مبكّر للفيضان يحدد الوقت المناسب لفتح بوّابات السد. استخدمت لهذا الغرض القيم اليوميّة للهطولات المطريّة وتدفقات النهر ومنسوب الماء في البحيرة. بُني لهذا الغرض عدد كبير النماذج مع تغيير هيكليّة الشبكة والقيم المستخدمة كمدخلات. أظهرت النتائج القدرة العالية لنماذج الشبكات العصبيّة الاصطناعيّة للتنبّؤ بحجم التخزين في البحيرة في الزمن t وذلك باستخدام قيم تدفق النهر والهطولات المطريّة في الزمن (t-3 , t-2 , t-1) ومنسوب الماء في البحيرة في الزمن (t-1)، أي قيمة المنسوب قبل يوم واحد من التنبّؤ، حيث بلغ معامل الارتباط بين القيم الحقيقيّة المقيسة لحجوم التخزين في البحيرة ومخرجات الشبكة R=99.97%، وجذر متوسط مربعات الأخطاء RMSE=1.55 MCM خلال مرحلة التحقق للشبكة. توصي هذه الدراسة بالتوسّع في استخدام الشبكات العصبية الاصطناعية في نمذجة الظواهر الهيدرولوجية والعمليات المتعلقة بالموارد المائية والتي تتسم بالتعقيد والتأثر بعدد كبير من العوامل، وذلك في ظل التغيرات المناخية الحاصلة، من أجل تفادي الآثار السلبية لها، لما لهذه الشبكات العصبية الاصطناعية من قدرة على التنبؤ بهذه التغيرات بدقة عالية.

الكلمات الدالة: التغيرات المناخية، حجم التخزين، الشبكات العصبية الاصطناعية، التنبؤ.

مقدمة
لقد أثرت التغيرات المناخية بشكل كبير على الهطولات المطرية من ناحية الشدة والتوزع المكاني والزماني، الأمر الذي أثر بشكل مباشر على قيم تدفقات الأنهار وحجوم تخزين البحيرات التي تتغذى منها. ولذلك أجريت العديد من الدراسات لإيجاد علاقة دقيقة بين الهطل والتدفق وحجوم التخزين الناتجة عنه بحيث تكون قادرة على التقدير والتنبؤ بتلك القيم بموثوقية عالية، وقد توجّه الاهتمام في السنوات الأخيرة إلى استخدام نماذج الشبكات العصبية الاصطناعيّة في نمذجة هذه الظاهرة نظراً لقدرتها الكبيرة على نمذجة العلاقات اللاخطيّة، حيث درس (Riad and Mania, 2003) علاقة الهطل جريان في المناطق شبه الجافة على حوض ساكب في المغرب باستخدام الشبكات العصبية الاصطناعية، وأظهرت نتائج الدراسة أن أسلوب الشبكات العصبية أكثر ملائمة لنمذجة علاقة الهطل جريان من نماذج الانحدار التقليدية، حيث بلغت قيمة معامل الارتباط بين القيم المقيسة والمتنبأ بها باستخدام الشبكات العصبية الاصطناعية 0.917 في حين بلغت 0.888 باستخدام نماذج الانحدار الخطي وذلك خلال مرحلة الاختبار لهذه النماذج [1].

واستخدم (Rajurkar, et al. 2009) نماذج الشبكات العصبية الاصطناعية من النوع MISOmultiple-input single-output لنمذجة قيم تصريف الحوض الساكب لنهر Narmada في الهند، واستنتج إمكانية استخدام هذه النماذج في عملية التقدير، حيث كانت قيمة جذر متوسط مربعات الأخطاء لأفضل شبكة 348.5 m^3/sec خلال مرحلة الاختبار، وذلك باستخدام ثلاثة عصبونات في طبقة الدخل للشبكة [2].

في حين طبق (Kuok, K. et al. 2011) الشبكات العصبية الصنعية لنمذجة العلاقة بين الهطول المطري الجريان السطحي، باعتبارها نظام لمعالجة المعلومات وهي قادرة على استقراء العلاقة بين المدخلات والمخرجات للعمليات بدون الحصول على معلومات فيزيائية عن هذه العمليات. لذلك تمّ بناء شبكات عصبية صنعيّة متعددة الطبقات وشبكات عصبية إرجاعيه للتنبؤ بالجريان السطحي الساعي لحوض Sungai Bedup في Sarawak.البيانات التي تمّ استخدامها هي بيانات دخل حالية وسابقة للهطول المطري بالإضافة إلى بيانات سابقة للجريان السطحي، بينما تضمنت بيانات الخرج قيم حالية للجريان السطحي. دربت الشبكات العصبية الصنعية باستخدام خوارزميات تدريب مختلفة، معدلات تعلم، عدد من العصبونات الخفية. تمت محاكاة النتائج باستخدام

معامل ارتباط (R)، معامل Nash-Sutcliffe (E) وخطأ الذروة. وبغرض تأكيد موثوقية وتعزيز قوّة التشكيل المثالي الذي تمّ الحصول عليه بوساطة الشبكات العصبية متعددة الطبقات والشبكات الصنعية الإرجاعية، تمّ التحقق بوساطة ست عواصف زمنية تحدث بمدد مختلفة. أظهرت النتائج أنّ أداء الشبكات الإرجاعية أفضل من أداء الشبكات المتعددة الطبقات. وأنّ الشبكتين قادرتين على محاكاة الجريان السطحي الساعي بدقة عالية. لذلك يمكن استخدام الشبكتين كمتنبئ للتدفق الإنذاري لاتخاذ الاحتياطات الضرورية للحماية من الفيضانات قبل حدوثه [3].

كما استخدم (Mittal, P; et al. 2012) نمطين من الشبكات العصبية للتنبؤ بالتدفقات الساعية لنهر في حوض Kolar في الهند، وذلك بالاعتماد على البيانات التاريخية للتدفق ومتوسط الهطول لثلاث محطات، وأشارت نتائج المقارنة إلى تفوق نموذج FF-ANN بدقة (R^2=0.98, RMSE=23.24)، على الشبكة ذات النظام الثنائي (Dual-ANN) بدقة (R^2=0.98,RMSE=27.16) [4].

كما قام (Aboodi, A. H. 2014) بتهيئة نموذجين من الشبكات العصبية الاصطناعية أمامية التغذية متعددة الطبقات تعتمد على خوارزمية الانتشار العكسي لتدريبها، وذلك للتنبؤ بالتصاريف الشهرية لنهر دجلة في مدينة بغداد، وسط العراق، حيث أشارت نتائج التنبؤ بتصاريف المجرى لشهر وشهرين بالاعتماد على البيانات السابقة للتصاريف لثلاثة أشهر، أن الشبكة المقترحة أداة فعالة للتنبؤ بتصاريف النهر على المدى القصير حيث بلغت دقة التنبؤ للنموذج الأول الذي بأخذ بعين الاعتبار تأخر زمني مقداره يوم واحد$Qt =f\{Qt\text{-}1\}$ (R^2=0.945 ،RMSE=118.12 m^3/sec) والنموذج الثاني الذي بأخذ بعين الاعتبار تأخر زمني مقداره يومين $Q_t =f\{Q_{t-1}, Q_{t-2}\}$ (R^2=0.914،RMSE=123.27m^3/sec)، وتبدأ القدرة على التنبؤ بالتضاؤل كلما ازدادت فترة التنبؤ [5].

كما استخدم(2015Thair, S.K; et al.) الشبكات العصبية الصناعية ANN، بتطبيقه أسلوب التغذية الأمامية متعددة الطبقات مع خوارزمية الانتشار الخلفي، في محاولة للتنبؤ بالقيم الشهرية للتدفقات الخارجة من خزان سد الموصل في العراق، وتخمين معادلة مثلى تستخدم في تشغيل السد، بالاعتماد على مجموعة بيانات من القياسات الحقيقية لمدى 23 سنة تغطي (1990-2012)، تتضمن المدخلات التدفق الوارد (It,It-1,It-2) والخارج (Qt) من الخزان والتبخر (Qt) والأمطار (Rt) وحجم التخزين (St)، وتم التوصل إلى أفضل تقارب بين القيم المقاسة ونتائج المحاكاة بعد أكثر من 1000 محاولة، وكان معامل التحديد (R^2) وقيم متوسط نسبة الخطأ المطلق (MAPE) بين القيم المقاسة والمحاكاة (0.972، 17.15) على الترتيب، كما كانت القيم المتوقعة مطابقة بشكل جيد للغاية مع القيم المقاسة، مما يشير إلى أن استخدام تقنية ANN يساعد في قرار تشغيل الخزان والتحديث في المستقبل، كما أنه نموذج مهم لاستكمال البيانات الناقصة والتنبؤ بالتدفقات الشهرية بدقة مرضية [6].

كما قام عمّار وآخرون باستخدام أنموذجين من الشبكات العصبية لنمذجة علاقة الهطل_ جريان في حوض نهر الكبير الجنوبي في سوريا بالاعتماد على البارامترات المناخية اليومية المأخوذة من المحطات المنتشرة في الحوض (3 محطات) للفترة بين (2004-2008)، مع استخدام عدة تأخيرات زمنية للمدخلات، حيث اعتمد أحد النموذجين شبكة Focused Time _Delay Neural network (FTDNN) مع خوارزمية Levenberg-Marquardat backpropagation والآخر استخدم الشبكة الديناميكية ذات التغذية الراجعة (NARX) وتبين أن النموذجين اللذين يوفران أفضل أداء في مرحلة المعايرة من حيث معامل الارتباط بين القيم المقاسة والمحاكاة للتدفقات اليومية قد بلغ (77.8%، 93.32%) على التوالي، في حين بلغ (93.69%) لمجموعة التحقق من صحة النموذج والتي تشكل 15% من البيانات الكلية [7].

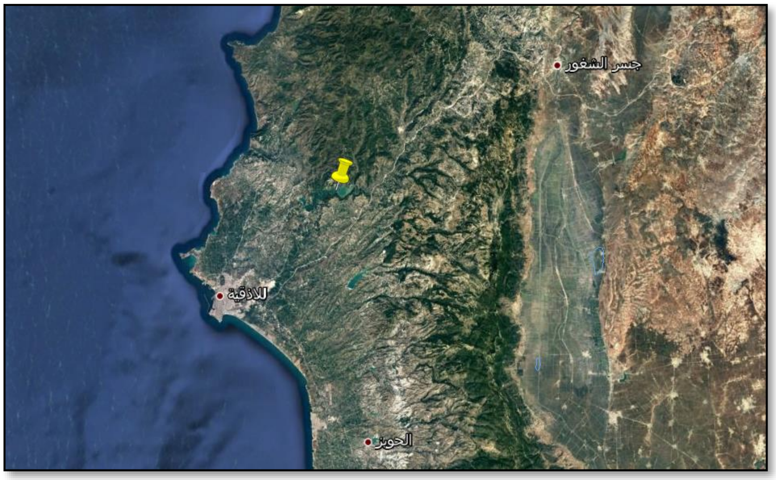
وفي دراسة مشابهة قام بها عمّار وآخرون على حوض نهر الكبير الجنوبي باستخدام شبكة FTDNN و NARX بمعماريات وبارومترات يومية مختلفة من هطول وجريان وحرارة ورطوبة نسبية، وبمقارنة أفضل أداء للشبكة المقترحة (NARX) مع نتائج أفضل معادلة انحدار تم التوصل إليها من تحليل الانحدار إحصائيا، وتم التوصل من هذه الدراسة إلى أن الموديل الذي تم التوصل إليه من الشبكة العصبية الصنعية هو أفضل من الموديل وفق الطريقة الإحصائية (برنامج SPSS)، بمعامل ارتباط (97.42%، 82.6%) على التوالي [8].

أهداف البحث وأهميته

تهدف هذه الدراسة إلى إيجاد نموذج للتنبؤ الدقيق بحجوم التخزين في بحيرة 16 تشرين في محافظة اللاذقية في الجمهورية العربية السورية باستخدام أسلوب الشبكات العصبيّة الاصطناعيّة، وتكمن أهميّة البحث في إمكانيّة المحافظة على أمان السد وسلامته من خطر الموجات الفيضانية الكبيرة بالاعتماد على القدرة العالية للنموذج على التنبؤ بقيم حجوم التخزين، وبالتالي يمكن استخدامه كنظام إنذار مبكر للفيضان يحدد الوقت المناسب لفتح بوابات السد.

منطقة البحث

ينبع نهر الكبير الشمالي من المنطقة الشمالية الغربية للجبال الساحلية، من المرتفع الواقع عند الحدود التركية على ارتفاع يتجاوز الـ (1100) م قاطعاً مسافة (89) كم، ليصب جنوب مدينة اللاذقية مباشرةً في البحر المتوسط، حيث تبلغ مساحة حوضه الصباب من المنبع حتى المصب $1097\ km^2$. ويبيّن الشكل (1) صورة جويّة للمنطقة المدروسة.



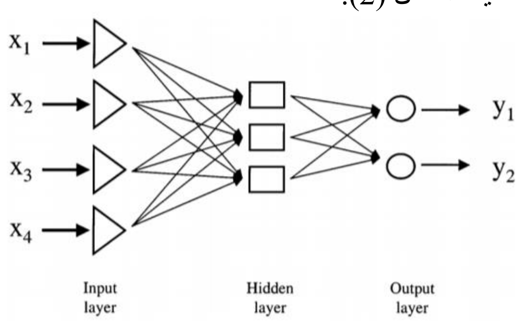
الشكل (1) : صورة جوية للمنطقة المدروسة.

طرائق البحث والمواد المستخدمة

تُعدّ الشّبكات العصبيّة الاصطناعيّة من أهمّ مجالات الذّكاء الاصطناعي، وهي عبارة عن أنموذج رياضي مبني على مفهوم الشّبكات العصبيّة الحيويّة، حيث تتكون من مجموعة من العصبونات الاصطناعيّة التي تحاكي سير ومعالجة المعلومات في العقل البشري. حيث تعتمد في صياغتها على محاكاة بنية وآليّة عمل الخلايا البيولوجيّة في الكائنات الحيّة، وذلك من ناحية القدرة على التعلّم من أنماط مختلفة من البيانات والسرعة العالية في إجراء عمليّات المعالجة.

تتكوّن الشبكة العصبيّة الاصطناعيّة بشكل أساسي من طبقة الدخل Input layer التي تحتوي على عدد من العصبونات ممثل لعدد مدخلات الشبكة العصبيّة، وطبقة مخفيّة Hidden layer واحدة أو أكثر والتي تضيف المرونة على عمليّة بناء الدوال الناقلة بين المدخلات والمخرجات، ثم طبقة الخرج للشبكة Output layer.

لكل نوع من أنواع الشبكات العصبية الاصطناعية خصوصية من ناحية الهيكلية وآلية معالجة المعلومات من خلال عدد ونوع العقد في كل طبقة، بالإضافة إلى نوع دوال التفعيل (Activation Function) المستخدمة وآلية تعديل الأوزان (Weights). ومن أهم تلك الدوال المستخدمة في بناء الشبكات العصبية[9](tan-sigmoid, log-sigmoid, pure).وتعتبر الشبكات العصبية الاصطناعية ذات التغذية الأمامية (Feedforward ANNs) من أكثر أنواع الشبكات العصبية الاصطناعية استخداماً، حيث يتكون هذا النوع من الشبكات من طبقتين على الأقل، كما توجد في غالب الأحيان طبقة خفية أو أكثر بين طبقتي الدخل والخرج، وسمي هذا النوع من الشبكات بهذا الاسم لأن جهة انتقال البيانات وإجراء العمليات الحسابية يكون إلى الأمام من طبقة الدخل للشبكة إلى طبقة الخرج عير الطبقات المخفية، الشكل (2).



الشكل (2): شبكة عصبية اصطناعية ذات تغذية أمامية.

إن الشبكات العصبيّة لا تُبَرمج وإنما تُدرَّب، ويمكن أن يتم ذلك من خلال العديد من خوارزميات التدريب (Training Algorithms) التي تتولى تعديل أوزان الشبكة لتقليل الأخطاء فيها، وتعتبر خوارزميّة الانتشار العكسي للخطأ (Back Propagation Algorithm) من أهم تلك الخوارزميّات وأكثرها انتشاراً، وفيما يلي شرح مبسّط لطريقة عمل هذه الخوارزميّة [10]:

1. يكون البدء بإدخال قيم معيّنة للدخل إلى الشبكة غير المدرّبة، حيث تقوم هذه الشبكة بإجراء الحسابات اللازمة للجمع الموزون وتطبيق دالّة التفعيل وحساب قيمة الخرج، وتبعاً لذلك فإننا سنحصل على قيمة عشوائيّة للخرج من الشبكة .
2. يتم حساب دالّة الخطأ بين قيمة الخرج التي تمّ الحصول عليها في الخطوة الأولى وقيمة الخرج المطلوبة.
3. لتقليل قيمة دالّة الخطأ يتم تعديل الأوزان في طبقة الخرج أولاً في اتجاه تقليل الخطأ ثم نشر أو نقل هذا الخطأ إلى الطبقة السابقة وتعديل الأوزان عند مداخل هذه الطبقة، وحساب قيم الخرج للشبكة مرّة ثانية في الوضع الجديد وحساب دالة الخطأ باستخدام الخرج الجديد والخرج المطلوب، وتعديل الأوزان مرّة أخرى في طبقة الخرج ثم نقل الخطأ الجديد إلى الطبقة التي قبلها وهكذا.
4. يتم تكرار التعليم عدد من المرّات حتى يصبح الخرج المحسوب مساوياً للخرج المطلوب وتتلاشى دالة الخطأ، أو تصبح قيمة هذا الخطأ ضمن الحدود المسموح بها والمحدّدة مسبقاً.

ويعد عدد مرّات التكرار هو المقياس لكي تتعلّم الشبكة ويطلق على هذا النوع من تعليم الشبكة بالتعليم الموجّه أو التعليم بإشراف (Supervised Learning).

تقييس البيانات

يتطلب عمل الشبكات العصبيّة الاصطناعيّة إجراء عملية التقييس لكل من متجهات المدخلات والهدف، وذلك لجعل قيم عناصرها قريبة من بعضها البعض لتقليل الخطأ بين القيم المحسوبة من الشبكة والقيم الهدف، وهذا يحسن من كفاءة العمليات الحسابيّة وأداء الشبكة، وأهم المعادلات الرياضيّة المتبعة لإجراء عملية التقييس:

$$P_{norm} = 0.5\left[\frac{P - P_{mean}}{P_{\max} - P_{\min}}\right] + 0.5 \qquad (1)$$

$$P_{norm} = \frac{P - P_{mean}}{P_{\max} - P_{\min}} \qquad (2)$$

$$P_{norm} = \frac{P - P_{mean}}{(P_{\max} - P_{\min})^{0.5}} \qquad (3)$$

$$P_{norm} = 2\left[\frac{P - P_{mean}}{(P_{\max} - P_{\min})^{0.5}} - 1\right] \qquad (4)$$

وذلك حيث أن: P القيم الأصلية. P_{norm} القيم المعدلة. P_{mean} متوسط القيم.
$P_{\max}$ أدنى قيمة. $P_{\min}$ أعلى قيمة.

سوف يتم بناء أنموذج الشبكة العصبيّة الاصطناعيّة بالاعتماد على برنامج الـ MATLAB وحزمة الأدوات الملحقة به -NN TOOL BOX وذلك نظراً لكفاءته العالية في هذه المجال، ولإمكانية الوصول بسهولة إلى الدوال العديدة الجاهزة التي يؤمنها البرنامج.

توجد معايير مختلفة للتحقق من الأداء الأفضل للشبكات العصبية، وفي هذه الدراسة تم استخدام جذر متوسط مربعات الأخطاء RMSE ومعامل الارتباط Rبين القيم الحقيقية المستخدمة والقيم الناتجة عن النماذج العصبية الاصطناعية لتحديد الشبكة ذات الأداء الأفضل، وفيما يلي المعادلات المعرفة لهذه العوامل الاحصائية المستخدمة [11]:

$$RMSE = \left[\frac{\sum_{i=1}^{n} (p_i - o_i)^2}{N} \right]^{0.5} \qquad (5)$$

$$R = \frac{\sum_{i=1}^{n} (p_i - \overline{p}).(o_i - \overline{o})}{\left[\sum_{i=1}^{n} (p_i - \overline{p})^2 . \sum_{i=1}^{n} (o_i - \overline{o})^2 \right]^{\frac{1}{2}}} \qquad (6)$$

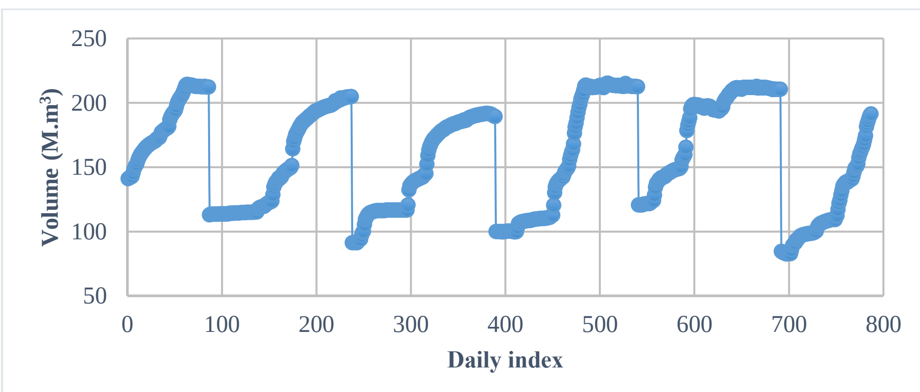
حيث أن: p_i : القيمة المتنبّأ بها. $\overline{p}$: المتوسّط الحسابي للقيم المتنبّأ بها. N : عدد البيانات.

o_i : القيمة المقيسة. $\overline{o}$: المتوسّط الحسابي للقيم المقيسة.

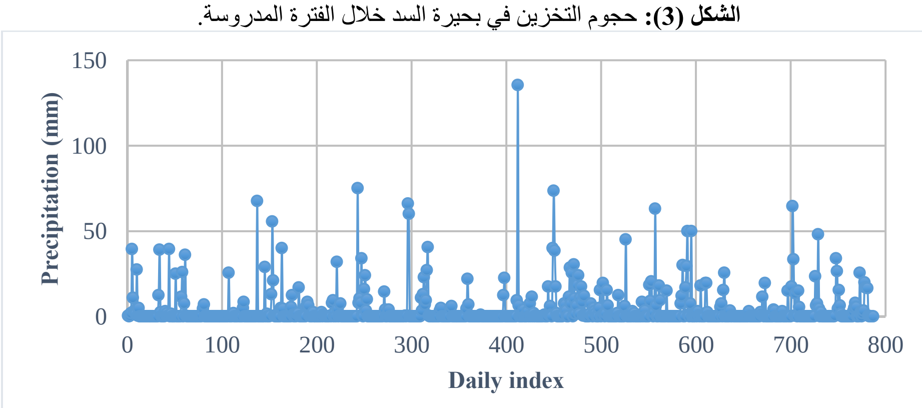
النتائج والمناقشة

استخدمت هذه الدراسة قيم حجوم التخزين في سد 16 تشرين على نهر الكبير الشمالي في الجزء الشمالي من الساحل السوري، ومناسيب المياه في بحيرة السد بالإضافة إلى الهطل المطري، وذلك خلال الأشهر الماطرة فقط (كانون الأول، كانون الثاني، شباط، آذار، نيسان)، حيث اشتملت مجموعة البيانات الكلية على 787 يوماً ضمن الفترة (31/12/2011–/2/20064)، وهي موضحة في الأشكال (3،4،5).

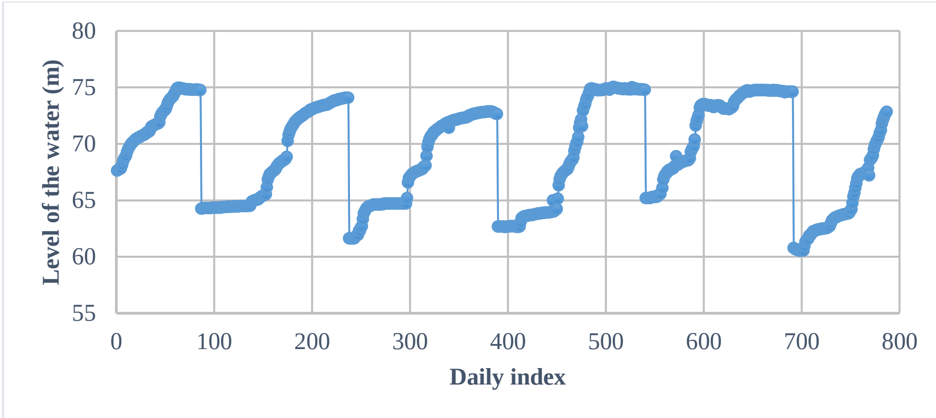
احتوت مجموعة البيانات المستخدمة على بعض البيانات المفقودة خلال عدد من الأيام المتفرقة من المدة المدروسة، الأمر الذي حال دون إمكانية استخدام بعض الأنواع من الشبكات العصبيّة الاصطناعيّة مع التأخرات الزمنيّة ضمن بيئة عمل برنامج الماتلاب، ولذلك تمت معالجة هذه المشكلة خلال عملية المعالجة للبيانات بإضافة عدد من العصبونات إلى نماذج الشبكات العصبية، تمثل المدخلات مع التأخرات الزمنيّة المطلوبة والتي تختلف باختلاف العنصر المؤثر.



الشكل (3): حجوم التخزين في بحيرة السد خلال الفترة المدروسة.



الشكل (4): بيانات الهطل المطري المستخدمة.



الشكل (5): مناسيب المياه في بحيرة السد خلال فترة الدراسة.

أُجري بدايةً عدد من التجارب على نسب مختلفة لتقسيم البيانات، وتبين أن النسب (80:10:10%)هي الأفضل، بحيث تمثل 80% لمجموعة بيانات التدريب (Training dataset)، 10% لمجموعة بيانات التحقق (Validation dataset)، (10%) لمجموع بيانات الاختبار (Testing dataset)، وكانت طريقة التقسيم على شكل بلوكات بحيث نحافظ على موثوقية المقارنة بين النماذج المختلفة بعد الانتهاء من عمليات التدريب والتحقق والاختبار.

قُيّست هذه البيانات باستخدام المعادلة رقم (1) وبالتالي أصبح مجال تغير جميع البيانات المستخدمة سواء في الدخل أو الخرج للنماذج وفي جميع المجموعات يتراوح بين الـ 0 والـ 1 وفقاً لطبيعة المعادلة المعتمدة لاستخدامها في عملية التقييس. وبعد ذلك أُدخلت هذه البيانات إلى الشبكات العصبية الاصطناعية بحيث تضمنت طبقة الدخل لهذه الشبكات على 7 عصبونات ممثلة لـ 7 مدخلات هي قيم تدفق النهر والهطولات المطرية بتأخرات زمنية من 1 وحتى 3(t-3 , t-2 , t-1) لكل منها، ومنسوب الماء في البحيرة بتأخر زمني مقداره يوم واحد(t-1). أما بالنسبة لطبقة الخرج للشبكات العصبية الاصطناعية فقد كانت عبارة عن عصبون واحد ممثل للخرج المطلوب وهو يمثل حجم التخزين في بحيرة السد في الزمن (t) المراد التنبؤ به.

بُني عدد كبير من النماذج من خلال تجارب متعددة تم من خلالها تغيير عدد العصبونات في الطبقة الخفية للشبكة، وخلال تغيير نوع توابع التفعيل للعصبونات في كل من الطبقة الخفية وطبقة الخرج، وكذلك خوارزميات التدريب، ودربت النماذج في كل حالة من هذه الحالات بـ 1000دورة تكرارية، يتم في نهاية كل منها اعتماد الدورة التكرارية الأفضل والموافقة لأقل خطأ ممكن للأنموذج.

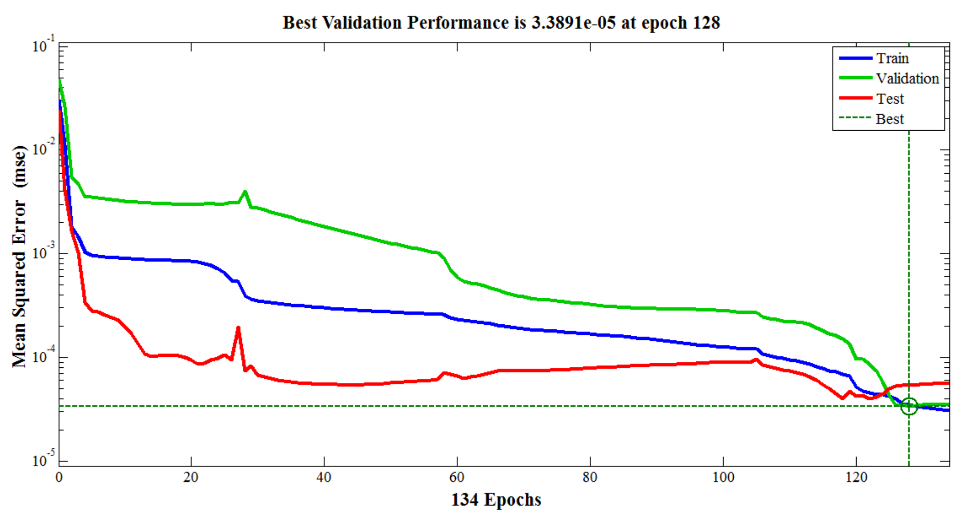
وأجريت عملية المقارنة بين النماذج التي تم الحصول عليها في كل حالة من الحالات وفق المؤشرات الإحصائية المذكورة سابقاً لجذر متوسط مربعات الأخطاء(RMSE) عن القيم الحقيقية المقيسة لحجوم التخزين والقيم الناتجة عن نماذج الشبكات العصبية الاصطناعية، ومعامل الارتباط(R) بين القيم الحقيقية المقيسة والقيم المتنبأ بها خلال مختلف المجموعات التي تم اعتمادها في هذه الدراسة، ويبين الجدول (1) المؤشرات الإحصائية المحسوبة لأفضل النماذج التي تم الحصول عليها.

الجدول(1): المؤشرات الإحصائية لأفضل نماذج الشبكات العصبيّة الاصطناعيّة.

Network Architecture	Activation Function	Train		Validation		Test	
		R %	RMSE $M.m^3$	R %	RMSE $M.m^3$	R %	RMSE $M.m^3$
7-8-1	tan sig.	99.92	1.52	99.95	2.11	9958	2.63
((7-10-1))	tan sig.	99.92	1.57	99.97	1.55	99.77	1.96
7-10-1	log sig.	99.91	1.66	99.96	2.20	99.65	2.42
7-11-1	tan sig.	99.93	1.50	99.95	2.00	99.76	2.01
7-12-1	tan sig.	99.86	2.07	99.93	2.44	99.83	1.68

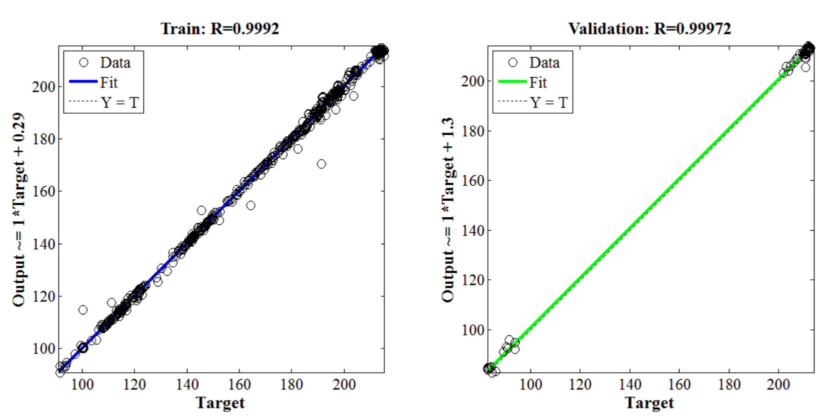
ومن الجدول نجد أن الشبكة العصبية الاصطناعية الأفضل والأكثر ملاءمة هي الشبكة العصبية ذات الهيكلية (1-10-7) التي تحتوي على 7 عصبونات في طبقة الدخل و 10 عصبونات في الطبقة الخفية وعصبون وحيد في طبقة الخرج ممثل لحجم التخزين المطلوب في الزمن (t)، وذلك بالاعتماد على المؤشرات الاحصائية خلال مراحل التحقق والاختبار أي على بيانات لم تستخدم في عمليات التدريب لنماذج الشبكات العصبية الاصطناعية، وكذلك نجد أن استخدام تابع التفعيل tan sigmoid activation function هو أكثر فعالية وملاءمة، ويساعد في الوصول إلى تقديرات أقرب من القيم الحقيقية أكثر من تابع التفعيل log sigmoid.

وقد بلغت قيمة جذر متوسط مربعات الأخطاء للشبكة (1-10-7) (1.96, 1.55, 1.57 $M.m^3$) من أجل مراحل التدريب والتحقق والاختبار على الترتيب، ومعاملات ارتباط (99.77, 99.97, 99.92%) لنفس المراحل على الترتيب. أما من أجل مجموعة البيانات الكلية فكان جذر متوسط مربعات الأخطاء يساوي $1.61 M.m^3$ ومعامل الارتباط 99.93%. ويبين الشكل (6) أداء الشبكة (1-10-7) خلال مراحل التدريب والتحقق والاختبار، واختيار الدورة التكرارية 128 المقابلة لأقل قيمة متوسط مربع خطأ مقيّس خلال مرحلة التحقق والذي يساوي 3.389×10^{-5} .

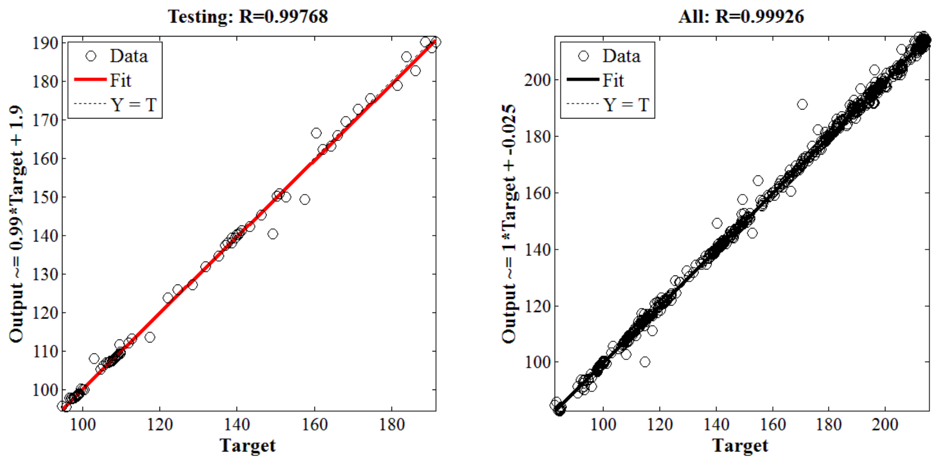


الشكل (6): أداء الشبكة (1-10-7) خلال مراحل البناء، واختيار الدورة التكرارية الأفضل.

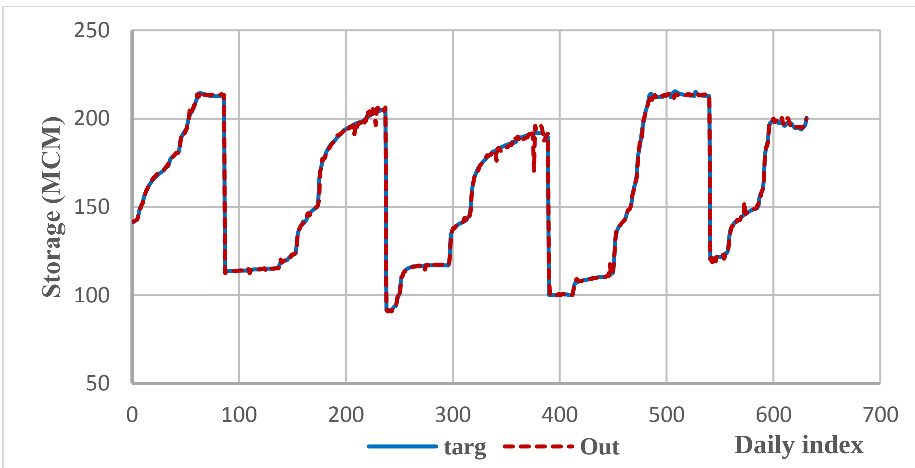
ويظهر الشكلين (7 ، 8) الارتباط العالي بين مخرجات الشبكة العصبية الاصطناعية والقيم الحقيقية المقيسة حيث بلغ % 99.92 خلال مرحلة التدريب، و %99.97 خلال مرحلة التحقق، و %99.77 خلال مرحلة الاختبار للشبكة أما على مجموعة البيانات الكلية فقد بلغ معامل الارتباط % 99.93، وهي قيم عالية تدل على التوافق العالي بين القيم الحقيقة والمتنبأ بها خلال مراحل التدريب والتحقق والاختبار للشبكة. في حين يظهر الشكلين (9، 10، 11) انطباقاً كبيراً بين القيم الحقيقة والمتنبأ بها خلال مراحل التدريب والتحقق والاختبار للشبكة.



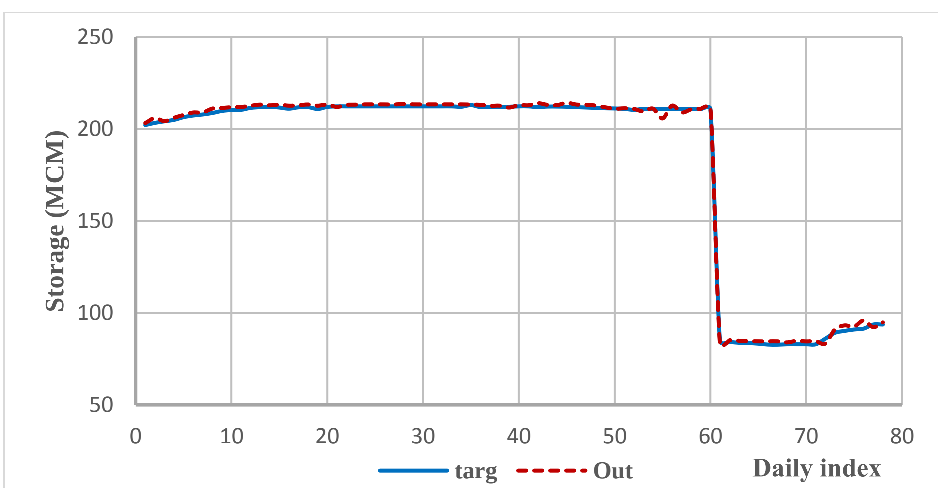
الشكل (7): الارتباط بين القيم المقيسة والمتنبأ بها لحجوم التخزين في بحيرة السد على مجموعة بيانات التدريب والتحقق.



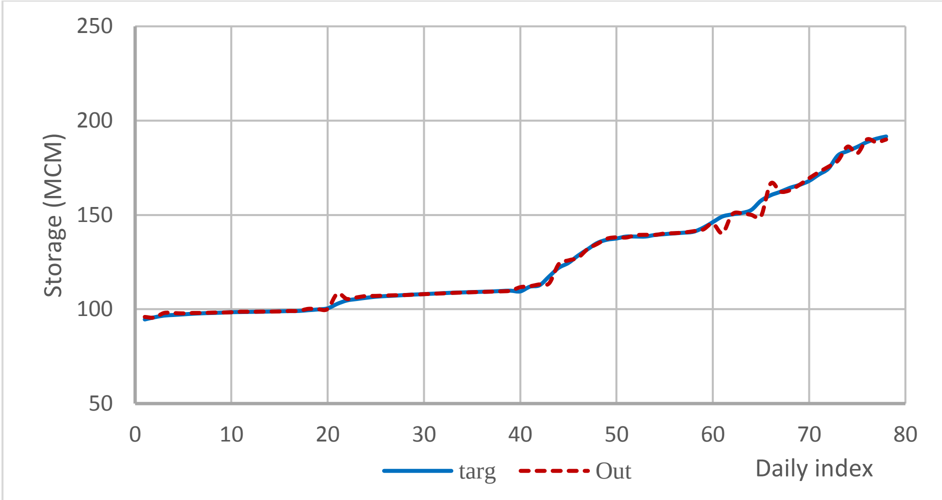
الشكل (8): الارتباط بين القيم المقيسة والمتنبّأ بها لحجوم التخزين في بحيرة السد على مجموعة بيانات الاختبار وعلى مجموعة البيانات الكلية المستخدمة.



الشكل (9): مقارنة بين حجوم التخزين المقيسة والقيم الناتجة عن الشبكة خلال مرحلة التحقق.



الشكل (10): مقارنة بين حجوم التخزين المقيسة والقيم الناتجة عن الشبكة خلال مرحلة الاختبار.



الشكل (11): مقارنة بين حجوم التخزين المقيسة والقيم الناتجة عن الشبكة خلال مرحلة التحقق.

الاستنتاجات والتوصيات

- إن الشبكة العصبيّة الاصطناعيّة ذات الهيكليّة (1-10-7)، وبمعامل ارتباط 99.97% وبجذر متوسّط مربعات الأخطاء 1.55 MCM خلال مرحلة التحقق، أي على بيانات لم تستخدم في عملية بناء النماذج وتدريبها، أثبتت قدرتها العالية على التنبّؤ بحجوم التخزين في بحيرة سد 16 تشرين بالاعتماد على بيانات التدفق النهر والهطولات المطرية ومنسوب الماء في البحيرة، وذلك بتأخرات زمنية مختلفة بين كل منها.
- أظهرت النتائج الموثوقيّة الكبيرة للشبكات العصبيّة الاصطناعيّة ذات التغذية الأمامية والانتشار العكسي للخطأ في عمليّة التقدير والتنبّؤ بحجوم التخزين في بحيرة سد 16 تشرين على نهر الكبير الشمالي، وذلك باستخدام بيانات قيم تدفق النهر والهطولات المطرية في الزمن (t-1 , t-2 , t-3) ومنسوب الماء في البحيرة في الزمن (t-1).
- توصي هذه الدراسة بالتوسّع في استخدام الشبكات العصبية الاصطناعية في نمذجة الظواهر الهيدرولوجية والعمليات المتعلقة بالموارد المائية وذلك في ظل التغيرات المناخية الحاصلة، نظراً لقدرتها الكبيرة في هذا المجال.

شكر وتقدير

هذا البحث مدعوم وممّول كلياً من قبل صندوق البحث العلمي والتطوير التقاني في وزارة التعليم العالي في سوريا.

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SESSION 4: DESALINATION MANAGEMENT

Keynote

Nuclear Desalination as a Long-Term Solution to Water Shortage in the GCC Countries

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Abstract
The Gulf Cooperation Council (GCC) countries are among the most water-scarce and arid regions in the world. GCC countries experience a huge deficit in the water resources. Rainfall varies in time and quantities among the Gulf States. The average annual precipitation is between 50 and 100 mm (2-4 in). The annual rate of water evaporation exceeds 3000 mm. Surface water resources are scarce. Underground water supplies are either limited or exhausted by the over-use.

Water consumption in the GCC countries has increased rapidly in the last few years. Agriculture accounts for more than 80% of water consumption. The GCC countries have experienced a dramatic increase in the water demand in last decade to satisfy the industrial development and agricultural growth. It is estimated that the total annual water consumption in the GCC countries is 26.5 billion cubic meters while the total annual water production is about 7.1 billion cubic meters. Water desalination is used to cover water shortages and fulfill the ever increasing national water demand in the GCC countries.

Most of the desalinated water in the GCC comes from thermal desalination plants including multi-stage flash (MSF) and multi-effect distillation (MED). Thermal desalination plants are energy intensive processes. Reverse osmosis (RO) is dominating in the brackish water desalination. However, there is a recent trend towards the use of RO for seawater desalination. Both thermal and electrical energy are required to drive thermal desalination plants while RO is only driven by electrical energy. Nuclear facilities are considered inexpensive means to provide both thermal and electrical energy for water desalination. They help in diminishing fossil fuel consumption and diversification of the GCC energy mix.

Nuclear power generation in the GCC countries is considered a favorable option to meet the fast-growing energy demand. The adoption of nuclear reactors for producing power to satisfy the energy demand and to provide a useable source of energy in the desalination plants will be a fruitful option. Nuclear reactors are used mainly for the production of either heat or power. In the nuclear heating reactors (NHR), heat can be extracted at various temperature levels, both in the form of hot gas or steam. The low pressure and temperature steam may be used in supplying the necessary energy to drive the MSF or any other distillation units. In the nuclear power reactor (NPR), electricity can be generated to drive the high-pressure pumps of the RO desalination plants. Developing the most appropriate plant configuration of a nuclear reactor (NHR or NPR) and desalination process (distillation or membrane) is indeed the most crucial factor that will determine the feasibility of nuclear desalination.

Steam and electricity can be produced easily by nuclear reactors. Nuclear reactors may be coupled with desalination plants (either MSF or RO). This integrated plant will be capable of producing power and water at reasonable cost. Maintenance and operating cost will drop significantly.

The implementation of nuclear desalination is practically essential in the GCC countries where massive quantities of water are desalinated associated with a fast increase in power demand. Nuclear energy is mature, economically competitive, sustainable with an outstanding record of safety and reliability. There is no technical impediment to the use of nuclear reactors for the supply of either heat or electricity or both to a desalination plant. This paper will discuss the potential of application of nuclear desalination in the GCC countries and its role in eradicating water shortages in the GCC countries. Various processes will be reviewed and most appropriate methods will be discussed.

Keywords: Desalination, Thermal Desalination Processes, Nuclear Desalination, GCC Water Consumption, Water Shortage Solution.

Keynote

Developments in Desalination in the Arabian Gulf Region, 1981-2016 Europe and the Gulf Region

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Abstract
The collaboration between Europe and Gulf regions has had significant impact on the development of desalination based on innovation and upscaling opportunities. Over the years research and development have led to the significant application of desalination technology and industry to ensure the water security in our regions and provided information and partnerships with other regions of the world. Data on publications, people, countries, plants and processes will be presented as well as some historical notes.

Keywords: Desalination, Innovation, Upscaling, Partnership, Gulf Regions.

Keynote

Design of mobile stand-alone solar driven reverse osmosis desalination plant for sustainable development in Egypt

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Abstract
Water desalination projects based on reverse osmosis technology are being introduced in Egypt to combat drinking water shortage in remote areas. Reverse osmosis (RO) desalination is a pressure driven process. This paper focuses on the design of an integrated brackish water and seawater RO desalination and solar Photovoltaic (PV) technology. A small Mobile PV driven RO desalination plant prototype without batteries is designed and tested. Solar-driven reverse osmosis desalination can potentially break the dependence of conventional desalination on fossil fuels, reduce operational costs, and improve environmental sustainability. Moreover, the innovative features incorporated in the newly designed PV-RO plant prototype are focusing on improving the cost effectiveness of producing drinkable water in remote areas. This is achieved by maximizing energy yield through an integrated automatic single axis PV tracking system with programmed tilting angle adjustment. An autonomous cleaning system for PV modules is adopted for maximizing energy generation efficiency. RO plant components are selected so as to produce 4-5 m^3/day of potable water. A basic criterion in the design of this PV-RO prototype is to produce a minimum amount of fresh water by running the plant during peak sun hours. Mobility of the system will provide potable water to isolated villages and population as well as ability to provide good drinking water to different number of people from any source that is not drinkable.

Keywords: Design, Reverse Osmosis, Photovoltaic, Energy, Desalination, Egypt.

1. Introduction

Desert regions in Egypt constitute more than 94% of the total area of the country. The other 6% of the area include mainly the cultivated lands in Nile valley and Delta. On the other hand the majority of Egyptian population is concentrated within the area of the Nile valley and Delta whereas less than 5% of the population are scattered in all desert areas. Such situation resulted in serious economic, social and environmental problems. The current total water supply in Egypt is about 57.5 billion m^3/year, from which there is a fixed 55.5 billion m^3/year from the River Nile. The per capita water share was 771 m^3/year in 2005, which is below the international standards of water poverty line of 1000 m^3/year. By the year 2025 this shortage will be severer, the total water demand will exceed 125 billion m^3/year resulting in a shortage of more than 30%.

Desalination is a separation process that produces two streams, fresh water and saline solution (brine). Saline water is classified as brackish water when the salt concentration, mostly sodium chloride, is between 1,000 ppm and 10,000 ppm, hard brackish water when the salinity is 10,000 ppm to 35,000 ppm, and seawater when the salinity exceeds 35,000 ppm [1]. Seawater and brackish water desalination are attracting more and more interest and attention, as they are most important methods to solve the problem of water shortage [2]. The reverse osmosis (RO) process, which relies on the semi-permeable character of a polymeric membrane to achieve molecular separation under the driving force of hydraulic pressure, is one of the most popular technologies currently being used for brackish water and seawater desalination for the advantages such as saving energy, modularity, flexibility, ability to construct small size plants, high permeate quality and minimal chemical addition [3-5].

Remote communities are often located in areas with access to seawater or brackish groundwater. For such communities, small-scale reverse osmosis (RO) desalination can provide fresh water. Desalination is an energy intensive process. Diesel generators or grid power are commonly used to power RO systems; however, diesel generators pollute the environment and their fuel is expensive. Grid power may not be available or may be expensive. Using photovoltaics to power RO desalination systems is a promising solution for such communities [6]. Solar energy coupled to desalination offers a promising prospect for covering the fundamental needs of power and water in remote regions, where connection to the public electrical grid is either not cost effective or not feasible, and where water scarcity is severe. Moreover, the coupling of reverse osmosis desalination with solar energy is a promising field of development in the desalination sector, with the potential to (i) improve its sustainability by minimizing or completely eliminating the dependence on fossil fuels (ii) significantly reduce the operational costs of desalination plants [7]. Despite a steady reduction in the energy consumption of pressure-driven membrane processes in recent decades, energy consumption is still a major cost component of RO desalination plants, accounting for 40–45% of total costs [8].

The solar-powered RO systems are principally can be classified into 3 groups: (1) solar thermal driven or Rankine cycle driven RO systems; (2) PV driven RO systems; (3) Hybrid (particularly Wind-PV) powered RO systems [9]. The Middle East and North African region has outstanding solar resources which can be captured for use either by (PV) devices or by direct absorption as thermal energy. The distribution of this resource is more evenly spread over the entire region than other Renewable Energy (RE) resources, which tend to be site specific. Huge areas are available for this resource to be utilized. Long-term development of this on a large scale will hinge on technical developments that will reduce the cost of electricity generated by PV or by solar thermal power plants.

Present time for both brackish and seawater desalination the RO constitutes a more realistic choice. Considering the energy supply, RO presents lower energy consumption comparing to other methods of desalination especially in countries where the conditions for solar-driven desalination are the most favorable, i.e., intense solar radiation and severe water scarcity exist. Several RO desalination systems driven by PV have been installed throughout the world in the last decades, most of them being built as experimental or demonstration plants. Some authors present experimental or simulation results [10, 11], while some others concentrate on cost analysis [12, 13]. Taking into account of the need and requirement of rural areas at present time it seems to be the development of small, autonomous, modular, flexible and reliable units, offering operation and maintenance at reasonable cost, in order to serve the segment of isolated users [14]. On that level, the development of battery-less systems, as well as the use of recovery devices, is of special importance. For this reason, intermittent operation of direct connected PV-RO system may be a promising option. This requires modification of common design rules for the electronics and the water processing part of the plant. The battery-less option has been discussed by some authors in PV desalination applications [15]. Advantages of battery-less systems with electronic power converters are simplified configuration, compact design, improved robustness and long life of all components of the power supply sub-system [16]. Battery less PV–RO systems are based on the idea that water storage is often more efficient and cost-effective than energy storage [17]. The main goal of this paper is to design and testing of a small mobile PV driven battery-less powered groundwater reverse-osmosis (PV-RO) desalinating unit. This unit is capable of desalinating brackish and saline groundwater points with salinity up to 25000 ppm and produces 4-5 m^3/day of potable water per day that complies with international standards.

2. Design methodology

Development of hybrids of solar and conventional desalination requires careful analysis and innovative engineering solutions. Hybrids of RO and solar energy are relatively less complicated than hybrids of thermal desalination [18]. A stand-alone RO desalination unit powered by solar is proposed. To predict the water production, 131 different water points are selected based on the available solar radiation data, sunshine hours and salinity of the feed water.

The proposed system includes of 2 main subunits—the energy production and the desalination subunits. The energy production subunit includes of PV array without batteries, and DC/AC inverter. The membrane separation section of the desalination subunit is fed via a high-pressure reciprocating pump, which is connected to energy production subunit for the recovery of energy by the brine stream leaving the process. The RO desalination unit consists of three 4x40inch spiral wound seawater Filmtec membrane modules. The DC power is produced from a PV array that consists of 6 TOPSUN TS-S415 Solar PV panels of total peak power of 2490 W that is connected to the DC motor. Taking account of this fact, a preliminary design of small scale PV powered RO battery-less desalination system is proposed in this study.

The system is battery-less as the low annual water storage cost in a tank (1%) compared to the electrical energy storage cost in batteries (12%) proves that it is more cost effective to store fresh water rather than to store electrical energy [19]. The proposed system is supposed to be a promising option by its compactness, its transportability, and its technical and economical feasibility (Fig. 1).

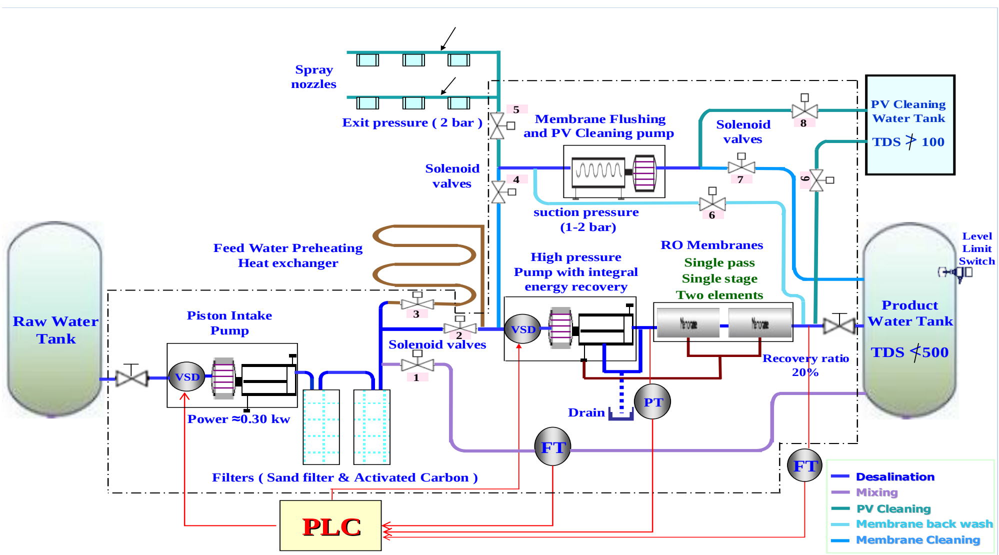


Figure 1: Schematic diagram for the integrated PV/RO system

2.1. Design Inputs

Tracking system should carry 6 PV modules each of dimension 1.96m x 1.308m x 40mm and weight 35.5kg and maximum allowable mechanical pressure=5400Pa, with 4 mounting points at 653mm distance from the mid points of the 2 long sides of the module. The overall dimensions of the RO unit are: L x W x H = 145cm x 45cm x 115cm.

The Tracking PV panel rotates automatically about the normal axis to the ground within an angle of about 220 deg. and tilts manually from the fully horizontal position to a tilted position making an angle of 60 deg. with the ground. All the system components should be carried on a trailer; considerations should be taken for transportation and operation.

2.2. Design step 1. Water salinity map in the area of study

a. Site Description

The area under investigation is located in the North Western Mediterranean Sea coastal zone of Egypt. It located between latitudes 30˚ 50` and 31˚ 40` N, and longitudes 25˚ 00` and 29˚ 40` E (Fig. 2).

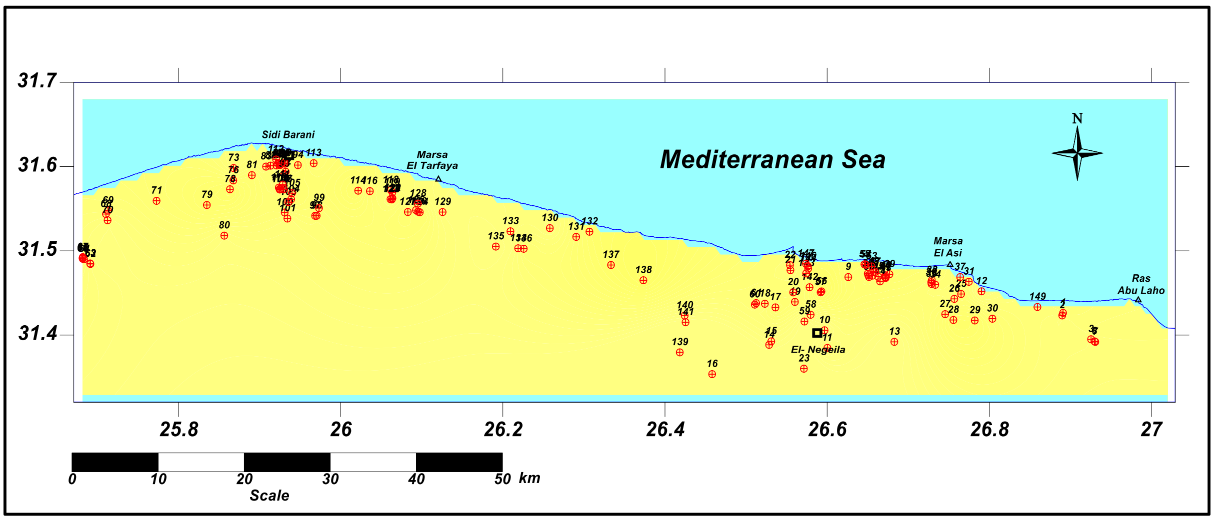


Figure 2: Groundwater well location map for the study area

The area stretches westwards about 104 Km length and 20 km average width. It is bounded on the north by the Mediterranean Sea. The selected area is considered one of the most promising regions for development. It can possess a good agricultural expansion, due to its favorable soil and water potentials in addition to its mild weather. So, at present, great efforts are directed to develop this zone which is mainly given a special priority in land reclamation. The water resources in study area are represented by groundwater. Moreover, the rainy season begins from October till January. The annual rainfall ranged from 100 mm/year to 181mm/year with mean of about 139.2 mm/year. The area is characterized by moderate to low temperature and heavy short rainfall storms in winter and high temperature and high rate of evaporation in summer. It attains its maximum temperature values during May, June, July and August. The rainy season begins from October till January. The rainfall occurs in the form of heavy short storms; hence the chance of surface water runoff and groundwater recharge is possible.

b. Water Sampling

Fieldwork took place within 2012-2013, during which water samples were collected from the study area. The present research is based on the results of 131 water samples (5 fresh samples, 9 saline samples and 117 brackish water samples) corresponding to all available water sources in the area. Two kinds of analyzed water samples were taken from each of the above water points for different measurements. The first kind is for the measurement of major cations, anions and minor elements. The second kind includes supra-pure nitric acid acidified samples for the measurements of trace elements and soluble heavy metals.

c. Site Measurements

In situ measurements of water samples location together with some physical and chemical characteristics of the collected water were determined in the field using GPS model (Magellan Nave 5000 pro.) for the determination of latitudes and longitudes and Electrical Conductivity meter (Jenway, model 470) for the determination of water salinity (EC in µS/cm) and temperature of the collected water samples. pH and dissolved oxygen were measured using pH meter (Jenway, model 3150) and DO meter (WTW, model oxi 315i), respectively. Depth to water was measured by using water level sounder Heron model dipper-T water level meter. Moreover, water level was measured by water level sounder with referring to ground elevation from the sea level (Fig. 3).

Figure 3: Site measurements for water quality and quantity

d. Laboratory Analyses

The analyses include the determination of EC, total dissolved salts (TDS), pH, concentration of major ions Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, SO_4^{2-} and Cl^{-}. The minor, trace and soluble heavy metals and nonmetals are, NH_4^{+}, NO_2^{-}, NO_3^{-}, PO_4^{3-}, B^{3+}, Al^{3+}, Fe^{3+}, Mn^{2+}, Co^{2+}, Cu^{2+}, Ni^{2+}, Cr^{3+}, Cd^{2+}, Pb^{2+}, Sr^{2+}, V^{2+} and Zn^{2+} in addition to BOD and COD. Measurements were carried out by EC meter model Orion (150 A^{+}), pH meter (Jenway 3510), Flame photometer (Jenway PFP 7), Ion selectivity meter (Orion model 940 with 960 titration plus), UV/Visible spectrophotometer (Thermo-Spectronic 300) and ICAP (thermo 6500). The obtained chemical data are expressed in milligram per liter (mg/l) or part per million (ppm).

e. Physical Characteristics of the Groundwater

The physical properties of the water samples were discussed through the measurement of electrical conductivity (EC) (Table 1).

Table 1: Chemical characteristics of 131 groundwater samples collected from the study area

	Concentration (mg/L)				Concentration (mg/L)		
	Minimum	Maximum	Median		Minimum	Maximum	Median
EC (ηm/cm)	393	36700	8840	B	0	4.72	1.11
TDS	337	22114	5106	Cu	0	0.09	0.0037
Na	30	7300	1500	Fe	0.05	13.96	1.365
K	7	316	51	Li	0	0.55	0.093
Ca	40.1	527.6	147.9	Mn	0	1.72	0.053
Mg	8.3	615	164.2	Mo	0	0.05	0.0015
CO_3	0	112.8	50.8	Ni	0	0.27	0.0058
HCO_3	160.6	779.8	292.4	P	0.01	1.36	0.2127
Cl	33.5	12592	2589.7	Pb	0	0.07	0.0054
SO_4	11	1536	318	Si	3.61	40.18	8.04
Br	1.1	219.2	39.5	Sr	0.74	29.37	8.96
I	0.01	1.36	0.066	V	0	0.32	0.0133
Al	0	18.97	0.73	Zn	0	0.39	0.0505

The conductivity of an aqueous solution is its ability to carry an electric current. The current is conducted in the solution by the movement of ions, and the greater the number of ions, and the higher their mobility, the higher the level of conductivity. Conductivity is expressed in units of microsiemens/cm (µS/cm). For this reason, the measurement of conductivity gives a good indication of the concentration of dissolved salts in water. The EC of the groundwater samples in the area of study is varied from 393 µS/cm (well No. 131) to 36700 µS/cm (well No. 47) with median value of 8840 µS/cm.

f. Chemical Characteristics of the Groundwater

Water salinity is the sum of all minerals substances detected from the chemical analyses. Different methods are used for water classification according to its salinity values. Natural water is classified into three main categories of total salinity; fresh water, brackish water and saline water. In the area of study, the salinity of the groundwater is ranged between 337 ppm at (well No.131) to 22114 ppm (well No. 47) with median value of 5106 ppm. According to this salinity classification, 10 samples representing 7.6% of total samples are fresh, 53 samples representing 40.5% are brackish and 68 sample representing 51.9% of the total samples are saline.

Moreover, major constituents (Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^{-}, SO_4^{2-}, Cl^{-} and SiO_2), as well as, minor and trace constitutes (K, CO_3, Ag, Al, B, Ba, Bi, Cd, Co, Cr, Cu, Fe, Li, Mn, Mo, Ni, P, Pb, Sr, V and Zn) of the groundwater sample are also analyzed to study their effect on the PV/RO conceptual design (Table 1).

Therefore, the data revealed from this part is very important for the conceptual design of our PV/RO stand-alone system due to the following:

1- 93.13 % of the groundwater samples in the area of study are not suitable for drinking due to higher contents of soluble salts which reflects the importance of our PV/RO to this area.
2- 51.9% of the groundwater samples are saline meaning that SeaWater (SW) membrane element will be preferred in our RO plant.

3- The higher contents of calcium, magnesium and silicate need anti-scalent addition in the plant.
4- Studying depth to water levels is very important for the calculation of the power for the pump.

2.3. Design step 3. Saline water RO unit sizing

Assuming that the daily operation time of the system is 6 h, seawater RO unit was chosen to cover the daily water needs of the population. The technical characteristics of the unit are:

- The RO plant is operated at constant Recovery Ratio of 30%.
- Operating Feed Temperature is 25°C.
- High pressure Pump efficiency is 70%
- Single Pass-Single Stage three-element membrane unit
- Membrane element (Filmtech SW30 -4040).
- Average Daily Working Duration is 6 hours.
- Feed water concentration 1000-25,000 ppm TDS
- Product water concentration <500 ppm TDS
- Fixed feed water flow rate
- Fixed permeate quantity

The unit contains three Filmtec spiral wound membranes (SW30-4040) in one pressure vessel, dosing pumps of 1.2 kW for the feed water pretreatment and a 0.25 kW washing pump.

Pre-Treatment: The incoming feed-water is pretreated to be compatible with the membranes by removing suspended solids, adjusting the pH, and adding a threshold inhibitor to control scaling caused by constituents such as calcium sulphate.
Pressurization: The pump raises the pressure of the pretreated feed water to an operating pressure appropriate for the membrane and the salinity of the feed water.
Energy recovery: Seawater reverse osmosis uses a very fine membrane that allows pure water to pass through, while mostly rejecting the relatively large salt molecules. The seawater feed must be pressurized (69 bar/1000 psi is typical), firstly, to force the water through the mechanical constriction presented by the membrane and, secondly, against the natural osmotic pressure. Not all of the feed water can be forced through the membrane; some, typically more than half, must be allowed to pass over the membrane (cross-flow) in order to remove the salt. This water, known as the concentrate or brine, comes out of the reverse osmosis module at a pressure only slightly below that of the feed pressure. In large RO plants, it is economically viable to recover the rejected brine energy with a suitable brine turbine. Such systems are called energy recovery reverse osmosis systems. Unfortunately brine turbines cannot be engineered for small RO plants due to the low brine flow rate [20]. In the last few years much research is being done to develop energy recovery systems compatible with small RO plants. Some companies have developed systems to directly recover the hydraulic energy contained in the high-pressure brine [21].

Prediction of power consumption in the presence of energy recovery device

The use of a pressure exchanger to recover the hydraulic energy in the brine line plays a dominant role in the reduction of the size of the high-pressure pump and resulted in the reduction of the energy consumption power for the seawater from 7.63kwh/m^3 (3.16kw) before recovery to 4.68kwh/m^3 (1.94 kW), which finally reduced the size of the hybrid energy system and the water production cost.

2.4. Design step 4. Modeling saline Water Reverse Osmosis

A. Model Description: ROSA 6.0.1 software is the latest version, used in the analysis in order to determine the performance of a membrane and energy requirements for desalination. The use of the model is influenced by the need to design a technically feasible RO system. The main inputs of the model include the amount of feed water and its chemical characteristics, feed water flow rate, feed water and concentrate feed pressures, temperature and pH. Then a configuration of the number of membranes, pressure vessels, and type of membrane, and feed and booster pumps is determined. After performing calculations, the model provides the amount of water produced and energy required. Booster pumps and an energy recovery turbine are applied (Table 2).

Table 2: Modeling brackish/saline RO unit

Feed flow rate	1.38 m3/h
Feed pressure	9.83-33.9 bar
Power consumption	0.17-1.14 kw/h
Permeate TDS	8.7-160ppm
Permeate product	0.43 m3/h
Mixing	52-1162 L

2.5. Design step 5. Calculation of the energy needs of the system

To calculate the energy needs of the system, first we calculated the total power requirements for the different parts of the system, given the maximum operation hours of the SWRO system, which is 6 h, the energy needs are shown in Table 3.

Table 3: The power and energy needs of the system

Type of load	Power (kW)	Duration (Hours)
High-pressure pump	1.2	6
Feed pump	0.250	6
Cleaning pump	0.1	0.1
Dosing pumps	0.25	4

2.6. Design step 6. PV system sizing to cover 100% of energy needs

2.6.1. Step 6.1. PV module tracking and tilting angle manipulation system

To maximize the total solar radiation collected, PV tracking system is realized. For a simple tracking system, the daily solar tracking is achieved by rotating the PV array about the solar tracking axis staring at the azimuth angle at sun rise and ending at the azimuth angle at sun set. This rotation is achieved by incremental azimuth angular movements based upon the location of the system. The azimuth angle range is determined for each month and set in the PLC. Thirty-six azimuth adjustment programs have been developed such that three programs for each month thus covering the whole calendar year. Actuation of the PV panel tilt for azimuth tracking and rotation of the PV panel for solar tracking are operated with a gear motor-based control system for adjusting the PV mounts system's position so as to collect maximum solar radiation. The gear motor controller module is built with low-cost microcontroller with built-in flexibility to accommodate seasonal position adjustments of the PV mounts. The system is configured for a solar radiation condition specific to the location of the system at the Northwest coast. Tracking system will operate with PLC that will command the electric AC motor to rotate the PV panels at specific timings; a gearing system reduces motor speed to 22.5 deg./min. A proximity sensor detects that the correct azimuth incremental change is performed. The above-described steps are executed daily starting at sunrise time minus 30 minutes. The last command is to rotate the system to the standby position which is detected by the limit switch.

Moreover, adjusting the tilting angle of the PV modules will result in a power increase of 7-8%. A simple design is proposed for our PV tracking system. Twelve tilting angles for the whole calendar year are calculated. Actual tilt angles measured during the whole year for AOI PV power plant are used to determine with the average values for each month. A PLC is programmed to command an AC motor engaged to a liner screw actuator to adjust the tilt angles according to the calculated average values. By using the local meteorological data from the area of suggested application, the daily solar radiation at different tilt angles was recorded (Table 4).

Table 4: Actual tilt angles measured during the whole year for AOI PV power plant together with the average values for each month.

Month	Average bet. 7:30 -2:30	Average bet. 10:30-11:30	Average
Jan	55	50	53
	55	53	
Dec	55	53	53
	55	50	
Nov	55	50	49
	53	41	
Oct	53	40	43
	52	30	
Sep	52	28	38
	53	18	
Aug	53	18	32
	52	9	
Jul	52	9	30
	52	7	
Jun	51	7	29
	51	9	
May	51	9	30
	46	18	
Apr	53	19	38
	52	28	
Mar	52	28	43
	53	41	
Feb	53	41	49
	55	50	

Two DC gear motors with selected gear ratio, control the rotation of a dual-axis PV array along and the azimuth (tilt) tracking axis *X*, and the solar tracking axis *Y* as shown in Figure (4).

Figure 4: Tracking mechanical drive

2.6.2. Step 6.2. Peak PV power needs

When the temperature of a photovoltaic module is increased, the efficiency drops due to thermal loses in the PV system. Therefore, using a proper PV cooling system is a mast to keep the temperature at ambient. Moreover, cleaning the PV panels from dust and dirt will also result in higher performance.

a. PV Cleaning system

Experts agree that power losses due to dust and dirt may range as high as 15% in some areas. According to the actual measurements at AOI, PV power plant 10 % losses were found. The present task deals with the design of a simple solar Panel cleaning system to automatically wash the PV modules. The solar panel cleaning subsystem will be controlled by a simple PLC to activate the PV cleaning process. The system can be programmed to wash PV modules at a frequency determined by dust and dirt conditions at the location of system deployment. A single nozzle will be attached to each PV solar panel. Water from the clean water tank is pumped to feed the cleaning nozzles with a copper or plastic line. A small DC pump is required to operate the system. Power requirements of the PV cleaning subsystem can be calculated as follow:

Required fresh water for cleaning PV module = 1.5 L/m^2

Total cleaning time for all modules = 5 minutes

The required volume of fresh water for cleaning a single PV module is

(1.3*2)*1.5 = 4 L

For 6 PV modules the total required volume of fresh water is 24 L

The required flow rate of the cleaning fresh water is 0.3 m^3/h

To perform proper PV cleaning, experience has shown that the exit pressure of the cleaning nozzles should be 2-3 bars. Consequently, power requirement for the PV cleaning subsystem is 67 watt.

2.6.3. Step 6.3: Selecting PV modules and number

To satisfy total peak power requirements of the system, the PV generator will comprise efficient poly crystalline PV modules, a relatively high output power modules is selected to minimize the number of modules for better mobility considerations. The chosen PV panels are TOPSUN TS-S415 with a peak power of 415 W/module and an MPP voltage of 49.53 V/module. The interconnection of the selected PV modules (series/parallel) is configured so that the output voltage of the PV generator will fit with the input voltage of the inverter. 5 KW off grid DC/AC inverter was selected (Table 5).

Table 5: Technical specification of the 5kw Off grid inverter

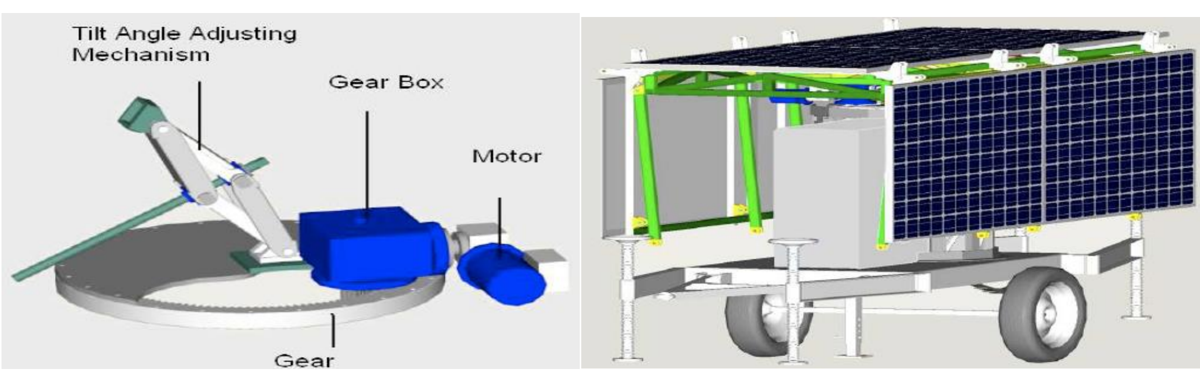
Model	PVES-005
I. Input	
Maximum voltage	DC550V
Voltage range (MPPT range)	DC200-510V
II. Output	
Nominal output power (kw)	5
Nominal AC voltage	AC220V ± 10%
Nominal frequency range	50Hz ± 5%
System specification	
MPPT efficiency	+99%
Conversion efficiency	+95%
Constant	Single phase
Control function	Auto Start & Stop/MPPT/ Auto Voltage Regulation

2.7. Design step 6. Design of mixing water system

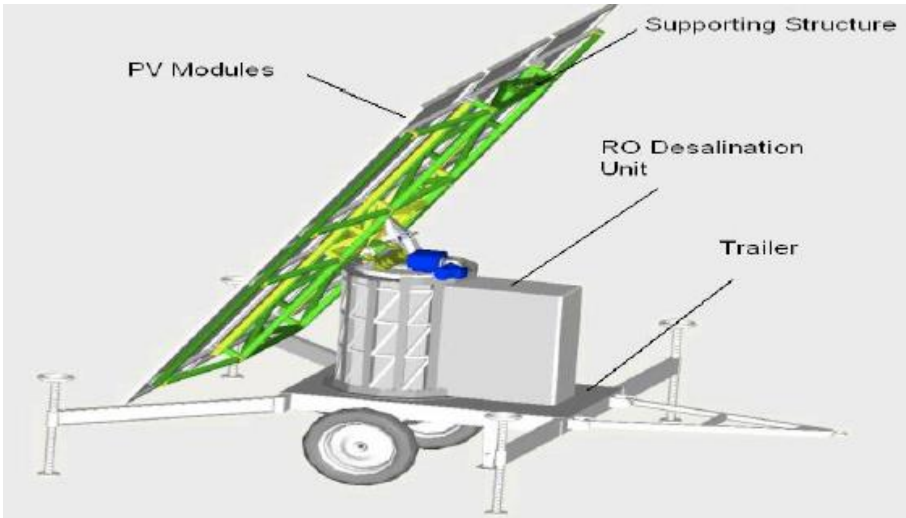
ROSA data shows that some water point, because of their low salinity after the desalination process, will be resulted in water product of very low salinity (less than 500 ppm). Low salinity water product is harmful for human body, but at the same time a good chance for water mixing. Mixing is a process to mix the low salinity water product with feed water under controlled and calculated process to reach the target value of salinity (500 ppm). Thus, resulting in an increasing in the amount of permeate product. Mixing calculation shows that we will be able to increase the permeate product by 52 to 1162 L.

2.8. Structural Design and Materials

The configuration of a foldable PV panel is selected for transportation considerations. The arrangement of PV panel is made as compact as possible such that the middle array is built of two PV modules, and two foldable modules are attached at each side of the middle array. The rotation about the normal axis to the ground is made by means of a slewing internally geared bearing that carries all the tracking system and is supported with a semi-circular cage structure of suitable height to allow partial containment of the RO unit for compactness considerations. The pane-tilting requirement is realized using a scissor jack that is designed with single joint connections to avoid the complexity of the traditional design of the geared links (Fig. 5).



Transportation mode



Operation mode

Figure 5: Main structure design

The structure carrying the PV modules is made by welding using standard square tubes 2” x 2” with various thicknesses (2.1, 3.2, 4.8, 6.4) all are made of commercial steel grade 37 (with yield stress 210~235 N/mm2). Stress analysis was made for the panel carrying structure using software ANSYS 12.0, the structure was modeled using frame and shell elements and solved under the above mentioned pressure loads on the PV modules (Fig 6).

Figure 6: Main structure

2.9. Complete system

The system is equipped with motorized valves for automatic operation as well as conductivity, pH, temperature, flow and pressure meters. Alarm controls for these variables and pressure drop at the membrane automatically monitor a secure plant operation. The PV power generation unit is equipped with power meter as well as temperature sensor for monitoring electrical yield and PV cell temperature. The inverter converts variable DC level to fixed amplitude AC output with fixed frequency to actuate variable speed drive of the high-pressure pump (Figure 7).

Figure 7: Mobile PV/RO Water Desalination Plant

2.10. Testing for PV/RO Water Desalination Plant

Factory testing for the PV power generator system with variable loads shows maximum power of 6.9 Amp. that can cover the power needed for the RO unit to desalinate all kind of water samples (brackish, saline and sea). Meanwhile, testing of the PV/RO desalination plant using synthetic saline feed water contains NaCl with concentration (5000-10500 mg/l) shows permeate salinity ranged from 32-65 mg/l with specific energy consumption (SEC) from 1.0-2.6 kwh/m^3 (Table 6). Finally, Table 7 shows the complete analysis of feed, raw and permeate water related to field-working of the PV/RO unit. Results show that feed groundwater of salinity 10930 µs/cm desalinated to be 53.7 µs/cm permeate water with SEC 1.7 kwh/m^3.

Table 6: Testing the efficiency of the PV/RO unit

Feed salinity (NaCl, mg/l)	Permeate salinity (mg/l)	Power (W)	SEC Kwh/m3
5000	32	866.4	1.9
6200	32	1050.9	2.3
8300	32	1162.8	2.6
10500	65	1143	2.5

Table7: Complete analysis of groundwater sample (Raw), fresh water product (permeate) and reject of the PV/RO desalination unit

1. Analysis of major cations & anions

No.	**pH**	**EC µs/cm**		**Ca^{++}**	**Mg^{++}**	**Na^{+}**	**K^{+}**	**Total cation (epm)**	**CO_3^{--}**	**HCO_3^{-}**	**SO_4^{--}**	**Cl^{-}**	**Total anion (epm)**
Raw	7.6	10930	ppm	168	280.7	1600	65.0	102.69	9.0	271.45	550	3200	106.43
			epm	8.38	23.08	69.57	1.66		0.30	4.449	11.44	90.24	
			%	8.16	22.48	67.74	1.61		0.282	4.180	10.75	84.79	
Reject	7.2	12960	ppm	180.6	362.31	1980	90.0	127.19	21.0	289.75	1100	3720	133.23
			epm	9.01	29.8	86.09	2.29		0.70	4.749	22.88	104.90	
			%	7.08	23.43	67.68	1.80		0.525	3.564	17.17	78.74	
Permeate	7.5	53.7	ppm	3.0	2.9	11.0	1.0		0	7.32	9.0	21.50	
			epm	0.15	0.24	0.478	0.026	0.892	0	0.12	0.19	0.61	0.913
			%	16.78	26.74	53.62	2.86		0	13.13	20.49	66.37	

2. Analysis of heavy metals (mg/l)

Parameter	Raw	Reject	Permeate
Al	<0.04	<0.04	<0.04
B	2.094	2.375	0.8495
Cu	0.0071	<0.006	<0.006
Fe	0.0341	0.04	<0.01
Mn	0.0501	0.064	0.0038
Sr	10.58	12.81	0.0214
Zn	<0.07	<0.07	<0.07
SiO_2	8.939	10.57	Nil

Summery and Conclusion

This work focuses on the integration of brackish water and seawater RO desalination and solar Photovoltaic (PV) technology. A small Mobile PV driven RO desalination plant prototype without batteries was designed. Solar-driven reverse osmosis desalination can potentially break the dependence of conventional desalination on fossil fuels, reduce operational costs, and improve environmental sustainability. Moreover, the innovative features incorporated in the newly designed PV-RO plant prototype are focusing on improving the cost effectiveness of producing drinkable water in remote areas. This was achieved by maximizing energy yield through an integrated automatic single axis PV tracking system with programmed tilting angle adjustment. An autonomous cleaning system for PV modules was adopted for maximizing energy generation efficiency. RO plant components were selected so as to produce 4-5 m^3/day of potable water. A basic criterion in the design of this PV-RO prototype was to produce a minimum amount of fresh water by running the plant during peak sun hours. Results show that feed groundwater of salinity 10930 µs/cm desalinated to be 53.7 µs/cm permeate water with SEC 1.7 kwh/m^3.

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Anti-Scale Magnetic Method as a Prevention Method for Calcium Carbonate Scaling

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Abstract
The effect of anti-scale magnetic method (AMM) in retarding scaling deposition is confirmed by many researchers, to result in new crystal morphology, crystal which has the tendency to remain suspended more than precipitated. AMM is considered as an economic method when compared to other common methods used for scale prevention in desalination plant as acid treatment and addition of antiscalant. The current project was initiated to evaluate the effectiveness of AMM in preventing calcium carbonate scaling. The AMM was tested at different flow velocities (1.0, 0.5, 0.3, 0.1, and 0.003 m/s), different operating temperatures (50, 70, and 90°C), different feed pH and different magnetic field strength. The results showed that AMM was effective in retarding calcium carbonate scaling deposition, and the performance of AMM depends strongly on the flow velocity. The scaling retention time was found to be affected by the operating temperatures, flow velocity, and magnetic strength (MS), and in general, it was found that as the operating temperatures increased the effectiveness of the AMM in retarding calcium carbonate ($CaCO_3$) scaling increased.

Keywords: Magnetic Field Strength, Flow Velocity, Scale Retention Time.

Introduction

Scaling is considered to be the biggest operating problem in desalination plants. The deposition of scales can lead to a decrease in the operating efficiency, and equipment life, as well as increase in the maintenance cost and energy consumption. Calcium carbonate ($CaCO_3$) scaling is considered as the most common scale in all desalination plants especially in reverse osmosis plant and in multistage flashing desalination plants. Therefore, it has received since special attention in desalination plant and at different operating temperatures (Segnit *et al.*, 1962; Langmuir, 1968; Brecevic and Nielsen, 1989; Cubillas *et al.,* 2005; Tarek *et al.,* 2012; Chaussemier *et al.,* 2015). $CaCO_3$ can be precipitated at three different polymorphs such as calcite, vaterite, and aragonite. Aragonite is considered as the easiest form of $CaCO_3$ and can be removed by flushing with water, because it is a soft scale; while calcite is a hard scale and it could usually be avoided by using antiscant or addition of acid. Aragonite is known with a unique morphology or crystal shape, which makes it be suspended more time than calcite scale. Furthermore, the solubility of aragonite is more than the solubility of calcite at the same temperature and condition (Morse *et. al.,* 1980).

Acid addition is considered as a reliable method to prevent calcite scaling in desalination plants, where acid was added to the feed water, to consume part of the bicarbonate in feed water and convert it to a carbon dioxide.

$$H^+ + HCO_3^- \longleftrightarrow CO_2 + H_2O \quad (1)$$

This type of treatment method will result in shifting reaction 2, which is responsible in the precipitation of $CaCO_3$ to the left side, and prevents precipitation of $CaCO_3$.

$$Ca^{+2} + HCO_3^- \longleftrightarrow H^+\uparrow + CaCO_3\downarrow \tag{2}$$

However, acid addition treatment method is always accompanied with corrosion problems and requires special care and precautions. Furthermore, acid cleaning forces the operators to shut down the plant, which could lead to less productivity and low availability. Antiscalant is also considered as a reliable method to prevent calcite precipitation inside desalination plants.

Scale inhibitor can also be considered as a reliable method used for a long time in desalination plant to control $CaCO_3$ scaling. Antiscalant is a chemical impurity that could modify or change the shape, size, and morphology of crystal formed during crystallization or scale formation processes (Greenlee *et. al.*, 2011). Polyelectrolytes as polycarboxylate, polyacrylates and polyphosphate have been reported as efficient inhibitors that could control $CaCO_3$ precipitation, by reacting with mineral nuclei to disrupt the crystallization process and keep the crystal particles dispersed in the scaling solution (Chauhan *et. al.*, 2012). Other types of antiscalant have the ability to retard the crystal growth rate to suppress the scale formation, and then control the scaling processes. The threshold inhibitors are special additives, where threshold inhibitors can retard scale precipitation for a sufficiently long period of time, and the scale will precipitate outside the desalination system. The influence of antiscalant on the precipitation of $CaCO_3$ was investigated by many authors at different operating pH, and the result confirmed the relation between the functional group in the Antiscalant and increasing the induction time (ß), which is the time required for precipitation of $CaCO_3$ (Amjad *et. al*., 1994; Tarek *et. al*., 2012).

Phosphonate antiscalant additives can be classified to be protonated phosphonate group (PO_3H^-) and fully dissociated group (PO_3^{2-}) that work according to adsorption model, where it can inhibit the growth of crystal by adsorption of the reactive surface site. At present, there are various types of phosphonate antiscalant chemicals, such as condensed polyphosphate, organo phosphate, and polyelectrolyte phosphate; however under neutral pH and low temperatures, linear polyphosphonates undergo relatively slow hydrolysis, and the rate of hydrolysis will increase as the operating temperature increases (Gryta, 2012). Furthermore, it is well-known, that special care must be taken to avoid hydrolysis of sodium hexameta phosphate (SHMP) antiscalant in dosing tank, where the hydrolysis process can be described in the following equation.

$$PO_3^- + H_2O \longrightarrow H_2PO_4^{2-} \longrightarrow PO_4^{3-} \tag{3}$$

The hydrolysis will result to losing the effectiveness of the antiscalant in preventing scaling deposition. Furthermore, hydrolysis process can create a phosphonate scaling risk as illustrated in the following equation

$$3Ca^{2+} + 2\,PO_4^{3-} \longrightarrow Ca_3(PO_4)_2 \tag{4}$$

However, high cost is a problem. It has been calculated that the cost of antiscalant chemicals accounts for about 10% in the production of freshwater in Dalian (Li Hai Yan *et. al.*, 2006). In Kuwait, the annual cost for using a low concentration (not exceeding 3 mg/l) of antiscalant chemicals, is about KD0.95 million (MEW, 2010). This annual cost is expected to increase as the production of desalination plant increases.

Even so, Antiscalant chemicals play an important role in preventing $CaCO_3$ precipitation in reverse osmosis system; they are prone to enhance biofilm growth on reverse osmosis membrane by either altering the membrane surface properties or by serving as nutritional source for microorganisms (Sweity *et. al.*, 2013). In addition, many types of chemical antiscalants on the market are harmful to the environment, and could result to serious environmental influence (Chauhan *et. al.*, 2012). Because of this, researchers have looked for a new promising treatment method referred to as anti-scale magnetic treatment method, which is a nonchemical treatment method, and it is expected to reduce the operating cost of desalination plant. Anti-scale magnetic method (AMM) is a physical pretreatment method, which has been applied as a controlling and/or preventing tool for several decades for the deposition of scale in the domestic and industrial water systems.

Although the operating cost of AMM is very low when compared to that of chemical antiscalant method, the AMM is still not totally accepted by the scientific research community. The main reason for that is the lack of repeatable data, where the AMM was reported to work in some applications and not in the others. Furthermore, until now a few and limited researchers have proposed a scientific theory, explaining the work of AMM. In the last few years, the attention to AMM had increased as an attractive, low cost, treatment method, to prevent scaling deposition in desalination plant. A literature survey has been conducted at KISR on the effectiveness of AMM in preventing $CaCO_3$ scaling. It was concluded that the AMM can be considered as an effective method in controlling $CaCO_3$ scaling (Ben Salah, 2015; Cefalas *et. al.*, 2010; Alimi *et. al.*, 2009; Eliassen *et al.* 1985; Hasson and Bramson, 1985; Baker *et. al.*, 1997; Sohnel and Mullin, 1988; Barrett and Barsons, 1998). Moreover, the result of literature survey confirmed that the AMM cannot totally prevent the formation of $CaCO_3$ crystals, but it can affect the scale formation process by increasing the retention or conducting time, producing crystals with different morphology (aragonite morphology), higher tendency for suspension and smaller in sizes, which can be carried out away with the brine water flow without Antiscalant treatment.

Furthermore, it was found that the effectiveness of the AMM method in preventing precipitation of $CaCO_3$ was strongly affected by the chemical properties of the scaling solution, magnetic field strength (MFS), water temperature, and flow velocity (Busch *et. al.*, 1986; Biochenko *et. al.*, 1977; Gryta, 2011; Cai *et. al.*, 2009; Gabrielli *et al.*, 2000). Because of the lower operating cost of AMM and the encouraging results obtained from the literature survey, AMM was tested at desalination research plant (DRP), to assess the effectiveness of the AMM in retarding CaCO3 scaling deposition or increasing the induction time ((ß) at different operating temperatures, different feed water pH and different MFS to identify favorable operating conditions for effective $CaCO_3$ scale prevention. The chemical composition of Kuwait seawater used in the experiments is shown in Table 1, where about 51% of Kuwait seawater showed chloride ions and 29.4% sodium ions. Sulfate ions also compose a high percentage of Kuwait seawater. Scaling of $CaCO_3$ is the dominated scale expected to precipitate when Kuwait seawater is concentrated to one or more concentration factor, as expected by Staff and Davis saturation index, followed by scaling of calcium sulfate, barium sulfate, and strontium sulfate, but with less amount than $CaCO_3$ scaling.

Table 1: The Chemical Composition of Seawater at Doha Site

Parameter	Concentration (mg/l)	% of TDS
pH	8.28	
Temp (°C)	27.38	
Conductivity (ms/cm)	61.8	
TDS (mg/l)	48529	
Turbidity	0.54	
Na^{+} (mg/l)	16353	29.408
Ca^{2+}(mg/l)	1030	1.25
HCO_3^{-} (mg/l)	130	0.327
Cl^{-}(mg/l)	25208	50.8
Mg^{2+}(mg/l)	1536	3.53
SO_4^{2-}(mg/l)	4429	9.49
Ba^{2+}(mg/l)	0.38	
K^{+} (mg/l)	589	1.08
Sr^{2+}(mg/l)	13	0.0308
PO_4^{3-}(mg/l)	0.23	0.0005

Experimental Procedures Description

The AMM testing unit was shown in Fig. 1. The test unit primarily consists of two tanks, A and B, fabricated from glass sheets and located inside two water baths to control the temperature of the tested solution. The testing unit also contained a variable speed pump, needle valves to control the flow, thermometers, a pH adjustment section, and a magnetic field section. The magnetic field section contains a permanent antiscalant magnets treatment unit (AMT)) as shown in Fig. 1 with north and south facing each other, as a source for the magnetic treatment around the pipe. The magnets were positioned orthogonally to the direction of the flow of fluid inside the pipe. Pairs were changed according to the magnetic field strength required. A Tesla meter was used to measure the strength of the magnetic field in each experiment. An automatic titrator, ion chromatography, spectrophotometer DRL/2000, and other instruments were used for analyzing scaling ions such as Ca^{2+} and HCO_3^{-} ions at the Doha Research Plant (DRP).

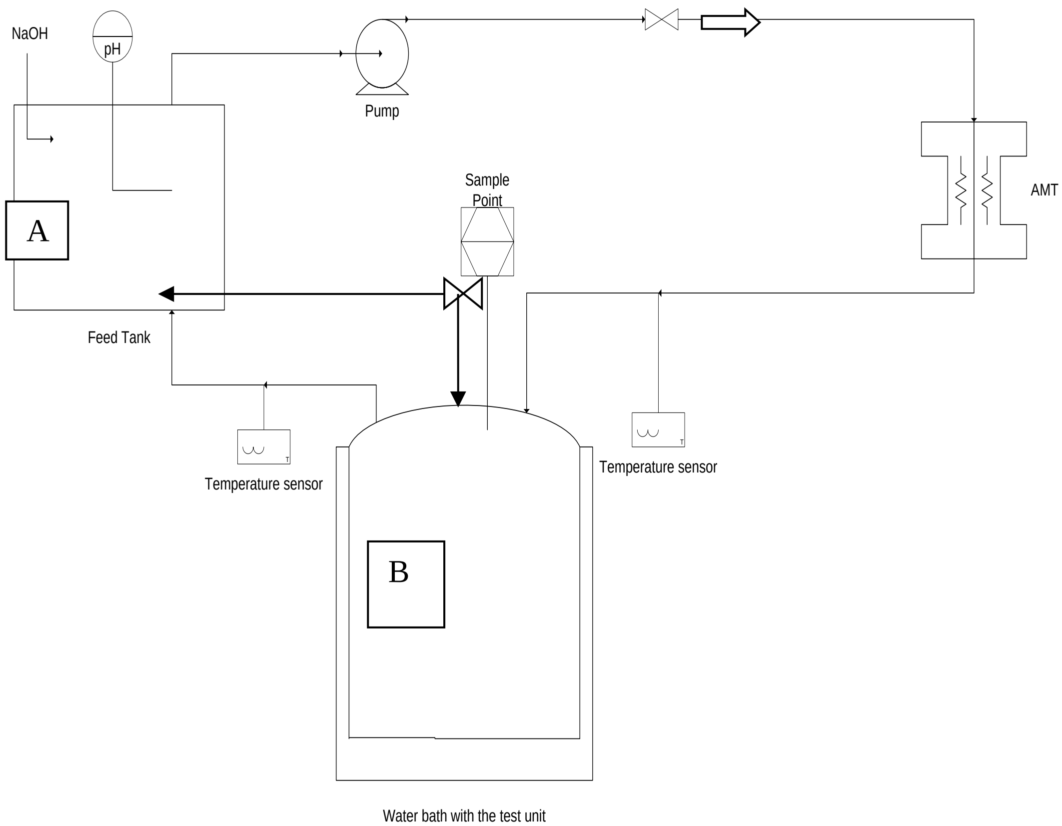

Fig.1: The antiscalant magnetic treatment testing unit

The two tanks, A and B, are connected to each by a valve and a variable speed pump, which was used to pump the test solution from tank A to tank B, and to circulate the test solution through the magnetic fields at a controlled flow velocity. Both tanks A and B were installed inside a water bath to enable temperature controlling during the tests. Two types of solutions were mixed to prepare the required precipitated salt. Calcium carbonate precipitated scaling ($CaCO_3$) was prepared by mixing two solutions, which are 0.5 M of $CaCl_2$ and 0.5 M of Na_2CO_3. Na_2CO_3 solution was considered as the base solution for preparing $CaCO_3$ scaling. Hence, the base solution was prepared at tank A; while $CaCl_2$ was prepared at tank B. First, the pHs of both tested solutions were adjusted to a desirable value using acid. Then, the temperatures were heated to a required testing temperature before mixing the two solutions, using the water baths at both tanks A and B separately. Then, the base solution was circulated through the AMT unit to be magnetically treated without mixing with $CaCl_2$ solution in Tank B, using a controlled valve and variable speed pump, for almost one hour. Then, the solutions were mixed, and the mixing time was considered as time zero for scale formation, and then, the samples were drawn from tank B every minute for bicarbonate analysis to test the effectiveness of the AMT unit in retarding scale deposition and increasing ß. Thus, three MSF were tested (0T, 0.48T and 0.96T), three operating temperature (50, 70 and 90 ºC), two PH values (8.3 and 9.5) and different flow velocities (1.0, 0.5, 0.3, 0.1 and 0.03 m/s).

Results and Discussions
Calcium Carbonate Scaling

The performance of AMM in retarding $CaCO_3$ at a pH of 8.3 and variable magnetic field and operating temperatures, are shown in figs. 2 to 13. Figures 2, 3, and 4 shows the performance of AMM at 0.5 m/s flow velocity, while Figs. 5, 6 and 7 show the performance of AMM at a flow velocity of 0.3 m/s. However, the flow velocity of 0.1 and 0.03 is shown in Figs. 8 to 10 and Figs. 11 to 13 respectively.

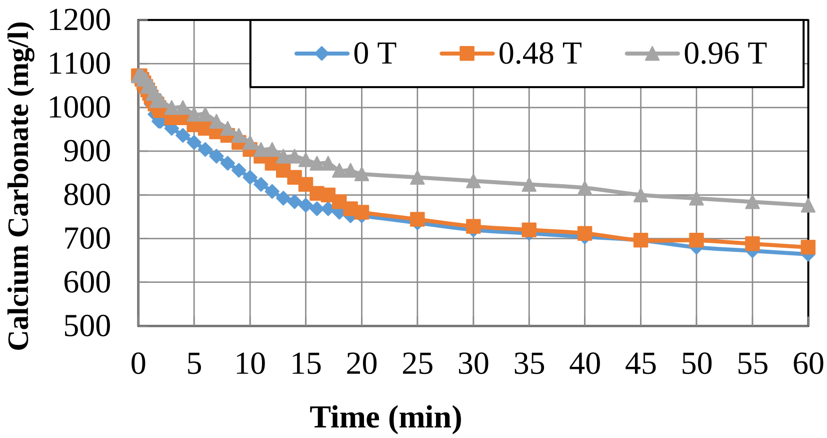

Fig. 2: Calcium carbonate concentration at 0.5 m/s velocity, pH 8.3 and 50°C at different magnetic field

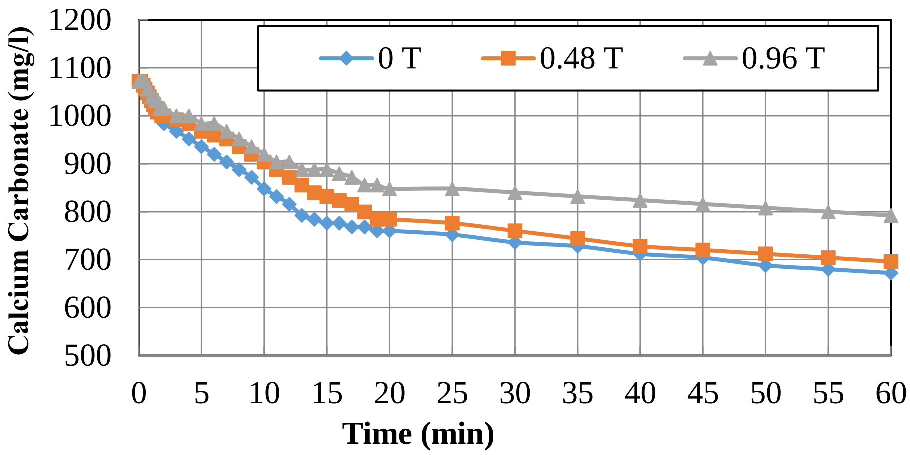

Fig. 3: Calcium carbonate concentration at 0.5 m/s velocity, pH 8.3 and 70°C at different magnetic fields

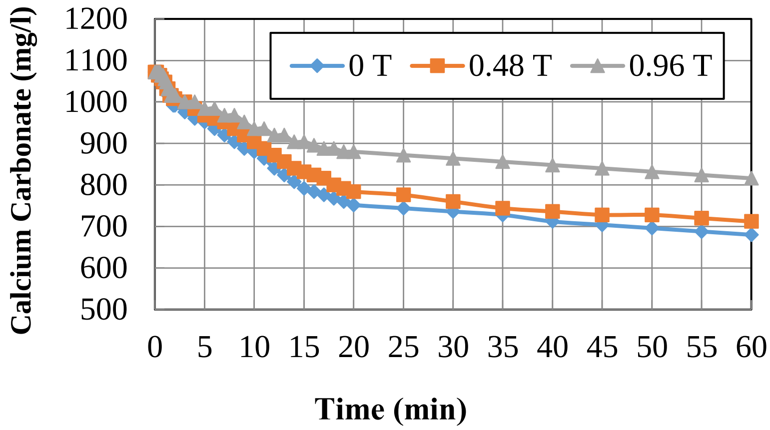

Fig. 4: Calcium carbonate concentration at 0.5 m/s velocity, pH 8.3 and 90°C at different magnetic field

Performance of Magnetic Treatment Method in Retarding Calcium Carbonate at a Flow Velocity of 0.5 m/s. The AMM was tested at three magnetic field strength which are 0 Tesla, (without magnetic treatment method), 0.48 Tesla and 0.96 Tesla. Although the differences between the three magnetic field is not too much clear in Figures 2 to 4. However, it is clear that the ATM decreased the potential for calcium carbonate scaling, and the power for retarding calcium carbonate by AMM can be increased when the applied magnetic field strength (MFS) is increased.

The AMM increased ß for calcium carbonate scaling at a concentration of 1000 mg/l of HCO_3^- from less than 3 min to 5 min at 0.96 T magnetic fields. Moreover, it can retard the carbonate scaling at a concentration of 800 mg/l of HCO_3^- for about 45 min as shown in Fig. 2, when compared to 12 min without applying AMM with increment equal to 2.75 times. The increment in ß is calculated as follows:

$$\text{Increment in ß} = \frac{\text{The retention time ß under AMM} - \text{retention time ß without AMM}}{\text{Retention time ß without AMM}}$$

Thus, it is clear that AMM is a selective treatment. However, knowing that the bicarbonate concentration in Kuwait seawater does not exceed 200 mg/l (Salman et. al., 2013), this implies that the AMM could be effective in retarding calcium carbonate scaling. Figs. 3 and 4 show the performance of AMM in retarding calcium carbonate concentration under pH 8.3 and flow velocity of 0.5 m/s and a temperature of 70°C and 90°C. Both figures show that the AMM could increase ß for about 50 min instead of 12 min without AMM at a concentration of 800 mg/l of calcium carbonate scaling, which represent an increment of 3.16 fold as shown in Figs 3 and 4 under 0.96 T. ß was increased to 60 min when the operating temperature was increased from 70°C to 90°C as shown in Fig. 4.

Performance of Magnetic Treatment Method in Retarding Calcium Carbonate at a Flow Velocity of 0.3 m/s. Figs. 5, 6, and 7 show the performance of AMM at different operating temperatures and different magnetic fields under 0.3 m/s of flow velocity.

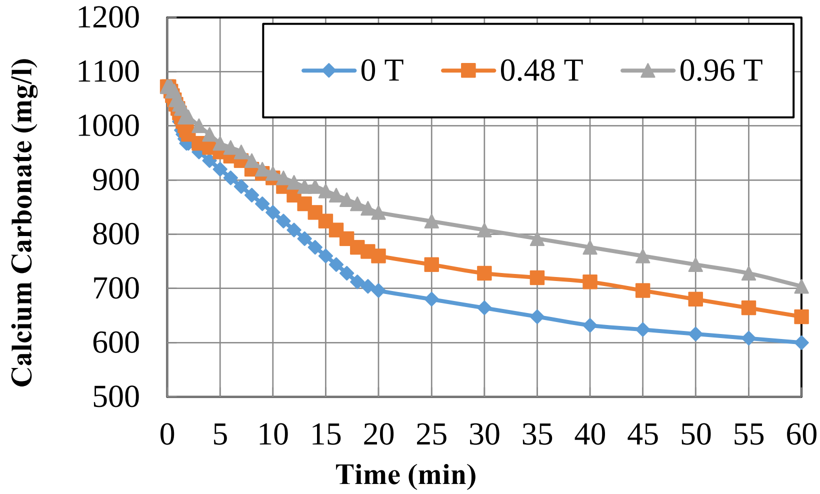

Fig. 5: Calcium carbonate concentration at 0.3 m/s velocity, pH 8.3, and 50°C at different magnetic field

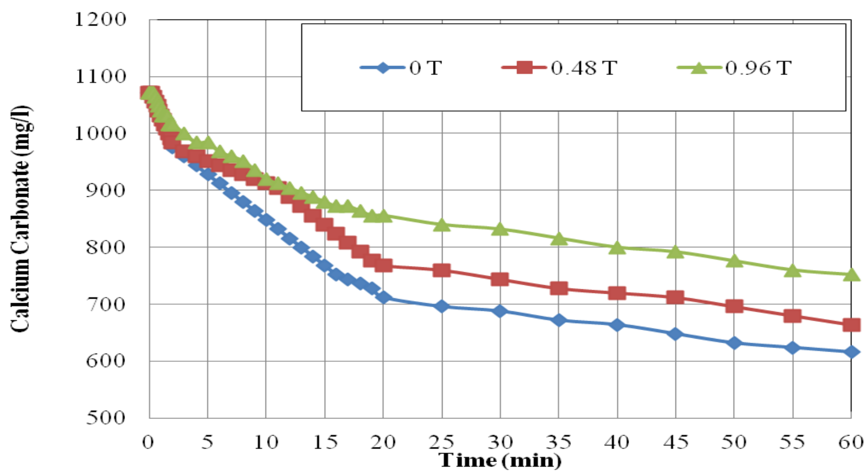

Fig.6: Calcium carbonate concentration at 0.3 m/s velocity, pH 8.3 and 70°C at different magnetic field

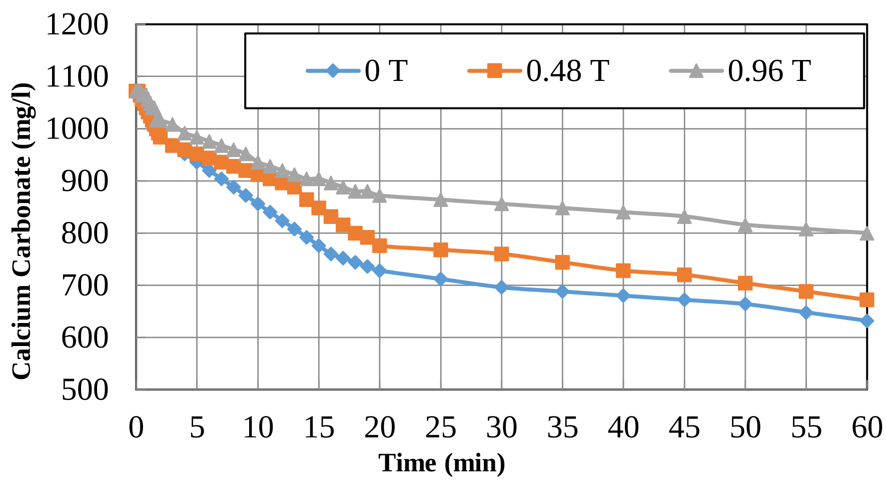

Fig.7: Calcium carbonate concentration at 0.3 m/s velocity, pH 8.3 and 90°C at different magnetic field

From Figs 5, 6, and 7, it is clear that the AMM succeeded in increasing the retention time from 11 min at 800 mg/l of calcium carbonate concentration to about 35 min at 0.96 T and an operating temperature of 50° C as shown in Fig. 5. Moreover, ß was increased from 12 min without AMM to about 40 min at an operating temperature of 70°C and 0.96 T as shown in Fig. 6. The ß at 800 mg/l of calcium carbonate concentration was increased from 14 min to 55 min as shown in Fig. 7.

Performance of Magnetic Treatment Method in Retarding Calcium Carbonate at a Flow Velocity of 0.1 m/s. Figs. 8, 9, and 10 show the performance of AMM at different operating temperatures and different magnetic fields under 0.1 m/s flow velocity.

From Figs. 8, 9, and 10, it is clear that the effective concentration level was decreased from 800 mg/l to about 700 mg/l, where noticeable rice in retention time can be found. The increment in ß at 800 mg/l was almost small and did not exceed 7 min at 0.96 T and an operating temperature of 90° C. However, at a concentration of 700 mg/l, marked rise in retention time ß was noticed. This implies that the performance of AMM decreased strongly, with a decrease in flow velocity, than that of a reduction in operating temperatures.

The AMM succeeded in increasing the ß from 17 min at 700 mg/l of calcium carbonate concentration to about 35 min at 0.96 T and an operating temperature of 50° C as shown in Fig. 8. Moreover, the retention time ß increased from 19 min. without AMM to about 35 min. at an operating temperature of 70°C and 0.96 T as shown in Fig. 9 at the same level of calcium carbonate concentration. However, at 90°C as shown in Fig. 10, the retention time ß at 700 mg/l of calcium carbonate concentration increased from 19 min to 40 min, which is an increase of 110.5 %.

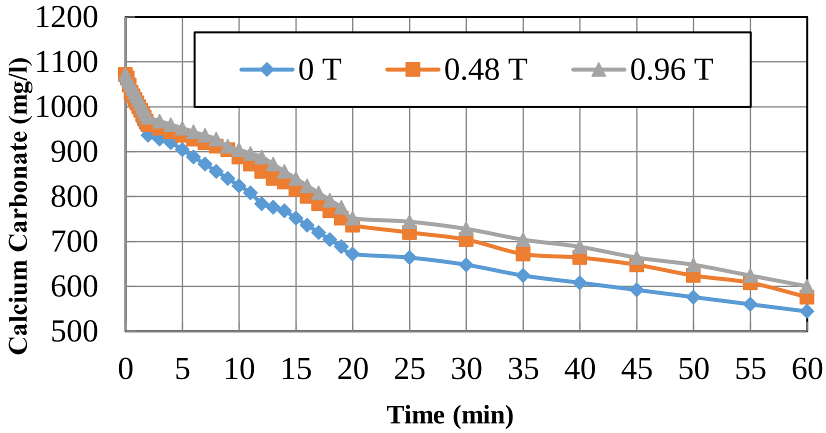

Fig. 8: Calcium carbonate concentration at 0.1 m/s velocity, pH 8.3 and 50°C at different magnetic field

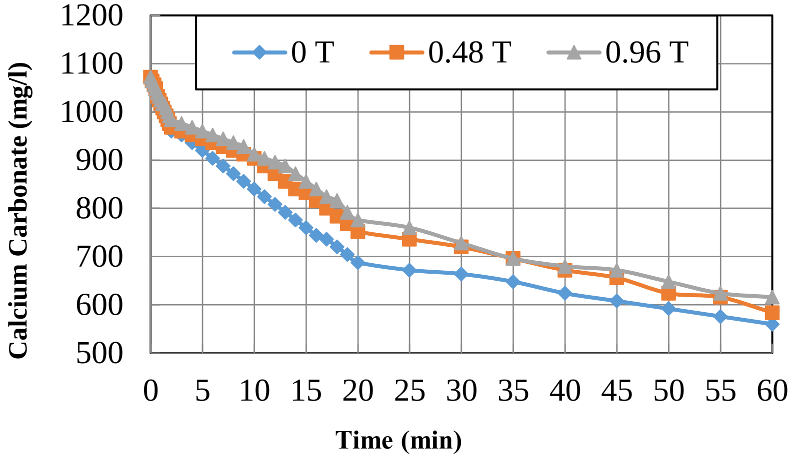

Fig.9: Calcium carbonate concentration at 0.1 m/s velocity, pH 8.3 and 70°C at different magnetic field

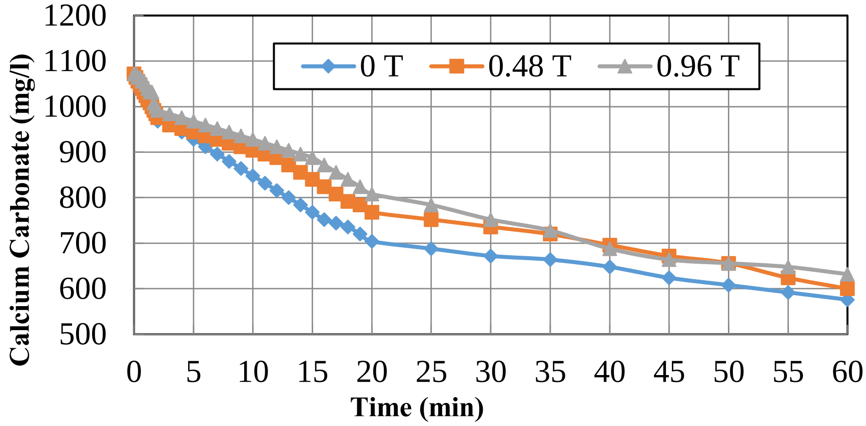

Fig. 10: Calcium carbonate concentration at 0.1 m/s velocity, pH 8.3, and 90°C at different magnetic field

Performance of Anti-Scale Magnetic Treatment Method in Retarding Calcium Carbonate at a Flow Velocity of 0.03 m/s. Figs. 11, و12 and 13 show the performance of AMM at different operating temperatures and at different magnetic fields under 0.03 m/s flow velocity.

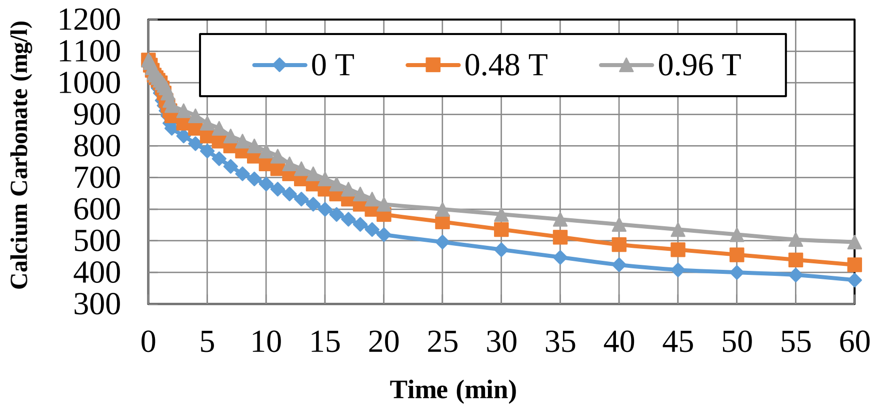

Fig.11: Calcium carbonate concentration at 0.03 m/s velocity, pH 8.3 and 50° C at different magnetic field

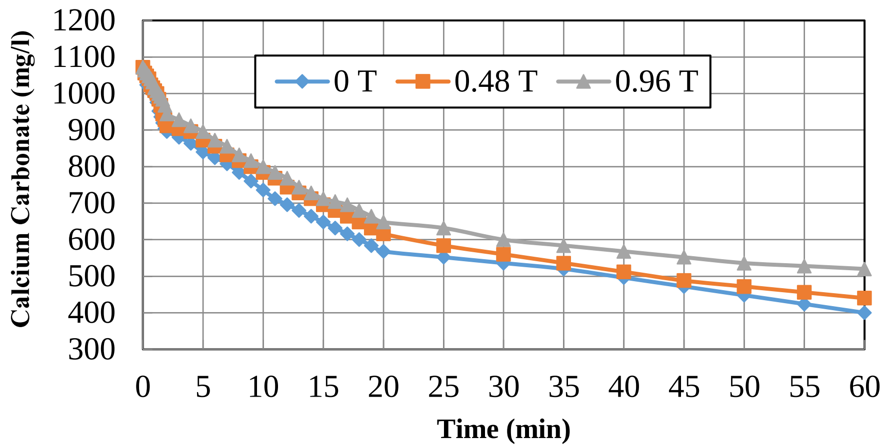

Fig. 12: Calcium carbonate concentration at 0.03 m/s velocity, pH 8.3 and 70° C at different magnetic field

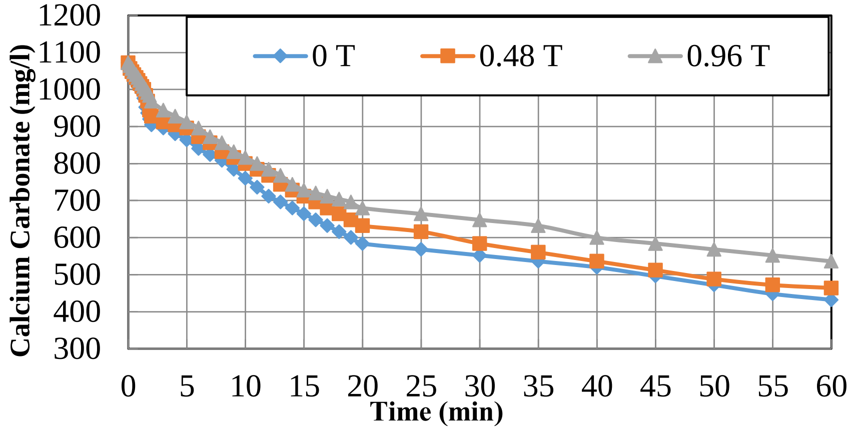

Fig. 13: Calcium carbonate concentration at 0.03 m/s velocity, pH 8.3 and 90° C at different magnetic field

From Figs. 11, 12, and 13 it is clear that the effective concentration level reduced from 700 mg/l at flow velocity of 0.1 m/s to about 500 mg/l at a flow velocity of 0.03 m/s, where a noticeable increment in the retention time can be found. Thus, the increment in ß at 700 mg/l was almost small and did not exceed 7 min at 0.96 T and operating temperature of 90°C. However, at a concentration of 500 mg/l, a big increment in retention time can be noticed. This confirms the fact concluded before, where the performance of AMM decreased more strongly with a decrease in flow velocity, than that of the decrease in operating temperatures or a decrease in magnetic field strength.

The AMM succeeded in increasing the retention time from 20 min at 500 mg/l of bicarbonate concentration to about 55 min at 0.96 T and an operating temperature of 50°C as shown in Fig. 11. Moreover, the retention time increased from 20 min without AMM to about 55 min. at an operating temperature of 70°C and 0.96 T as shown in Fig. 12 at a concentration level of 550 mg/l of bicarbonate. However, at 90°C as shown in Fig. 13, the retention time at 700 mg/l of bicarbonate concentration increased from 19 min to 40 min, which represents an increment of 110.5 %.

Performance of Magnetic Treatment Method in Retarding Calcium Carbonate at pH of 9.5. Figures 14 to 16 show the performance of the AMM at a flow velocity of 0.5 m/s at different operating temperatures at different magnetic field strengths and a higher pH of 9.5.

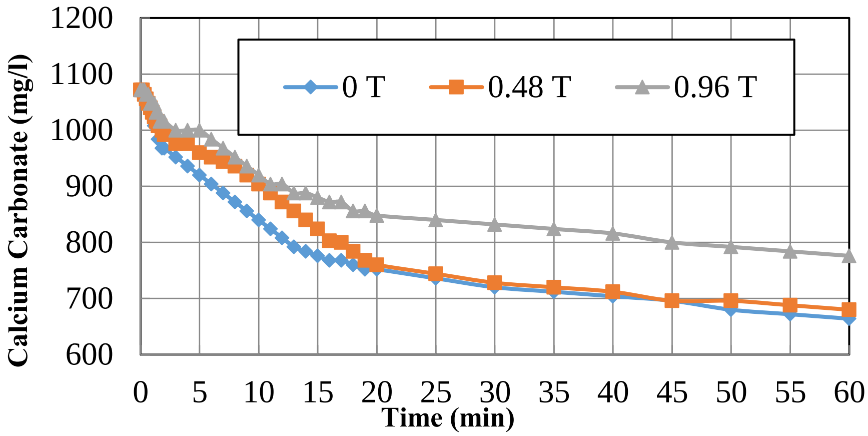

Fig.14: Calcium carbonate concentration at 0.5 m/s velocity, pH 9.5, and 50°C at different magnetic fields

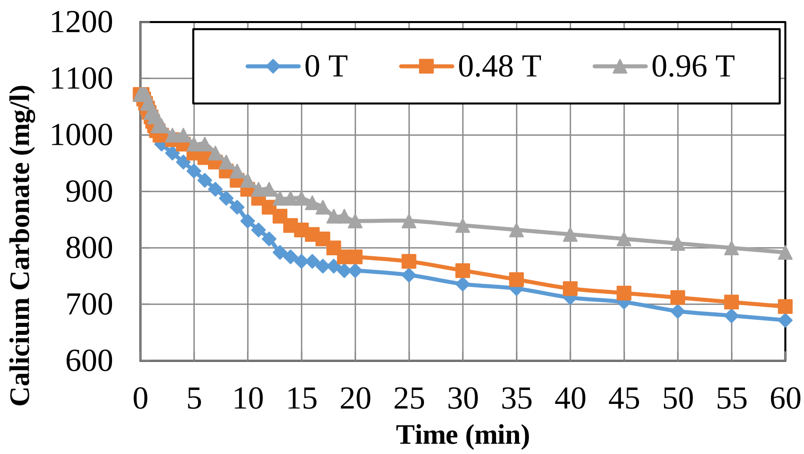

Fig.15: Calcium carbonate concentration at 0.5 m/s velocity, pH 9.5, and 70°C at different magnetic fields.

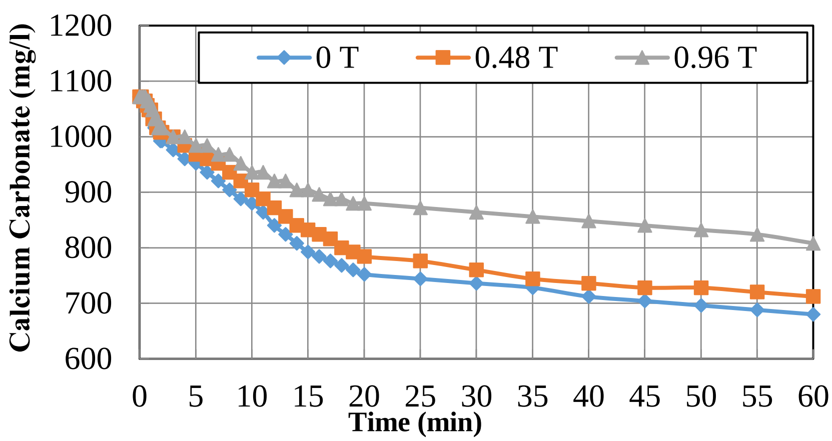

Fig.16: Calcium carbonate concentration at 0.5m/s velocity, pH 9.5, and 90°C at different magnetic fields

The result showed a similar performance of AMM at 9.5 to that at pH 8.3. At pH of 9.5, the AMM effectiveness was found to be increasing with increasing magnetic field from 0.48 T to 0.96 T as shown in Fig. 14. This trend was observed also at 70 and 90°C (Figs. 15 and 16).

It is clear from Fig. 14that the AMM at a pH of 9.5 and flow velocity of 0.5 m/s increased the retention time at 800 mg/l from 12 min to about 45 min using 0.96 T magnetic fields with an increment of 2.75 equal to exactly the increment at a pH 8.3. On the other hand, the retention time increased from 12 to about 55 min at 800 mg/l concentration as shown in Fig. 15. However, the AMM could increase the retention time at 800 mg/l from 14 min to about more than 60 min, as shown in Fig 16. Hence, we can conclude that the AMM shows the same performance at a pH of 8.3 and 9.5.

Critical Flow Velocity Using Magnetic Treatment Method for Retarding Calcium Carbonate. Table 2 summarizes the performance of AMM at different flow velocities where it is clear that the critical velocity was 0.5 m/s for calcium carbonate scaling, and when the flow velocity exceeded this value, the AMM was not a more effective method in retarding carbonate scale as shown in Table 2.

Table 2: The Effect of Different Flow Velocity on the Performance of Magnetic Treatment Method for Retarding Calcium Carbonate Scaling Solution

Flow Velocity (m/s)	Effectiveness
1.0	No effect
0.5	Effective
0.3	Effective
0.1	Effective
0.03	Effective

The performance of AMM in retarding calcium carbonate at different flow velocities is presented in Figs. 17, 18, and 19 for four flow velocities (0.5, 0.3, 0.1, and 0.03) and the three operating temperatures as 50, 70, and 90°C.

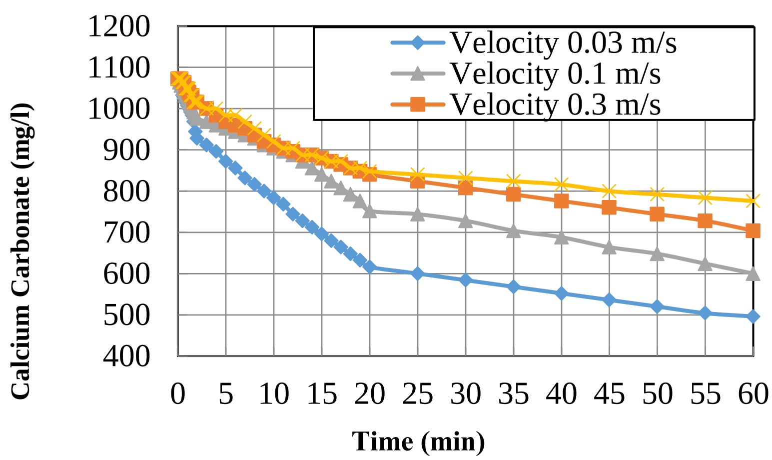

Fig. 17: Calcium carbonate concentration at pH 8.3, 50°C, and 0.96 T magnetic fields at different velocities

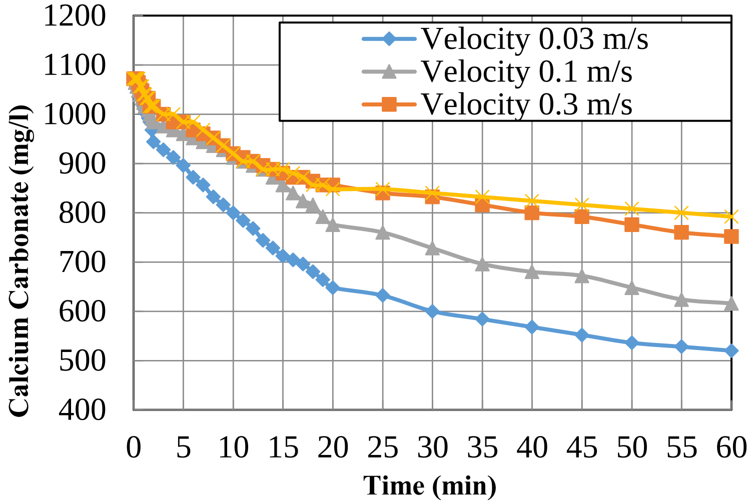

Fig. 18: Calcium carbonate concentration at pH 8.3, 70°C, and 0.96 T magnetic field at different velocities

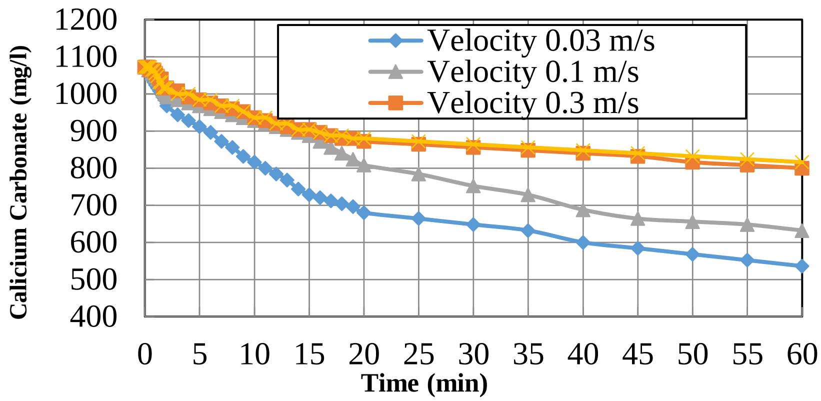

Fig. 19: Calcium carbonate concentration at pH 8.3, 90°C, and 0.96 T magnetic field at different velocities

Fig. 17 shows the performance of AMM at 50°C; while Figs. 18 and 19 show the performance of AMM in retarding calcium carbonate at 70 and 90°C, respectively.

It is clear from Fig. 17 that the effective concentration decreased as the flow velocity decreased, where at 0.5 m/s, the effective concentration was 800 mg/l which decreased to 500 mg/l at a flow velocity of 0.03 m/s. It can be concluded from Fig. 17 that the performance of AMM improved when the flow velocity increased from 0.03 m/s to 0.1, then to 0.3, until a critical flow velocity, equal to 0.5 m/s was reached. After the critical flow velocity, the effect of AMM would be demolished.

Figures. 18 and 19 confirm the fact that as the flow velocity increased, the effectiveness of AMM in retarding calcium carbonate increased. Furthermore, Figs. 18 and 19 confirm the effect of temperatures, where, as the operating temperature increases, the performance of AMM improved.

Performance of Magnetic Treatment Method in Retarding Calcium Carbonate at Different Operating Temperatures. Figures. 20, 21, 22, and 23 show the effect of different operating temperatures on the performance of AMM under the highest magnetic field strength at 0.96 T and a pH of 8.3, and different operating temperature.

It can be concluded from Fig. 20 that when the flow velocity was low at 0.03 m/s, the calcium carbonate scaling can be retarded for about 20 min at 50°C and a concentration of 600 mg/l, the retention time increased to 30 min when the operating temperature increased to 70°C. However, the retention time increased to 40 min when the temperature increased to 90°C.

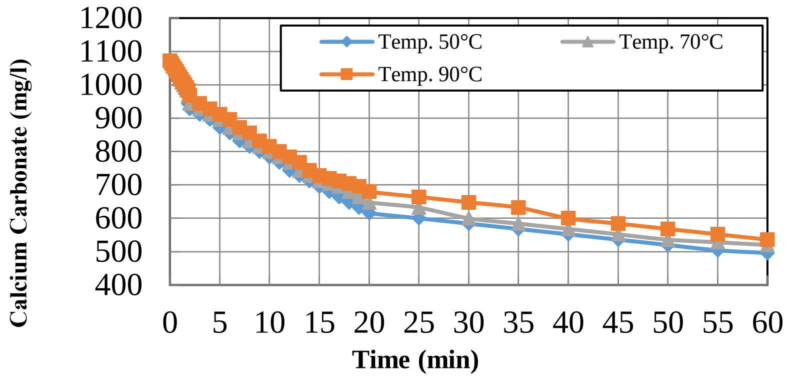

Fig. 20: Calcium carbonate concentration at 0.03 m/s velocity, pH 8.3, and 0.96 T magnetic field at different temperatures.

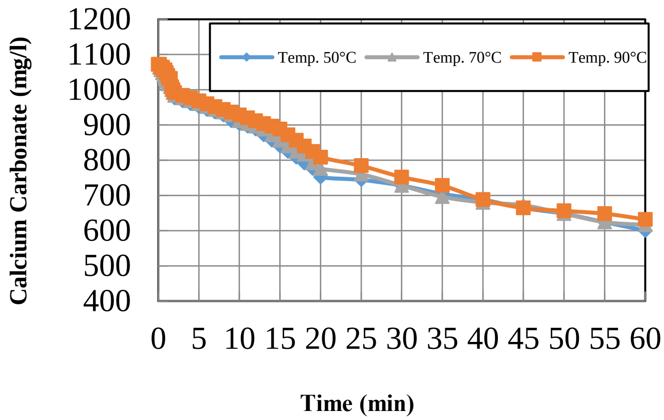

Fig. 21: Calcium carbonate concentration at 0.1 m/s velocity, pH 8.3, and 0.96 T magnetic field at different temperatures.

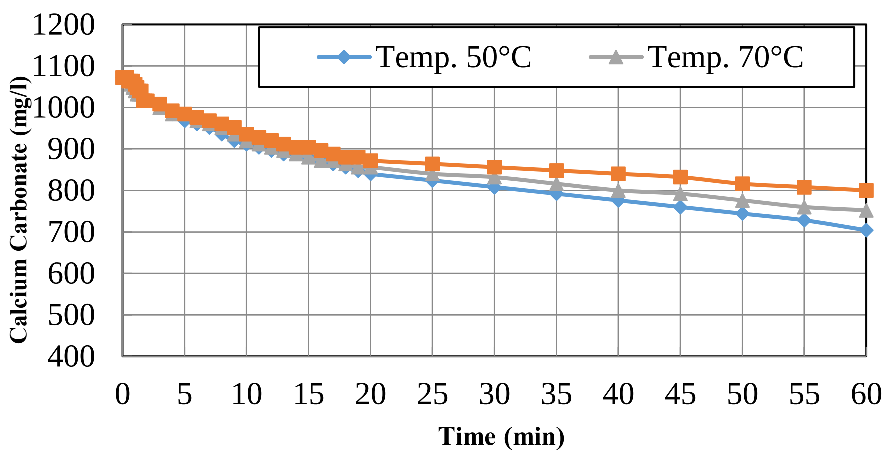

Fig. 22: Calcium carbonate concentration at 0.3 m/s velocity, pH 8.3, and 0.96 T magnetic field at different temperatures.

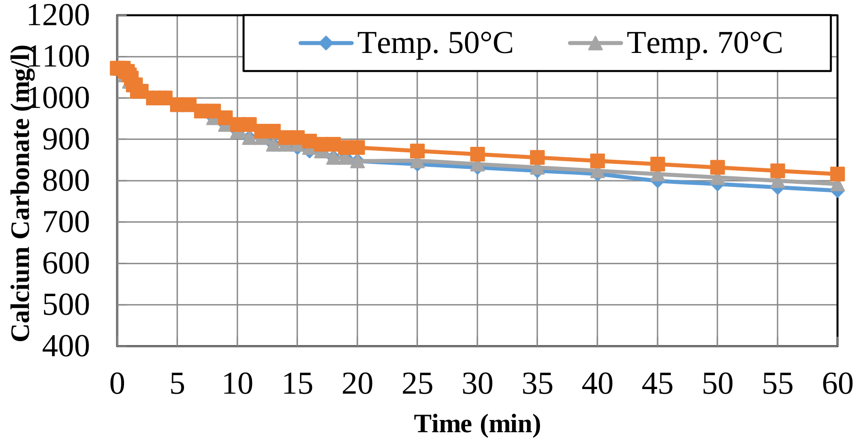

Fig. 23: Calcium carbonate concentration at 0.5 m/s velocity, pH 8.3, and 0.96 T magnetic field at different temperatures

The same trend in Fig. 20 was observed within Figs. 21, 22, and 23 as the temperature increased and the retention time increased, which implies that as the operating temperature increased, the performance of AMM in retarding the calcium carbonate scale improved.

Effect of pH on the Performance of Magnetic Treatment Method in Retarding Calcium Carbonate. Figures 24 to 26 show the effect of different pH on the performance of AMM under 0.5 m/s flow velocity and a variable operating temperature and magnetic field.

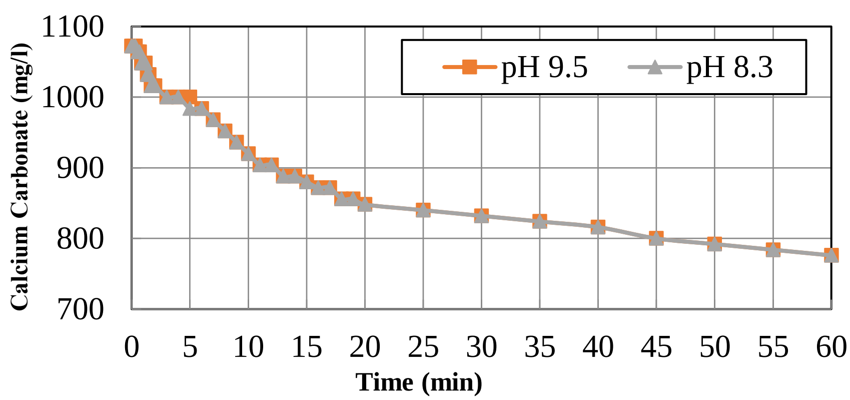

Fig. 24: Calcium carbonate concentration at 0.5 m/s velocity, 50°C, and 0.96 T magnetic field at different pH

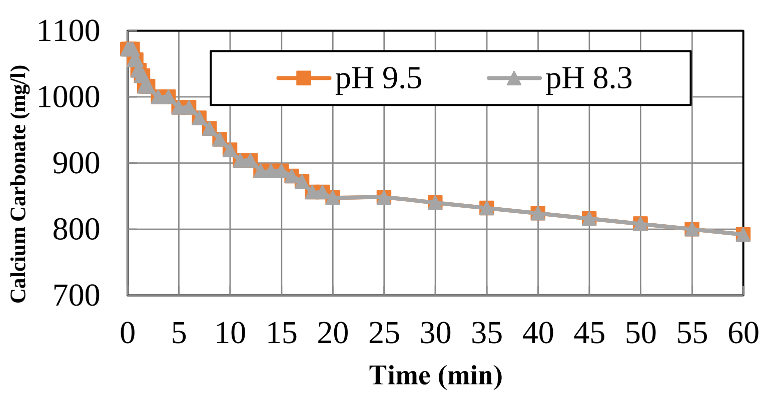

Fig. 25: Calcium carbonate concentration at 0.5 m/s velocity, 70°C, and 0.96 T MFS and different pHs

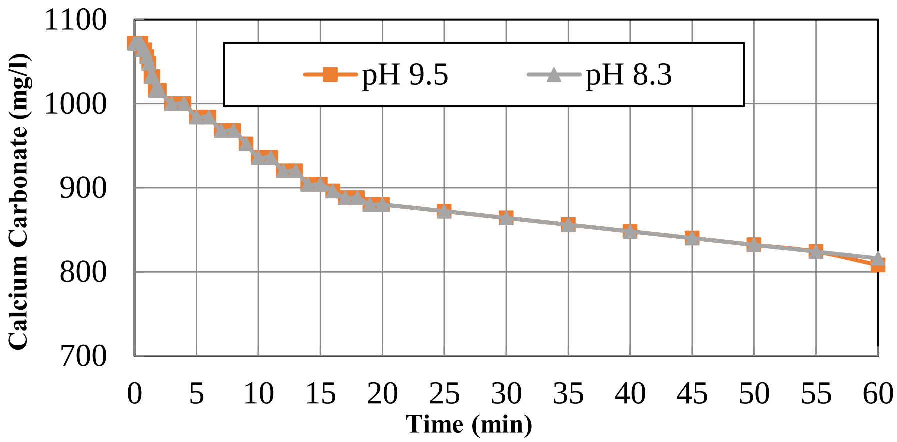

Fig. 26: Calcium carbonate concentration at 0.5 m/s velocity, 90°C, and 0.96 T MFS at different pHs

It was found that from previous Figs. 23, 24, 25, and 26, the effect of pH on the performance of AMM in retarding calcium carbonate at high flow velocity (0.5 m/s) was negligible, where a similar effect was found in Figs. 24, 25, and 26. Hence, pH cannot be considered an effective parameter on the performance of AMM in retarding calcium carbonate scaling.

Conclusion

Based on the test results and data analysis, the following conclusions have been derived:

- It was confirmed that the effectiveness of AMM increased as the magnetic field strength increased.
- The performance of AMM in retarding calcium carbonate could depend on different parameters as flow velocity, operating temperatures, and magnetic strength.
- AMM decreased the potential of calcium carbonate scaling, at a concentration of 800 mg/s of calcium carbonate and at a flow velocity of 0.5 m/s by a three-fold increase.
- The power to retard calcium carbonate using AMM increased when the applied magnetic field was increased.
- The power to retard calcium carbonate using AMM increased when the operating temperatures were increased.
- AMM was effective in retarding calcium carbonate at a concentration level of 700 mg/l when the flow velocity was 0.1. However, the effective concentration level decreased to 500 mg/l as the flow velocity decreased to 0.03 m/s.
- The flow velocity is the key parameter of the performance of AMM in retarding calcium carbonate, while other effecting parameters had lower effect on the performance of AMM in retarding calcium carbonate.
- The performance of AMM in retarding calcium carbonate scaling at pH 8.3 and 9.5 was found to be similar, and the pH cannot be considered an effective parameter on the performance of AMM in retarding calcium carbonate scaling.

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Cost Effective - High Performance Scale Inhibitor for Thermal Desalination MSF Unit

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Abstract
Thermal desalination Plant's performance and distillate production (Distillate) are strongly affected by the capability of the scale control chemical treatment to keep heat exchange surfaces1,2, brine heater tubes, demister pads and flash chamber free of deposits (i.e. scale deposits) during normal operation of the units. To keep the heat exchange surfaces in high performance and clean condition the formation of calcium carbonate should be effectively controlled by using highly effective scale inhibitor 3,4. A good plant design combined with a careful plant operation and high performance antiscalant ALBRIVAP® DSB (M) A are the key factors in inhibiting the scale formation and avoidance of repeating the acid cleaning 5,6
A vast range of research and field trials have been carried out to find the most cost-effective scale control technologies for thermal desalination. In this work the new, recently developed Italmatch's antiscalant **'ALBRIVAP® DSB (M) A'** has been tested on MSF units in UAE. The trials have been executed on two different units, manufactured by Fisia Italimpianti having a capacity of 17.5 MIGD and Weir Westgarth unit having a capacity 7.5 MIGD. The performance of the two units has been monitored for 3 month trial period at different Top Brine Temperatures (TBT) in the range between 105-110 ^{o}C with the objective to optimize antiscalant dose rate. The operation parameters were closely monitored all over the trial period and the heat exchange surface inspection has been executed after the trial. In this work, we represent the performance of the scale inhibitor in 7.5 MIGD Weir Westgarth unit and prove its efficiency to maintain the maximum unit efficiency at low dosing as low as 2 pm.

Key words: Thermal Desalination, Scale Inhibitor, Antiscalant, Desalination Plant.

1. Introduction

ALBRIVAP® DSB (M) A is an advanced liquid antiscalant treatment manufactured by Italmatch for use in sea water evaporative desalination processes.
DEWA granted permission for a 90 days trial of this ALBRIVAP® product to be carried out on one of the units of "G" Station - a multi stage flash sea water evaporator manufactured by Weir Westgarth. This trial, intended to prequalify the ALBRIVAP® product for use on the Weir Westgarth units, started with commissioning on 21st of March 2015 following a pre-trial inspection of the Distillation Unit.
A trial schedule (below) agreed with DEWA outlined the Top Brine Temperature (TBT) and antiscalant dose rate to be followed during the 90 days trial period.
This report summarises the performance parameters monitored during the 97 days of the trial.

2. Performance Monitoring

With ALBRIVAP DSB(M)A having the unique property of being readily detectable in the recirculating brine stream a combination of chemical and thermal monitoring techniques could be used to assess product antiscalant performance.

- The thermal performance of the unit was assessed by monitoring:
- Distillate production relative to flash range and recycle brine flow.
- Gained Output Ratio.
- Heat Transfer Coefficients for the Brine Heater & Heat Recovery sections.

The brine chemistry of the unit was assessed by monitoring:

- Recycle Brine concentration relative to make up water quality.
- Recycle Brine alkalinity relative to make up water quality.
- Residual of antiscalant remained in recycle brine after adsorption onto the surface of active crystallites.

The criteria used for assessing an acceptable product performance were considered to be:

1. The stability of thermal performance including distiller output, GOR and Heat Transfer Coefficient.
2. An acceptable level of deposition within the unit on final inspection and the absence of hard alkaline scale deposits on heat transfer surfaces.

To meet these criteria for a successful antiscalant performance Italmatch recommended that a minimum level of 1.5 ppm of reserve antiscalant should be present in the recirculating brine stream under all operational conditions. In terms of actual operational activity it should be noted that some deviations from the originally agreed plan occurred and this is due to some operational complications which is solved within very short time and it is noted in the graphs as drop peaks. The trend analysis generated from the data collected is presented in the sections below and includes supporting comments relevant to the Unit's operation.

2.1. Thermal Efficiency

Figure 1 shows the temperature behaviour through the 97 days; the Sea water temperature, Brine bottom temperature and the Make-up temperature are increasing in parallel towards the end of the 97 days which is normal at this at this time of the year. Due to the increase in the temperature the flash range decreases towards the end of the trial.

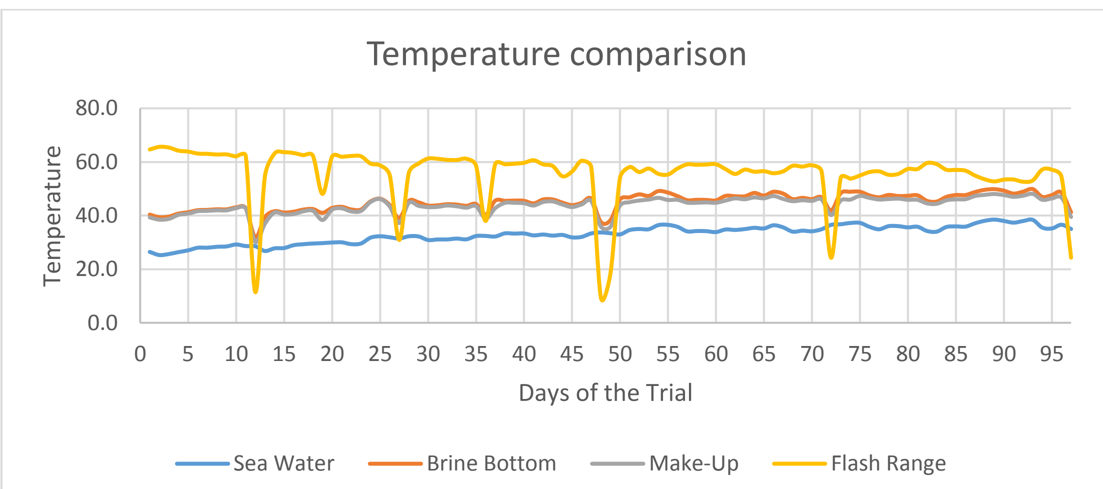

Figure 1: Temperature behaviour through the 90 days of the trial

The Top Brine Temperature shown in Figure 2 has been maintained on the range of the planed protocol of the trial and it has kept within +/- 2 degrees around the 105 ^{o}C all over the 97 days of the trial.

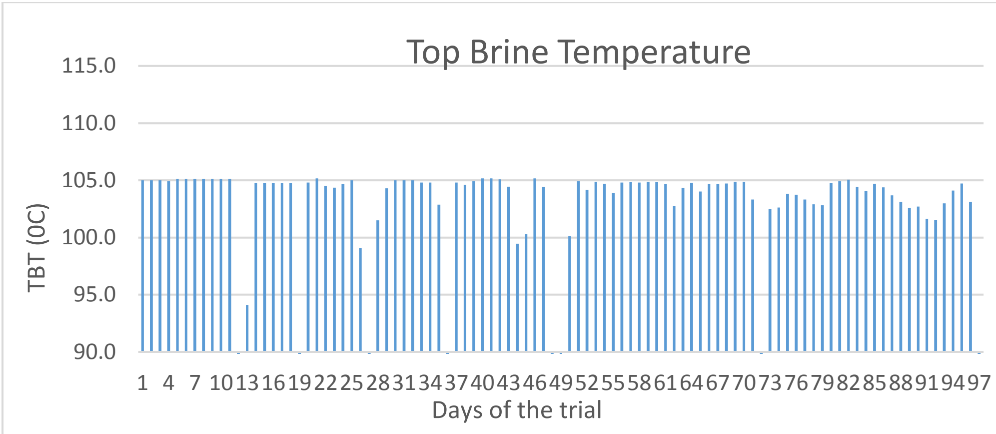

Figure 2: The Top Brine temperature through 90 days of the trial

2.1.1.Distillate Production versus Flash Range

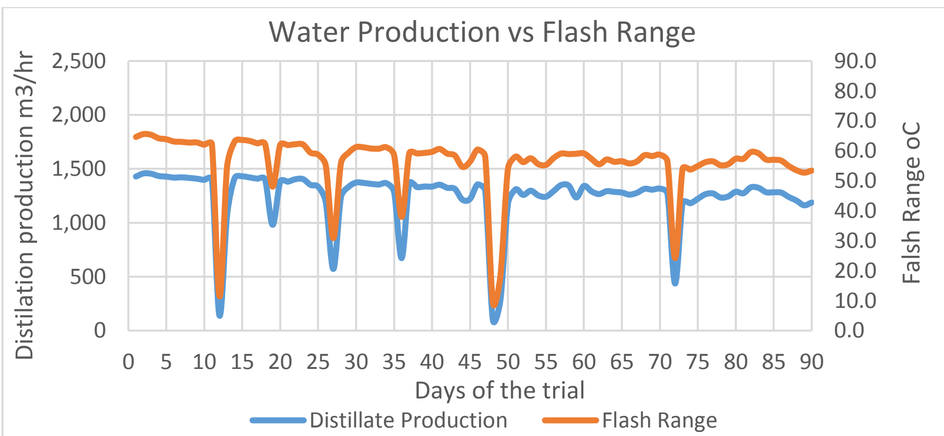

Figure 3: Effect of Flash range on the production rate

Figure 3 is showing the effect of the flash range on the production rate. The distillate production rate has the average 1343 m^3/hr all over the trial period at the average 105^0C TBT (excluding tripping days) which is within 6% of the design figure (Original conditions) of 1421 m^3/hr. As shown in the figure the distillate production generally tracked the trend in Flash Range throughout the operating period.

2.1.2.Distillate Production versus Recycle Brine Flow

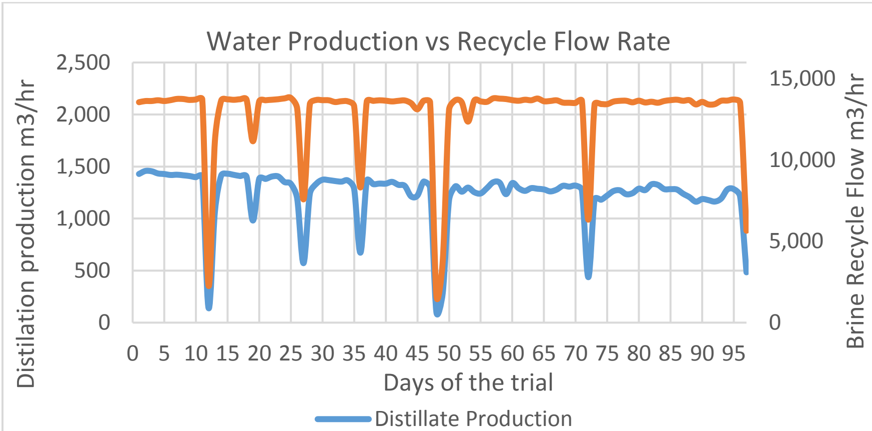

Figure 4: Relationship between Bribe recycle flow rate and production rate

Figure 4 show that the Recycle brine flow averaged 13,985 m^3/hr for the trial period (excluding the tripping days) which is in line with design condition (14213 m^3/hr). The Flash Range was therefore the key parameter dictating the fluctuations in distillate production.

The Recycle Brine flow rate has a slight effect on the product because it has been maintained constant most of the trial period.

2.1.3.Distillate Quality

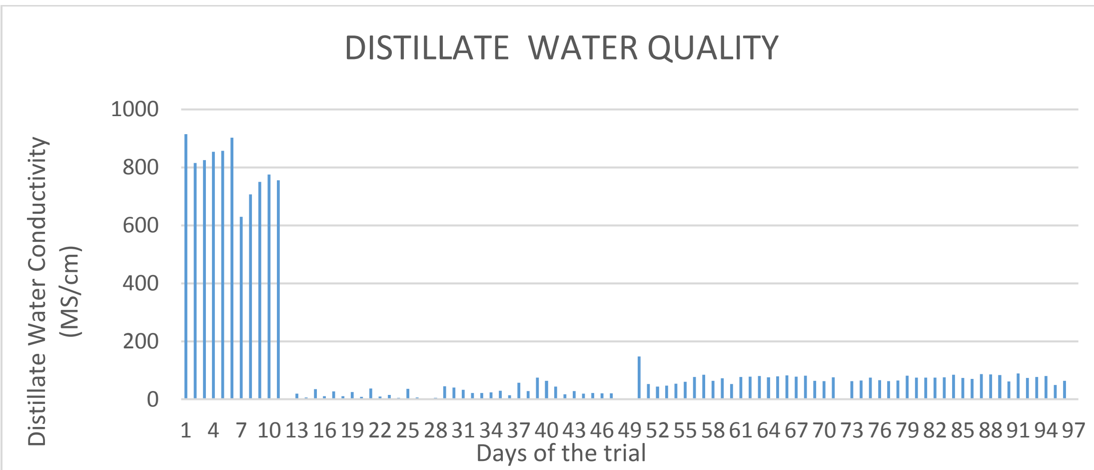

Figure 5: Distillate behaviour through the 90 days trial

As shown in Figure 5 apart from the high values in the first two weeks due to leaking problems the distillate conductivity was maintained below 100 µS/cm for the trial period with minor interruption due to antifoam flow disturbance.

2.1.4.Gained Output Ratio

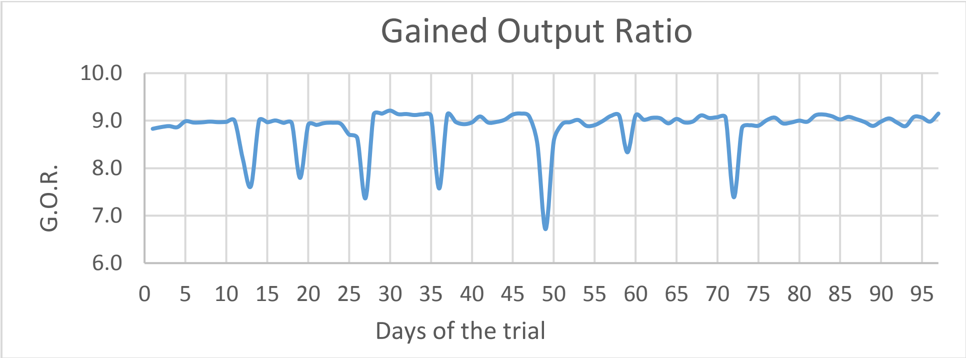

Figure 6: Gain-output Ratio (G.O.R) behaviour on the 90 days trial

From Figure 6 it is noticeable that GOR trend in the same range all over the trial period and has the average value of 9 with slight increase towards the end due to improve in the performance. This is a strong indicator that the antiscalant chemical is performing efficiently in controlling any deposits in a soft and easily removed form.
The GOR trend for this operating period compares favorably with that of the baseline at the beginning of the trial on 21st of March 2015
There was no indicated loss of efficiency during the high temperature evaluation period covering the tripping days.

2.1.5. Heat Transfer Coefficient – Brine Heater (Heat Input Section)

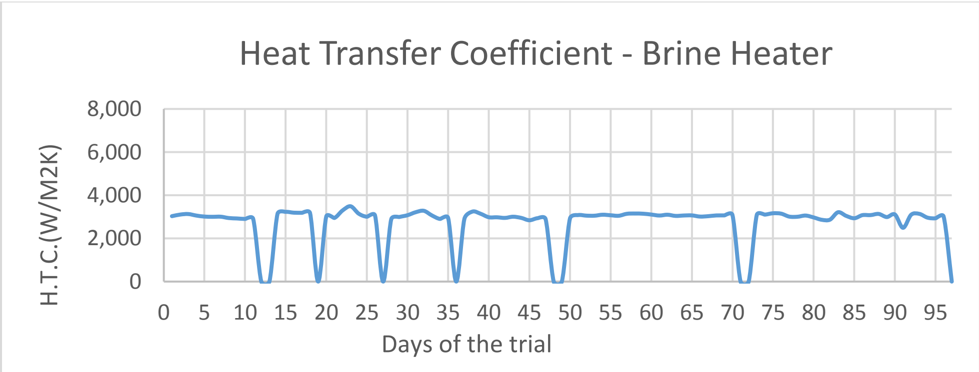

Figure 7: Behaviour of Heat Transfer Coefficient for brine heater throughout the 90 days trial

The Heat transfer Coefficient of the brine heater Figure 7 has the average value of 2962 (w/m^{2}k) all over the trial period and well maintained in the same range towards the end of the trial. The graph drops in the tripping days. The thermal efficiency of the Brine Heater is best illustrated by the Fouling Resistance trend Figure 8 which shows the Brine Heater to be maintained in the same range despite the tripping days and with no evidence of alkaline scale fouling.

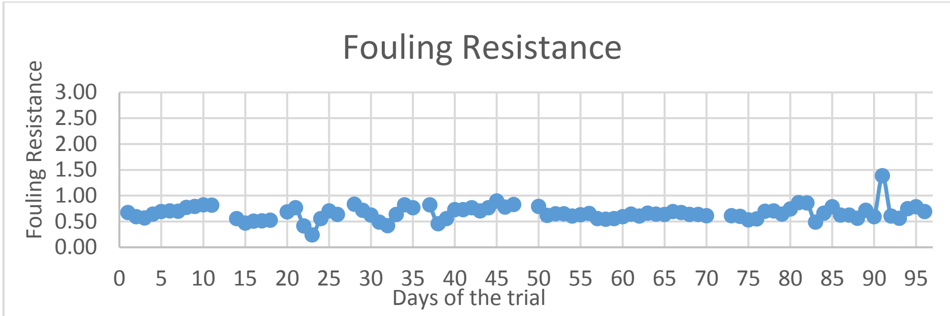

Figure 8: Fouling Resistance behaviour throughout 90 days trial period

It is noticeable that the fouling resistance was maintained in same range all over the trial period. There is enough evidence that the efficiency of the ball cleaning system has a major effect on the fouling as the amount of replaced balls increased the fouling values decreased to the normal values.

The fact that the thermal efficiency of the brine heater recovered quickly following the replacement of lost / damaged balls is a strong indicator that any deposits formed within the unit are in a soft, easily removed form which is confirmation that the antiscalant is functioning efficiently.

2.1.6. Heat Transfer Coefficient – Heat Recovery Section

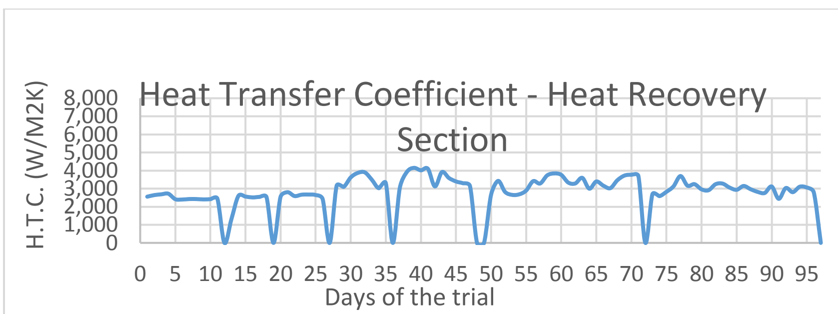

Figure 9: Heat Transfer Coefficient of Heat Recovery

With 16 Stages the Heat Transfer Coefficient of the Heat Recovery Section is notoriously difficult to monitor. However the readings shows that the values are kept in the same range all over the trial period with a noticed improving towards the end of the trial after the maintenance in Day 27**.**

2.1.7. Ball Cleaning System Performance

The ball cleaning system (BCS) was operated at the recommended frequency of 24 cycles per day throughout the trial period. The ball charge was that recommended at 500 blue + 500 red making a total charge of 1000 balls. The balls were checked and sorted once per week and any lost or damaged balls replaced. In addition the complete ball charge was replaced every 4^{th} week.

The percentage of balls replaced at each sorting operation is recorded below shown in Figure 10. It was noticeable that, following the replacement of lost balls the fouling is decreased. This recovery is a strong indicator that the antiscalant is working effectively by controlling any deposits formed in a soft mobile form that can be easily removed by the action of ball cleaning and limited in mass by the shear force of the circulating brine.

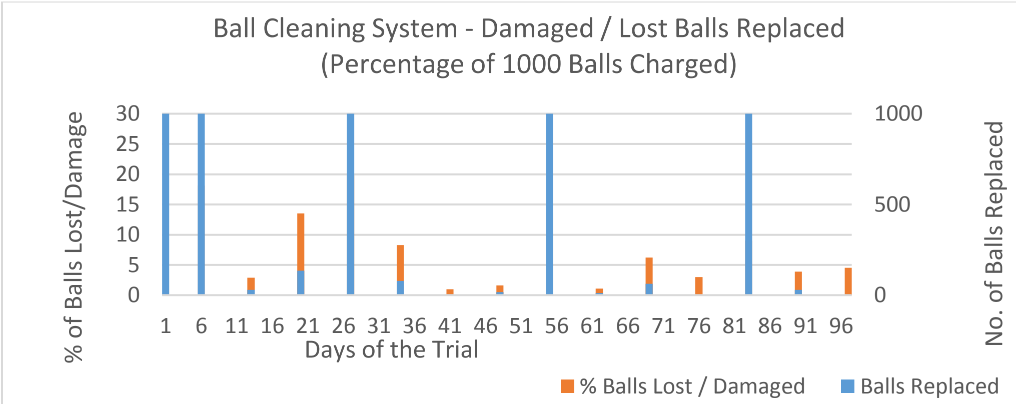

Figure 10: Ball cleaning system all over the trial

2.2. Brine Chemistry and Chemical Dosing

2.2.1. Antiscalant Chemical Dosing

G Station Desalination units are equipped with 2 antiscalant dosing tanks. The level of chemical in the dosing tank is monitored by a sensor and the level relayed for recording in the CCR. The analyzed dose rate and the target dose rate are shown in the Figure 11. The represented values of the dose rate are an average daily basis.

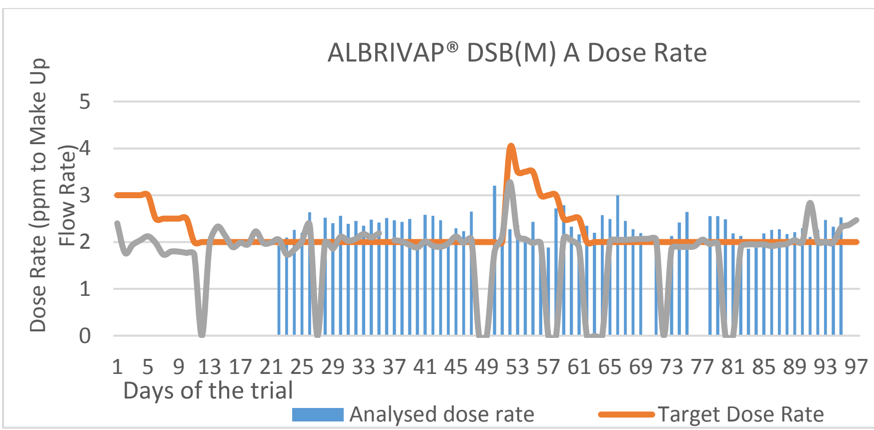

Figure 11: Comparison between analysed, target and calculated Antiscalant dose rate

In line with DEWA Station practice, the target dose rate was increased by 0.5 ppm whenever the sea water turbidity increased above 10 NTU. Over the 97 days trial period this occurred in several occasions and is represented by the "spikes" in the dose rates graphed above. With allowances made for the increases in dose rate necessitated by sea water conditions the average optimised dose rate for operation at 105°C TBT was kept within the 5% of target dose rate.

2.2.2. Reserve Antiscalant Present (in recycle brine stream)

The level of ALBRIVAP DSB (M) A antiscalant in the recycle brine stream was measured using a simple & rapid analytical method. The sample was first filtered through a 0.45µ filter to remove any product adsorbed onto the surface of micro crystallites & the result expressed as ppm of "Reserve Antiscalant Present" (RAP). This reserve of product is effectively the antiscalant free and available to protect the Plant from the formation of hard alkaline scale which can rapidly foul heat transfer surfaces. Long term and wide ranging practical experience has shown that, provided a minimum level of 1.5 ppm of RAP exists in the recirculating brine stream then the ALBRIVAP product will function efficiently as a scale inhibitor and the heat transfer surfaces will be maintained free of alkaline scale deposits.

The unit was sampled on each working day throughout the 97 days trial and the results are presented as a scatter graph below.
The results show that the RAP level was maintained above the minimum recommended level of 1.5 ppm throughout the 90 days trial period. For operation at 105˚C TBT a dose rate of 2.0 ppm was sufficient to maintain the safety margin of 1.5 ppm as RAP. The first 3 weeks data are not available but afterwards data show the residual levels were kept above 2.0 ppm all the time.

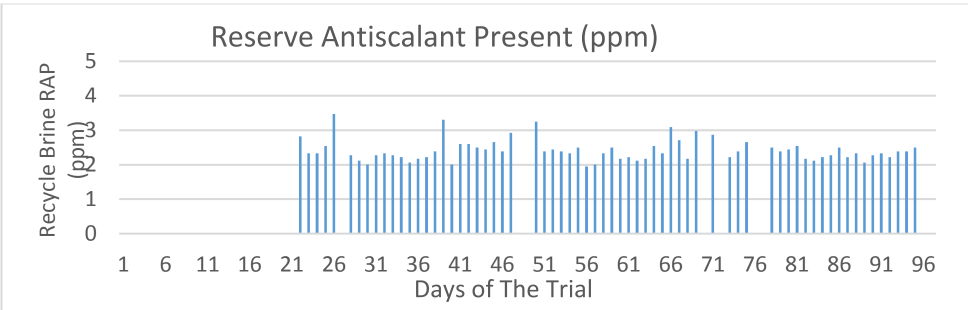

Figure 12: The Chemical residual in the Recycle Brine over 90 days of the trial

2.2.3. Sea Water Turbidity

An increase in seawater suspended solids will reduce the active level of the antiscalant chemical and can be detected by an increase in sea water turbidity. Seawater turbidity should be monitored and, during periods of high turbidity (>10 NTU), ALBRIVAP DSB(M)A dose rates should be increased by 0.5 ppm to maintain the minimum recommended free residual (after sample filtration) in the recycle brine.

The Laboratory staff checked the turbidity at “G” Station intake water basin on a daily basis. The results are presented below in Figure 13 The Laboratory Chemist would notify the CCR when the turbidity increased above 10 NTU and this happened on different occasions during the 97 days test period.
There was high turbidity in several occasions due to rough sea and the necessary action has been taken.

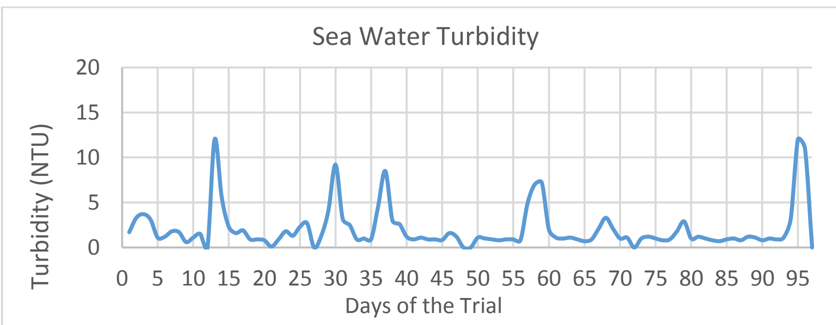

Figure 13: Sea Water Turbidity throughout the trial period

2.2.4. Recycle Brine Concentration

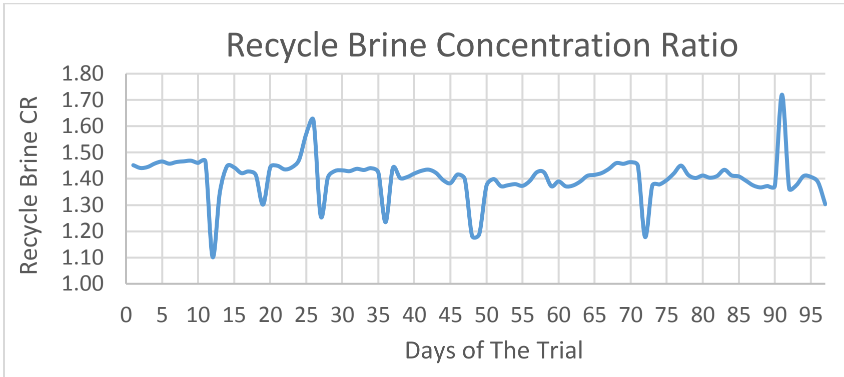

Figure 14: The concentration factor for 90 days

The recycle brine concentration ratio (CR) represented in Figure 14 was measured on a regular basis throughout the 97 days trial period by the central Lab staff (using chloride analysis). The Operation staffs were asked to maintain the Recycle Brine CR below 1.4 to ensure there was no practical probability of forming Calcium Sulphate deposits during operation. This was generally achieved but with some difficulties to maintain this value because of the unit age. Under these operating conditions with a CR averaging 1.41 across the 97 days trial period there would be no risk of forming Calcium Sulphate deposits on heat transfer surfaces.

2.2.5. Loss of Total Alkalinity (LTA)

The Loss of Total Alkalinity shown in Figure 15 from the recycle brine can be a strong indicator that alkaline scale species are precipitating from the brine stream and potentially fouling heat transfer surfaces. It is generally thought that, provided the LTA is below 5ppm then precipitation is unlikely to be occurring. In reality this is a difficult test to reproduce accurately in the presence of free available chlorine in the recycle brine stream & this is generally the case with the chlorinating regime in use on G Station. For practical purposes & based on a wealth of experience on plants across the Middle East, Italmatch believe that LTA to be an important indicator but only when considered in conjunction with the Reserve Antiscalant Present in the brine stream.
The LTA was measured routinely by the Lab staff and is presented below.

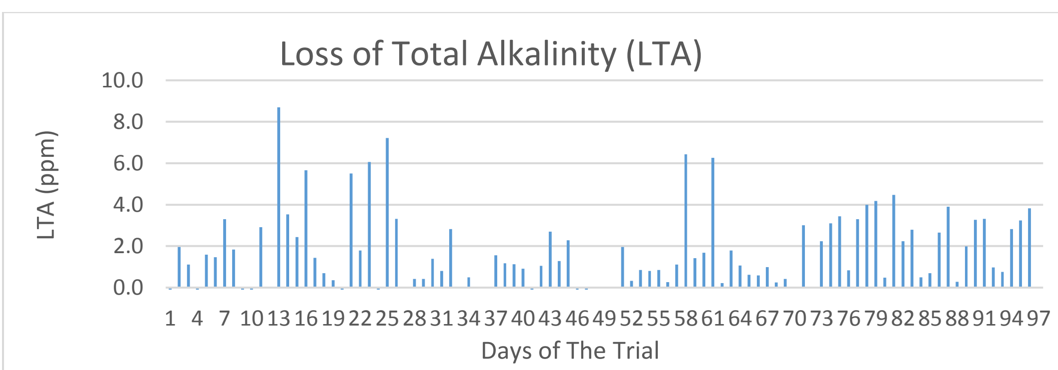

Figure 15: behaviour of the Loss of Total Alkalinity over 90 days

The LTA during the 97 days operating period was maintained below 5 ppm most of the time. A number of results were above 5 ppm but in each case the Reserve Antiscalant was present at well above the minimum level of 1.5 ppm and these results were therefore not considered significant. The normal Laboratory routine is to measure LTA once per week but this frequency was increased to daily analysis during periods of operational sensitivity such as increases in TBT or optimizing dose rates.

3. Unit Condition – End of Trial Inspection

The general conclusion of the inspecting parties was that the distiller was in an acceptable clean condition with no evidence of any hard scale deposits on heat transfer surfaces.
The heat transfer surfaces (brine side of tube bundles) were inspected in the Brine Heater & Heat Recovery Stages 1 to 3 and found to be in clean condition with no evidence of tube side fouling.

On the pre-trial inspection it has been noticed a light, patchy layer of hard scale was observed on the walls of the Flash Chambers in Stages 1 to 5. This layer of hard scale progressively reduced in thickness, cracked and some of them has been removed by using ALBRIVAP DSB (M) A. The demister pads have very light deposits (paint) of salts with thickness less than 0.5 mm. Generally the demister pads have kept the clean conditions during the 97 days trial period.

In summary, all the heat transfer surfaces within the distillation unit were observed to be in clean condition with virtually no evidence of alkaline scale fouling.

3.1. Summary of Results

- The thermal efficiency of unit G-21was maintained at a steady & stable level throughout the 97 day of the trial period (include shutdown time). The data confirms how the ALBRIVAP DSB (M) A is maintaining the performance of the unit.
- The operating data in the reported period indicated that there would be no fouling of heat transfer surfaces during the use of ALBRIVAP DSB (M) A as an antiscalant on Distillation Units of Weir Westgarth design.
- Also there is a strong evidence that the ALBRIVAP DSB (M) A managed to react with the deposits already exist before starting the trial and make it lose and this is clearly shown in the fouling values and the post- trial inspection.
- The Concentration Ratio of the recycle brine was successfully maintained within the recommended limits throughout the trial period.
- LTA measurements interpreted in conjunction with antiscalant reserve levels predicted the efficient control of alkaline scale precipitation throughout the trial period.
- The active reserve of ALBRIVAP DSB (M) A was successfully maintained above the minimum level of 1.0 ppm throughout the trial period.
- The antiscalant chemical dosing was carefully monitored throughout the trial period and the target level of 2.0ppm dose rate for 105^0C TBT was successfully maintained within a range of +/- 0.1 ppm. The average dose rate by dosing tank level drop was 2.0 ppm which, within limits of flow meter accuracy, is an acceptable performance.

4. **Conclusion**

The steady and stable thermal data over this 90 days trial period indicates that ALBRIVAP DSB (M) A can be safely used to maintain the operating efficiency on Weir Westgarth designed Multi

Stage Flash Desalination Units. ALBRIVAP DSB (M) A is unique in that the reserve of active product available to control alkaline scale fouling in thermal Distillation Units can be readily determined in recycle brine streams by a simple on site analytical method. This method can be adopted on a routine basis to ensure the operational safety & efficiency of the Distillation Unit. Analysis of the brine chemistry concluded that there would be no risk of forming hard alkaline scale on the heat transfer surfaces of the distillation unit. This prediction was confirmed on the final inspection.

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Primary Energy Consumption for the Efficiency Comparison of all Desalination Processes

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Abstract
Presently, the derived energies based performance ratio (PR) comparisons of all desalination processes are misleading industry for selecting most efficient desalination method for sustainable water supplies. In combined cycle gas turbine (CCGT) based power and water plants, the level of exergy destruction is the key to calculate primary energy proportion consumed by individual processes. The estimated PR=110 of desalination processes based on primary fuel i.e. oil or gas is limited to less than 15% of thermodynamic limit (TL=828) due to processes operational limitations. These low efficiency processes are not only unsustainable for future water supplies in GCC countries but also polluting environment by adding tremendous amount of CO2.
For future sustainability, the desalination processes PR must be raised to next higher level, 25-30% of TL. The higher efficiency for desalting processes will not only save primary fuel but also environment by reducing CO2 emission. We proposed a tri-hybrid thermally driven desalination cycle to overcome conventional processes limitation to achieve sustainable water supply goal. The proposed cycle experiments and simulations demonstrated the highest performance, PR=180: highest reported in the literature up till now.

Keywords: Thermal Desalination, Hybrid Desalination, Performance Ratio, Thermodynamic Limit, Sustainable Desalination.

Steady-state analysis of a desalination system based on the principle of Natural Vacuum Distillation

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Abstract
As the world's population grows, the fresh water demand also increases. Many regions in the world have now turned to desalination to meet the fresh water demands. Most of the desalination processes rely on fossil fuels for the energy requirements. Due to the environmental concerns associated with the burning of the fossil fuels, and the fear of the depletion of the fossil fuel sources, renewable energy promises to provide a sustainable alternative for desalination. Natural Vacuum Distillation (NVD) has recently been introduced as a feasible method to implement renewable energy. NVD makes use of the barometric pressure of a column of water to create a vacuum chamber, where water can be evaporated at low temperatures. If a column of water, with a sealed top, is allowed to drain under the effect of gravity into a container of water open to atmosphere, then it will stop draining after the head of the water column (approximately 10.3 m) equals the atmospheric pressure acting on the surface of water in the container. The space above the water level in the top of the column will thus have a natural vacuum created. The benefit of such a system is that no additional pumping power is required to create vacuum. Under such low-pressure conditions, saline water can be easily evaporated at relatively low temperatures, and then condensed to obtain freshwater. Renewable energy sources like solar thermal energy or waste heat sources from existing installations in the industry can be employed to provide this energy for evaporation of the water. In this study, a new design for a seawater desalination system based on the principle of NVD is presented. The effect of different parameters on the performance of this system is studied. The parameters whose effect is reported are the mass accommodation factor, the brine withdrawal rate, the inlet temperature of heated seawater, the temperature of the cooled desalinated water and the external heating load. Effect of these parameters on the brine exit temperature, brine concentration and the evaporation rate has been presented. Calculations show that a fresh water production rate of almost 27 kg/day is possible with inlet saline water temperature of 60 ^{o}C and a fresh water cooling temperature of 20 ^{o}C. The evaporator diameter used in the study is 0.65 m. Brine withdrawal rate of 1 kg/h and a mass accommodation factor of 1×10^{-6} was used to obtain the above-mentioned production rate.

Keywords: Water Desalination, NVD, Natural Vacuum Distillation, Low Temperature Desalination.

1. Introduction
As the world's population grows, the fresh water demand also increases. According to a study, population is growing faster than the rate of water supply [1]. Many regions of the world, especially arid and semi-arid areas, turn to desalination to cope with problems of freshwater shortage. Middle East, due to the extreme shortage of freshwater sources, accounts for up to 53% of the worlds installed desalination plants [2]. Desalination processes are energy intensive processes. Fossil fuels account for the major source of energy for desalination processes [3]. The combustion of these fuels, and other issues like the concentrated brine discharge and elevated

water temperatures add to environmental concerns regarding the desalination processes [4]. Hence, there has been a keen interest in looking for alternative technologies to operate desalination processes using renewable energy. Over the years, many studies have been presented on desalination processes that have been driven by renewable energy sources including solar energy, wind energy, geothermal energy, biomass energy and tidal energy [5, 6]. One of the technologies that has been introduced in the recent years is the Natural Vacuum Distillation (NVD) technique.

Natural Vacuum Distillation uses the barometric pressure of a column of water to create a space above the column of water, which is at near vacuum condition. This low-pressure environment allows for evaporation of water at relatively lower temperatures. If a column of water, with a sealed top, is allowed to drain into a container of water under the effect of gravity, then it stops draining after the head of the water column equals the atmospheric pressure acting on the water in the container. The space above the water level in the sealed end will thus have a natural vacuum created. A system based on this principle is capable of creating vacuum without using any evacuation pump. Under such low-pressure conditions, saline water can be easily evaporated at low temperatures, with minimal energy input, and subsequently condensed to obtain fresh water.

The first such system to use the barometric height of water to produce natural vacuum and use it for desalination was suggested by Reali. He showed that if a column of freshwater and another column of saline water were both connected by the same overhead vacuum space, then the water vapor will move from the saline water column to the freshwater column provided the saline water column is at higher temperature than then freshwater column. The author calculated that an energy of only 2461 kJ per kg of freshwater produced was required for such a desalination process if the two columns were maintained at a temperature difference of 5 ^{o}C. Later studies by other researchers showed further enhancements to the process. Some of these include the attempt to resolve issues of vapor transport from the saline water column to the freshwater column [7, 8], addition of a third column for brine withdrawal [9, 10] and use of low-grade heat sources for providing the energy required for the temperature difference between the two columns [11]. Additionally, some studies presented the idea of using a multi-stage process for enhanced water production rates [12, 13, 14]. A review of the various desalination systems using NVD has been presented by Rashid et al [15].

2. Proposed NVD desalination system

The proposed system is designed as a semi-sphere with a cylindrical base as shown in Fig. 1. This tank is the main component of the new desalination system. It is evacuated using NVD by filling the entire tank with water and then letting it to drain under its own weight. Three outlets are provided at the bottom of the tank for connection to the seawater storage, brine withdrawal and the freshwater outlet. The water storage drums are located at a height of almost 10.3 m below the NVD tank to allow for the barometric height of water. The cylindrical base of this tank is composed of an inner cylindrical space, which is the evaporation chamber and an outer annular space that serves as the freshwater chamber. The evaporation chamber has a diameter of 0.65 m and a height of 0.50 m. The freshwater chamber has an outer diameter of 1.20 m and an inner diameter of 0.90 m. A solar collector or any other low-grade heat source may be used to heat the feed seawater. Alternatively, the spherical top of the tank can be made of glass to allow direct heating using solar energy. An insulating material in the annular space separating the two chambers minimizes the heat losses on either side. The heated seawater enters the evaporation chamber under the influence of the atmospheric pressure on the seawater storage drum. Due to the extremely low pressure in the tank, water will evaporate even at relatively low temperatures. The vapor from the evaporation chamber rises to meet the cooled portion of the spherical roof and then under the influence of the gravity, falls along the sloping walls into the outer cylindrical portion of the base where freshwater is collected. The roof is cooled by using cold seawater circulated in cooling coils spiraling along the roof only in the portion above the freshwater chamber. The storage drums for the brine and the freshwater should be located at a lower elevation than the seawater feed drum. This allows the water in the water lines flowing to these drums to move downward, while the water in the feed seawater line moves upward.

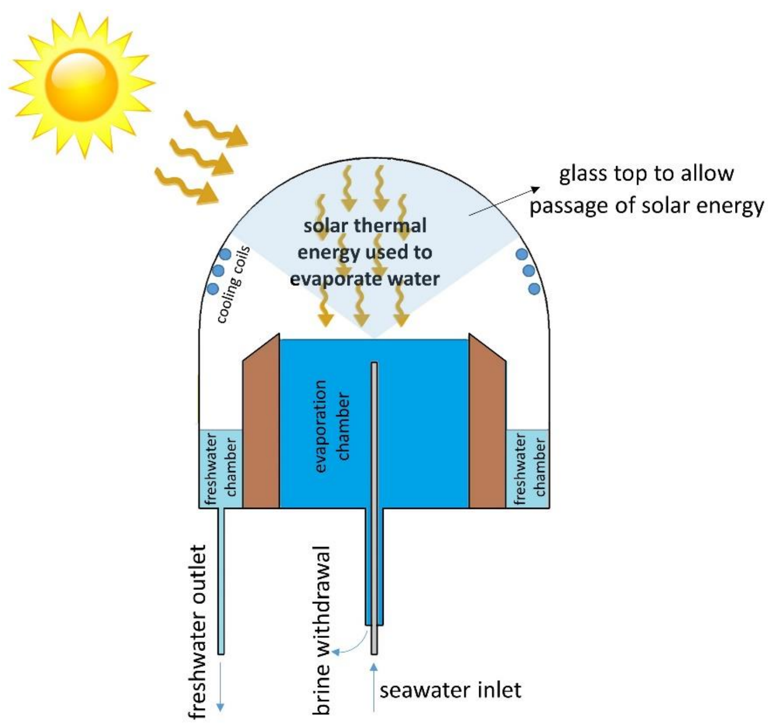

Figure 1: Schematic representation of the proposed NVD desalination system

This new geometry allows solving the problem of vapor transfer from the evaporator to the condenser side. Additionally, the configuration allows the heat to be transferred from the solar collector outlet line to the feed water to conserve more energy. The system also includes a condenser using cold seawater, pumped using solar power, to make the system feasible in the hot climate regions.

3. Mathematical Model

The mathematical model is presented for the evaporator section of the system. It will be assumed in the model that all water evaporated in the evaporator section, condenses and flows into the fresh water chamber, hence no modeling is needed for the condenser side. The steady-state mathematical model is obtained from mass, energy and solute balances on the system.

A simple representation of the evaporation chamber is shown in Fig. 2. We have one inlet stream to the system which is the heated sea water stream. There are two outlets for the system, which are the brine withdrawal stream, with a controlled withdrawal rate, and the water evaporation at the surface of the water column in the evaporator. The seawater enters with a temperature T_s and concentration C_s (3.5%). The system is assumed to be a well-mixed system such that the temperature, T_b, in the entire system is uniform and the outlet brine stream concentration, C_b, is considered same as the water in the evaporator.

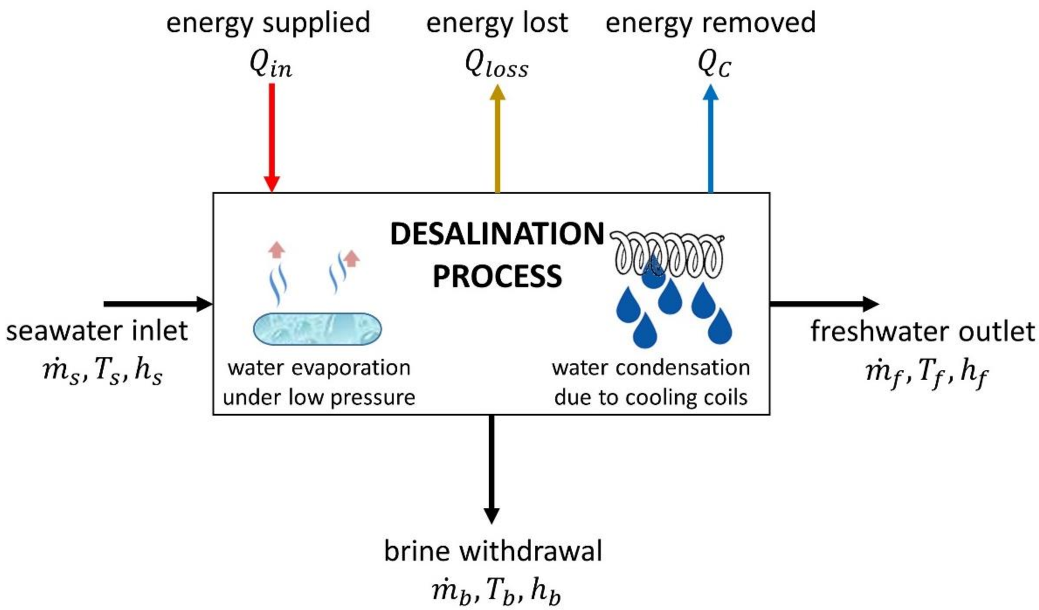

Figure 2: Representation of the Evaporation section in an NVD process

The equations defining the model are given below:

Mass balance:

$$\dot{m}_s = \dot{m}_b + \dot{m}_f \tag{1}$$

where $\dot{m}_s$ is the seawater inlet flowrate, $\dot{m}_b$ is the brine withdrawal rate and $\dot{m}_f$ is the evaporation rate.

Energy balance:

$$\dot{m}_s H_s + Q_{in} = \dot{m}_b H_b + \dot{m}_f H_f + Q_{loss} \tag{2}$$

where H_s, H_b and H_f are the seawater, brine wand freshwater enthalpies respectively. The heat added to the system is indicated by Q_{in} while Q_{loss} is the heat lost during the process.

Solute balance:

$$\dot{m}_s C_s = \dot{m}_b C_b \tag{3}$$

where C_s and C_b are the inlet seawater and the brine salt concentrations respectively.

The evaporation rate in the system is given by the equation presented by Bemporad [16] in his study:

$$\dot{m}_f = A \times \alpha_m \times \left(f(C_b) \frac{p(T_s)}{\sqrt{T_s + 273}} - \frac{p(T_f)}{\sqrt{T_f + 273}} \right) \tag{4}$$

where
A is the cross-sectional area of the evaporation section,
α_m is the mass accommodation factor,
$f(C_b)$ is a correction factor for salt concentration,
T_s is the temperature of the salt-side (i.e. evaporation section temperature),
T_f is the temperature of the cooled freshwater side,
$p(T_s)$ and $p(T_f)$ are the saturation pressures of water at the two temperatures

The correction factor $f(C_b)$ is given by the following equation, as given by Bemporad:

$$f(C_b) = 1 - 0.0054C_b \qquad (5)$$

Thermophysical properties of seawater as a function of temperature and salt concentration are given by Sharqawy et al [17].

4. Results and Discussions

The effect of the change of the parameters was studied based on a steady state model assuming perfect mixing in the evaporation tank, such that the temperature and concentration was assumed constant throughout. The effect of the following parameters was investigated:

1. $\boldsymbol{\alpha_m}$ (the Mass Accommodation Factor)
2. $\dot{\boldsymbol{m}}_{\boldsymbol{b}}$ (the Brine Withdrawal Rate, kg/h)
3. $\boldsymbol{T_s}$ (the inlet temperature of heated seawater, ^{o}C)
4. $\boldsymbol{T_f}$ (the temperature of the cooled desalinated water, ^{o}C)
5. $\boldsymbol{Q_{in}}$ (the external heating load, W)

The variables whose values were considered from the results are:

1. $\boldsymbol{T_b}$ (the brine exit temperature, ^{o}C)
2. $\boldsymbol{m_f}$ (the freshwater production rate, kg/h)
3. $\boldsymbol{C_b}$ (brine concentration, %)

4.1 Effect of changing the value of the Mass Accommodation Factor

The value of α_m was varied from 1×10^{-9} to 1×10^{-5} to study its effect on the variables aforementioned. Other parameters were held constant as listed below:

$\dot{m}_b$	1 kg/h
T_s	60 ^{o}C
T_f	20 ^{o}C
Q_{in}	0 W

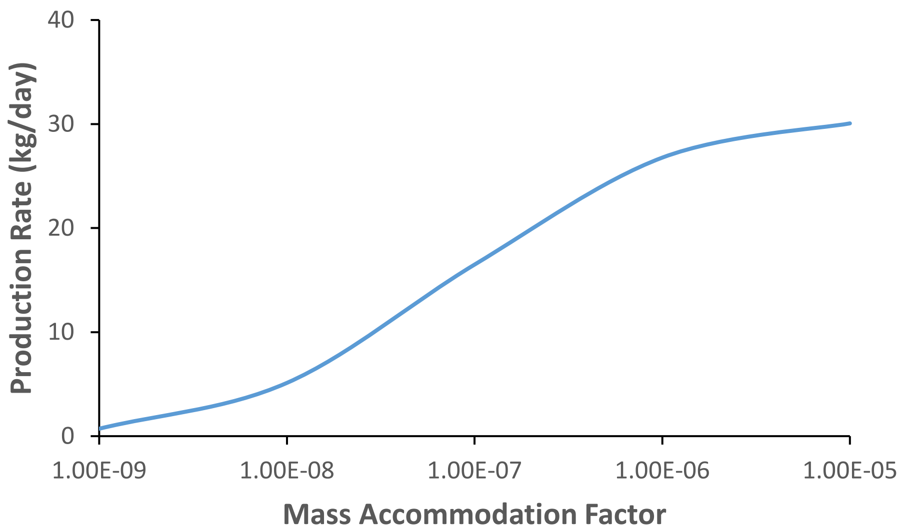

Figure 3: Effect of the Mass Accommodation Factor on the Water Production Rate

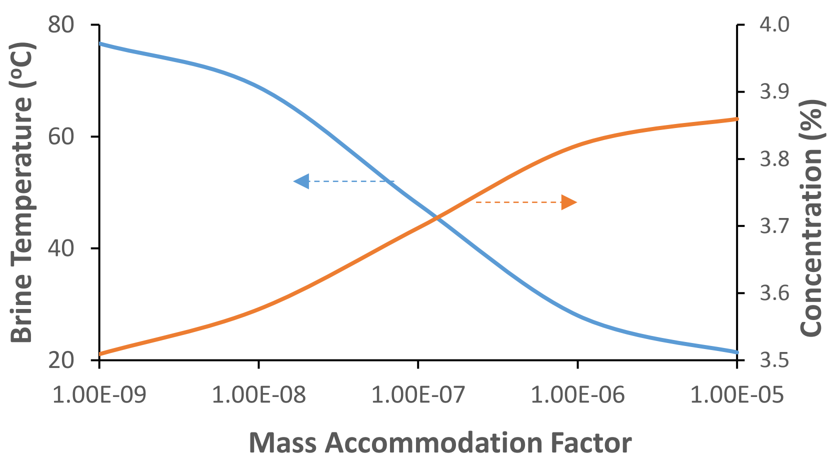

Figure 4: Effect of the Mass Accommodation Factor on the brine temperature and concentration

The water production rate was seen to increase exponentially with a rise in the value of α_m. We can see from Fig. 3 that the evaporation rate approaches a certain maximum possible value, after which it remains constant as the temperature of the water in the evaporation tank equals the cooled desalinated water temperature and no further evaporation is possible. This is because the driving force for the evaporation is the temperature difference between the two sides. As can be seen from Fig. 4, the brine exit temperature also drops exponentially with increase in the value of α_m. This is because a higher value of α_m means more evaporation and incidentally a higher drop in the temperature of the water in the evaporation tank. On reaching a relatively high value of α_m, the exit temperature seems to be constant approaching the temperature of the cooled desalinated freshwater side. The concentration shows a steadied increase with increase in the value of α_m. This is expected because higher evaporation rates with increase in the α_m, means a more concentrate brine at the exit.

It must be noted that the value of α_m to be used in the calculations should be determined experimentally and is not chosen independently.

4.2 Effect of changing the Brine Withdrawal Rate

The value of $\dot{m}_b$ was varied from 0.01 to 1.5 kg/h to study its effect on other variables. Other parameters were held constant as listed below:

α_m 1×10^{-6}
T_s 60 °C
T_f 20 °C
Q_{in} 0 W

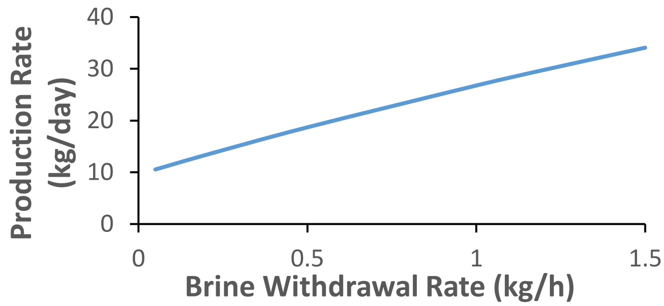

Figure 5: Effect of the Brine Withdrawal Rate on the Water Production Rate

We can see in Fig. 5 that the increase in the brine withdrawal rate has a significant effect on the evaporation rate. As, the withdrawal rate is increased, the evaporation rate too goes up. This is because the increase in the brine withdrawal rate means a higher brine exit temperature. The reasons for this is that the hot seawater fed to the evaporation chamber, spends less time in the evaporation tank and the effect of cooling due to evaporation is reduced. The exit temperature is higher when the brine withdrawal rate is higher, this automatically causes the evaporation rate to rise because the water in the evaporation tank will be at a higher temperature and hence the driving force for the evaporation (i.e. ΔT) will be higher.

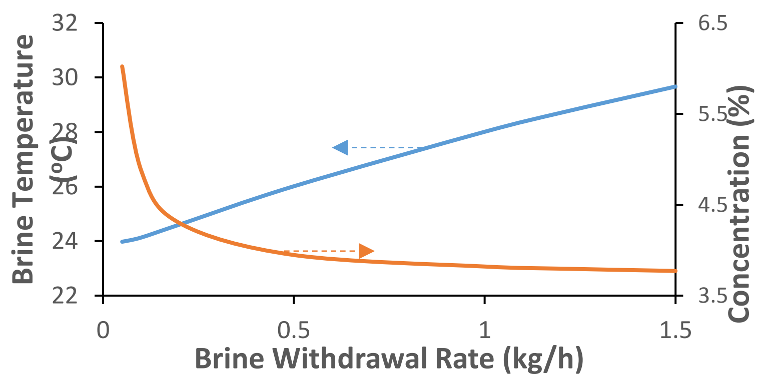

Figure 6: Effect of the Brine Withdrawal Rate on the brine temperature and concentration

With an increase in the brine withdrawal rate, we can see a drop in the concentration. This is very much expected, as lesser time is allowed for the seawater to remain in the tank due to increased withdrawal rates, and hence lesser changes in its conditions. From these results, we deduce that a higher withdrawal rate is preferred for the system. The lower the concentration in the system, the more preferable it is for the design, as it will cause lesser scaling and corrosion problems. However, higher withdrawal rates mean higher heating load required for the inlet seawater. Therefore, an optimal withdrawal rate has to be determined based on the evaporation rate, concentration of the brine and the added cost of heating the inlet temperature. It is obvious from Fig. 6 that higher withdrawal rates mean higher exit temperature, and this exit stream is discharged out of the system carrying with it the energy that was required for heating it. Some recovery system should be designed to retrieve some of the energy lost through this exit stream.

4.3 Effect of changing the Inlet Seawater Temperature

The value of the seawater feed temperature was varied from 30 °C to 80 °C to see how it affects the system behavior. Other parameters were held constant as listed below:

α_m 1×10^{-6}
$\dot{m}_b$ 1 kg/h
T_f 20 °C
Q_{in} 0 W

We see a linear relation between the inlet and the outlet temperatures. As the inlet temperature increases, the exit temperature also increases, as would be expected. However, the slope is not a steep one and a change of almost 0.12 degrees in the exit temperature is noted for a unit change in the inlet temperature. Higher inlet temperature means a higher driving force for the evaporation process. This can be seen clearly in Fig. 7 below. The conclusion for temperature is thus a straightforward one; the higher the inlet temperature the better will be the output. However, we have to consider the cost of this increase in temperature.

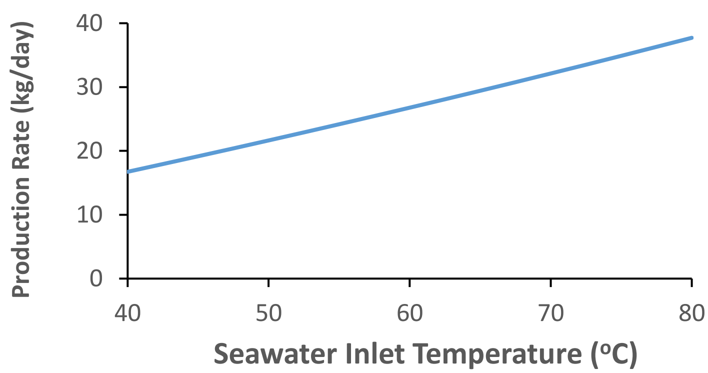

Figure 7: Effect of the Seawater Inlet Temperature on the Water Production Rate

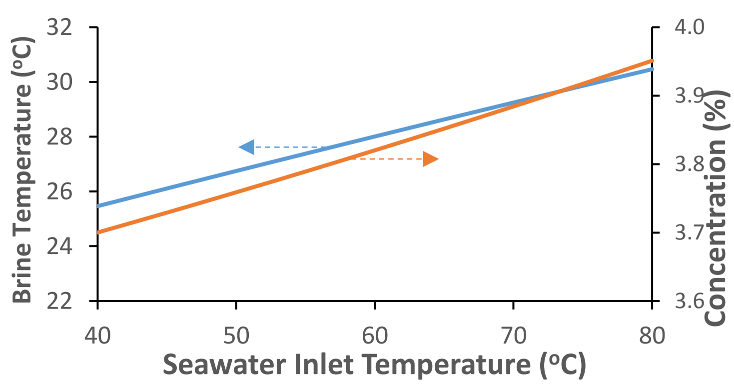

Figure 8: Effect of the Seawater Inlet Temperature on the brine temperature and concentration

A rise in the temperature means more evaporation, and hence a more concentrated brine discharge (see Fig. 8). We have already discussed the issues related to the increased concentration rates, and once again, we see that we have to reach a trade-off between the evaporation rates required and the acceptable increasing in concentration of the brine. Although, the rise in concentration here does not appear to be much, we have to remember that we have considered perfect mixing in the evaporation tank for this model. In a more realistic scenario, we should expect the concentration distribution to be uneven and could rise significantly near the surfaces and stagnant regions of the tank.

4.4 Effect of changing the Freshwater Temperature

The value of freshwater chamber temperature was varied from 10 ^{o}C to 26 ^{o}C to see how it affects the system behavior. The range selected was not a big one because there is a limit on how low we can manage to get the temperatures and an upper limit on how high we can allow the temperature to be in order to get a reasonable production rate. Other parameters were held constant as listed below:

α_m 1×10^{-6}
$\dot{m}_b$ 1 kg/h
T_s 60 ^{o}C
Q_{in} 0 W

We can see from Fig. 9 that an increase in the Freshwater Chamber temperature leads to a decrease in the water production rates. The higher the temperature on this side, the lower the driving force (ΔT) and hence we see a drop in the evaporation rate.

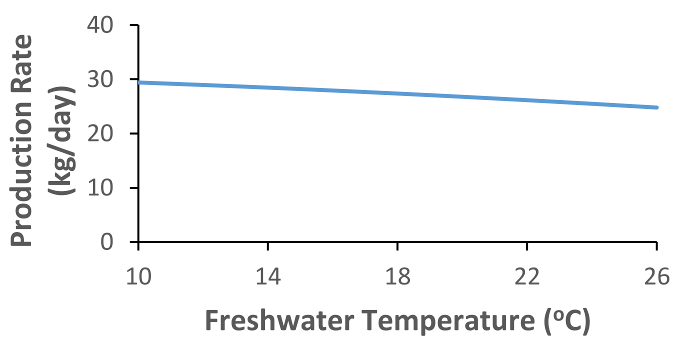

Figure 9: Effect of the Freshwater Temperature on the Water Production Rate

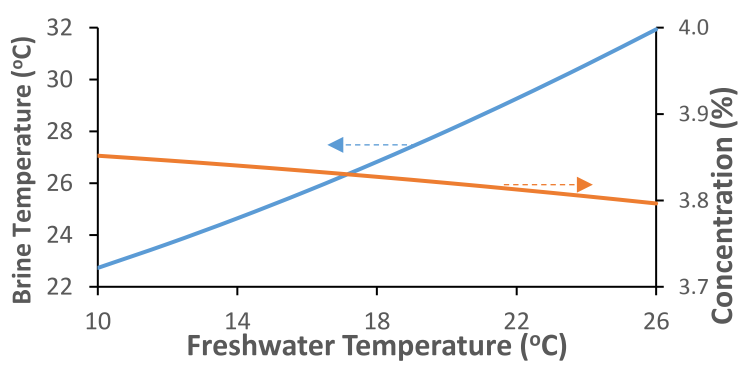

Figure 10: Effect of the Freshwater Temperature on the brine temperature and concentration

Also we can see in Fig. 10 that the higher the temperature on the cooled desalinated water side, the higher shall be the temperature of the brine exit stream. This is because the evaporation rate decreases with an increase in the cooled desalinated water temperature. This drop in the evaporation rate means a lesser cooling effect on the water in the evaporation tank and hence the brine temperature in the exit stream is higher. The concentration of the brine stream is lower with higher temperatures on the cooled desalinated water chamber. This is again because of the drop of the evaporation rate, lower evaporation rates mean lesser changes in the concentration of water in the evaporation tank.

4.5 Effect of changing the External Heat Load

Although the system is designed to be using only solar energy, the effect of adding external power to heat the water was investigated to see the benefits, if any, of this extra heating. If beneficial, the heat could be added through solar electrical panels. Values of Q_{in} that were considered ranged from 0 to 100 W. Other parameters were held constant at the following values:

α_m 1×10^{-6}
$\dot{m}_b$ 1 kg/h
T_s 60 ^oC
T_f 20 ^oC

We see that by adding an external power source for heating the water in the evaporation tank, we can get much enhanced results. The benefit of adding the heat source has to be balanced with the cost of this heat load to be able to decide how much heat should be added to the system, if one does decide to have this extra heat load option. The evaporation rate increases with the increase in the external heating load as seen in Fig. 11. The cost of this heating needs to be evaluated properly to see if it is really an advantage to add this external heating load. Adding 100 W of heating load increases the evaporation rate by more than 4 times, which seems to be a huge advantage considering that the suggested heat load is not very high and the cost for such heating will not be too much.

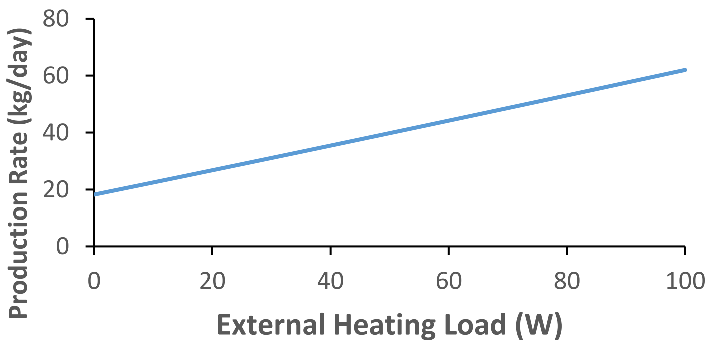

Figure 11: Effect of the External Heating Load on the Water Production Rate

As we can see from Fig. 12, the brine temperature rise with respect to the heat load is logarithmic. The rise in temperature increases the evaporation rate, which could cause the slope to narrow down as the power is increased. Another issue that needs to be considered is the issue of concentration. With the increase in the external power, the evaporation rate increases dramatically, which causes the concentration to also to go up. An increase of almost 3 times in the concentration can be seen with this increase in the external power. Scaling can be a huge problem if considerations are not made to cope with this. An optimization needs to be done to select the proper amount of heating to be added to the system, if one wishes to avail the option of extra heating.

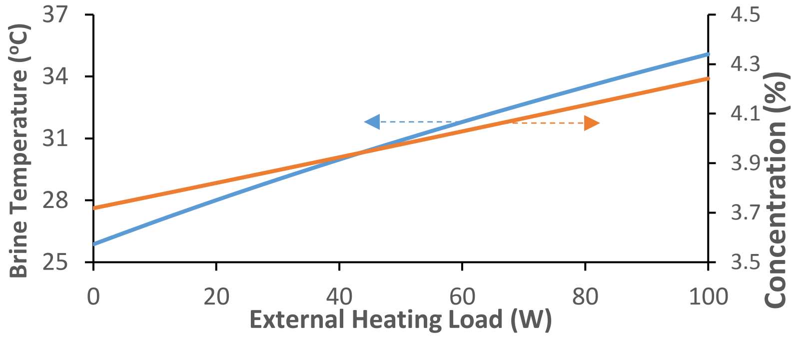

Figure 12: Effect of the External Heat Load on the brine temperature and concentration

5. Conclusion

The effects of the changes of the parameters on the performance of the system was discussed. From the discussion, it can be concluded that the value of α_m has a huge impact on the results. This is an experimentally determined factor and the correct value to be used in the calculations can only be determined after experimental observations. The brine withdrawal rate analysis shows that the higher the rate, the better the results but a compromise has to be made between the increased water production rate and loss of the energy by withdrawing higher rates. Similarly, lower temperatures are preferred on the freshwater side but this temperature will depend on the availability of the temperatures on the cooling rate and the process used for this purpose. Adding an auxiliary heating load to the evaporation section also boosts the production rate, hence it is advised to avail a renewable energy heat source for the purpose of reutilization of waste heat available from any other simultaneous process being carried out.

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Assessment of Groundwater Quality in State of Qatar for Agriculture and Domestic Water Supply Applying Membrane Processes

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Abstract
In arid and semi-arid regions, groundwater is the main water resource worldwide due to the absence of surface water resources. The GCC countries are situated in extremely arid zones with very low endowment of renewable water resources. As a result, most of GCC countries depends mainly on groundwater supplies for agriculture sector and for domestic water supply for rural communities as well as in case of emergencies. In state of Qatar, groundwater is mainly used for agriculture purposes which representing 92% of the total groundwater abstractions. There are two main challenges facing groundwater management in Qatar. The first challenges is the low precipitation rate coupled with high evaporation rate, hence groundwater aquifer recharge is minimal. The second challenge is the intrusion of both seawater and saline deeper aquifer water that caused by over-abstraction of groundwater compared to its recharge. This intrusion results in groundwater quality deterioration, mainly salinity increase. Therefore, the trend of using desalination systems for abstracted groundwater is increasing. In this paper, the qualitative assessment of groundwater resources in Qatar is extensively discussed and analyzed in terms of water quality parameters such as pH, salinity, concentration of major ions, and more importantly the saturation indices for the main scale forming constituents, that limit water recovery in reverse osmosis (RO) desalination systems when used to produce good quality water from brackish groundwater. The study illustrate the maximum achievable recovery utilizing traditional RO system, relating it to both salinity and saturation of scale forming constitutes.

Keywords: Groundwater Quality, Agriculture Water, Domestic Water, Membrane Desalination.

Introduction
Groundwater is the main water resource in arid and semi-arid zones worldwide due to the absence of surface water sources such as rivers and lakes. Fresh groundwater represent about 30% of the total fresh water, and about 0.76 % of the total water available globally, while saline/brackish groundwater represent about 0.93 % of the total water available globally, compared to 0.007% for rivers and lakes, and 96.54% for seawater (Gleick, 2001).

The Gulf Cooperation Council countries (GCC) in particular are good examples of arid area with harsh climatic conditions and very limited surface water resources. The GCC countries are situated in extremely arid zones with very low endowment of renewable water resources. The region is mostly a desert with the exception of narrow coastal areas and mountain ranges. The average annual rainfall ranges from 70 to 130 mm except in the coastal zone along the Red Sea in southwestern Saudi Arabia and along the Gulf of Oman on the eastern shore, where orographic rainfall reaches more than 500 mm, along with total annual evaporation rate ranges from 2,500 mm in the coastal areas to more than 4,500 mm inland (Abulrazzak, 1995; Al-rashed & Sherif,

2000). Large deep aquifers are present in the region, which contain non-renewable supplies of fossil water, but have a finite life and quality limitations.
Due to such limited freshwater resources, GCC countries depends mainly on groundwater supplies for agriculture sector and domestic water supply for rural communities, and on seawater desalination for domestic water supply in large coastal cities, and for industrial purposes. In addition, groundwater resources receives higher attention from GCC countries as the main water supply in case of emergency i.e. water security, and to provide water supply during the down time of major desalination plants in case of emergency. The GCC countries have been listed in the top 15 nations with groundwater having the largest share in the total annual freshwater worldwide, which is mainly used for irrigation purpose with share of about 84 – 97 % (National Groundwater Association, 2013).

State of Qatar, as many GCC states does not have surface water in form of rivers, streams, nor lakes; furthermore, it has one of the lowest precipitation rate worldwide. Average annual rainfall are low, variable, unpredictable, and highly erratic. The average annual rainfall during the last 20 years is 82 mm with very high annual evaporation rate of about 2200 mm (The World Bank, 2015).

Groundwater abstractions are dominated by abstraction for agriculture purposes with about 230 MCM (million cubic meter) in 2012 (92% of all groundwater abstractions). The two main groundwater basins are the Northern and Southern Groundwater Basins. Both the Northern and Southern basins rely on rainfall for replenishment. The Northern Groundwater Basin is considered the most important source of water of acceptable quality for agriculture (water salinity ranges between 300–3,000 mg/l). The Southern Groundwater Basin has a higher water salinity and not fully suitable for agriculture (water salinity ranges between 3,000-6,000 ppm) (Amer, 2008).

State of Qatar has a continuous groundwater quality monitoring programme, administrated by Water Department at Ministry of Environment, since 1996, which has a total of 100 monitoring wells (from overall 344 wells) span all over the country, with detailed analysis of the main quality parameters, namely pH and electrical conductivity, along with analysis for the major cations: Ca^{++}, Mg^{++}, Na^{+}, and K^{+}; anions: HCO_3^{-}, Cl^{-}, and SO_4^{--}, in addition to SiO_2 (Ministry of Environment MoE, 2013) which is utilized in this study for the qualitative assessment of groundwater for membrane desalination of about 50 production wells.

Methodology

In most cases of groundwater desalination, the recovery is controlled by scaling with sparingly soluble salts usually dissolved in groundwater. The supersaturation of key salts such as $CaCO_3$, $CaSO_4$, and SiO_2 in brackish groundwater as feed to RO and concentrate streams has to be quantified in order to identify the key components that limit recovery. Supersaturation of some other sparingly soluble salts such as CaF_2, $BaSO_4$, $SrSO_4$, and $Mg(OH)_2$ are usually present as well. However due to the low concentrations of F^{-}, Ba^{2+}, Sr^{2+} relative to other components, these salts are not of major concern relative to the former salts which will result in higher amount of scale to be formed. Furthermore, the antiscalent addition can mitigate the formation of such minor scales to much higher saturation index relative to the major scale salts. For example Vitec 3000® by Avista Technology, which is broad spectrum antiscalent, can be used with supersaturation limits up to 3.5K_{sp}, 20K_{sp}, 105K_{sp}, and 1000K_{sp} for $CaSO_4$, $SrSO_4$, $BaSO_4$, and CaF_2 respectively (Avista Technology, 2016).

During water desalination, the concentration of different constituents, and ions, are increased, mainly due to the decrease in the amount of solvent i.e. water present, and this increase is directly proportional to the system recovery, i.e. recovery of 50 %, means almost doubling the salt concentration, while that of 75 %, present an increase of 4 folds. Upon concentration of some constituents naturally present in water, it starts to precipitate, as their ion activity product exceed the solubility product for such salts. In general, for salt ions or electrolytes present in water, it dissolves according to the following dissolution reaction (Stumm & Morgan, 1996):

$$A_mB_n(s) \Leftrightarrow mA^{n+}(aq) + nB^{m-}(aq) \tag{1}$$

Equilibrium conditions can be represented by:

$$\{A_mB_n(s)\} = \{A^{n+}(aq)\}^m \{B^{m-}(aq)\}^n \tag{2}$$

The conventional solubility expression or solubility product can be represented by:

$$K_{s0} = \{A^{n+}(aq)\}^m \{B^{m-}(aq)\}^n \tag{3}$$

$$SI = \frac{IAP}{K_{s0}} \tag{4}$$

Where:

$\{A_mB_n(s)\}$ = concentration of solid present in water

$\{A^{n+}(aq)\}$ = Aqueous concentration of A, with valence of (+n)

$\{B^{m-}(aq)\}$ = Aqueous concentration of B, with valence (-m)

K_{s0} = solubility product

$IAP = \{A^{n+}\}_{act} \{B^{m-}\}_{act}$ = Ion Activity Product

SI = Saturation index

The result of such equation indicate one state of three, summarized as:

i- Oversaturated/precipitates: .... IAP > K_{S0} ....and ....SI > 1,

ii- Saturated/equilibrium: .... IAP = K_{S0} ....and ....SI = 1,

iii- Undersaturated/dissolves: .... IAP < K_{S0} ....and ....SI < 1,

Literature contains massive data on solubility and solubility products of different sparingly soluble salts present in desalination system such as calcium carbonate (Greenlee, Testa, Lawler, Freeman, & Moulin, 2010; Pervov, 2015; Sheikholeslami, 2003), calcium sulfate (Azimi, Papangelakis, & Dutrizac, 2007; Dydo, Turek, & Ciba, 2003; Marshall & Slusher, 1966;

Sheikholeslami, 2003; Zarga, Ben Boubaker, Ghaffour, & Elfil, 2013), and silica(Carroll, Mroczek, Alai, & Ebert, 1998; Freeman & Majerle, 1995; Okamoto, Okura, & Goto, 1957). A more comprehensive list of complied data for solubility products of different solids at different conditions is available in the work of Stumm & Morhan (Stumm & Morgan, 1996). This literature work has been utilized in the membrane desalination field by membrane manufacturers as well as antiscalent formulators to develop packages that quantify the supersaturation of these compounds at different conditions for the feed and brine streams.

Antiscalent manufacturers and formulators have developed some guidelines for the antiscalent doses to be used with membrane desalination systems, and more advancement has resulted in the development of software. In this study, Avista Advisor developed by Avista Technologies (Avista Technologies, 2013), has been used, which is capable to project the doses of different chemicals such as biocide, coagulant, pH modifiers and more importantly antiscalent for membrane systems. Avista Advisor antiscalent dosing software has been used to assess the supersaturation of different sparingly soluble salts present in groundwater of about 50 wells in production in the State of Qatar, and to predict the maximum achievable recovery for each groundwater.

Results and Discussion

Figure (1) shows the salinity of groundwater wells considered in this study. The figure shows that none of the wells have a groundwater quality suitable for drinking, i.e. salinity less than 500 mg/l (USEPA, 2016 and Qatari standards), while those with salinity less than 1,000 mg/l representing only 6% of the total groundwater wells, and about 18% of the wells have groundwater salinity suitable for irrigation purposes i.e. salinity of less than 2,000 mg/l (Ayers & Westcot, 1994). The figure also shows that about 14 % of the wells have salinity more than 5,000 mg/l. Hence it can be concluded that the majority of groundwater wells (i.e. about 81.6%) have a salinity higher than 2,000 mg/l, which is to be considered in this study for assessing groundwater quality for desalination.

Calcium and carbonate/bicarbonate ions are one of the dominant components in groundwaters, this is mainly due to the contact of groundwater with carbonaceous rocks bearing calcium carbonate (limestone), which dissolve in water. Carbonate system in water is highly pH dependent system, and under normal pH of groundwater, bicarbonate will be the dominant anion. Supersaturation of calcium carbonate $CaCO_3$ can be assessed through different indexes, however in desalination processes, calcium carbonate saturation is usually expressed as Langelier Saturation Index (LSI) as defined by equation (5) for waters with salinity less than 5,000 mg/l, or Stiff and Davis Saturation Index (SDSI) as defined by equation (6) for waters with salinity higher than 5,000 mg/l (Wilf, 2007), LSI and SDI calculations in this section has been performed using Advisor (Avista Technologies, 2013), and for both approaches positive values mean that water super saturated with respect to calcium carbonate (i.e. values higher than 0.5).

$$LSI = pH - pH_s \tag{5}$$

$$SDSI = pH - (9.3 + K - pCa - pAlk \tag{6}$$

Where: pH = actual pH value of water, pH_s = pH that corresponds to saturation of ions forming calcium carbonate, K = constant obtained from monogram for the water system depending on the ionic strength.

$pCa = -\log[Ca^{2+}]$

$$pAlk = -\log[HCO_3^-]$$

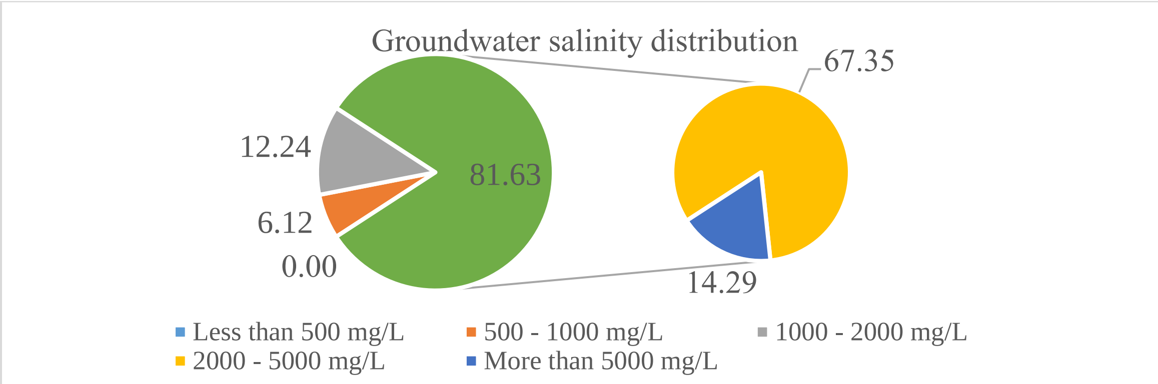

Figure 1: Salinity distribution of groundwater wells of different groundwater aquifers.

Figure (2) below shows that more than 75% of the groundwaters are supersaturated with respect to calcium carbonate, and becomes more supersaturated to limits exceeds those allowable upon use of proper antiscalent, which has a limit of about 2.5 to 3.0 for LSI (Avista Technology, 2016), which in turn limits the desalination system recovery, or require acid pretreatment to modify the pH of water to more acidic medium, which is in turn more costly and can result in corrosion problems in the system. Several works have been performed on de-supersaturation of calcium carbonate present in RO desalination brine in order to improve the suitability of brine for further water recovery, mainly through lime softening processes (Pervov, 2015).

Calcium and sulfate ions are also of the dominant components in groundwaters, this is mainly due to the contact of groundwater with gypsum rocks in the groundwater aquifer. In contrast to calcium carbonate, calcium sulfate are pH independent, and precipitate as gypsum i.e. calcium sulfate dehydrate $CaSO_4.2H_2O$ at normal temperatures i.e. below 40 ^oC, which represent the transition point between gypsum and anhydrite $CaSO_4$ (Azimi et al., 2007).

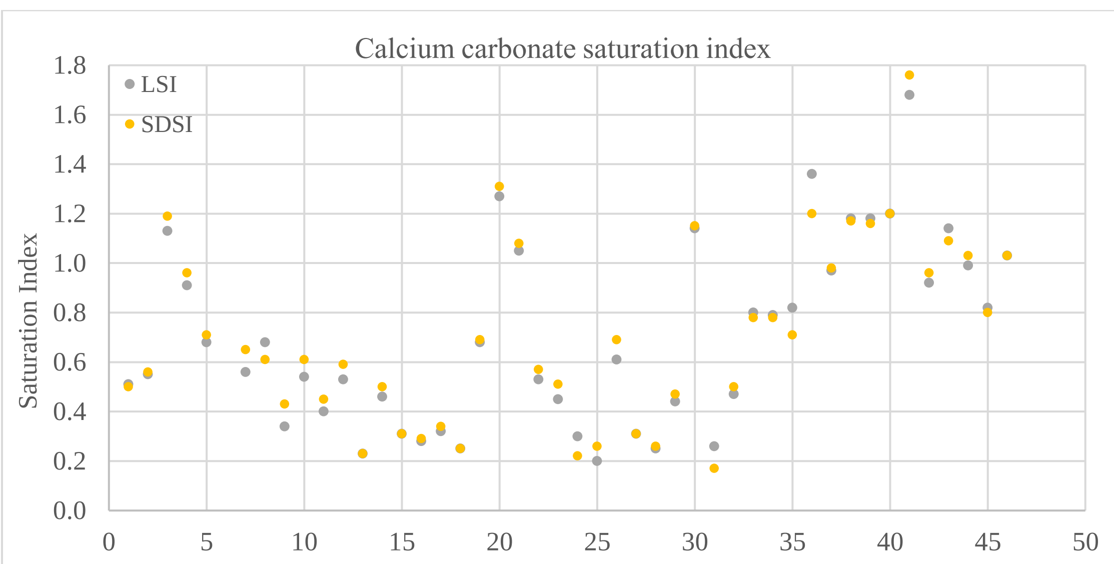

Figure 2: Saturation index for calcium carbonate in groundwater

Figure (3) below shows the saturation index of gypsum in groundwaters under study, saturation calculations has been made through the antiscalent performance assessment software Advisor (Avista Technologies, 2013). Interestingly most of the groundwaters were found to be undersaturated with respect to gypsum, with saturation index of negative value, except for 7 wells representing 15% of the wells, in which groundwater is already saturated with respect to gypsum. However upon RO desalination assessment, it was found that scaling due to calcium sulfate is the main recovery limiting of the system, not calcium carbonate. This can be explained due to the fact that antiscalents added during feed pretreatment for desalination can mitigate the effect of scaling due to calcium carbonate to a higher level than mitigation of calcium sulfate or gypsum scaling, in addition calcium carbonate scaling can be significantly reduced by pH modification, which is not the case with gypsum.

Amorphous silica present in groundwaters is mainly due to contact with silicate rocks such as feldspar and others. Silica present in groundwater present a persistent problem in case deposition of silica occurs on membrane surface, as it damage the membrane itself and it is very hard to clean during the chemical cleaning of membrane system. As result it was set as desalination standard to limit the silica concentration in the brine of desalination systems to only 120 -150 mg/l (Avista Technology, 2016; Wilf, 2007).

Figure (4) shows that groundwaters in this study are undersaturated with respect to silica, however upon desalination, the brine will have a high concentration, reaching close to the set limit for silica of 120 – 150 mg/l in about 25% of the groundwaters. This in turn indicate that any chemical treatment process of brine should consider the removal of silica, along with removal of sulfate and calcium in order to have the brine suitable for further water extraction in RO desalination.

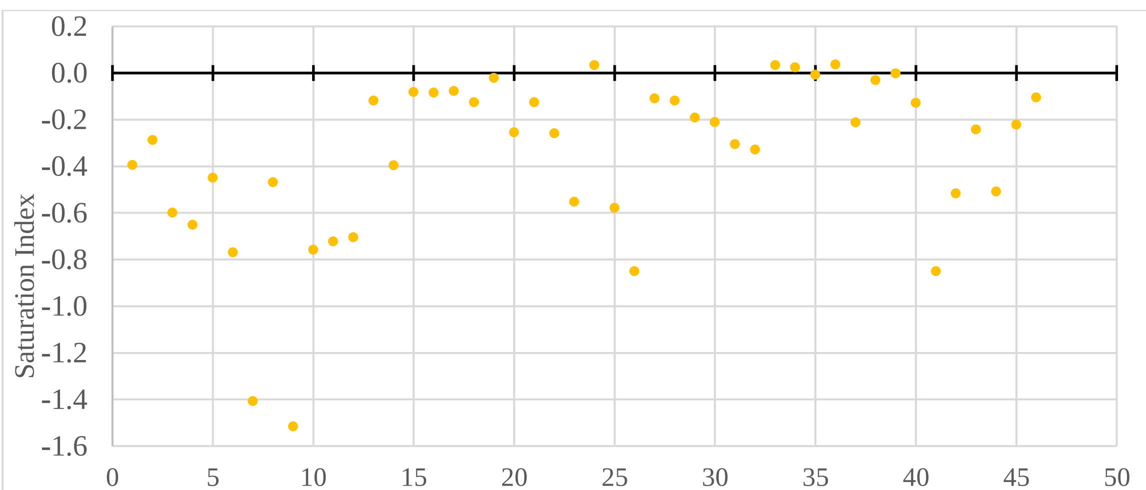

Figure 3: Saturation index for calcium sulfate or gypsum in groundwater

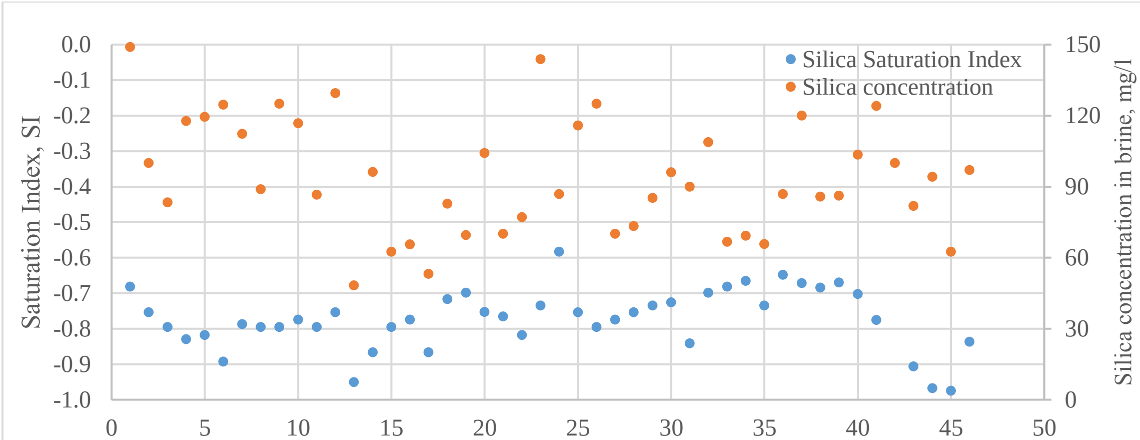

Figure 4: Saturation index of groundwater feed, and silica concentration in brine of brackish groundwater desalination

Figure (5) below shows the maximum attainable recovery in brackish groundwater RO membrane desalination systems, which was found to be in 90% of the cases limited by saturation due to supersaturation with respect to gypsum. As shown in the figure, the systems recovery ranges between 60 – 90 %, leaving 10 – 40 % of the water as brine needs to be properly managed.

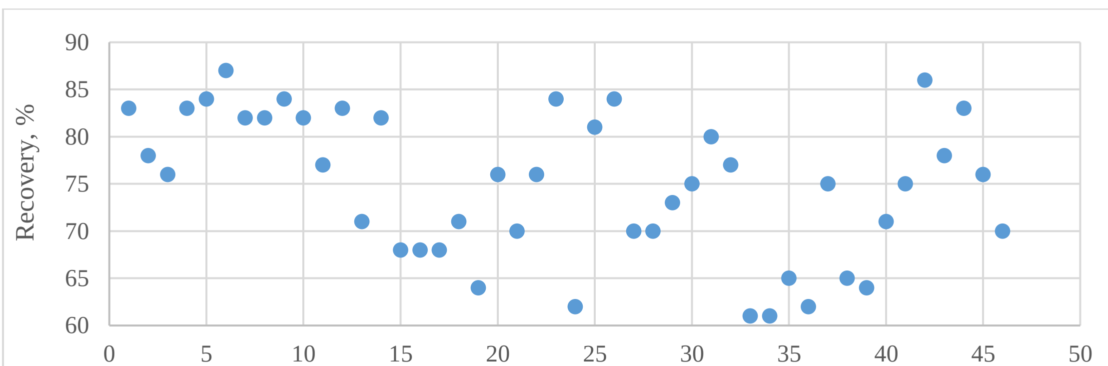

Figure 5: Maximum attainable recovery in brackish groundwater RO desalination system

In order to have a better understanding of membrane system recovery limitation for groundwaters, it is important to explore the dependence of maximum attainable system recovery on different quality parameters, specifically salinity and different saturation indices. Figure (6) below shows the maximum attainable recovery for different groundwater salinities, it is clearly shown that there is no direct relation over the salinity range of groundwater wells in this study. High salinity groundwaters of more than 6,000 mg/l were found to have a maximum attainable recovery ranging from 60 % to 83%, with similar trend shown for those with salinity less than 3,500 mg/l to range as well from 60% to 87%.

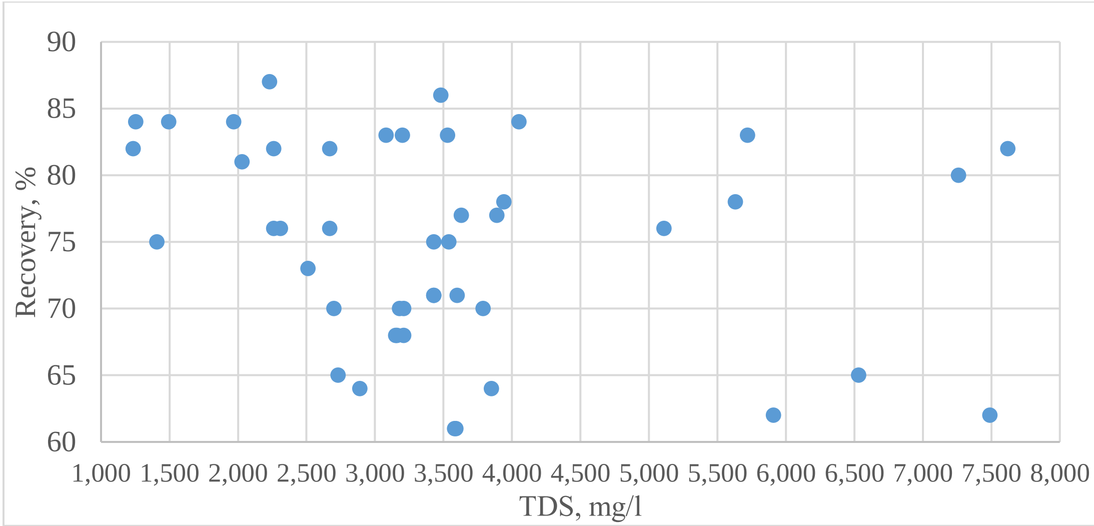

Figure 6: Maximum attainable recovery for different groundwaters salinity

Figure (7) below shows the maximum attainable recovery for different groundwaters with respect to saturation with gypsum, it is clearly shown that there is an inversely proportional relation over the range of groundwater wells in this study. The figure shows that generally, the maximum attainable recovery drops dramatically with the increase of gypsum saturation index, except for very few cases, in which the system was found to have low recovery of about 75% although of the low gypsum saturation index.

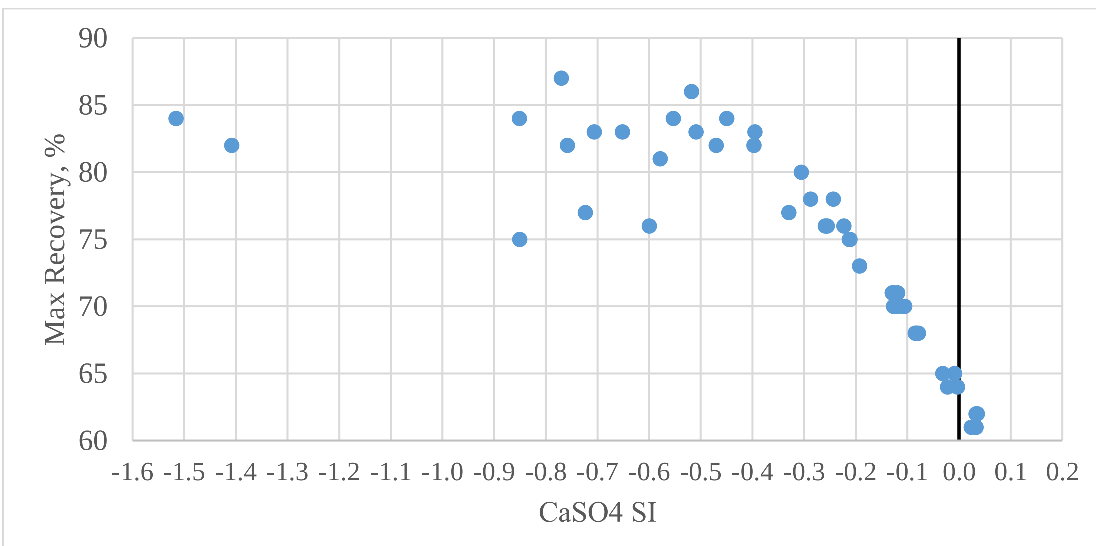

Figure 7: Maximum attainable recovery at different groundwaters gypsum saturation

Figure (8) below shows the maximum attainable recovery for different groundwaters with respect to silica concentration, it is clearly shown that there is no clear direct relation, however it was noticed that for silica concentrations of about 30 mg/l, recovery ranged from 65% to 75% depending on gypsum saturation index, and generally no recovery above 75% was obtained at silica concentrations above 30 mg/l.

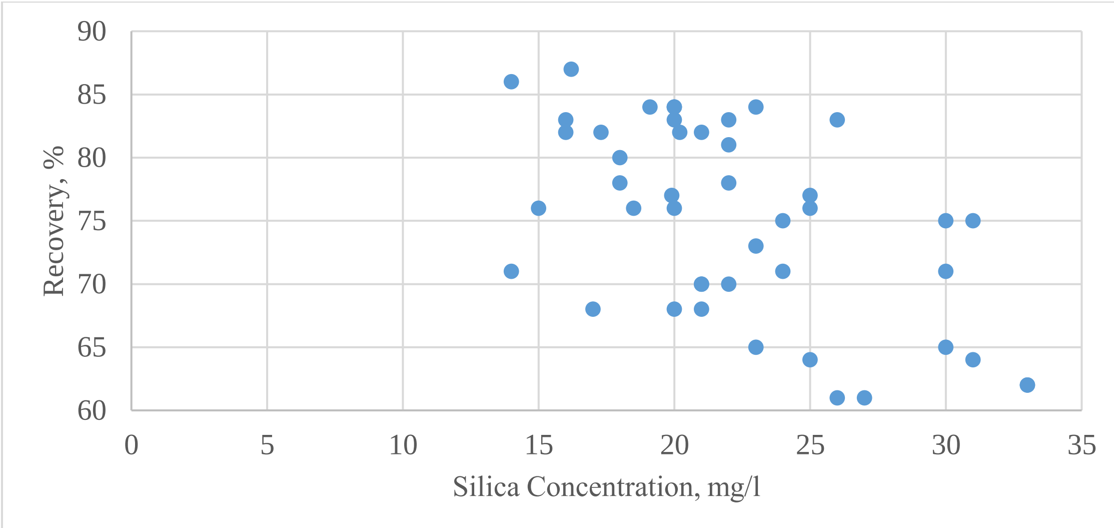

Figure 8: Maximum attainable recovery at different groundwaters silica concentration

Conclusion

Due to the absence of surface water resources, the dependence on groundwater in Middle East and North Africa, MENA region in general and Gulf Cooperation Council GCC countries in particular becomes essential. Groundwater is the main water source for agriculture purposes and domestic water supply for rural communities, in Qatar groundwater abstraction was mainly used for agriculture purpose with share up to 92%. Due to the limited freshwater resources in Qatar, preservation of available groundwater resources becoming very crucial, hence a groundwater monitoring program was launched in 1996 with more than 100 monitoring wells to closely assess and evaluate the groundwater resources both quantitatively and qualitatively, in which a set of production wells were studied here to assess the performance of membrane desalination systems.

The groundwater quality in terms of salinity and saturation indices for different sparingly soluble and scale forming salts were explored in this study, which showed that the application of desalination processes, and more specifically membrane desalination (RO) is becoming more needed due to decreasing groundwater quality (i.e. high salinity) for different purposes of domestic drinking water and agriculture water supply. Supersaturation with respect to gypsum salts due to the high calcium and sulfate concentrations encountered in groundwater was found to be the main recovery limitation for membrane desalination systems, in which the recovery was in the range from 60 – 87 %. Limitation due to silica found in Qatari groundwater was found to be second to limitation due to gypsum and was present in few cases in which recover was limited to about 75%.

Brine or concentrate management from groundwater desalination systems usually limits the wide application of such systems as most of these systems are located far from coastal area i.e. inland desalination (i.e. disposal issue). As most of groundwaters desalination system recoveries were found to be mainly limited by supersaturation with respect to gypsum, it is paramount to develop treatment processes which efficiently de-supersaturate the brine produced from such inland desalination systems to enable higher overall recovery of groundwater desalination systems.

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Making Better Decisions for an Uncertain Future with Monte Carlo Simulation

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Abstract
In an uncertain world, building spreadsheet models that allow decision makers to understand how that uncertainty can impact upon their business have become increasingly important. Techniques such as Monte Carlo simulation, sensitivity analysis, and stress testing are no longer an esoteric curiosity practiced by a few analysts in niche areas. Nowadays, many businesses use such tools as part of their everyday, mainstream analysis, and it is often embedded within organisational decision-making and risk frameworks. The presentation will give a practical and light-hearted overview of how Monte Carlo simulation works, and will examine how the technique has been applied to water demand forecast & capital project estimation models within the utilities sector.

Keywords: Monte Carlo simulation, Risk Modelling, Demand Forecasting, Project Management, Sensitivity Analysis.

SESSION 5: MUNCIPAL WATER MANAGEMENT AND SECURITY

Keynote

Effective Management of Water Utilities -NRW Diagnosis and Reduction Strategies

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Arab Countries Water Utilities Association (ACWUA)

Abstract

There exists a gap in performance between different water utilities in their ability to achieve sustainable levels of water loss. This gap has been a subject of speculation that over the years produced potential solutions, such as capacity building and training, infrastructure rehabilitation, and use of new devices and technology. Still, even today, water loss remains a challenge with annual losses surpassing ten billion dollars worldwide according to World Bank estimates.

The financial limitations to implementing a major in most utility management are real, so are the cases of capacity shortage. However, it can be argued that the water sector is by nature a non-profit public service, even with the increasing and successful role the private sector is playing, which by its nature removes the strategic aspects of water management and operation at the utility level, and gives a more short-term service oriented role to public water utility daily management and decision making. This, if shown to be a major factor, would result in a difficulty in addressing strategic objectives such as reducing NRW even when resources and knowledge are made available.

To investigate this concern, a USAID funded research project under FABRI and within the MENA NWC program was launched to diagnose the causes that govern NRW performance, and to develop tools and strategies to help tackle these causes. The project team under ACWUA, with Aqaba Water providing the Principle Investigator, concluded that many basic factors that are needed to enable and sustain water loss reduction good practices and water management in general are either completely or partially missing, even with favorable external factors. Moreover, there is a gap between perceived performance and actual implementation, as well as lack of understanding of the relevance of these factors on actual water loss reduction.

Developing these ideas further, the author, with cooperation with the NRW task force formed worked with the AfWA towards developing the NRW Toolkit including a new version of the diagnostic tool, as well as a new version of the diagnostic tool for ACWUA. These tools aim at providing web based access for the ACWUA and AfWA NRW task forces, and utilities, to diagnose the needed improvement and propose improving actions. These user tools are a start to develop a new set of operational specifications, benchmarking methodology, and performance indicators that guide and monitor the performance in terms of actions and goals on the long way before a performance impact can be achieved, and measured.

Keywords: NRW, Water, Loss, Practices, Procedures, Diagnostic, Monitoring, Benchmarking.

Keynote

Management and Security of Municipal Water at the GCC Countries

Mohammed Alrashid,
KISR

Abstract

In most countries agricultural water demand is the biggest; however, in half of the GCC countries municipal water is the main consumer (50%-70&). Moreover, municipal water is in direct and daily contact with all consumers. Therefore, its quality and quantity control and management is essential and its security is a strategic and sensitive issue. Many technical and socio-economic dimensions are related to municipal water as it is mostly comes from desalinated water through huge networks and storage systems.

This paper will give a background on municipal water situation, at the GCC countries, in relation to other water sectors. Also, the paper will discuss the challenges facing municipal water and the solution suggested. Since most of the municipal water comes from desalinated water, the energy-water connection will be highlighted. Finally, factors necessary for optimum management of municipal water will be discussed, in addition to recommendation for more secure municipal water.

Keywords: Agriculture, Security, Municipal, Consumers, Management.

Water Resources and Desalination: The Libyan Perspective: A Review (in Arabic)
مصادر المياه في ليبيا وتقنية تحلية المياه كخيار إستراتيجي لحل أزمة المياه

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الملخص
تقع دولة ليبيا في شمال إفريقيا ومصنفة على أنها ثالث أكبر دولة في قارة إفريقيا من حيث المساحة حيث تقدر مساحتها بحوالي 1,759,549 كيلو متر مربع وبساحل يبلغ طوله 1,980 كيلو متر. إن أكثر من 90% من مساحة البلاد تعد أرضا صحراوية أو شبه صحراوية. يبلغ عدد سكان ليبيا حوالي 6 مليون نسمة، 78% منهم يعيشون في المدن الكبرى كالعاصمة طرابلس وبنغازي ومصراتة والبيضاء وسبها. بالرغم من الرقعة الجغرافية الكبيرة التي تتمتع بها ليبيا وبالرغم من الساحل الطويل الذي تملكه، إلا أن مشكلة المياه لا تزال إحدى أبرز المشاكل التي يعاني منها المواطن وتؤرق المسئولين في الدولة لاسيما مع تزايد عدد السكان والنشاطات الزراعية والصناعية المصاحبة للتطور العمراني.
إن إنخفاض معدل سقوط الأمطار في ليبيا والإستنزاف الحاد للمياه الجوفية بحفرالآباروتداخل مياه البحر مع المياه الجوفية كلها أسباب وعوامل ساهمت في مشكلة شح المياه وتغير نوعية المياه الجوفية وبالتالي فقدانها لكثير من جودتها. كما إن الوضع الراهن الغير مستقر لمشروع النهر الصناعي الذي يعد المصدر الرئيسي للمياه للمناطق الساحلية الليبية يزيد من حدة أزمة المياه. بناءً على ما سبق، هناك حاجة ملحة للبحث عن حلول لأزمة المياه في ليبيا والبحث عن خيار إستراتيجي ناجع لإنهاء هذه الأزمة وبالتالي توفير إحتياجات المواطنين من المياه وتعويض الفاقد من المياه الجوفية.
تقنية تحلية المياه هي إحدى الخيارات الإستراتيجية المطروحة التي من شأنها أن تكون الخيار الأول والأخير لحل مشكلة المياه محليا وفي دول الإقليم الاخرى التي تعاني من نفس المشاكل. تقنية تحلية المياه هي التقنية الرئيسية التي تم تطويرها باستمرار خلال العقود الثلاثة الأخيرة لتوفر الإحتياجات المتزايدة لمياه الشرب. الهدف من هذه الورقة هو: أولاً تسليط الضوء على مصادر المياه التقليدية وغير التقليدية في ليبيا. ثانياً عرض ملخص عام لتاريخ إستخدام تقنية تحلية المياه في ليبيا ولماذا يجب التركيز على هذه التقنية في السنوات المقبلة لتكون الخيار الإستراتيجي الأول لحل أزمة المياه.

الكلمات الدالة: مصادر المياه، مياه جوفية، النهر الصناعي، تحلية مياه البحر.

1. المقدمة
تبلغ مساحة ليبيا 1.7 مليون كيلو متر مربع ويبلغ عدد سكانها 6 مليون نسمة. تسعون في المائة من السكان يعيشون في مساحة تقدر بأقل من عشرة في المائة من المساحة الكلية، والتي تتمثل في الأغلب على الشريط الساحلي، وتقدر الكثافة السكانية في المنطقة الوسطى والمناطق الجنوبية بأقل من شخص واحد لكل كيلو متر مربع [1]. وتصنف قارة إفريقيا على أنها إحدى أكثر القارات جفافا. معدل سقوط الأمطار السنوي في ليبيا يتراوح بين 100 و600 ملي متر في الجزء الشمالي. يعد الجزء الشمالي الساحلي أكثر المناطق التي تستقبل أكبر كميات من الأمطار، بينما الجزء الجنوبي فيستقبل كميات شحيحة من الأمطار تقدر بأقل من 10 ملي متر سنوياً. خمسة في المائة فقط من كامل التراب الليبي يستقبل كميات من الأمطار تتجاوز 100 مليمتر سنوياً. بعض أجزاء ليبيا لا تستقبل أي كميات من الأمطار على الإطلاق [2،3].

كميات المياه المتاحة في ليبيا المقدرة حسب بيانات سنة 2012 كانت 3890 مليون متر مكعب في السنة، منها 3650 مليون متر مكعب مياه جوفية و170 مليون متر مكعب مياه سطحية و70 مليون متر مكعب مياه تحلية. بناءً على البيانات المتاحة فإن كمية المياه المستهلكة في سنة 2012 بلغت 5830 مليون متر مكعب، يذهب الجزء الأكبر منها لقطاع الزراعة بنسبة 83%، بينما الإستخدام المنزلي فنسبته 12% وبلغ إستهلاك المياه في قطاع الصناعة 5% [4،5]. نلاحظ أن كمية المياه المستهلكة تجاوزت كمية المياه المتاحة مسببة عجزا مائيا مقداره 1940 مليون متر مكعب.

إن مشكلة ندرة المياه هي إحدى أعظم التحديات في ليبيا في الوقت الحاضر وكذلك في المستقبل إذا لم يتم إتخاذ قرارات حاسمة لحل هذه المشكلة. إستناداً لبعض التقارير; ليبيا على قائمة أكثر الدول التي تعاني أزمات حقيقية في المياه، كما صنفت بشكل دائم بأنها إحدى أكثر الدول في العالم التي تفتقد للأمن المائي [7،6].

بالرغم من الحقيقة المثبتة بأن تقنية تحلية المياه هي إحدى مصادر المياه الإستراتيجية البديلة لحل أزمة المياه والتي تزداد أهميتها بشكل مستمر نتيجة التقدم العلمي والتقني المصاحب لهذه التقنية، فإن الحكومة الليبية السابقة لم تستثمر بشكل جدي في قطاع التحلية، مع إن تقنية تحلية المياه قد ظهرت في ليبيا لأول مرة منذ عقد الستينيات. عوضا عن الإستثمار في تقنية تحلية المياه فإن مسئولي النظام السابق كان لهم رأي آخر لحل مشكلة المياه وتوفير الإحتياجات المائية للمواطنين حيث إتجهوا لتنفيذ أكبر مشروع هندسي لنقل المياه الجوفية العذبة من الوسط والجنوب لمدن وقرى الساحل الليبي الذي يعاني شحا في المياه العذبة عبر أنابيب عملاقة سمي هذا المشروع بالنهر الصناعي. في الوقت الذي يعد فيه مشروع النهر الصناعي من أكبر المشاريع في الهندسة المدنية وقام بتزويد بعض المدن الليبية الكبرى بإحتياجاتها المائية، إلا أنه لم يحل مشكلة المياه بشكل نهائي ولا تزال أزمة المياه في ليبيا تحتاج إلى حلول جدرية وأكثر فاعلية.

نحاول في هذه الورقة العلمية أن نسلط الضوء على مشكلة شح المياه محليا وكذلك النتائج المترتبة عليها. بداية سنسلط الضوء على أسباب مشاكل المياه، من ثم سنتحدث عن مصادر المياه المختلفة في ليبيا، يلي ذلك مناقشة قصيرة حول مشروع النهر الصناعي الذي تم تبنيه خلال العقود الثلاثة الأخيرة من قبل حكومات النظام السابق ليكون الخيار الأهم لتوفير المياه الصالحة للشرب والزراعة وحتى الصناعة. بعد ذلك يأتي الحديث حول التجربة الليبية مع تقنية تحلية المياه. أخيراً، سنحاول دعم وتوطين خيار تقنية تحلية المياه ليكون الخيار الأول والإستراتيجي لأزمة المياه في ليبيا.

2. مشكلة شح المياه في ليبيا

العديد من الدول في العالم مثل الدول العربية، دول غرب أسيا وأستراليا تعاني من أزمات مياه. وليبيا هي إحدى هذه الدول وتم تصنيفها على إنها إحدى الدول الستة والثلاثين في العالم التي تعاني شحا شديدا في المياه بمعدل 4.84 [6]. فيما يلي عرض لأهم الأسباب التي تقف وراء مشاكل المياه في ليبيا.

- الإستنزاف الحاد والجائر للمياه الجوفية
- إنخفاض معدل سقوط الأمطار
- الزيادة المفرطة للنشاطات الزراعية على الشريط الساحلي
- تداخل مياه البحر
- إنخفاض رسوم المياه لدرجة انعدامها في كثير من الأحيان
- إنعدام وجود خطط إدارية وهندسية واضحة فيما يتعلق بشئون المياه
- إنعدام وجود إستراتيجية شاملة فيما يتعلق بقطاع المياه عموما
- غياب الوعي العام لدى المواطنين للإستخدام الأمثل لمصادر المياه
- الضعف الإداري المتعاقب في الهيئة العامة للمياه

3. مصادرالمياه في ليبيا

يوجد نوعان من مصادر المياه في ليبيا; مصادر مياه تقليدية (طبيعية) تشمل المياه السطحية والمياه الجوفية والتي تمثل معاً 97.3% من مصادر المياه في ليبيا، ومصادر مياه غير تقليدية تشمل تقنية معالجة وإعادة إستخدام مياه الصرف الصحي وتقنية تحلية المياه والتي تمثل معاً 2.7% [8]. إن مشروع النهر الصناعي هو أحد مصادر المياه في ليبيا وتم تصنيفه من قبل المختصين بأنه أحد مصادر المياه الغير تقليدية.

3. 1. مصادر المياه التقليدية

<u>المياه السطحية</u>

إن المياه السطحية تعد مصدرا محدودا جدا من مصادر المياه في ليبيا حيث تساهم فقط بما نسبته 3% وهذا قد يُعزى لحقيقة كون ليبيا لا تملك أي أنهار جارية وعدد قليل جدا من البحيرات. من ناحية أخرى تمتلك ليبيا عددا من العيون الطبيعية، بعضها ذات نوعية مياه جيدة، كما إن بعض هذه العيون ذات معدلات ضخ مرتفع مثل عين الزيانة (5580 لتر/الثانية)، عين كعام (350 لتر/الثانية)، عين الدبوسية (170-230 لتر/الثانية) وعين تاورغاء (2000 لتر/الثانية) [شكل 1]. يوجد حوالي 185 عينا طبيعية بمعدل ضخ أقل من 5 لتر/الثانية مثل عين برادة (3.0 لتر/الثانية)، عين الشرشار (1.0 لتر/الثانية)، عين شيسة (0.8 لتر/الثانية)، عين طيبة (0.5 لتر/الثانية) وعين تانغت (0.1 لتر/الثانية) [5،4،1].

تجدر الإشارة إلى أن البيانات المتوفرة حول العيون الطبيعية سالفة الذكر هي بيانات قديمة وبحاجة إلى تحديث. هذه البيانات تم جمعها خلال عقدي السبعينات والثمانينات وبالتالي قد لا تمثل الظروف الحقيقية الحالية لهذه العيون. بناء على ما سبق لا يستطيع أحد أن يشير هنا إلى المواصفات الفعلية لهذه العيون الطبيعية.

شكل 1. عين تاورغاء

تم إنشاء عدد 16 سداً رئيسياً من أجل حجز مياه الأمطار والإستفادة منها بسعة كلية 385 مليون متر مكعب وبمتوسط سعة تخزينية سنوية 61 مليون متر مكعب [جدول 1]. يتم إستخدام مياه الأمطار المتجمعة في هذه السدود أساسا في الزراعة وبعض المشاريع الصناعية وفي أحيان أخرى لإحتياجات السكان. أكبرثلاثة سدود هي سد القطارة وسد وادي كعام وسد وادي المجنين بسعة تصميمية 135، 111، 58 مليون متر مكعب على التوالي. إضافة إلى ما سبق تم إقرار إنشاء عدد من السدود الجديدة وبهذه السدود يتوقع أن ترتفع كميات مياه الأمطار المحتجزة سنويا لتصل إلى 120 مليون متر مكعب [4].

جدول 1. السدود في ليبيا

رقم تسلسلي	الحوض المائي (المنطقة المائية)	عدد السدود	السعة التخزينية (مليون متر مكعب)	متوسط التخزين السنوي (مليون متر مكعب)
1	الجبل الأخضر	5	160.6	15.95
2	الكفرة والسرير	4	8.14	1.8
3	سهل جفارة	3	96.6	25.5
4	الحمادى الحمراء	4	119.4	17.4
الإجمالي			**384.74**	**60.65**

المياه الجوفية

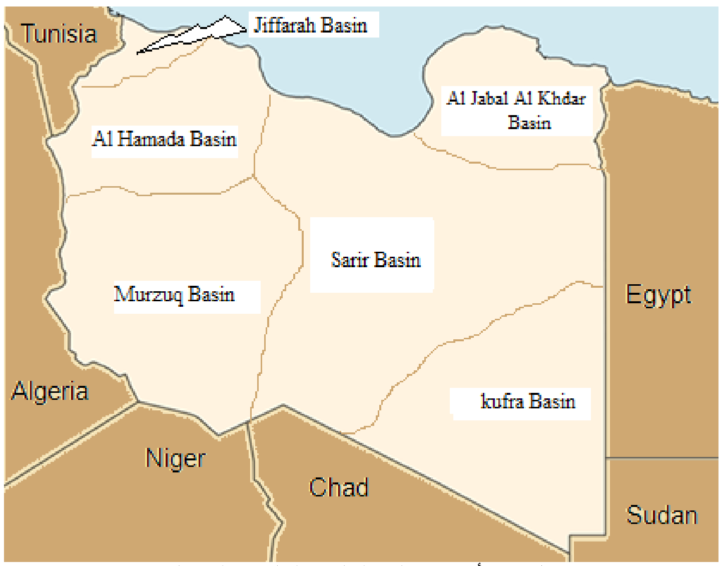
تعد المياه الجوفية المصدر الرئيسي للمياه في ليبيا حيث تشكل ما نسبته 98% من مصادر المياه المختلفة الموجودة [9]. يقدر المحتوى الكلي للمياه الجوفية 99,500 كيلو متر مكعب بمدى -غير مؤكد- يتراوح بين 64,600 و234,000 كيلو متر مكعب [10]. وتنقسم مصادر المياه الجوفية في ليبيا إلى نوعين: الأحواض السطحية والتي تتأتى مياهها من مياه الأمطار ويعد هذا النوع متجددا، أما النوع الثاني فيعرف بالأحواض العميقة وهذا النوع غير متجدد. يتواجد النوع الأول من المياه الجوفية في الأحواض المائية الشمالية مثل حوض سهل جفارة وحوض الجبل الأخضر وحوض الحمادى، بينما يتواجد النوع الثاني من المياه الجوفية -الأحواض العميقة- في الجزء الأوسط والجنوبي من البلاد مثل حوض مرزق وحوض الكفرة والسرير [جدول 2].

تجدر الإشارة إلى أن النوع الثاني والذي يطلق عليه أيضا بالمياه الجوفية الأحفورية (fossil water) تم إكتشافه بطريق الصدفة في منتصف القرن العشرين عندما بدأت شركات النفط بالتنقيب عن النفط في الصحراء الجنوبية. نتج عن ذلك إكتشاف خمسة أحواض مائية جوفية [1]. الشكل رقم (2) يوضح الأحواض المائية الرئيسية. المياه الجوفية المتجددة هي المياه التي تتجدد سنويا

بمياه الأمطار، والمياه الجوفية غير المتجددة هي الأحواض المائية العميقة (الأحفورية) والتي لا تتجدد إلا بمعدلات بطيئة جدا على مقياس الزمن البشري ولهذا تم إعتبارها غير متجددة.

جدول 2. مواصفات الأحواض المائية الجوفية الرئيسية

الحوض المائي	المساحة (كيلو متر مربع)	نوع المياه	السعة التخزينية التقديرية (كيلو متر مكعب)
سهل جفارة	18,000	متجددة*	-
الحمادى	215,000	متجددة	4000
الجبل الأخضر	145,000	متجددة	-
مرزق	350,000	غير متجددة*	4800
الكفرة والسرير	700,000	غير متجددة	-



شكل 2. الأحواض المائية الجوفية الرئيسية في ليبيا

موازنة بين الإحتياج المائي والمصادر المائية المتوفرة

وفقا للمعلومات المتحصل عليها من الهيئة العامة للمياه، يتوفر في الأحواض المائية الرئيسية حوالي 10^6x3820 متر مكعب. جدول (3) يوضح الحالة المائية (الإحتياج المائي والمصادر المائية) لسنة 1995 لكل حوض من الأحواض المائية الرئيسية.

جدول 3. الموازنة المائية بين الإحتياج المائي ومصادر المياه المتوفرة (المصدر: عمر م. سالم)

الحوض المائي	عدد السكان (مليون نسمة)	الإستهلاك المائي (10^6x م^3)			الإحتياج الكلي (10^6x م^3)	المياه المتوفرة " سطحية وجوفية" (10^6x م^3)	الموازنة (10^6x م^3)
		الزراعي	المنزلي	الصناعي			
سهل جفارة	2.24	965	170	65	1200	273	-927
الحمادى	0.92	360	70	25	455	459	4
الجبل الأخضر	1.27	469	96	35	600	288	-312
مرزق	0.24	886	18	2	906	1500	594
الكفرة والسرير	0.13	696	10	18	724	1300	576
الكلي	4.8	3376	364	145	3885	3820	-65

من خلال جدول (3) نستطيع بوضوح ملاحظة أن توزيع السكان غير متجانس في مناطق الأحواض المائية. معظم الكثافة السكانية تتركز بشكل رئيسي في سهل جفارة ومنطقة الجبل الأخضر. هذا التوزيع الغير متساوي وكذلك النشاطات الزراعية المكثفة في المناطق الساحلية تجعل من الهوة بين الإحتياج المائي ومصادر المياه المتوفرة كبيرة. بالرغم من أن الأرقام المدرجة في جدول (3) هي إحصائيات لسنة 1995، إلا أن الخبراء يتوقعون أن عدم الإتزان بين الإحتياج المائي ومصادر المياه المتوفرة سيزداد مستقبلا خاصة في الأحواض المائية الشمالية إذا لم يتم إتخاذ إجراءات حاسمة وعاجلة بهذا الشأن.

3. 2. مصادر المياه غير التقليدية
تشمل مصادر المياه غير التقليدية في ليبيا كلا من النهر الصناعي ومياه الصرف الصحي المعالجة ومياه التحلية. الجزء التالي من هذه الورقة سيتناول عرض تفصيلي لمصادر المياه غير التقليدية.

النهر الصناعي

يعد مشروع النهر الصناعي أحد أكبر وأغلى المشاريع الهندسية لضخ ونقل المياه. وفقا لبرنامج الأمم المتحدة الخاص بالبيئة (UNEP)، فإن مشروع النهر الصناعي هو أحد أكبر مشاريع الهندسة المدنية في العالم. ولقد تم إقرار المشروع ليوفر للمجتمع الليبي إحتياجاته من المياه وذلك عن طريق ضخ المياه من الأحواض المائية الجوفية في عمق الصحراء -حوض النوبي- ونقلها عبر شبكة طويلة وهائلة من الأنابيب المدفونة إلى قرى ومدن وبلدات الساحل الليبي حيث تتركز معظم الكثافة السكانية وتتركز مشكلة شح مياه الشرب. وفقا للوكالة الدولية للطاقة الذرية (IAEA)، فإن حوض النوبي يعد من أكبر وأهم الأحواض المائية الجوفية في العالم. تبلغ مساحة الحوض المائي مليوني كيلو متر مربع ويخزن حوالي ضعفي حجم المياه الموجودة في بحر قزوين. ومن العوامل التي حفزت على إقرار مشروع النهر الصناعي قبل أكثر من ثلاثين سنة أنه سيكون أكثر جدوى إقتصادية وأقل تكلفة بخمس مرات من أي خيار آخر من مصادر المياه البديلة.

تم تصميم المشروع من خمس مراحل على أن يكون الهدف النهائي مع إكتمال مراحل المشروع هو نقل كميات هائلة من المياه تقدر بستة مليون متر مكعب في اليوم سيتم جلبها من مصادرها الجوفية في الجنوب إلى الشمال حيث هناك حاجة ملحة ومتزايدة لمياه صالحة للشرب وآمنة صحيا. مع إن مشروع النهر الصناعي أعتبر على أنه أحد المشاريع الضخمة المتخصصة في أنظمة نقل المياه تم تصنيف هذا المشروع على أنه أحد مصادر المياه غير التقليدية، بالرغم من أن المياه المنقولة عبر أنابيبه هي مياه جوفية أصلاً [4].

بالرغم من أن المياة المجلوبة بواسطة مشروع النهر الصناعي وصلت لبعض المدن الرئيسية على الساحل الليبي كالعاصمة طرابلس وبنغازي ومصراتة، إلا أن السكان لا يشعرون بالإرتياح الكامل لشرب هذه المياه وعوضا عن ذلك يقومون باستخدامها في أعمال الغسيل والتنظيف والنشاطات الزراعية والصناعية. عدم الإرتياح لشرب هذه المياه نتج بسبب أن المياه المجمعة في خزانات كبيرة لا يتم تحليلها أو معالجتها بصفة مستمرة مما قد يترتب على هذا الأمر عدم مطابقتها للمواصفات الليبية القياسية لمياه الشرب [11].

إستنادا على المعلومات المذكورة في الفقرة السابقة المتعلقة بجودة مياه النهر الصناعي وعدم مطابقتها لمواصفات مياه الشرب القياسية وبناءً على الوضع الحالي الغير مستقر لمشروع النهار الصناعي والعراقيل التي تقف دون إكتماله أو حتى إستمراره على المسار الذي صمم من أجله، فإن أزمة شح المياه لا تزال أزمة قائمة في معظم المدن الليبية، وبالتالي هناك حاجة ملحة للبحث عن حلول جدرية لمشكلة شح المياه.

معالجة مياه الصرف الصحي

إن تزايد عدد السكان في ليبيا طيلة العقود الثلاثة الأخيرة، خصوصا في سهل جفارة والجبل الأخضر كان عاملا رئيسيا لإنشاء عددا من محطات معالجة مياه الصرف الصحي في الريف والحضر. وفقا للبيانات المتحصل عليها من شركة المياه والصرف الصحي يوجد عدد 23 محطة معالجة موزعة في جميع ربوع ليبيا. عشر محطات فقط من بين هذه المحطات هي محطات عاملة وثماني محطات عاطلة وخمس محطات واقعة تحت أعمال الصيانة أو يمكن صيانتها من قبل إدارة الشركة.

تم تصميم محطات معالجة المياه بشكل أساسي لتوفر مياه مناسبة للقطاع الزراعي. أكبر هذه المحطات موجودة في طرابلس ومصراتة وسرت بسعة تصميمية: 110000، 24000 و21000 م^3/اليوم على التوالي. إضافة لما سبق، فإن معظم المحطات المتبقية هي ذات سعة تصميمية متوسطة وصغيرة يتراوح مداها بين 370 و6700 م^3/اليوم.

تقدر كمية مياه الصرف الصحي المطلوب معالجتها حوالي 1324054 م^3/اليوم، وتقدر كمية مياه الصرف الصحي المعالجة حاليا بحوالي 145800 متر مكعب/اليوم، أي أن نسبة المياه المعالجة فعليا إلى إجمالي كمية المياه المطلوب معالجتها تمثل 11% فقط والباقي يتم ضخها للبحر والأحواض الترابية والآبار السوداء.

تحلية المياه في ليبيا

إن مصطلح تحلية المياه يعني عملية إزالة الأملاح الذائبة من الماء، وبالتالي إنتاج المياه العذبة من البحر والآبار [12]. إن عدد محطات التحلية العاملة في العالم اليوم يصل إلى 15988 محطة. تنتج هذه المحطات حوالي 66.5 مليون طن من المياه العذبة يوميا [13]. تحلية مياه البحر إما أن تتم بواسطة تقنيات حرارية والتي تساهم بنسة 50%، أوتقنيات الأغشية الأسموزية والتي تساهم بالنسبة المتبقية.

وتعد تحلية المياه ثاني أهم مصدر للمياه في ليبيا. بدأ إستخدام تقنيات التحلية في ليبيا منذ بداية عقد الستينيات، ومع ذلك فإنه قد تم إنشاء عدد قليل فقط من محطات التحلية منذ لك الوقت. يوجد حاليا عدد 21 محطة تحلية عاملة، بسعة تصميمية كلية 525,680 م^3/اليوم. تمثل تقنيات التحلية بالطرق الحرارية 95% من التقنيات المستخدمة، بينما تمثل تقنيات التحلية بواسطة الأغشية الأسموزية 5%. تساهم تحلية المياه في الإمداد المائي المحلي بنسبة 1.4% حسب تقديرات سنة 2002 [14]. يلخص جدول (4) محطات تحلية المياه العاملة محليا مع قدرتها التشغيلية ونوع التقنية المستخدمة في كل محطة.

جدول 4. محطات التحلية العاملة على الساحل الليبي

موقع المحطة	نوع التقنية	السعة التصميمية	عدد الوحدات	سنة التشغيل
طبرق	MED*-TVC*	40,000	-	1977-2002
بومبا	MSF*	30,000	3	1988
درنة	MED-TVC	40,000	-	-
سوسة	MED-TVC	10,000	2	2000
سوسة -إمتداد	MED-TVC	40,000	-	
أبو ترابة	MED-TVC	40,000	-	2006
زليتن	MSF	30,000	3	1992
الزاوية	MED-TVC	80,000	-	-
زوارة	MED	40,000	-	2006
زوارة-إمتداد	MED-TVC	40,000	-	-
طبرق	MSF	24,000	4	1977
تاجوراء	RO*	10,000	2	1984
مصراتة	MSF	30,000	3	1987
سرت	MSF	10,000	1	1986
الزاوية 2	MED	2,500 x 2	2	2006
غرب طرابلس	MED-TVC	5,000 x 2	2	1999
الخمس	MSF	10,560 x 3	4	1985
شمال بنغازي	MED-TVC	4,800 x 1	1	2005
شمال بنغازي 2	MED-TVC	2,500 x 2	2	2007
درنة	MED-TVC	4,700 x 1	1	1998
هراوة	MSF	500 x 1	1	1989
السعة التصميمية الكلية		**525,680**		

*MSF- تقنية التحلية بواسطة التبخير الوميضي متعدد المراحل
*MED- تقنية التحلية بواسطة التبخير متعدد الأثر
*TVC- تقنية التحلية بواسطة ضغط البخار
*RO- تقنية التحلية بواسطة الأغشية الأسموزية (التناضح العكسي)

تجدر الإشارة إلى أن محطات التحلية المُشار إليها في جدول (4) هي تحت إدارة جهات حكومية مختلفة متمثلة في الشركة العامة للكهرباء والشركة العامة لتحلية المياه والشركة العامة للمياه والصرف الصحي. وفقا للمعلومات المتحصل عليها من الشركة العامة لتحلية المياه فإن كمية المياه المحلاة المنتجة من المحطات التابعة للشركة لسنة 2010 قدرت بـ 71 مليون متر مكعب. كما أن الشركة العامة لتحلية المياه أعلنت بأنه قد تمت المصادقة على إنشاء عدد 15 محطة تحلية مياه جديدة معظمها سيعمل بتقنية الأغشية الأسموزية. وإضافة إلى محطات تحلية مياه البحر فإن هناك عدد من محطات تحلية مياه الآبار تابعة للشركة العامة للمياه والصرف الصحي. أكثر من نصف هذه المحطات عاطلة عن العمل ويقدر عدد المحطات العاملة بسبعة محطات فقط موزعة في كل من سرت والواحات وصبراتة وطبرق.

4. تحلية المياه الحل الإستراتيجي لمشاكل المياه

بالرغم من أن تقنية تحلية المياه أصبحت مصدرا مهما من مصادر المياه للعديد من دول الإقليم والمنطقة والتي تعاني من أزمات في شح المياه إلا أنها لم تصر بعد ذات أهمية إستراتيجية في ليبيا لأسباب سياسية بالدرجة الأولى. بناء على العرض التفصيلي أحيانا والمختصر أحيانا أخرى لمصادر المياه المختلفة في ليبيا في الأجزاء السابقة من هذه الورقة فإن خيار توطين تقنية تحلية المياه في ليبيا يجب أن يؤخذ بعين الإعتبار وبشكل جدي ليكون البديل الرئيسي والحل النهائي لأزمة المياه. فيما يلي عرض لأهم الأسباب التي تجعل من تحلية المياه مصدرا مهما من مصادر المياه في المستقبل القريب في ليبيا.

- الإستنزاف الحاد للمياه الجوفية
- الإزدياد المستمر للإحتياجات المائية
- الوضع الغير مستقر لمشروع النهر الصناعي
- إتساع الرقعة الجغرافية لليبيا تجعل من عملية نقل المياه الجوفية عبر أنابيب -كما هو الحال في مشروع النهر الصناعي- ولمسافات طويلة غير إقتصادية
- الإنخفاض الملحوظ في كلفة تحلية مياه البحر للمتر المكعب الواحد
- وفرة مياه البحر بساحل طويل وجودة جيدة وخالية نسبيا من العديد من الملوثات
- تركز الكثافة السكانية في ليبيا في المدن الساحلية
- خلق فرص عمل كبيرة لشريحة مختلفة من الخريجين وذوي الخبرة
- إن وفرة الغاز الطبيعي في المنطقة سيساهم في خفض كلفة المياه المنتجة خصوصا عندما يؤخذ بعين الإعتبار إنشاء المحطات المزدوجة لإنتاج الكهرباء وتحلية المياه

إضافة إلى الأسباب السابقة فإن بعض الدول العربية كدول الخليج العربي عموما والمملكة العربية السعودية خصوصا والتي تتشابه مع ليبيا كثيرا في الظروف المناخية وندرة المياه على أراضيها لها تجربة ناجحة جدا في مجال تقنية تحلية مياه البحر والتي جعلت منها رائدة في هذا المجال، حيث تنتج حوالي 26% من المياه المحلاة في العالم [15،16]. إن هذا المثال العربي الإيجابي الحي يعزز ويدعم مسألة توطين تقنية تحلية المياه في ليبيا وتجعلها من أولويات المرحلة القادمة للحد من أزمة المياه.

5. الإستنتاجات والتوصيات

بعد النظر المستفيض في مصادر المياه المختلفة في ليبيا والوضع الحالي لكل منها يمكن إستخلاص الإستنتاجات والتوصيات التالية:

- إن قطاع الزراعة هو أكثر قطاع مستهلك للمياه في ليبيا (80% على الأقل) وفي ذات الوقت يساهم بنسبة منخفضة جدا في الإقتصاد المحلي لذلك يجب أن يتم إستخدام تقنيات الري الحديثة للمحافظة على المياه المتاحة.
- إن غياب الإدارة الرشيدة في كل المؤسسات المعنية بالمياه سبب العديد من مشاكل الأرشفة والتوثيق. لذلك يتحتم أن يكون هناك تعاون مشترك بين هذه المؤسسات وباقي المؤسسات الأهلية الأخرى للبحث عن حلول جدرية لإعادة ترتيب وأرشفة كل الوثائق الخاصة بمصادر المياه وتحديثها على أسس علمية سليمة.
- بالرغم من أن مشروع النهر الصناعي حد جزئيا من أزمة المياه للجزء الشمالي من البلاد، إلا أنه لا يعد مصدر مستقرا لكل الظروف والمتغيرات. ما حدث في السنوات الخمس الأخيرة أثبت هذه النقطة، فسكان العاصمة طرابلس عانوا مرارا وتكرارا من الإغلاق المتعمد للإمداد المائي من مشروع النهر الصناعي بسبب أعمال الشغب والتخريب والسرقة والإبتزاز أيضا. بالتالي فإنه يتوجب وبشكل جدي وعاجل على الشركة المسؤولة على إدارة مشروع النهر الصناعي التعاون مع الحكومة لوضع حد لكل من يعرقل وصول المياه لمستحقيها من المواطنين، وإلا فإن أزمة المياه ستتصاعد وبشكل لا تُحمد عواقبه.
- لقد أثبتت تقنيات تحلية مياه البحر وتحلية مياه الآبار جدواها الإقتصادية. كما يرى الكثير من الخبراء بأن التطور المستمر لتقنيات التحلية سيخفض في التكلفة الإنتاجية للمياه المحلاة. بناء على ذلك فإن تقنية تحلية مياه البحر يجب أن يتم توطينها على طول الساحل الليبي، بينما تحلية مياه الآبار فيجب العمل على توطينها في باقي المناطق الليبية لاسيما الوسطى والجنوبية.
- يجب على المؤسسات المعنية بالمياه أن تؤسس وبشكل عاجل فرق ولجان تفتيش وتقييم لمحطات التحلية المتوقفة والعاطلة عن العمل وكتابة تقارير فنية تفصيلية حول هذه المحطات على أن تتضمن هذه التقارير كلفة الصيانة كلما دعت الحاجة. هذه التقارير من شأنها أن تسهل الأمر للسلطات الحكومية مع القطاع الخاص لإتخاذ القرارات الصائبة حول هذه المحطات. إن بقاء محطات التحلية العاطلة عن العمل على وضعها الحالي من شأنه أن يخلق مشاكل تقنية، إجتماعية وبيئية ستظهر أثارها عاجلا أو آجلا.

- يوصى بأن يستمر مشروع النهر الصناعي كمصدر ثان -غير رئيسي- للمياه للمدن الساحلية وباقي المدن الليبية ليعوض الفاقد من المياه وقت الحاجة إلا أننا لا نوصي بإستكمال مراحله التي لم تكتمل بعد في حال تبين أنها غير مجدية إقتصاديا.
- يوصى أيضا بأن تقدم السلطات الحكومية مبادرات جدية في إتجاه إعادة إستخدام المياه وذلك بدعم الأبحاث العلمية في هذا الحقل، والذي يمكن أن يتأتى عن طريق البحاث في المراكز البحثية والجامعات.

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Assessment of the Water-Energy Nexus in the Municipal Water Sector in the Eastern Province, Saudi Arabia.

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Abstract
When it comes to water and energy, it is hard to have one without the other. Water is required to produce energy and energy is necessary in water production and management. This water-energy interrelation "Nexus" was investigated and discussed in Saudi Arabia using the Eastern Province as a case study. The Eastern Province water-energy nexus was assessed within the municipal sector focusing on the electric energy footprint in water value chain (groundwater, desalination and wastewater treatment "WWT") and water footprint in electric energy generation (thermal power plants). The study aimed to shed light on the Eastern Province contemporary nexus circumstances and conditions using the year of 2013. The study revealed that the Eastern Province is highly dependent on energy for water provision. Similarly, its energy dependency on fresh water resources is also major and evident although it decreases as we move closer to coastal areas. Thermal desalination is by far the most energy intensive stage among the entire Eastern Province water cycle. In 2013, it was estimated that desalination occupied 13% of the Eastern Province energy generation capacity and 5% of the Kingdom capacity. Substantial energy input in desalination in the Eastern Province is attributed to the provision and conveyance of water to the capital Riyadh (desalination; transmission). As for groundwater pumping it was estimated that 206.2 GWH was used for pumping (268 MCM) in 2013. WWT primary, secondary and tertiary energy requirement was revealed to be the least (2-108 GWH). On the other hand, water footprint in electricity generation was estimated to be at an average of 739307.5 m^3 in 2013 (0.125 m^3/kWh) and is relatively high compared with the norm of gas combustion turbine cooling water requirement around the world. Anthropogenic Greenhouse Gases (GHG) emission mainly in the form of CO_2 was computed to be around **17** Million Ton of carbon dioxide equivalent (CO_2e) for the entire water supply chain. Again, desalination had highest carbon footprint throughout the whole water cycle (16.9 MT of CO_2e). Nevertheless, carbon emissions from electric energy generation through power plants had significantly exceeded the entire water supply chain's carbon footprint. Finally, alternative mitigation options of management and technologies fixe were reviewed and suggested to reduce energy consumption in water cycle, minimize the water footprint in electric generation and mitigate associated GHG emission.

Keywords: Thermal Power Plant; Environmental Impact; Carbon Footprint; Energy Recovery; Management and Mitigation.

1. Introduction

Water production and management require energy, likewise energy exploration, transformation and production need water to be achieved (WWAP, 2014). This interdependency or "nexus" (Figure 1) is becoming more apparent and important especially when attempting to address the integrated management of water and energy resources specifically for countries which lack renewable freshwater resources. Saudi Arabia, like the rest of the GCC countries, is experiencing rapid population growth in, agricultural and industrial development, all coupled with increasing standards of living and changing lifestyle and consumption pattern. The high per capita water and energy demands represents a critical issue specifically for a country that is considered severely poor in natural freshwater sources with already depleting non-renewable fossil groundwater resources that are witnessing deterioration both in quality and quantity.

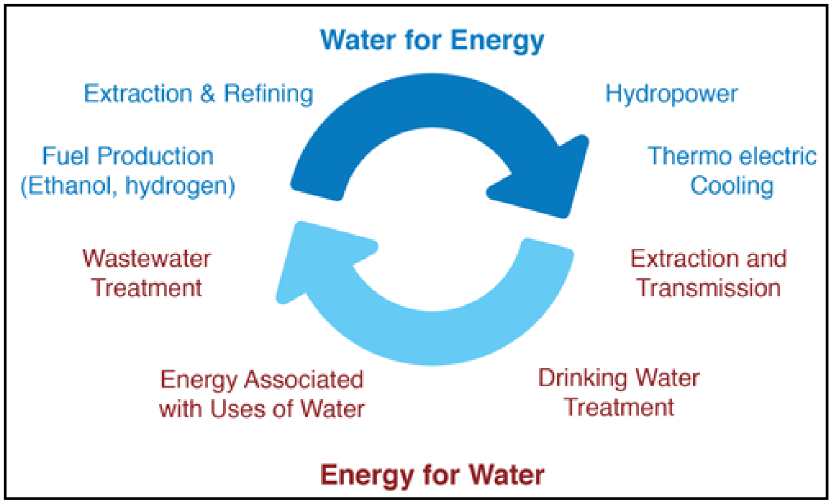

Figure 1: Water-Energy Nexus (WBCSD, 2009)

The ability of the Kingdom to bridge the water supply-demand gap by the fossil fuel-intensive desalination is considered unsustainable and could pose major risks on socio-economic development and environmental wellbeing. Thus an understanding and an in-depth assessment of the water-energy interlinkages and the risks they two have on each other must be achieved so these risks are mitigated and opportunities in resource efficiency and sustainability are identified.

In general, there is a knowledge gap in the nexus in Saudi Arabia and the GCC in general, where quantitative data that aid to scientifically understand the interdependency between water-energy is lacking. This data is very important in helping to recognize the nexus nature and dynamics, which ultimately could be a very helpful tool in implementing an integrated water-energy management approach and coupled policy making. Furthermore, environmental risk assessment of current and future scenario as well as opportunity loss is somehow overlooked or don't exist.

The main objective of the study is to bridge the water-energy nexus knowledge gap and to understand the current nexus relationship and dynamics in the region. This is made by producing quantitative data that estimate how much energy goes into the water value chain and vice versa under the designed and operational conditions of Saudi Arabia, as well as estimating the nexus associated environmental externalities in terms of greenhouse gases (GHGs) emission. In addition, the study explores and provides management alternatives and recommendations to help optimize energy consumption in the water value chain and similarly reduce water consumption in the energy generation sector, which in turn could be used to pave the way for formulating and implementing nexus management approach for water and energy at a country level. The method adopted is a case study review using Eastern Province of Saudi Arabia as stud area utilizing approved mathematical equations in estimating the water-energy nexus values. Data is gathered mainly from operating plants or published governmental water-energy documents as well as related scientific literature.

2. Study Area

The kingdom of Saudi Arabia is located in the southwest corner of Asia, being an intersection between Europe, Asia and Africa continents (Figure 2). The Kingdom occupies over 2.15 million km^2 which represent around 80% of the Arabian Peninsula with a total of 30 million inhabitants.

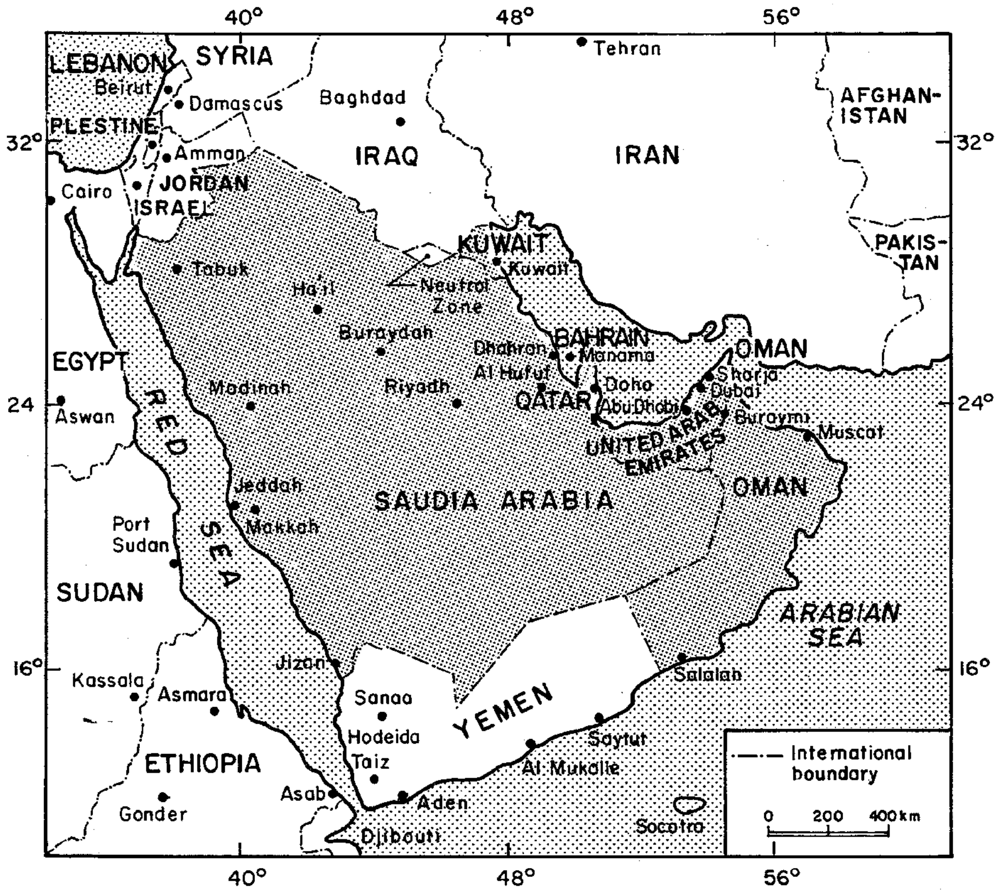

Figure 2: The Kingdom of Saudi Arabia (AL-Rashed and Sherif, 2000)

The study focuses on the water-energy nexus in the water and electric energy production domain at the Eastern Province of Saudi Arabia for the municipal sector. The scope includes: energy requirements in the water value chain primarily (desalination, groundwater and wastewater treatment) and water requirements in electric energy production. The study takes into account the business year of 2013 for which a complete data for the Eastern Province's water and energy is available. The Eastern Province is of high importance economically, geographically and socially in the Kingdom among other Provinces with a total area of 9900 km^2. The Province includes around 23 councils and the major cities are Jubail, Dhahran, Dammam, Khobar, Ras Tanura, Qatif, Hassa and Khafji. The Province is rich in oil and gas production among other petrochemical industries. In 2013 the total population in the Eastern province was 4.65 million inhabitants. The population growth rate in the province is calculated at 3.7% for the period 2004-2010 (CDSI, 2013).

The Eastern Province water supply consists of conventional (Groundwater) and unconventional (Desalinated Seawater and Treated Wastewater) water sources. In 2013 the total supplied water to the Eastern Province from all water sources (Groundwater and Desalinated) was estimated at 599 MCM (MOWE, 2013); 54% of this is supplied by groundwater and 55% by desalinated seawater, whereas 234 MCM of treated wastewater was reused, which represents around 25% of the total treated WW volume (345 MCM) in the same year with a rate of 947280 m^3 treated per day. Table (1) summarizes water supply for the year (2013) at the municipal sector of the Eastern province as per MOWE annual report (2013), while Table (2) provides some groundwater characteristics of the Province.

Table 1: Eastern Province Municipal Water Supply and Demand (MOWE, 2013)

Region	Municipal Demand (2013, MCM per Year)	Municipal Demand Growth Rate (2006-2013)	Contribution of Desalination (2013, %)	Contribution of Groundwater (2013, %)	Treated WW (2013, MCM)	Reused Treated WW (2013, %)	Per Capita Consumption (2013, M^3 per Person)	Supplied Water from all Sources (MCM)
Eastern Province	599	2.9	55	45	345	25 (234 MCM)	129	599

Table 2: Eastern Province Principle Groundwater Aquifers Reserve, Recharge Rate and Water Quality (MOWE, 2012).

Aquifer	**Reserve (MCM/Y)**	**Recharge (MCM/Y)**	**TDS (PPM)**	**Average Depth (m)**
Dammam	45000	200	2600-6000	218
Neogene	130000	360	2400-4000	
Umm Er Radhuma	190000	406	2000-5000	

Saudi Arabia is considered as the world leading desalination nation. Seawater desalination capacity in 2013 exceeded 1 Billion m^3 (1.006 BCM) with 5.4% increase compared to 2012 production (954.9 MCM). Table (3) contains desalination plants specification including process type, production design capacity as well as the cities they serve in Eastern Province.

Table 3: Breakdown of Eastern Province Seawater Desalination Production in 2013 (SWCC, 2013; MOWE, 2013).

City	**Supplied Water MCM**	**Technology Used**	**Plant Name**	**Total Supplied MCM**
Jubail	32	MSF	Jubail MSF 1&2	34.5
	2.5	MED	IWPP MARAFIQ	
Khafji	7.5	MSF	Khafji MSF 2nd	7.5
Rest of Eastern Province Cities.	120	MSF	Khobar MSF 2&3	281 (Eastern Province Grand Total 323 MCM)
	161	MED	IWPP MARAFIQ	
Riyadh	306.5	MSF	Jubail MSF 1&2	335 (Riyadh Grand Total 335 MCM)
	28.5	RO	Jubail RO	

**Rest Of Eastern Province Cities include; Damamm, Khobar, Qatif, Dhahran, Safwa, Siyhat, Ras Tanura, Abqaq and Hufof.*

Treated municipal wastewater (WW) is another important unconventional water source in the Kingdom, although reused water it is underutilized. In total KSA reused 14% (181 MCM) of its treated WW (1261 MCM) in 2013 with a daily treatment average of 3.5 MCM KSA wide. Most wastewater treatment plants (WWTP) in Eastern Province are tertiary stage treatment plants. As for energy Saudi Arabia, electric energy is generated strictly through thermal power plants jointly by SEC and SWCC with small contribution from small entities. Percentages of electric energy production at the Kingdom by producers (SEC, SWCC and others) are shown in Figure (3). Table

(4) summarizes the total number of thermal plants in the Kingdom, their production capacities and their owner (producer).

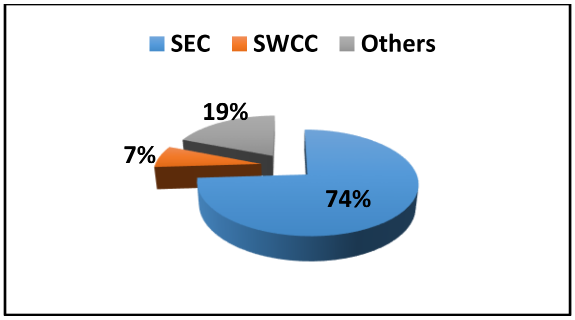

Figure 3: Distribution of Generation Capacities among Producers (ECRA, 2013)

Table 4: Capacities of Generation Units of Licensed Entities (ECRA, 2013)

Producing Entity	**Number of Plants**	**Production Capacity (MW)**
Saudi Electric Company (SEC)	46	51,525
Saline Water Conversion Cooperation (SWCC)	6	5,018
Others	24	13,218
Total	**76**	**69,761**

Others include; Saudi Aramco, Jubail Water and Electricity Company, Tihamah Power Generation Company, Shuaibah Water and Electricity Company, MARAFIQ-Yanbu and other small firms.

The majority of SEC power plants in the Kingdom use Natural Gas as primary fuel. Per capita electricity consumption has been rising steadily in Saudi Arabia. In 2013 per capita electricity consumption in the kingdom was 8.37 MWH. Per capita consumption in the Eastern Province was 13 MWH during the same year, and is expected to rise.

3. Results and Discussion

The energy footprint (in the form of electric energy) in the water value chain namely; groundwater, desalination and WWTP in the Eastern Province for the year 2013 were determined and are summarized in Table (5). On the other hand, water requirement for energy generation (electricity) was 739,307 m^3 (0.125 m^3/kWh) for thermal power plants. The following sections discuss each water value chain energy footprint separately.

Table 5: Eastern Province Water Value Chain Energy Requirements of 2013

Water Value Chain		**Energy Requirements kWh/m^3**
Stage	Process	Energy Range/(Average)
1.Groundwater	Pumping	0.764
2.Desalination	MSF	41.5
	MED	39.5
	RO	7.4
	Transmission	0.87
3.WWTP	Primary WWT	0.255-0.258 (0.56)
	Secondary WWT	0.362 (0.362)
	Tertiary WWT	0.314-0.75 (0.532)

3.1. Energy for Water

a. Groundwater

It is estimated that under the Eastern Region conditions (in terms of average depth of water and pumping efficiency), the average energy required for groundwater pumping is equal to about 0.764 kWh/m^3 (Figure 4).

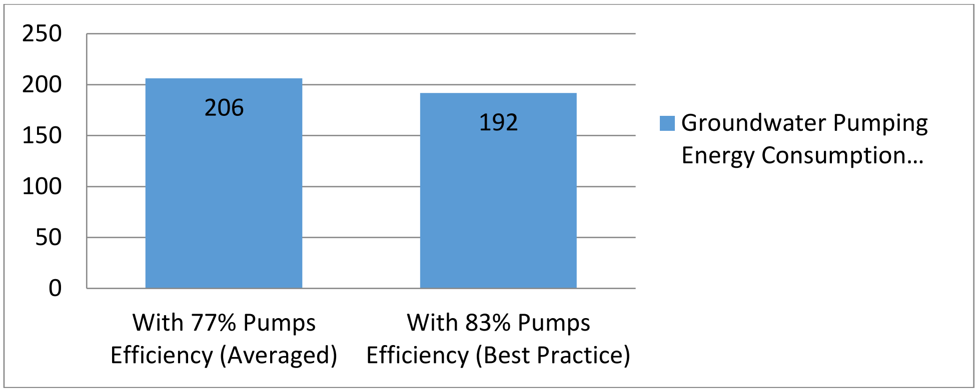

Figure 4: Electric Energy Requirements for Groundwater Pumping from Eastern Province Principle Aquifers

b. Desalination

MSF is by far the most energy intensive process among the rest of desalination technologies in Eastern Province with energy consumption reaching 19,339 GWH in 2013 representing 74% of total energy input in seawater desalination. Further to desalination operation, the energy requirement transmission of desalinated water to the Eastern Province cities is plotted in Figure (7). Transporting desalinated water to eastern Province cities (demand) is of low energy intensity (0.87 kWh/m^3) in comparison with desalination operation and amounted to about 281.4 GWH in 2013 to distribute water to end users. However, Riyadh water transport energy requirement is higher. This is because conveying water to the Riyadh area consists of long distance water transmission of over 500 km and elevation around 700 m, which has the potential to swing the energy requirements of desalinated water transmission and desalination as a whole. Conveying water to the capital Riyadh required 1,407 GWH (4.2 kWh/m^3), which is five times the energy required to transport and convey desalinated water to the Eastern Province major cities. Transporting desalinated water to Riyadh consumed more energy than RO desalination plant (210 GWH) dedicated to supply water to Riyadh.

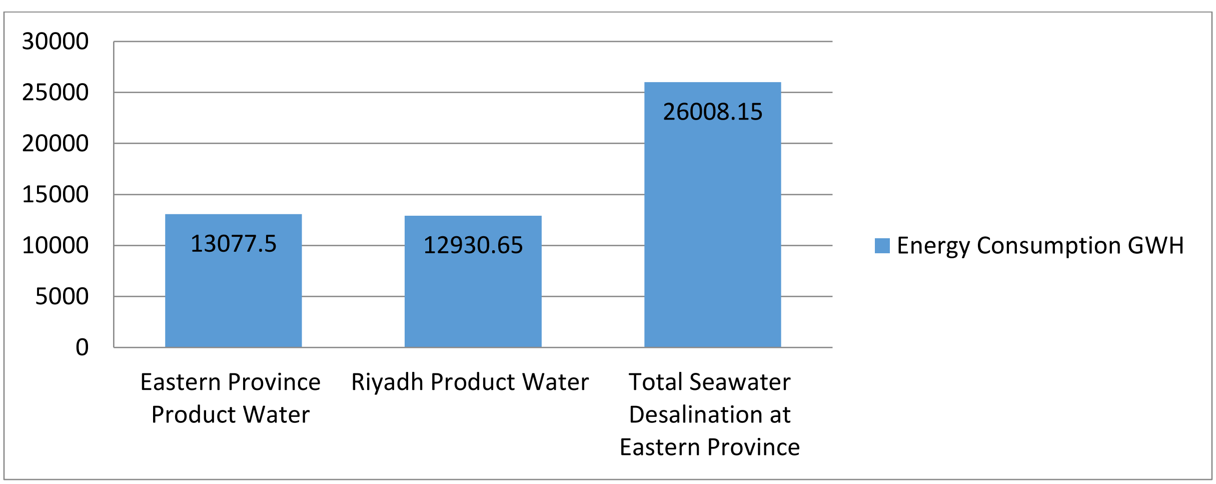

Figure 5: Energy Footprint of Seawater Desalination at Eastern Province and Riyadh

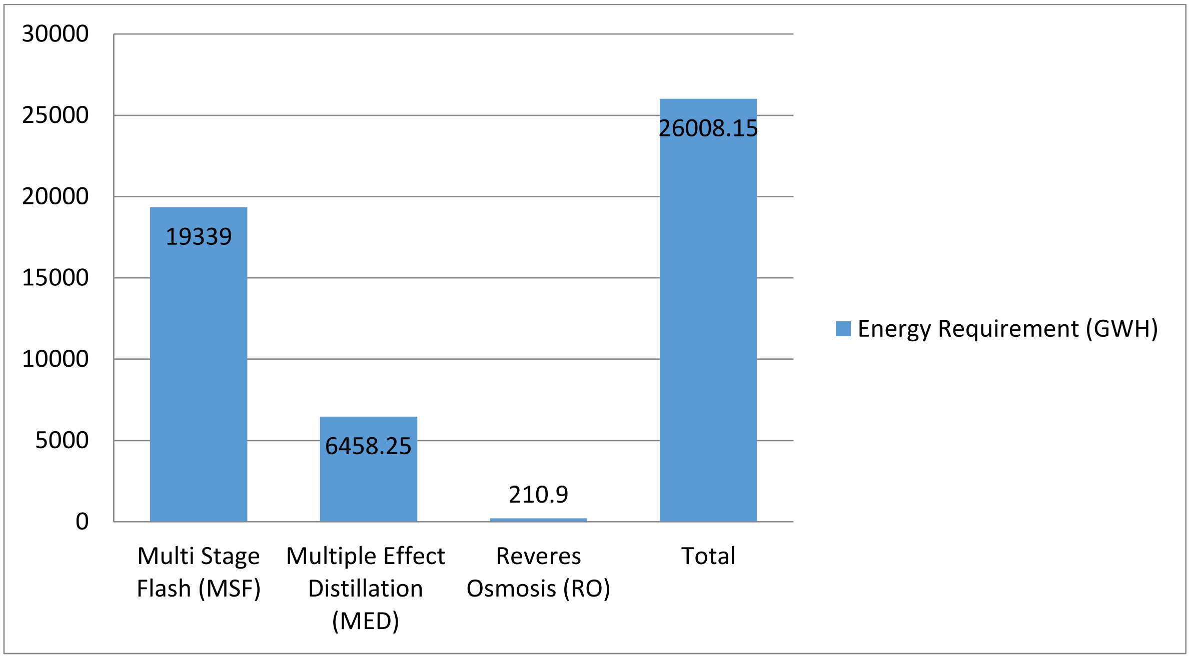

Figure 6: Electric Energy Consumption of Water Production through Desalination at Eastern Province According to Technology Employed

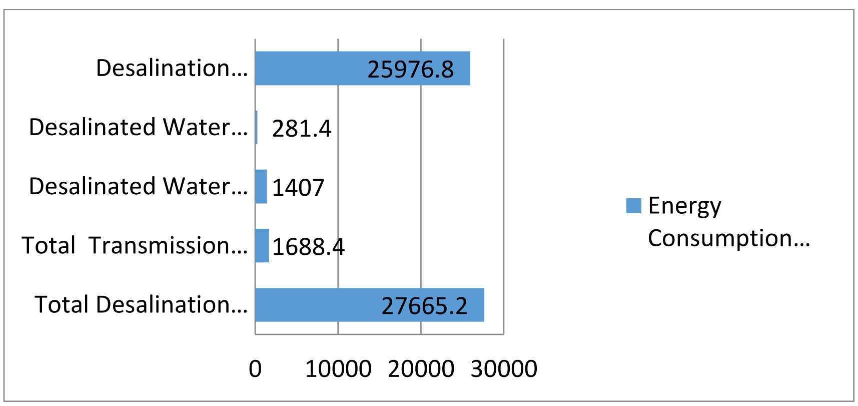

Figure 7: Electric Energy Consumption of Desalination Operation and Transmission

c. Wastewater Treatment (WWT)

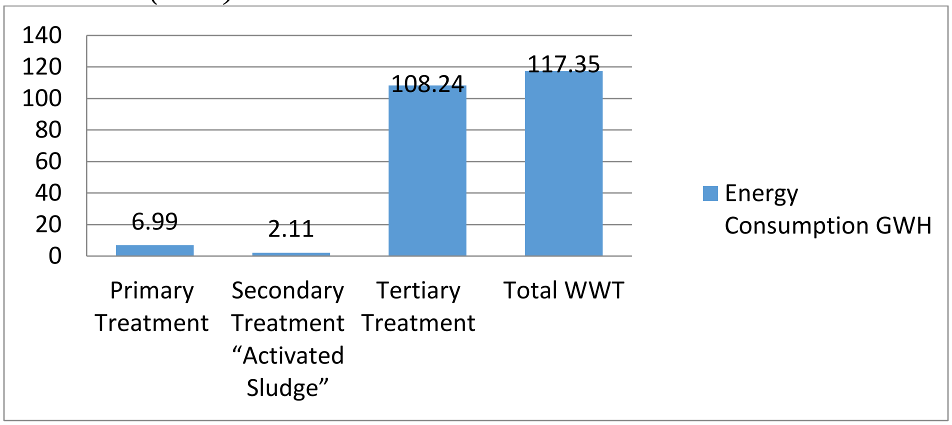

Figure 8: WWTPs Electric Energy Consumption in the Eastern Province

Figure (9) shows the energy consumption in the water value chain (groundwater, desalination and WWTPs) in 2013 in the Eastern Province. Desalination is by far the dominant energy consumer in the whole water value chain of the Eastern Province, especially the MSF technology followed by MED technology. Therefore, the desalination sector offers a prime aspect for a promising area of improvement that any energy efficiency technologies, process optimization, management plans and R&D should target in the Eastern Province.

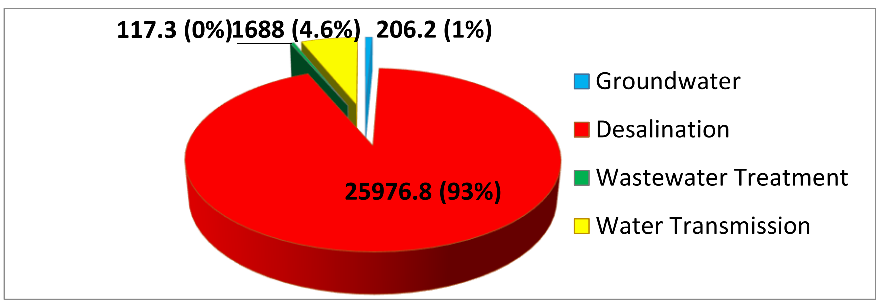

Figure 9: Water Value Chain (Groundwater, Desalination and WWTPs) Electric Energy Consumption in 2013 at the Eastern Province, in GWh and percentage.

3.2. Water for Energy

The water footprint embedded in electric energy production (thermal gas power plants) in the Eastern Province represented primarily by cooling water and was determined to be 3.6 MCM in 2013 (Figure 10) used mainly from shallow aquifers. Water intensity for the assessed power plants is presented in Table (6) and is in the range of 0.125 m^3/kWh. This is comparable if not marginally higher compared with other values reported in the literature **(Pate *et al*, 2007)** for cooling which is "negligible". Yet, this water remains of high values if considered on annual bases and the fact that it is obtained from non renewable groundwater, placing further pressures on an already stressed groundwater. Probably, this represents a water conservation opportunity should this water be replaced with other non-conventional water sources; i.e., treated wastewaters.

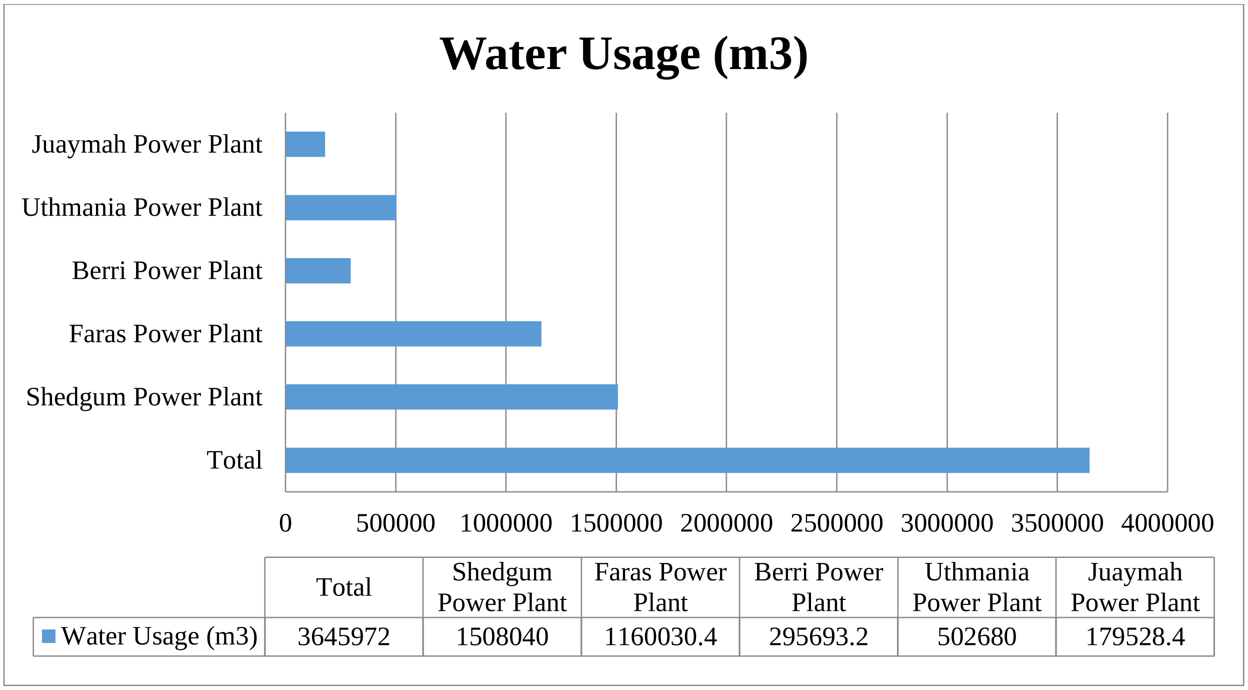

Figure 10: Cooling Water Requirements in Thermal Power Plants of the Eastern Province.

Table 6: Water Intensity for Power Plants in Eastern Province.

** Data obtained from SEC directly, data originally was in the form of m^3/month of cooling water-Plants*

Plant	Design Capacity	Water Usage (m^3/y) 2013	MWH	m^3/MWH	Average m^3/MWH
Shedgum Power Plant	1429.5	1508040*	12522420	0.120	0.125
Faras Power Plant	1058.7	1160030	9274212	0.125	
Berri Power Plant	278.1	295693.2	2436156	0.121	
Uthmania Power Plant	412.2	502680	3610872	0.139	
Juaymah Power Plant	169.5	179528.4	1484820	0.120	

shown data are the only available one.

Externalities -Carbon Footprint

Carbon dioxide (CO_2) emission associated with the water supply chain in Eastern Province is represented in Figure (11). From the figure it can be established that desalination is the dominant carbon emitter through the entire water supply chain, around 16.8 Million Ton of Carbon Dioxide (CO_2) equivalent were attributed to desalination in the Eastern Province. Figure (12) breaks down CO_2 emission as per technology used in the entire water production value chain at Eastern Province. It is clear that plants using MSF technology are the highest contributor to CO_2 emission.

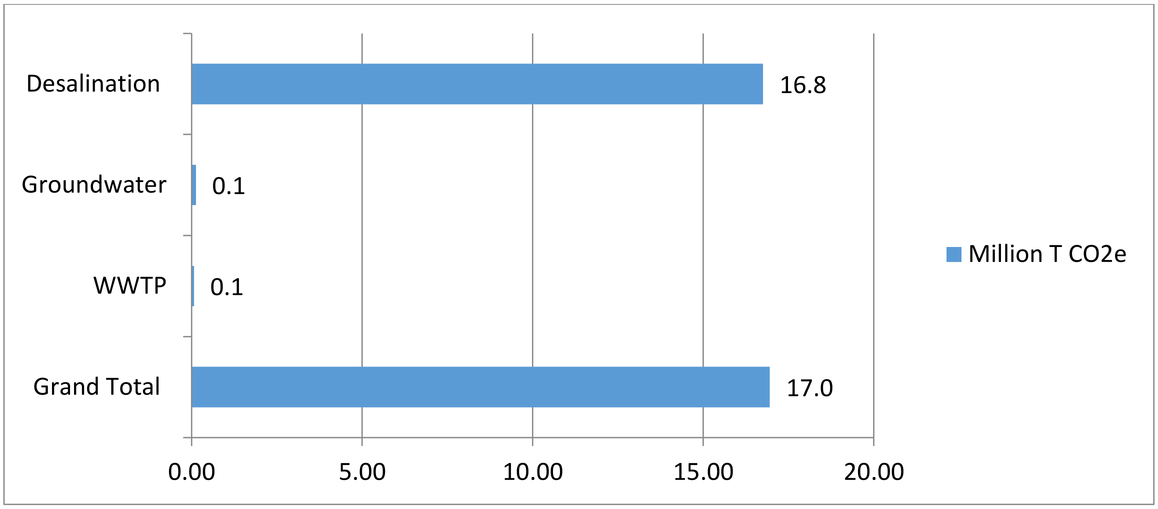

Figure 11: CO_2 Emissions from Eastern Province Water Value Chain

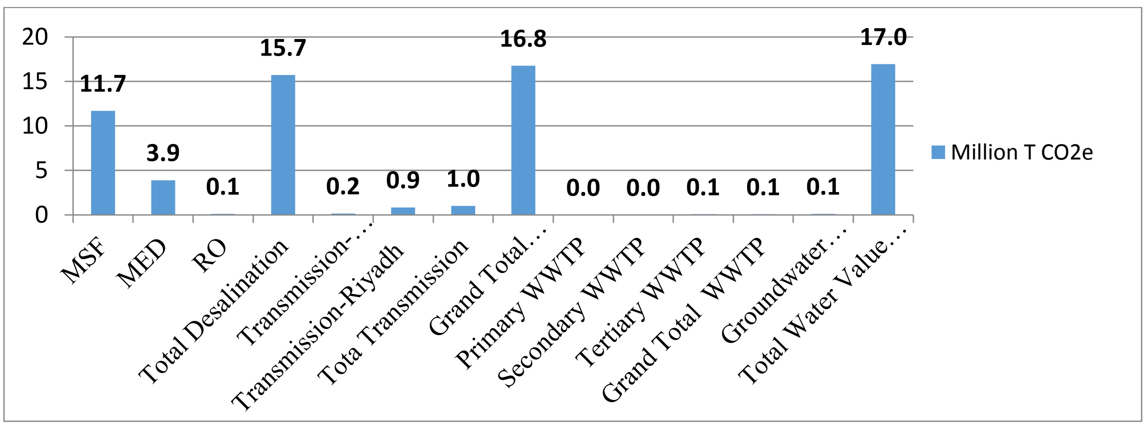

Figure 12: Breakdown of CO_2 Emission as Per Technology Used in the Entire Water Production Value Chain in the Eastern Province (2013)

The carbon footprint in energy production (power plants) is shown in Figure (13). Thermal power plants evidently had significantly higher CO_2 emission compared to water industry as carbon emission from power plants is approximately 3000 times the entire water supply chain's carbon emission in the Eastern Province.

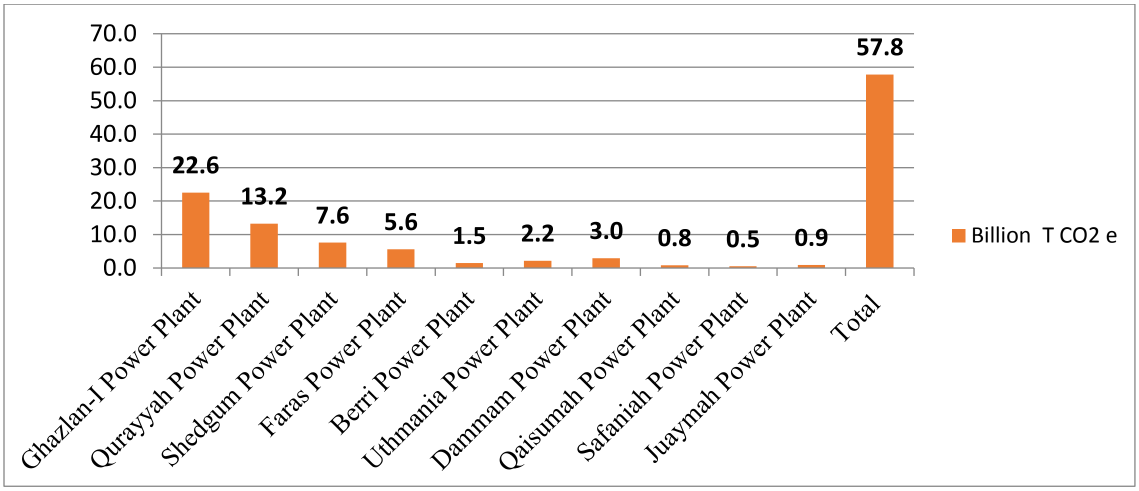

Figure 13: Electric Power Plants CO_2 Emission in Eastern Province (2013 Design Capacity)

4. Proposed Mitigations Measures

a. Raising conservation awareness and water saving devices

Raising public awareness in water conservation could reduce consumption by 10% in municipal sector according to MOWE (2013). Water saving devices that are distributed for free could save up to 20% of water usage in domestic domain. Consequently, a successful deployment and implementation of both segments of this policy would reduce the per capita consumption of the Eastern Province from 129 to 91 m^3 per capita. Therefore, around 176 MCM could be saved on the circumstances of the business year of 2013. The municipal water demand would drop to be in the range of 422 MCM compared with the actual 599 MCM should these policies are made and put in place. Accordingly, around 4,418,920, 4,205,960 and 375 metric tons of GHG emission (CO2e) in desalination (MSF), MED, and groundwater, respectively, could be avoided and mitigated from this water saving

b. BWRO as a potential supply to Riyadh

The provision of water to the capital Riyadh through Brackish Water RO (BWRO) proven to be more energy efficient (requires less energy 4.4 kWh/m^3) compared to the coastal Salt Water RO (SWRO) (11.6 kWh/m^3) or MSF (45.7 kWh/m^3) used to provide water to Riyadh taking into account the substantial distance this water has to travel and the energy embedded in MSF or SWRO operation.

c. Hybrid Desalination

The hybrid desalination system configuration (MSF/RO) offers various operational flexibility, economical (Figure 14), energy and environmental advantages which could further lower both SWRO and MSF energy requirements and increase water recovery along with GHG emission reduction and minimizing the potential marine environmental impacts. Hybrid desalination may hold the key to allow for further optimization of desalination energy requirements.

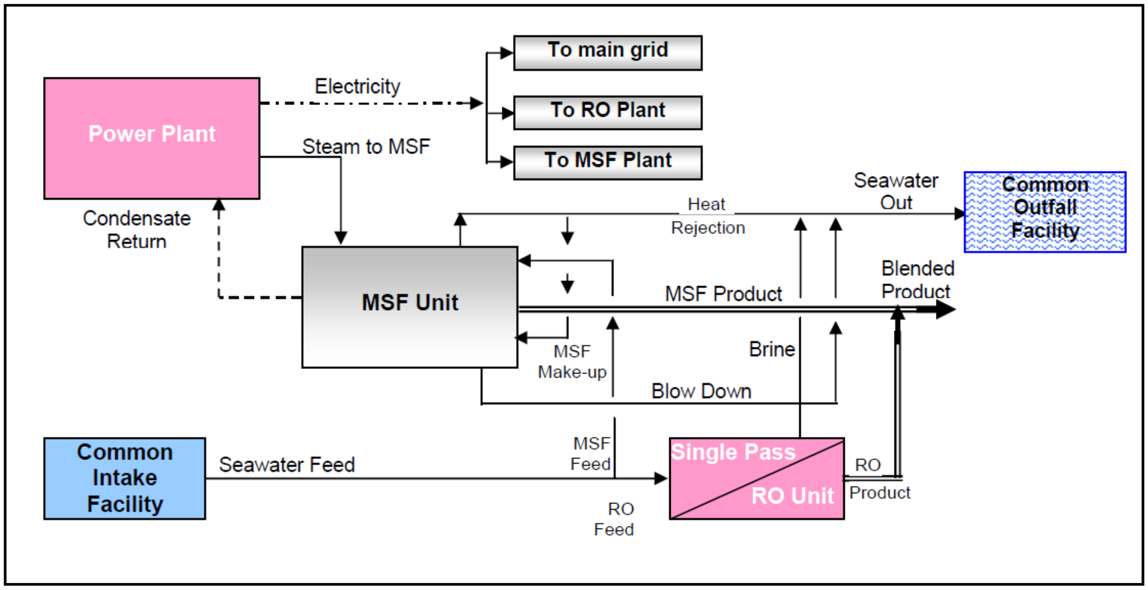

Figure 14: Simple Hybrid MSF/RO Configuration (Hamed, 2014)

d. Renewable Energies

Using solar desalination to produce water is a very attractive option as it provides free clean and secure energy, reduce the carbon footprint and minimize fossil fuel desalination. Solar desalination could be a promising venue to Saudi Arabia and Eastern Province. MSF, MED or RO could be driven though solar energy. However, using CSP to directly heat MSF or MED is proven to be inefficient (Darwish, and Mohammad Khaleel 2014). The best configuration was found to be solar RO driven by photovoltaic cells. Furthermore, the use of CSP to generate power with steam extracted to MSF/MED (partially using some of the steam to drive MSF or MED) have potential and is a viable option (Darwish, and Mohammad Khaleel 2014).

e. Treated effluent as coolant in power plants

Not all treated wastewater at Eastern Province is reused. Large amount of tertiary treated wastewater is discharged into the Arabian Gulf or some shallow bays, which is a lost opportunity under the scarcity conditions of Saudi Arabia. The use of treated wastewater as coolant medium in thermal power plants offers great potential in reducing the water demand for cooling which currently appears to have extra burden on the already depleted groundwater sources, thus serious consideration should be given to utilize the partially wasted WWTP treated effluents.

5. Conclusion and Recommendations

5.1. **Conclusion**

Water and energy are inevitably linked and interrelated in Saudi Arabia, as demonstrated by the case study. Water is used for energy generation and energy is used for water production, transmission and treatment. The water-energy nexus in the municipal sector in the Eastern Province of Saudi Arabia does not differ from other parts of the world in this respect. Substantial Energy goes into water production specifically thermal MSF/MED desalination, which was revealed to be the most energy-intensive process and represents the majority of energy input in the water value chain (around 41 kWh/m^3). On the other hand, large volumes of water are being used in energy production. The Eastern Province thermal power plants are dependent on groundwater for cooling specially the inland plants (0.125 m^3/kWh); coastal power plants utilizing seawater for cooling and power generation. The Eastern Province's water-energy nexus is affected by the distance from coastal area of the Arabian Gulf where electricity dependency on freshwater resources becomes more pronounced as we move away from coastal area, while water provision/management is fully fossil fuel-energy dependant. Therefore, the area’s water dependency on energy is more prevalent. Furthermore, Riyadh water provision (through coastal desalination and conveyance) is a key feature of the water-energy nexus in the Eastern Province which influences the shape of the nexus significantly. Riyadh desalinated water energy requirements is almost comparable to the entire Eastern Province water production energy requirements.

GHG emission associated with the current water cycle exceeded 15 Million Tons of CO_2 equivalent, mainly attributed to thermal desalination, whereas energy generation through power plants has significantly surpassed water supply chain in terms of GHGs. CO_2 emission from power plants was 3000 times that associated with the entire water cycle at the Eastern Province reaching 57 Billion Tons of CO_2 equivalent. It was estimated that the energy requirement for the entire water cycle represents 5% of the Kingdom total electric generation capacity and a staggering 13% of the Eastern Province electric energy generation capacity. This was largely dominated by thermal desalination operation and transmission followed by groundwater pumping and lastly wastewater treatment plants operation. The water footprint in electric energy generation is found to be high for the available plants water consumption data compared with other similar gas fired turbine power plants around the world. The water is mainly used for cooling and is extracted from brackish groundwater aquifers.

Broadly speaking, water provision and management in the Eastern Province is highly dependent on energy, and energy generation is highly reliant on water resources specifically as we move inland away from coastal areas. The ability of the kingdom to produce water and energy through fossil fuel burning would help in bridging the gap in water and energy demand. However, potential long term environmental sustainability concerns are associated which need to be thoroughly assessed and mitigated through a strategic nexus approach implementation and robust research and development. In Saudi Arabia, desalination is inevitable and cannot be ruled out but it can/should be made more environmentally friendly through mitigation alternatives (increased efficiency and the use of renewable energies). Similarly dependency on water for cooling is not sustainable option in energy sector.

5.2. **Recommendations**

Energy consumption for water production is relatively high especially thermal desalination, which has shown to be a highly energy-intensive process. It is recommended to reduce energy consumption in water supply chain (specifically at MSF plants) through increased process efficiency and, using renewable energies or hybrid systems configuration.

Water requirements for cooling in energy generation plants is considered to be high if compared with global consumption values. Consequently, water usage at power plant should be minimized through wastewater substitution (using treated effluent as cooling medium) or elimination by adopting other cooling technologies; e.g., dry cooling or others. Furthermore, energy generation through fossil fuel is not a sustainable option and contributes largely to GHG emission. Therefore, renewable energy generation is highly recommended through different techniques.

There is no integrated water-energy research and development entity in the GCC countries. Currently, the effort is scattered and separated. The overlapping R&D is necessary as per the nature of the water-energy nexus to achieve best available results and best degree of resources sustainability. Therefore, a mechanism to initiate and conduct integrated water-energy R&D and provide data to be used to envision water-energy interrelation and tradeoff in the Saudi Arabia and the GCC countries is strongly recommended to be established.

The water input in power generation (electricity) is often neglected or overlooked. Therefore, including water consumption as a key performance indicator (KPI) at SEC annual reports, is needed to enforce self-reporting mechanism.

This study utilized the energy requirements for wastewater treatment plant reported in the literature as no data is available on energy consumption of WWTP in the Eastern Province or Saudi Arabia at large. Therefore, it is so imperative to conduct a comprehensive and systematic energy intensity audit for all WWTP in the Saudi Arabia to establish a baseline for treatment level energy consumption.

A hybrid desalination system could bring major advantages to current eastern Province desalination practices. Therefore, investigating the feasibility of adopting a full hybridization instead of simple current hybrid MSF RO system in the Eastern Province is recommended. Furthermore, acceleration and support of the examination of the tri-hybrid NF/MF/RO configuration is recommended.

Renewable driven water cycle has a major potential for Saudi Arabia. Support and implement initiatives related to solar/geothermal desalination, solar or wind groundwater, energy recovery from WWTP.

Riyadh water provision and conveyance are key aspects of Eastern Province water-energy nexus, which requires substantial energy input. Therefore, it is recommended to assess the feasibility and sustainability of BWRO as option to provide Riyadh with water. Furthermore, in the case of coastal desalination investigating the utilization of renewable energy (preferably solar) in water transmission operation to Riyadh form coastal desalination (RO) is recommended. This is because transporting water to Riyadh has higher energy footprint than coastal seawater RO desalination energy requirements.

Modeling the water-energy nexus in Saudi Arabia with reliable future scenarios projection that account for sensitivity/uncertainty analysis would be of high value to both knowledge and the truthful implementation of the nexus approach. It is recommended to conduct similar research on the nexus employing water and energy modeling software preferably WEAP-LEAP programs which could result in a more valuable and precise representation of water-energy long-term interrelation in the area.

Acknowledgement
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Municipal Water Security in Bahrain: Stakeholder Analysis and Scenario Projections

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Abstract
There is increasing pressure on the municipal water system in Bahrain, similar to other GCC countries, due to increase in population and consumption rate. This is coupled with physical challenges in the distribution network, due to excessive leakage, that consequently hinder the endeavour to sustainable results. This study tries to investigate the various stakeholders and their perception about the status of the municipal water sector, prevailing challenges and possible solutions. Those inputs were further deconstructed to identify potential managerial interventions that could be employed to improve the sustainability of the municipal water system. Each intervention was then modelled, using WEAP, and projected for 20 years. The modelling scenarios showed that maintaining the status-quo (BAU) would not be possible without incurring substantial financial cost in the form of expansion in desalination capacity. Additionally, the results of the individual scenarios; leakage and per capita reductions have shown positive improvement in the system. The most favourable scenario was identified when both interventions are considered in combination. This intervention would limit the municipal water requirement to levels below the current level and would yield potential savings in expenditure.

Keywords: Sustainability, Discourse Analysis, Groundwater, Desalination, WEAP.

1. Introduction

Society in Bahrain, and the Arabian Peninsula in general, have relied on the availability of limited groundwater sources to meet their water demand and had exhibited water conscious traditions (Solh & Van Ginkel, 2014). The people in the region had worked either in pastoralism, trade or fishing along the Arabian Gulf and Red Sea coasts. The situation changed dramatically with the exploration of oil in the 1930s. More significantly after the oil prices hike of 1973, the Gulf states have since then emerged as an overwhelming financial power with capital and political ambitions to transform their societies (El-Sherbini, 1980). However, such drastic development would not have been possible without vital resources such as freshwater, a scarce resource in the GCC (Alnaser & Alnaser, 2011).

To cater for the water demand of such transformation, fossil groundwater has played an important role to supply all sectors (agriculture, industrial and municipal). The region embarked in many ambitious agriculture projects to achieve food self-sufficiency (Elhadj, 2008) that were later abandoned in many GCC countries due to economic and environmental costs. Consequently, the over-exploitation of groundwater has resulted in aquifer depletion as well as water quality degradation (Al-Zubari, 1998; Darwish *et al.*, 2014; Dawoud, 2005). Under these conditions of degrading groundwater quality and ever-increasing population and urbanization, to meet drinking water demands governments in the region resorted to desalination. The policy change marks the prioritisation of groundwater to deal with the emergency cases and thus restrict its withdrawals (Al-Rashed & Akber, 2015). In essence, countries in the Gulf approach desalination as a new source for water to alleviate the deterioration that is experienced in groundwater (McDonnell, 2013).

This is clearly manifested in the case of Bahrain, where domestic water supply has shifted from the reliance on groundwater to desalination (Figure 13). Desalination was introduced in Bahrain in 1975 and has developed very rapidly to counteract the shortage and quality deterioration in groundwater resources and to meet water quality requirements for drinking/domestic water standards. Until the mid-1980s, the municipal sector relied mainly on groundwater and was augmented by desalinated water in small ratios. However, with increasing population and urbanization major expansion in desalination plants occurred and desalinated water has become the main component of municipal water supply with little augmentation by groundwater. Figure 13) shows the continuous increase of desalinated water share in the municipal water supply. Desalinated water ratio has risen from 7% in 1980 to 90% in 2014, which significantly improved the quality of the municipal water supply in the Kingdom.

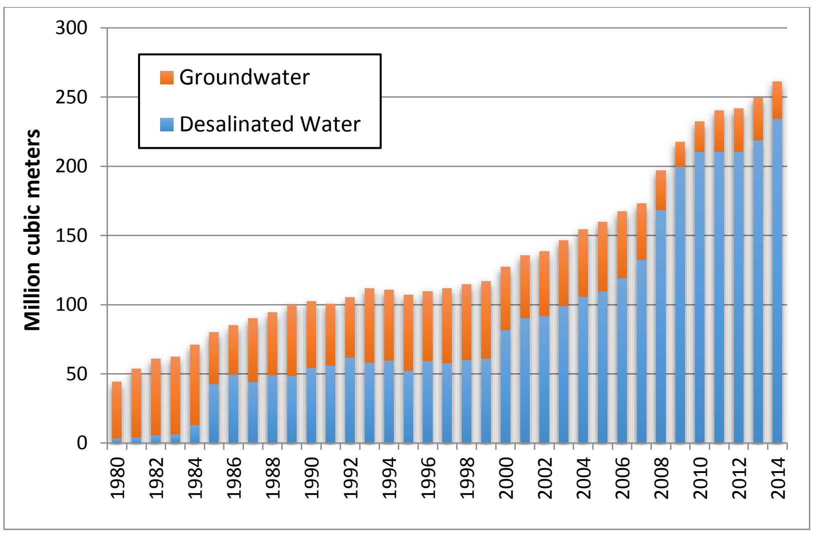

Figure 13: Desalinated water and groundwater meeting municipal sector water requirements in Bahrain (1980-2014) (data source: EWA)

However, the water institutions in Bahrain, as indicated by the World Bank (2005), suffer from very systemic problems of up to 30% of supply is non-revenue water with physical leakage representing the majority of these (World Bank, 2005). Al-Zubari (2015; 1998) highlights that 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, supplied, recycled, or reused. Additionally, similar to the other GCC countries, water tariffs remain relatively low in the kingdom and with high per capita consumption rate. However, recently, water supply tariff has been modified for more cost recovery. Those challenges would potentially reduce the system security should no intervention is taken place. It is also important to acknowledge the severity of the associated costs (financial, economic, social and environmental), if no management remedy action is adopted. Therefore, while this inquiry tries to investigate the understanding of municipal water security among the various stakeholders in view of all the challenges, it also tries to examine how sustainable the water management system is in accordance to the various stakeholders' projections.

2. Water Security and Sustainability Concepts

2.1 Short term water provision vs. long term and sustainable approach

The concept of Water Security has gained momentum over the past two decades (Cook & Bakker, 2012) of which various disciplines and practitioners frame it differently. Interpretation of the concept therefore varies in spatio-temporal scale. The variation ranges from narrow and defined to broad and integrated (Ibid). This is dependent on the natural water endowment that each country possess and the financial ability and experience to harness and channel water for security purposes (Grey & Sadoff, 2007).

With reference to the broad and long term framing of water security, Turton (1999) argues that a society with a low "adaptive capacity" could be regarded as being resource poor. Beek & Arriens (2014) charted adapting and coping capacities as important elements to the achievement of water security. They state that there are three dimensions to the achievement of sustainable water security namely; economic, environmental and social. To advance the social dimension of water security, they emphasise the importance of building resilience in communities in the face of extreme water events (Beek & Arriens, 2014).

Similarly, in the GCC countries, and in accordance to the GCC Unified Water Strategy (2016-2035), the WSTA 11th Gulf Water Conference and Parliamentarian manual, the adopted definition of water security is synonym to sustainability, which is also inclusive of the notion of "securing" water. A sustainable water resources management system can be defined as "*a system that can supply adequate amount of water with the required quantity to various development sectors, under the lowest financial, economic, social and environmental costs, to achieve maximum social benefits in terms of added value and contribution to the overall national development, on long term bases*" (GCC Unified Water Strategy, 2016; Al-Zubari, 2012; Parliamentarians' Manual, 2013[3]).

McDonnell (2013) highlights her surprise that the public in the Abu Dhabi Emirate, UAE, lacks the interest and knowledge in engaging with water related issues in the Emirate although these issues are high on the political agenda. This situation in Abu Dhabi can be viewed as a representative to the rest of the Gulf states of which the public appreciation of the resource is very limited and therefore translates into wasteful practices (The Economist Intelligence Unit, 2010). This can be interpreted as a scarcity of a second order as defined by Ohlsson (1998) that functions as a hindrance to the achievement of sustainable water security.

McEvoy (2014) reported on the effects of incorporating desalinated water into the municipal water supply portfolio in the arid city of Cabo San Lucas, Mexico. The study includes multi-scalar analysis of narrow and broad setting to the concept of water security. She contrasted the potential that desalination may play to increase water security in the narrow sense by addressing the pre-existing inequalities in water-supply. Desalination helps delivering water to working-class neighbourhoods that would otherwise pay more for water delivery from private water trucks. On the other hand, the study conducted a discussion of alternative water management options for achieving sustainable water security, in broad sense, which this inquiry is aiming to achieve.

[3] The manual is in Arabic language

2.2 Prevailing definition of sustainability in water sector

There is a systematic shift towards what is seen as Water Emergency in the GCC countries as identified in the academic literature by Al-Otaibi and Abdel-Jawad (2007), and Darwish (2014). This is manifested in the recognition of the strategic importance of groundwater to alleviate any potential harm to the water supply, namely from desalination plants. Al-Otaibi and Abdul-Jawad (2007) argued that the proper definition of water security in arid countries as “Available and secured enough quantities of fresh water to meet normal/rationing demand under emergency situations until water production facilities are constructed or rehabilitated”. They cited the reason of such customised definition due to the realisation that water security could only be reached from within the country. However, it also raises the question on whether this arrangement of relying on desalination could yield sustainable and long term results considering the challenges faced by the water management sector in the GCC and in Bahrain more specifically.

3. Methodology (Inter-disciplinary inquiry)

There is little that societies could accomplish if they fail to understand the extent of the problem and its causes, and visualise potential options for remedy. Therefore, the method employed in this research is interdisciplinary of which both the stakeholders’ understanding and aspiration are examined utilising social and engineering tools. Firstly, the authors engaged with various stakeholders to examine their understanding of the severity of the issue surrounding municipal water sector in Bahrain and the role played by desalination. Secondly, the research tries to project the stakeholders’ views on how the outlook of the water sector in the long term; twenty (20) years from now. The projection is then examined by utilising WEAP package. Finally, the different scenario outputs are discussed and contrasted to determine the level of sustainability each projection could aspire to achieve.

3.1 Stakeholder mapping and classification

The authors mapped several units of analysis according to their involvement in the water sector in Bahrain. The classification identifies three streams of different degree of influence and responsibility (Friedman and Miles, 2002). These categories are upstream, affiliated and downstream. The upstream category mainly consists of Ministry of Electricity and Water Affairs, Electricity and Water Authority (EWA), Committee of Utilities and Environment in the Parliament and Consultative (Shura) Council. The affiliated bodies comprise of science and technology, and environmental NGOs, Environment Supreme Council, academics and media outlets. The downstream category comprises of consumers in the domestic sector.

3.2 Interviews, Focus-groups and Media discourse analysis

Interviews and focus groups were the main source of information about challenges around the municipal water sector in Bahrain and the potential ways to navigate those challenges in the future. Furthermore, several media release around water sector were gathered, coded and analysed.

3.3 WEAP package (policy evaluation tool)

WEAP (Water Evaluation and Planning) package is an initiative of the Stockholm Environment Institute and has wide appeal here in the region by providing decision making tool that evaluate potential scenarios around water, and when coupled with LEAP, energy; for the purpose of this inquiry, only water is taken under consideration. The corresponding views of the stakeholders are translated into dynamic model scenarios, which therefore are used for the integrated simulation of the water management system in Bahrain and assessment of its sustainability. Figure 14 shows the schematic diagram of the model highlighting the water supply management systems' elements in the kingdom of Bahrain.

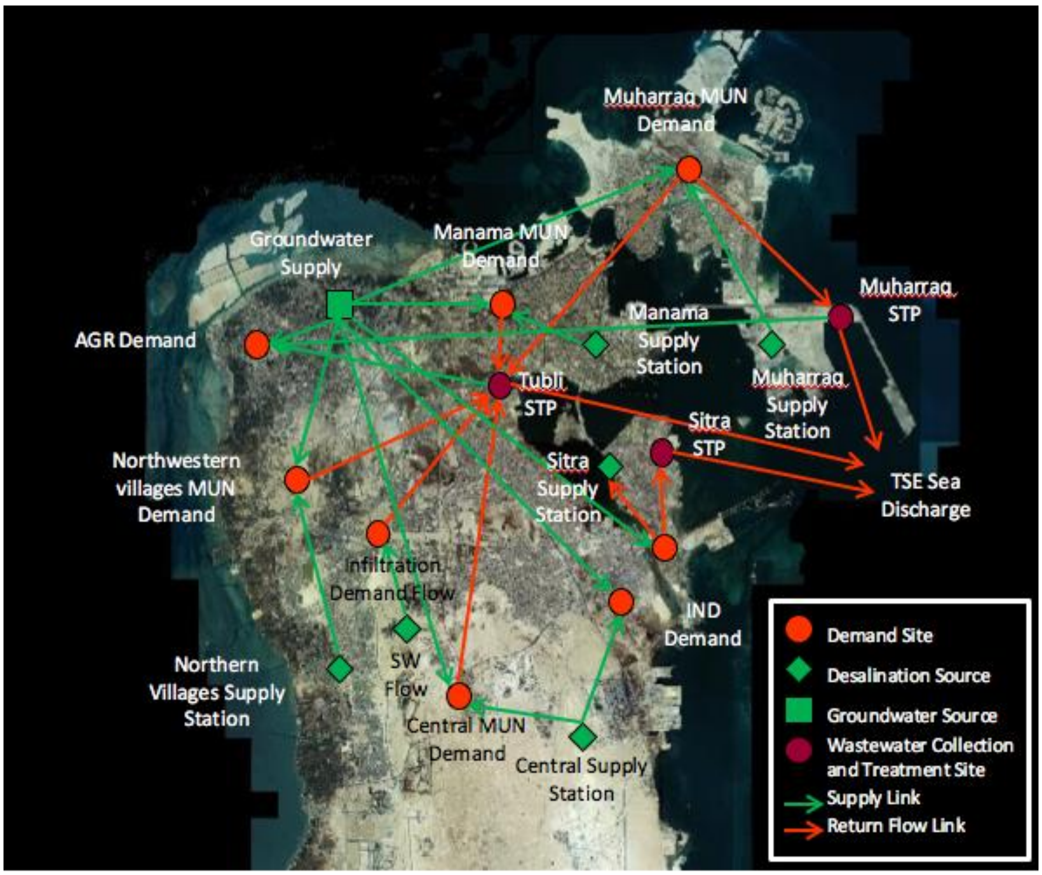

Figure 14: Conceptual WEAP Model for the water resources system in Bahrain

4. Findings

4.1 Stakeholder Analysis

The overwhelming respond from the majority of stakeholders and media release affirm that the arid condition of Bahrain with lack of surface water and precipitation are the main obstacles to securing water in the municipal sector. The second prominent factor, highlighted by practitioners and academics, is the non-revenue water associated with leakage in the distribution network. Others factors such as limited wastewater reuse, unsustainable utilisation of shared groundwater, climate change were discussed marginally. There was little emphasis however on the relevance of population growth and consumption rate from the end user and practitioners' point of views.

4.2 Prominent themes (focus-groups) and suggested scenario options

There have been unanimous consciences on the severity of the challenges facing the municipal water sector among all stakeholders, though due to various reasons and factors. While the policymakers, public authorities and practitioners stress the uncertain financial climate that could jeopardize any contracted desalination capacity expansion as well as the importance of minimising the impact on groundwater, academics and NGOs showcase their concern around unsustainable practices in the water sector. Those practices are, but not limited to, the disproportionate leakage in the distribution network that could range between 23-31%. Additionally, the excessive rate of consumption per capita is among the highest in the world, of around 500 Litres/capita/day. On the other end of the inquiry, the end users highlight the necessity to maintain reliable water supply and avoid disturbance especially in the summer season.

The corresponding scenarios according to the above discourse of stakeholders could be summarized in Table (1).

Table 1: Details of WEAP scenarios

Scenario	**Proposed By**	**Tools / Interventions**
Business As Usual (BAU)	Consumers	Maintain population growth, consumption rate
Capacity expansion and reducing groundwater abstraction	Public Authorities (EWA), practitioners	Increase desalination capacity by building more plants
Leakage reduction in the distribution network	Academics, NGOs	Investment in leakage control unit to ensure the reduction of leakage to 10% over the study period*
Reduce consumption rate	Academics, NGOs, media	Awareness and water saving devices*

*In accordance to international best practices / benchmark

4.3 Results of isolated scenarios and combinations

Figure (3) shows the anticipated results of the different scenario projections by utilising WEAP software package. Figure 3 a) refers to the business as usual scenario (BAU) of which no management interventions are taking place. The graph shows that the municipal water supply requirement will grow from under 250 Mm^3 to nearly 350 Mm^3 between 2010 and 2035. However, Figure 3 b) and c) show that the municipal water supply requirement would benefit greatly should either of those two interventions has taken place. The most favourable scenario would be Figure 3 d) of which both supply and demand managerial interventions are considered to effect. This scenario projection not only cap the increase in municipal water supply requirement but also decrease the requirement to less than the current. These efficiency measures can obviate or delay the need for physical infrastructure investments, i.e., expansion in desalination and wastewater treatment capacity, reducing burden on current financial and energy resources and providing real gain to society.

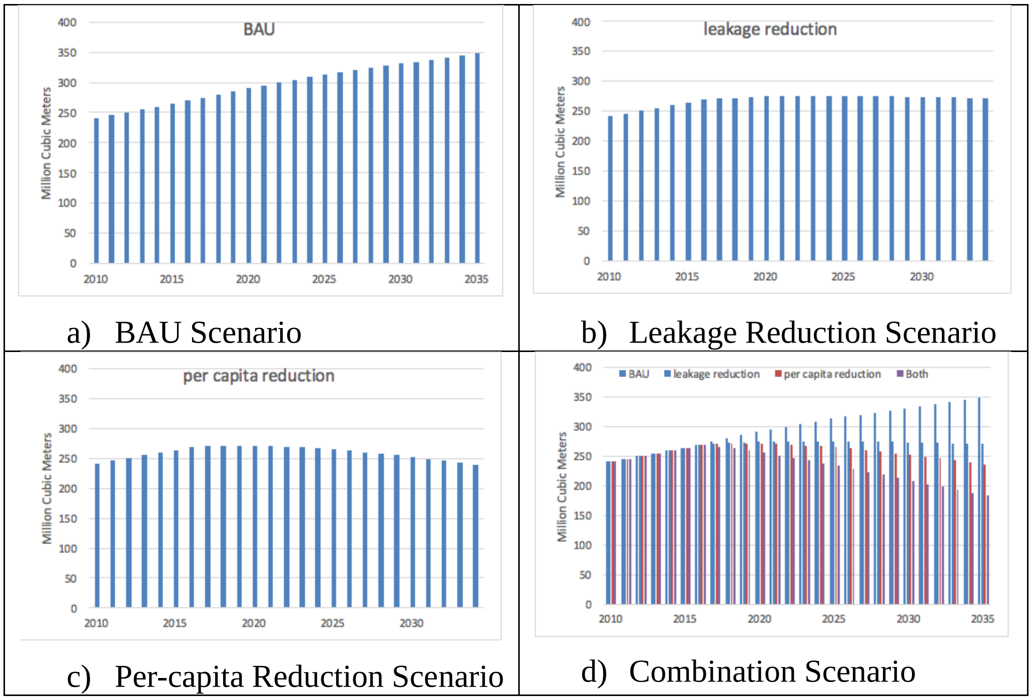

Figure 3: Anticipated Municipal Water Supply Requirement in Bahrain for the period 2016-2035 under the different Scenarios (note: 2010-2015 actual)

5. Discussion and Conclusion

The results of the inquiry highlight the disparity of how the various stakeholders view the challenges that surround the water sector. It also suggests very individualistic solutions to what they perceive as water security. All in all, all stakeholders expect desalination to continue to play a vital role in supplying the municipal water sector and they expect the supply sector to remain stable in the long run despite all obstacles and challenges. In accordance with their view of the necessary interventions, modelling results show that there is no single solution to achieving sustainable results in the municipal sector without incurring significant cost. Therefore, the optimum approach to attaining sustainable results in the municipal water sector would need to rely on a combination of interventions that takes into account soft and hard approaches. Those approaches would necessary need to address and reflect the importance of valuing water as a resource in an arid condition where production and supply come at huge cost.

The anticipated municipal water supply requirement under the combination scenario would, to great extent, postpone the need of expanding in desalination as well as wastewater treatment facilities, and would potentially limit any groundwater abstraction. The result arrangement of this scenario would be favorable and in-line with how water security and sustainability is viewed in the region. The aggregation of the inquiry results reflects the continuing central role that desalination would play in the future.

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SESSION 6: SURFACE WATER MANAGEMENT

Development of Water Resources and its Impact on Socio-Economic Structures

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Abstract
Climate change and population growth are two of the most important drivers for water supply problems in semiarid regions such as the Middle East. Leveraging water resources will help to (re)cultivate abandoned regions as well as to develop unpopulated areas. Water availability for the local population is a crucial success factor for initiating positive socio-economic effects. This presentation will introduce methods to analyze the direct, indirect and induced socio-economic effects of a specific water resource development project. The analysis will be designed as a quantitative panel study (cross-sectional survey), with focus on the perception of and adaption to changing water supply situation by the local population and is complemented by a qualitative longitudinal analysis.

Keywords: Water Resource Development; Direct, Indirect and Induced Socio-Economic Effects; Longitudinal and Cross-Sectional Study.

Introduction
The importance of water, as a source of life, living and prosperity, as an input to almost all agricultural and industrial production, a source of energy, a transportation medium, as well as a base of a healthy environment and a habitat for wildlife (Grey and Sadoff, 2007), cannot be overestimated. In this regard, access to improved domestic water supply can have huge impacts on people's standard of living. Households might benefit from better health through higher quantity and quality of water and therefore better hygiene, time savings due to the removal of the requirement to collect water, savings through a cheaper water price, greater well-being through reduced stress and conflicts over scare water resources, enhanced educational outcomes as a result of more time and improved health, better environmental sanitation, higher productivity and income, more investments, and last but not least better nutrition and higher food security (Moriarty and Butterworth, 2003).

Some progress has been made in recent years in providing clean, reliable, efficient and also financially sustainable drinking water (Lohani *et al.*, 2016), however there are still at least 780 million people without adequate access to it. Another 2.5 billion people lack access to safe sanitation systems, and it is estimated that between 2 to 5 million people die every year as a result of preventable water-related diseases – most of them children (Cooley *et al.*, 2014). 1.2 billion people live in areas where human water use has exceeded sustainable limits and another 500 million in areas where this condition is forthcoming (Molden *et al.*, 2007).

Although water quality and scarcity is already a major global challenge to humankind, in the future the growing population and climate change will become the most important drivers for water supply problems and therefore aggravate the situation further. In 2006, about 700 million people in 43 countries lived below the critical value of 1,700 m³ of water resources per person per annum, which is conventionally treated as the minimum quantity needed to grow food, support industry and maintain ecological functions, and it is estimates that by the year 2025 this number could increase to up to 3 billion people due to population growth (UNDP, 2006). Additionally the

availability and quality of water will become the main pressures on, and issues for, societies under climate change (Bates and Kundzewicz, 2008).
Especially semi-arid and arid areas, such as the Middle East, will have to face climate impacts as the loss of agricultural land, desertification and reduced recharge of aquifers (FAO, 2011), which, in turn, have strong impacts on the population and their socio-economic structure. Additionally persistent growth of population and increase in personal demand, due to changes in usage behavior, may burden existing water resources further. Since the irrigation practices of the Gulf Cooperation Council (GCC) countries depend mainly on nonrenewable resources, such as fossil waters, there is an urgent necessity to explore and develop new water resources in this area particularly (Al-Rashed and Sherif, 2000). Furthermore, the development of water resources in order to avoid water scarcity contributes to reduced social tension and subsequently prevent water related conflicts and decrease emigration (Biswas, 2012).

Taking into account that the earth provides – with better water management – enough water to meet the individual, ecological, agricultural and business needs (Biswas, 2012) and that most water shortages are a result of an imbalance between population and precipitation distributions (Bouwer, 2000), water resource development (WRD) (that must involve the usage, conservation and control of water and related resources (Stewart, 1966)), can help to meet the needs of a growing population in the context of climate change.

Based on a concise literature review, this paper will highlight what the direct, indirect and induced socio-economic effects of WRD projects are and will introduce methods how to analyze these effects. The methodical approach is thereby a combination of cross-sectional and longitudinal studies: a cross-sequential study.

State of research of socio-economic effects of WRD projects

There are several studies, evaluating the ecological impacts of WRD projects (e.g. Leigh and Sheldon, 2008), and some studies evaluating their economic impacts – most of them considering dams (Robinson et al., 2008; Blignaut and van Heerden, 2009). Various methods already exist to quantify the direct and indirect economic effects and to put them into a ratio in order to estimate the total impact of a project via multiplier analysis. The key methods are the Input-Output and Semi-Input-Output models, Social Accounting Matrices based models (including IMPLAN models) and Computable General Equilibrium models (Bhatia and Scatasta, 2008). A common feature of this models is that they are quantitative tools used to assess the financial benefits or costs of a project on a macro-economic level using a top-down perspective. Moreover, most of those approaches provide a retrospective view on an already existing project.

In contrast, studies that explicitly evaluate the socio-economic impacts of a particular WRD project on a micro-economic level using a bottom-up perspective are rather rare. As a summary for the current state of research with regard to micro-economic approaches and to highlight the similarities of these studies, hereinafter three of them are presented. They are representative and have been selected on the one hand because of their methodical approach, and on the other hand due to the limited amount of high-quality research.

Tortajada (2000) analyzes the direct social, economic and environmental impacts of the Atatürk Dam in Turkey eight years after its construction. The author interviewed key national and international stakeholders from planning and implementation institutions, as well as representatives of the affected population, private sector institutions and non-governmental organizations. Tortajada asserted that the construction had large socio-economic impacts on the local population. The most significant positive impacts include as a higher employment rate through new jobs created in agro-industries, reduced emigration and higher immigration, new economic activities, increased agricultural production through a shift in the production scheme, and an improvement of the lifestyle of the farmer in general and. But conversely the negative impacts include the resettlement and return of inhabitants and a poor wastewater management that might put the health of the local population at risk.

Bizoza and Umutoni (2012) evaluated the socio-economic impacts of a rain water harvesting project in Southern Province, Rwanda. They compared the results of a population survey on indicators such as socio-economic characteristics, household assets, land use and tenure, crop production, livestock, food security and health of the people living in the research area with those of a selected control area. The authors came to the conclusion that there are not yet significant effects of the previously constructed rain water harvester and recommend a different harvester system that is more affordable.

Saxena (2012) considered the agro-economic, socio-economic and environmental impacts of the Kangsabati Project in India in a post-project evaluation. Using primary and secondary data, the author analyzed the socio-economic status of the inhabitants of the project area compared with those of a nearby control area without benefits from the project. He concluded that the construction lead to an increased income for all types of households in the project area, higher immigration, lower emigration and a higher literacy rate compared with the control area. As the main negative effect, he identified that 35,000 people were displaced and 175 villages were submerged by the dam construction.

In summary, it can be affirmed that most of the studies that consider the socio-economic effects of a specific WRD project have a retrospective view: In the absence of available data of the pre-project situation the authors manage to estimate the effects e.g. by comparison of the project area with a control area. This might be a solution for a benchmark for the success of a project – albeit a suboptimal one. On the one hand the choice of the control region often seems to be arbitrary and on the other hand the method cannot prevent side effects, which only take place in one of the examined regions. Both may distort the analysis. Therefore the optimal way to analyze the socio-economic impact of a WRD project is to obtain data from the area prior to the commencement of the project.

Direct, indirect and induced socio-economic effects of WRD projects

The impacts of a WRD project on society and economy as well as on the environment can be categorized as direct, indirect and induced, and additionally as negative and positive – even though, a clear distinction is not always possible and various authors have different definitions of what a direct, indirect and induced impact is (Bhatia *et al.*, 2008). Hence the following overview gives a possibility to define them.

According to Bhatia *et al.*, (2008) direct impacts include (inter alia):

- net benefits of the project outputs in the project area,
- positive health benefits,

- eco-system benefits,
- non-irrigation benefits of irrigation canals,
- social, economic and cultural costs of a possible resettlement,
- value of lost ecosystem/historical/cultural heritage sites,
- negative health impacts.

Indirect (or secondary) impacts can be (inter alia):

- benefits from inter-sectoral production linkages through the supply of inputs for other sectors or the demand for outputs from other sectors on a regional, interregional and national level,
- negative impacts on some sectors of inter-sectoral linkages from increased project outputs,
- increase/decreases in factor productivity,
- economic and non-economic benefits/costs from migration into or reduced migration out of the region.

And induced (or tertiary) impacts can (inter alia) be understood as:

- positive impacts (regional/interregional/national) on output of increased income, expenditures for local/regional workers,
- positive impacts of increased remittances outside the region,
- positive income effects of reduced prices of goods and services provided by activities that are direct outcomes of the project-benefits of non-marginal output changes
- negative effects through increased public debt burden, if project is financed with public funds
- negative environmental impacts of increased incomes, changes in the structure of expenditure and changes in employment patterns.

As the summary indicates, there is a spatial separation between direct effects that are considered to take place locally, and indirect and induced impacts that are believed to take place regionally, interregionally and/or nationally. Additionally, positive effects, such as a higher labor potential through increased immigration into the project region, might be accompanied by negative impacts, e.g. a higher utilization of infrastructure. Also some impacts are mutually dependent (Bhatia *et al.*, 2008).

Methods to Evaluate the Socio-Economic Impacts of WRD Projects
While some of the introduced direct, indirect and induced effects are comparatively easy to measure at a first glance, e.g. quantitative effects like immigration and emigration on the basis of the number of people moving in or out of the study area, other impacts are difficult to include or even to quantify. For example, improved quality of life through the access an increased quantity and perhaps quality of water can only, if at all, be estimated by the local population itself. These

impacts can be considered simultaneously as s crucial part of a benchmark for the success or failure of a project. Therefore it is vitally important to take them into account when evaluating the success of a WRD project in general.

As it has been highlighted in the literature review, there are several methods known to measure the direct and indirect economic impacts from a macro-economic perspective. Also there have been some attempts to estimate the direct, indirect and induced socio-economic effects of a WRD project in general. However, to assess those effects from a micro-economic perspective, we suggest to use a survey among the population affected. To do so, there basically are two survey instruments known to social sciences: cross-sectional studies and longitudinal studies (Häder, 2015).

A cross-sectional study is a singular survey in social science, taken place at a specific time. Its objective is to point out certain coherences between two or more issues. A longitudinal study in contrast is a survey repeating the analysis at different times to show the effects of a certain intervention. A panel study, as a form of a longitudinal study, focuses on an examination unit (specific households or persons) at multiple times (Häder, 2015). Both study designs have advantages and disadvantages. A cross-sectional survey for instance focuses on a comparison between different groups of people, while a longitudinal survey allows the comparison of the same people at different times (Rindfleisch *et al.*, 2008). A further comparison of cross-sectional and longitudinal survey is provided in Table 2.

We suggest to combine both designs to minimize intrinsic disadvantages and to emphasize their advantages, in order to validly evaluate the direct, indirect and induced socio-economic impacts of a specific WRD project from a micro-economic perspective.

Table 2: Comparison of cross-sectional and longitudinal survey designs. Adapted from: Rindfleisch *et al.*, 2008

Cross-Sectional Survey Design	Longitudinal Survey Design
Interest in current structure	Interest in temporal change
Heterogeneous measurement format and scales	Homogeneous measurement format and scales
Unclear point of data collection	Clear point of data collection
Between subject design (Comparison between different groups)	Within subject design (Comparison of the same person, e.g. before and after)
Likelihood of alternative explanations low	Likelihood of alternative explanations high

A cross-sequential study, as a combination of cross-sectional and longitudinal study is “a way of achieving the benefits of the longitudinal method while minimizing the problems” (Farrington, 1991). Within the context of a WRD project, as we suggested, this should involve two cross-sectional surveys, one before and one after project implementation. They are accompanied by a longitudinal study throughout the entire project term. As illustrated in Figure 15, the number of subjects varies depending on the project progress and the survey type.

The cross-sequential surveys are designed as quantitative samples with the objective to question as many subjects affected by the project as possible, in order to obtain reliable quantitative data for the project evaluation – differentiated e.g. according to socio-demographic characteristics. Subsequently any issues regarding usage behavior, the amount of water used or the monetarized benefit can be responded to. In addition the proposed longitudinal survey is designed qualitative and therefore complements the cross-sectional surveys in at least three ways: Firstly, as an iterative procedure, it provides the foundation for the cross-sectional survey by bordering possible questions and by giving the chance to adapt these questions to the local conditions and culture before starting the cross-sectional survey. Secondly, it opens up the possibility to identify and react to critical points during the project term, for instance concerning behavioral changes. This in turn offers the chance to adapt the survey strategy. Thirdly, it can raise the possibility of modification of an ongoing project. This is especially relevant for the project implementation in order to raise the acceptance of the local population.

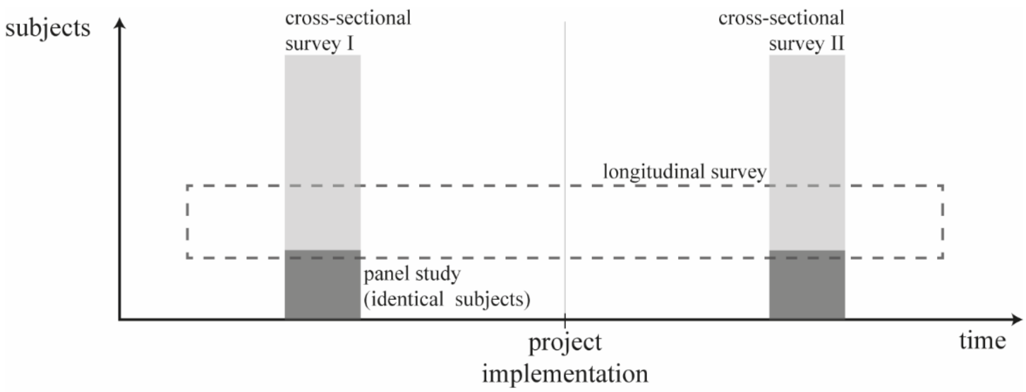

Figure 15: Schematic illustration of the cross-sequential design

Initially, as part of the longitudinal survey, there will be qualitative interviews with local actors to gain insight in the existing socio-demographic structures and to identify relevant issues for the local population. Furthermore, it is considered to collect qualitative data as part of the longitudinal survey, such as a “water diary”. This will provide deeper insights in the daily use and utilization of water and therefore reveal changes of use, which would otherwise have remained underutilized.

The proposed approach of a cross-sequential study to evaluate the socio-economic impacts of a certain WRD project has some major benefits for the local population as well as for the project planner. A major advantage of the suggested approach compared to others, is that by collecting and using own source data the analysis on the whole is much more likely not to be biased – for example by the evaluation of sources provided by the government or governmental institutions, given that these sources have a one-sided view on the project’s success. Additionally a more extensive project accompaniment and the documentation of the project’s impacts might help to improve upcoming projects by learning from and reducing mistakes and improving the project’s acceptance.

The combination of both research designs has huge advantages. The cross-sectional studies can capture both, the pre- and post-project situation, and in combination with a longitudinal study will reduce the weaknesses of the individual methods. Moreover the iterative procedure, the combination of qualitative interviews and quantitative data collection, will help to increase the reliability of the studies’ findings.

Summary and Outlook

Water is the single most important resource for the well-being of people (Huq *et al.*, 2012). At the same time the availability and quality of this precious resource comes under pressure in many regions due to population growth, climate change and changes of use, along with a higher consumption. Therefore, there is a high urgency for governments, especially in semi-arid and arid areas, to make additional investments in water resource development. But investments alone do no one any good, without a comprehensive assessment of the project success.

According to Rangachari (2006) there have been over 4,000 water resource development projects completed in India that involve the construction of dams. However there are almost no well-researched articles evaluating their performance and therefore it is nearly impossible to clarify whether a project has fulfilled the stated objectives or not. The author identifies the lack of data of the pre- and post-project condition as the major problem.

Therefore it is important to develop and apply methods to identify, qualify and quantify the socio-economic effects of WRD projects. The presented approach of a cross-sequential design has thereby many advantages compared to e.g. the retrospective comparison of the project area with a control area on a macro-economic level. This advantages meet finally the needs of the local population – to increase their acceptance and the degree of utilization – and the needs of the project planner to avoid potential mistakes of the past.

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Impacts of the Proposed Water Resources Development Projects in the Blue Nile Basin on Nile River Inflows at Aswan

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Abstract
The Eastern Nile Basin (Blue Nile, Baro Akobo Sobat, Tekeze Atbara Setit, and Main Nile) contributes about 85% of the annual Nile River inflows arriving at Aswan. The Blue Nile (Abbay) is the major sub-basin of the Eastern Nile that contributes about 67 % of the Nile River inflows at Aswan. Recently, the Blue Nile becomes target for large scale unilateral water-based infrastructure development projects (dams, hydropower, and irrigated agriculture) in Ethiopia and Sudan. The main objective of this paper is to investigate the impacts of the proposed water-based development projects in the Blue Nile Basin on the inflow, pool elevation and hydropower generation at High Aswan Dam (HAD) in Egypt. For this purpose, two models were configured and offline coupled to simulate the system hydrology and the water balance in the basin. The basin hydrology is simulated using the Soil Water Assessment Tool (SWAT) model and runoff was generated at sub-watershed scale. Then water balance at the river scale is simulated using the HEC Reservoir Simulation Model (HEC ResSim). Sensitivity analysis was carried out and resulted in the most sensitive parameters that were used to calibrate and validate the models using ground observations of flow discharges at El-Deim, Khartoum, Dongola stations in addition to reservoir water levels at HAD. Model performance is evaluated using Nash–Sutcliffe parameter and the coefficient of determination showing adequate performance of the modeling system. The developed modeling system for the Blue Nile Basin is employed to carry out a baseline simulation (i.e. current conditions without any future developments) in addition to seven expected scenarios. The modeling system is configured to study the impacts of several development scenarios of the hydropower potential in the basin (4 dams), irrigated agriculture development projects, and combined hydropower and irrigation agriculture developments. Hydropower scenarios include the effect of the construction of Renaissance, Karadobi, Beko Abo and Mandaya dams. Dam scenarios resulted in an average reduction of the annual inflow at Aswan up to 10.7 BCM and a maximum reduction of annual power at HAD up to 32 %. The combined hydropower and irrigation schemes' scenarios resulted in an average reductions up to 14.3 BCM of the annual inflow at Aswan and a reduction of 55 % in annual hydropower production at HAD.

Keywords: Blue Nile, Eastern Nile, GERD, High Aswan Dam, SWAT, HEC ResSim.

Introduction
Egypt, Ethiopia, Sudan, and South Sudan are sharing the sub-basins of the Eastern Nile as shown in Figure (1a). The Eastern Nile Basin is crucial for Egypt because it contributes 85% of the Nile River inflow arriving at Aswan. Furthermore, the Blue Nile (BN) Basin is the most important basin among other Eastern Nile sub-basins because it contributes about 67% of the Nile River inflow arriving at Aswan. The BN originates in the Ethiopian highlands. In its journey towards the downstream, it joins with many tributaries, draining the central and northwestern parts of Ethiopia as shown in Figure (1b) [1]. The BN basin is subject to various water resources development projects at the upstream countries. In the Ethiopian portion of the BN there are more than 120 potential hydropower sites that have been identified [2]. The four largest proposed

projects being considered are hydropower dams on the main stem of the BN River, namely Karadobi, Beko Abo, Mandaya and Border dams, [3]. Recently, the Border Dam has been replaced with the Grand Ethiopian Renaissance Dam (GERD). These proposed projects have potential of affecting the Nile inflow arriving at Aswan and accordingly the High Aswan Dam (HAD) pool elevation and hydropower generation, so such impacts needs to be assessed in detail.

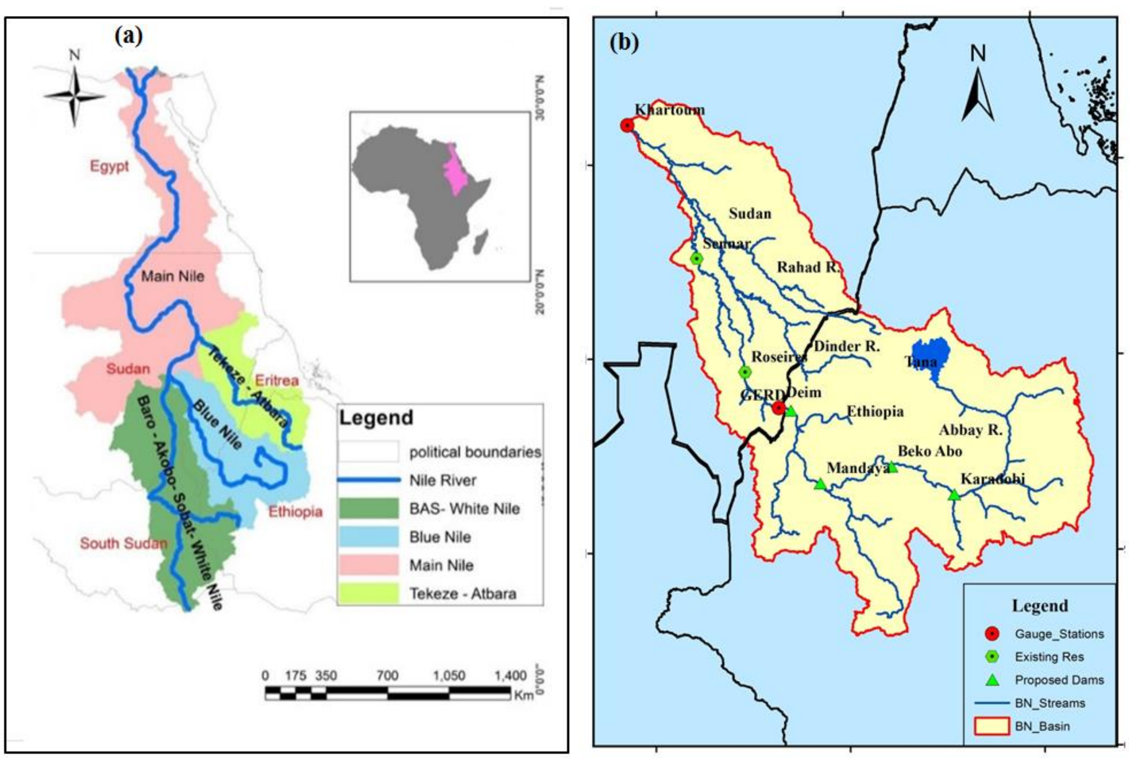

Figure 1: (a) Main sub-basins that constitute the ENB, (b) Main Rivers, and Drainage Catchments of BN

Several researchers' have investigated the EN water resources development projects and its impacts on the downstream countries. In 2013, Sief El-Din used the River Basin Simulation Model (RIBASIM) to assess the impacts of different proposed water resources development projects in both Ethiopia and Sudan on HAD, but this study did not include the GERD as it was not declared yet[4]. Instead of the GERD, the old Border dam was studied. Furthermore, the study period was limited to the period from 1979 to 1989 representing a drought period so that the impacts were extremely severe [4]. Eastern Nile Technical Regional Office (ENTRO) carried out many studies in 2012 as a part of the Eastern Nile Planning Model (ENPM) project. Among these studies, five different models (SWAT, Hec-ResSim, Mike-She, RiverWare, and Ribasim Models) were used separately to simulate the EN water resources [5, 6]. Only using SWAT model to simulate the flow at the river scale had some limitations because the model has limited capabilities in dam's simulation. The limitations of using Hec-ResSim model were the relatively short simulation period (14 years from 1966 to 1979) in addition to ignoring all of the existing and the proposed irrigation projects in the basin. Mike-She and RiverWare models were used to simulate the impacts of the construction of the major four dams on the main stem of the BN River without including the irrigated agriculture development schemes which are expected to have a significant impact. Ribasim Model was used to simulate the impact of the same major four dams in addition to including some irrigated agriculture areas without taking the majority of the expected irrigated agriculture areas into consideration.

In 2011, Gharib estimated the effect of the Nile upstream development projects in Ethiopia and Sudan on the Nile River inflow to HAD using the Nile Decision Support Tool (Nile-DST) which is a comprehensive water resource simulation model for the entire Nile Basin [7]. The stochastic approach was used to assess the impacts of the development scenarios on HAD. In addition to the historical time series, a stochastic inflow series was synthetically generated to study the full range of the indicators (length of each time series is 90 years). This study investigated the impact of the expected hydropower projects (Border, Mandaya, and Beko Abo dams) in addition to the majority of the irrigation schemes. The main limitations of this study was using the characteristics of Border dam (lower elevation and storage volume) which is the old version of GERD in addition to not including the effect of Karadobi dam. In 2003, Abdel Ghany developed a tool to help the decision maker in analyzing the impacts of the proposed water resources developments in the Blue Nile Basin on Egypt [8]. The study investigated only the impacts of the expected small dams on the tributaries of the Blue Nile, in addition to the Border and the Mandaya dams.

The main objective of this paper is to study the impacts of the expected hydropower projects (major four dams) and the potential irrigation schemes on the Nile River inflows at HAD over a relatively longer simulation period (from 1982 to 2003) using a coupled modeling system that consist of SWAT model for hydrology simulation and the Hec-ResSim model for water system modeling.

Study Area

The Blue Nile sub-basin, located in the center of the eastern portion of the Eastern Nile Basin is the largest inflow contributor of the Eastern Nile Basin system accounting 67% of the inflow at Aswan (about 56 BCM/year) [9]. The Blue Nile sub-basin covers two countries, namely Ethiopia and Sudan. The total area of the sub-basin is 311,382 Km^2 of which Ethiopia comprises about 64% and the remaining 36% is located in Sudan. The source of the Blue Nile is the Little Abbay, which originates in the Ethiopian Highlands and flows into Lake Tana (surface area of 3,000 km^2). The Blue Nile leaves Lake Tana and flows to the southeast in a large circle for about 935 km before reaching Roseires near the border between Ethiopia and Sudan as shown in Figure (1b). The river receives several tributaries on its way from Lake Tana to Roseires, which increase the flow tenfolds. The mean discharge at Roseires/Diem for the period 1940-1982 is about 49.5 BCM. The river continues its journey to the Sennar dam at a much milder slope for another 270 km. Because of no tributaries in this reach, the flow at Sennar is about 2 BCM less than that at Roseires [10]. Between Sennar and the basin outlet to the Nile at Khartoum, the Blue Nile receives two major tributaries, the Dinder and the Rahad.

The mountainous topography is largely located in the Ethiopian highlands in its eastern portion (2000 masl to 2500 masl). The flat low-lying areas of the sub-basin starts close to the Ethio-Sudan border and extends westwards into the Sudanese land to Khartoum (500 masl at the border to 340 masl near Khartoum) as shown in Figure (2a). Rainfall in the BN basin ranges from nearly 2,000 mm/year in the Ethiopian Highlands to less than 200 mm/year at the junction with the White Nile as shown in Figure (2b). Although the BN basin is the second largest drainage area in Ethiopia, it has the highest runoff, estimated to be 51 BCM/year [11]. The BN basin accounts for

50 percent of water runoff in Ethiopia. It also contributes 67% of the Nile discharge into Lake Nasser.

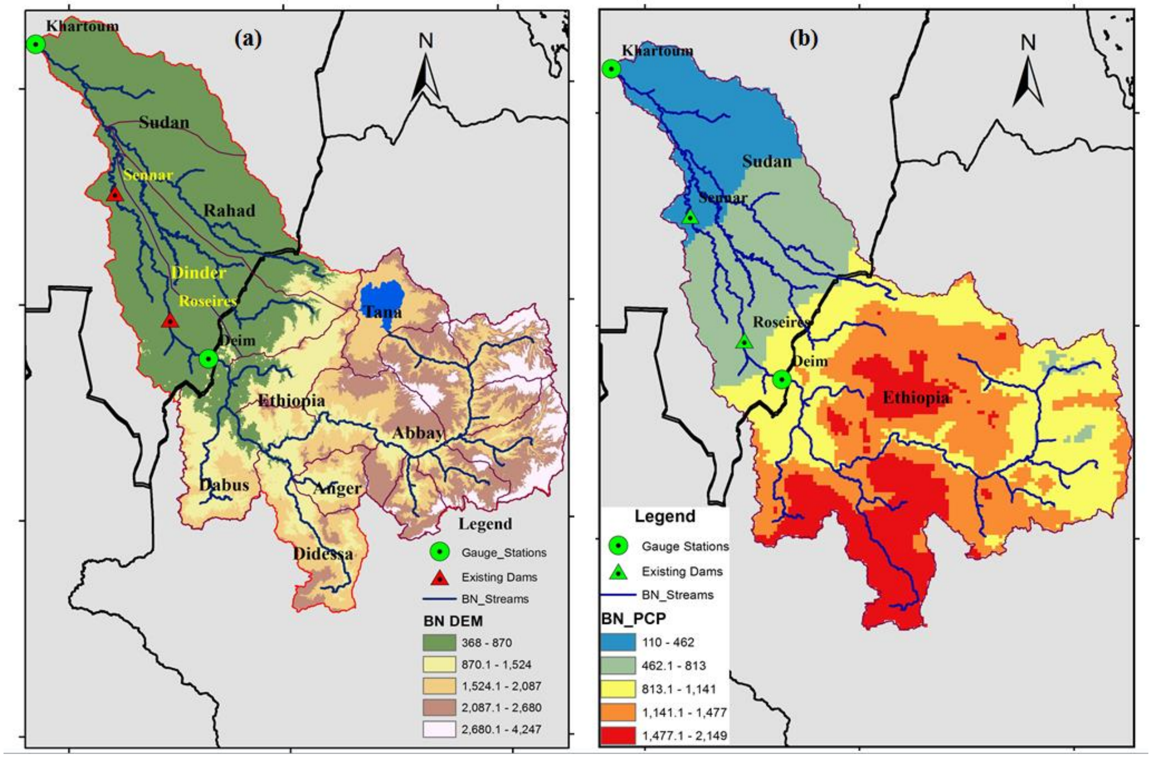

Figure 2: (a) DEM of the BN basin and (b) Mean annual rainfall over the BN basin

Methodology

SWAT Model setup requires terrain data, soil type data, land cover/land use data, meteorological data. Observed river flow data are also needed for the calibration and validation of the model [12]. SWAT output which is mainly comprised of simulated time series flow data were used to force the HEC-ResSim model. HEC-ResSim model requires schematic data, data about development projects (e.g. dams and irrigation schemes), and the flow data acquired from SWAT to simulate the base case scenario after the model verification. Finally, the proposed development scenarios in the Blue Nile basin were formulated and simulated to assess the effect of the different proposed development projects on the downstream countries with respect to received river inflow, dam pool elevation, and hydropower generation at HAD. Figure (3) shows the flowchart of the research methodology.

BN-SWAT Model

Data Collection

The 90 meters void filled SRTM DEM was used in this study provide the terrain data required for watershed delineation.

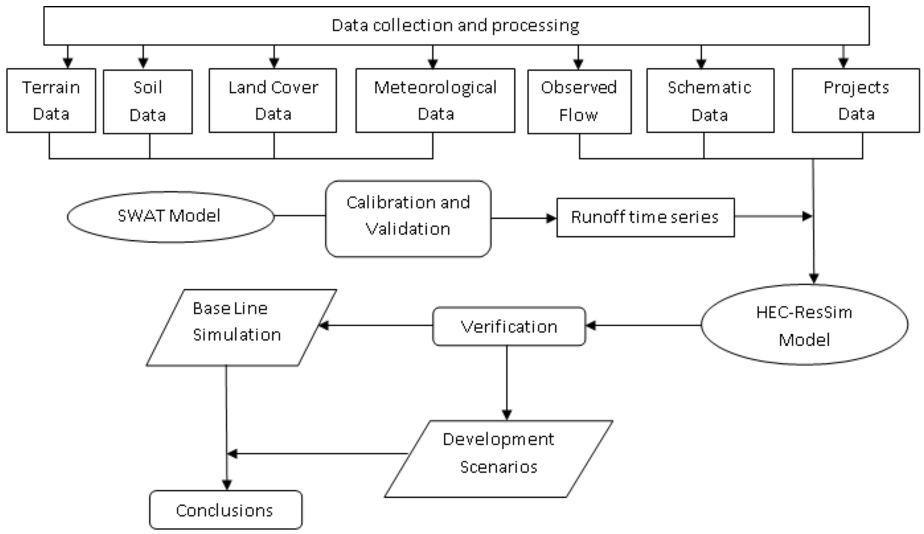

Figure 3: Flowchart of the research methodology

The 15 arc-second HydroSHEDS river network dataset was used to define the streams and rivers. The Globcover product map with 300 meters resolution was used to define the land cover categories. The soil categories were based on the soil data produced as a part of a water balance model project for eastern Nile basin [5]. The Climate Forecast System Reanalysis (CFSR) meteorological data set that includes data for rainfall, temperature, wind speed, solar radiation, and relative humidity with a resolution of about 38 Km covering the period from 1979 to 2010 produced by the NCEP was used to provide the meteorological fields.

BN-SWAT Model Setup

The BN basin delineation has been performed with Khartoum chosen as the catchment outlet. The Blue Nile Basin is divided into 40 sub-basins depending on the existing and proposed dam locations, and the discharge gauge locations. Two reservoirs have been added to the BN-SWAT model: Roseires and Sennar reservoirs located in Sudan. The BN-SWAT model was forced for the period 1979 –2010 on a monthly time step. Manning's equation was used to calculate the flow rates and velocities. Muskingum River routing method was used for river routing, the SCS curve number method has been used to represent the hydrological losses, and Penman-Monteith equation [13] has been used to simulate the Potential Evapotranspiration (PET).

BN-SWAT Model Calibration and Validation

Sensitivity analysis is carried out to demonstrate the most sensitive parameters that affect the flow in SWAT model. A total of 27 parameters were identified as the most sensitive parameters. For the calibration and uncertainty analysis of the BN-SWAT model a standalone computer program for calibrating SWAT model has been used (SWAT-CUP4). The BN-SWAT model has been calibrated for the period from 1982 to 1990, and validated for the period from 1991 to 2000 at two selected discharge stations: El-Deim Station for the Upper Blue Nile Basin, and Khartoum Station for Blue Nile at Sudan as shown in Figures (4). The Nash-Sutcliffe Efficiency (NSE), and the coefficient of determination (R^2) were used in evaluating the calibration process. The goodness of the fit was decided based on the performance rating values [14], in which the calibration performance rating can be classified as unsatisfactory, satisfactory, good, and very good corresponding to the NSE values of less than 0.5, 0.5-0.65, 0.65-0.75, and greater than 0.75, respectively. The model performance for the calibration and validation process was accepted according to the adopted statistical measures.

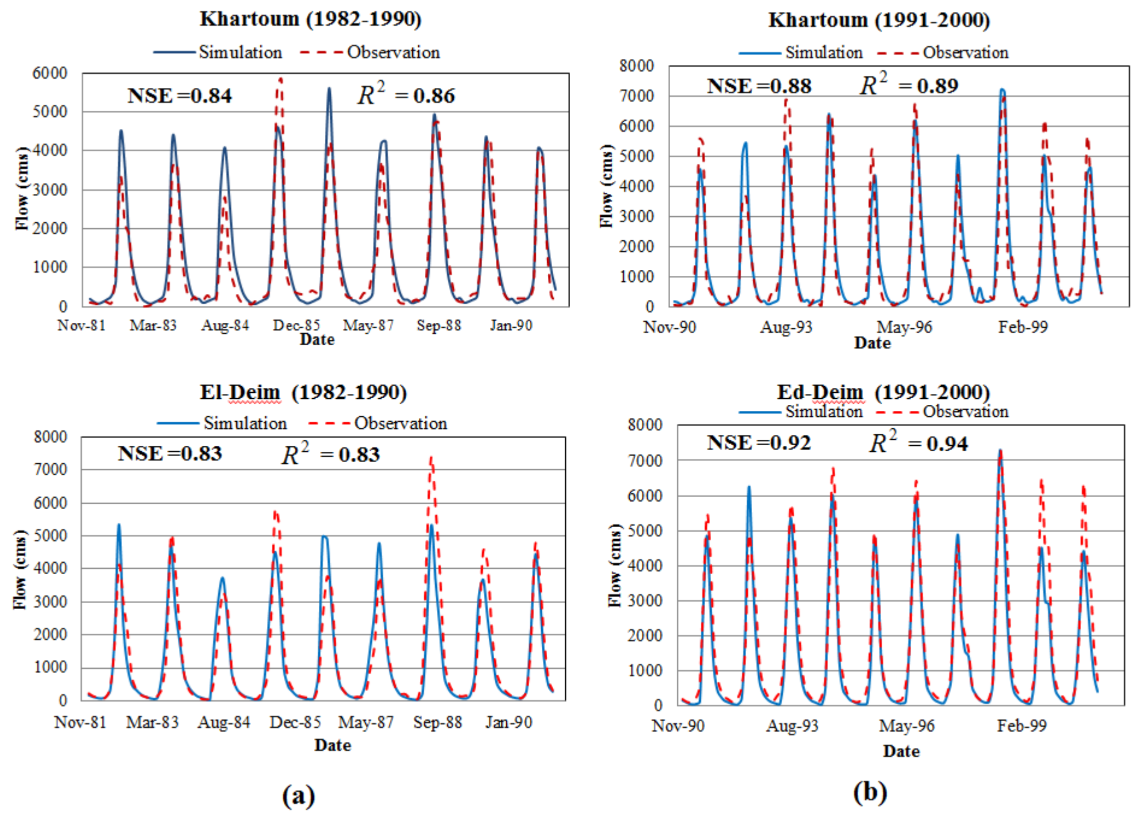

Figure 4: Calibrated flow results for SWAT at Khartoum and El-Deim stations, and (b) Validated flow results for SWAT at Khartoum and El-Deim stations

BN-HEC-ResSim Model

BN-HEC-ResSim Model uses Muskingum routing method for reach routing, the local flow data has been defined for each junction representing a sub-basin [15]. In order to study the impacts of proposed development projects on the Nile inflows arriving at HAD, the stream alignment was extended beyond the boundaries of the BN basin to include other rivers and catchments of Atbara and White Nile including the High Aswan Dam (HAD). The flow data time series were extracted from the BN-SWAT model for the BN sub-basins, where for the White Nile and Atbara basins, observed time series of river flows were used. HEC-ResSim Model requires physical reservoirs data as well as operational reservoirs data for the existing and proposed dams. The main source for the physical data and operational data for all the reservoirs was the ENTRO Hydropower Toolkits [5]. The BN-HEC-ResSim model simulated the study area for the period from 1982 to 2003 without any consideration of any development projects, the Roseires Heightening was completed in 2013, and the Merowe Dam was completed in 2010, and this case is considered Zero Case Scenario. The BN-HEC-ResSim Model was verified on by comparing the simulated flows against observed flows at 3 flow gauge stations (Ed-Deim, Khartoum, and Dongola) as shown in Figure (5). The model results were satisfactory based on the calculated statistical parameters (R^2, NSE], [14]. Finally the BN-HEC-ResSim model was verified against the pool elevation at HAD using the Zero Case simulation for the entire period from 1982 to 2003.

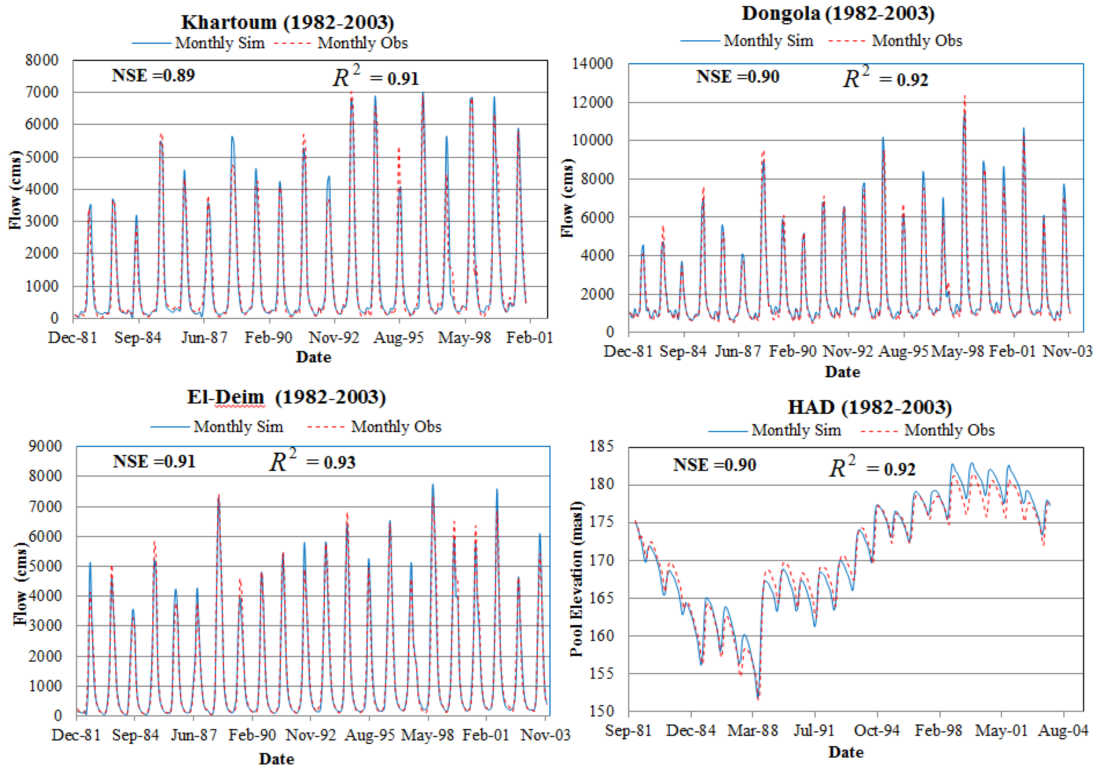

Figure 5: Verification results for HEC-ResSim at Khartoum, El-Deim, and Dongola station and monthly pool elevation at HAD

Results

Baseline Simulation

Upon verifying the Zero case of the BN-HEC-ResSim Model for the period from 1982 to 2003, the Baseline Case is configured to represent the current development conditions in the basin. The Baseline Case includes the Roseires Heightening, Merowe Dam, and the recent irrigation schemes in Ethiopia and Sudan. Through the Baseline Simulation, one can assess the impact of the Roseires heightening as well as the impact of Merowe Dam. Figure (6a) shows the impact of the baseline case scenario on the monthly flow at Dongola station in which the peak flow reduced from 18,200 MCM to 14,700 MCM, while the flow increased at the low flow period (January to May). Figure (6b) shows the impact of the baseline case scenario on both the pool elevation (P.E) and the hydropower generation at HAD, where the pool elevation at HAD has decreased to reach the maximum reduction of 4.21 m at 1996 and then HAD begun to recover till it was fully recovered at 2003. The same trend is observed for the total hydropower in HAD, but it reached the maximum reduction of 2228 Gw.hr at 1999 then the full recovery was at 2003. Table (1) illustrates the reductions in inflow, pool elevation, and hydropower at HAD due to the baseline case.

Table 1: Reductions in inflow and HAD pool elevation and HP due to Base Case Scenario.

Scenario	**Reductions**		
	Annual Flow (BCM)	Annual Pool Elevation (m)	Annual Power (%)
Baseline Case	2.15	2.25	5.1

Development Scenarios

The proposed water resources-based development projects in the BN basin can be broadly classified into Hydropower projects as well as Hydropower & Irrigation scenarios as shown in Table (2).

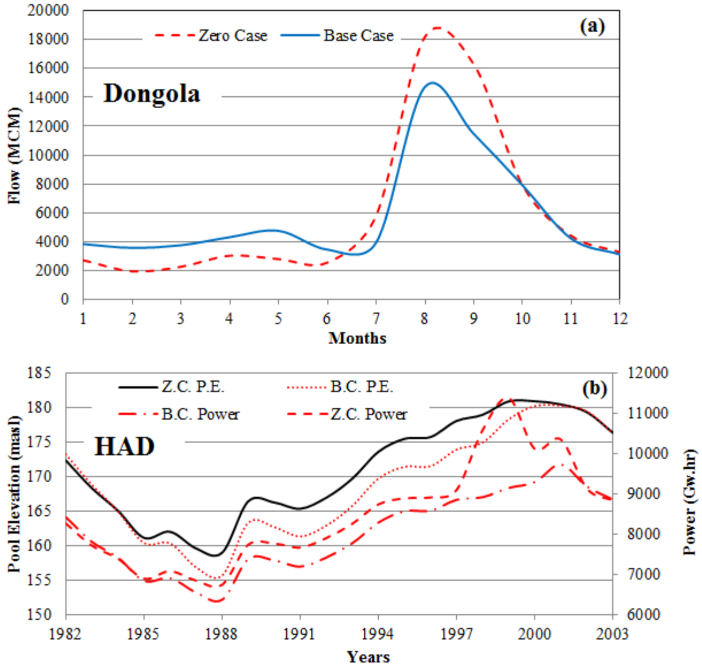

Figure 6: (a) Mean monthly flow at Dongola station for Base Case Scenario, and (b) Base Case Scenario impacts on HAD

Table 2: Description of the potential upstream development scenarios.

Scenario type	Scenario No.	Description
Hydropower scenario	1	GERD (Renaissance dam)
	2	GERD + Karadobi
	3	GERD + Beko Abo
	4	GERD + Mandaya
	5	GERD + Karadobi + Beko Abo + Mandaya
Hydropower &Irrigation scenario	6	GERD + Irrigated agriculture development
	7	GERD + Karadobi + Beko Abo + Mandaya + Irrigated projects

Hydropower Scenarios

In the Hydropower scenarios, four proposed dams were considered in Ethiopia GERD, Karadobi, Beko Abo, and Mandaya dams with their characteristics shown in Table (3) [5].

Table (3): Specifications of the Proposed Dams in the Hydropower scenarios.

Dam	GERD	Karadobi	Beko Abo	Mandaya
Full Supply Level (masl)	640	1146	1062	800
Minimum Operation level (masl)	590	1100	1010	760
Storage (BCM)	74	40.2	31.70	48.10
Storage area (Km^2)	1874	445	404	736
Installed Capacity (MW)	6000	1600	1940	2000

A total of five hydropower scenarios have been assumed including combinations of the four proposed dams as illustrated in Table (2). Scenario (1) assessed the impact of GERD only on HAD inflows, pool elevation, and hydropower. At Dongola Station, the peak flow in August drops by 8250 MCM while the trend shows increasing flows at the low flow period (January to May and November to December) as shown in Figure (7a). HAD faced a decrease in the pool elevation during the entire simulation period and it did not not recover from the effect of the GERD. HAD's pool elevation decreased to a minimum value of 147.36 masl after 6 years from the beginning of the GERD filling as illustrated in Figure (7b). In all other hydropower scenarios, it was noticed an increase in the inflow reduction at Dongola and further decrease in the HAD's pool elevation (refer to Figure 7). It worth to mention that for all other hydropower scenarios, It was assumed that there will be an adequate time lag between the construction of any two successive dams so that HAD could recover from the effect of the construction and the filling of the previous dam. Another assumption is that each new dam was assumed to be filled over duration of 5 years.

Hydropower + Irrigation Scenarios

Three proposed irrigation schemes have been considered in this study, namely the Didessa diversion, Fincha diversion, and Kennana schemes which requires irrigation demands of 0.417, 0.261, and 3.5 BCM/year, respectively. Those proposed irrigation schemes were used to develop two additional scenarios 6, and 7 as shown in Table (2). The negative impacts of these scenarios are obvious as shown in Figure (8). HAD faced a decrease in the pool elevation for the entire simulation period and it did not recover from the effect of these developments. The pool elevation decreased to a minimum value of 146.4 masl after passing 21 year from the beginning of the dam filling for Scenario 07. At Dongola station, the peak flow in August dropped by 8,586 MCM and 9,160 MCM in scenarios 06 and 07, respectively. Table (4) shows the maximum and mean reductions at HAD with respect to the inflow, the pool elevation, and the hydropower due to such upstream development projects.

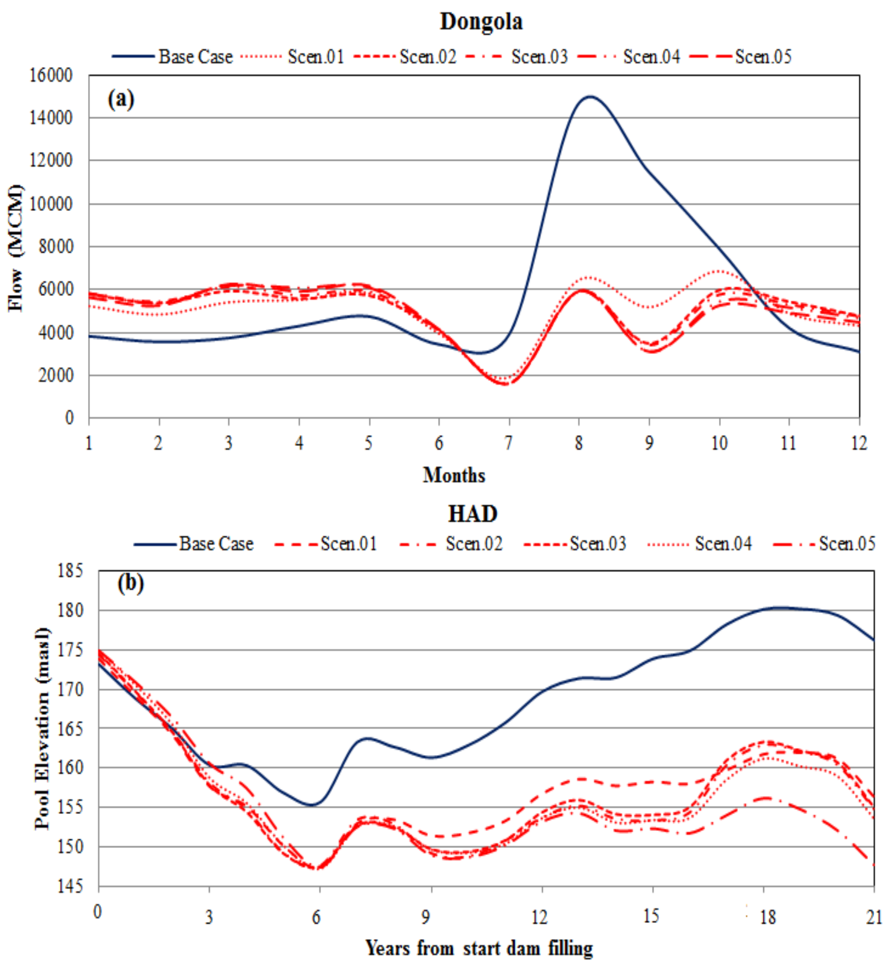

Figure 7: (a) Dongola Station Mean Monthly flow, (b) HAD Annual Pool Elevation for Hydropower Scenarios

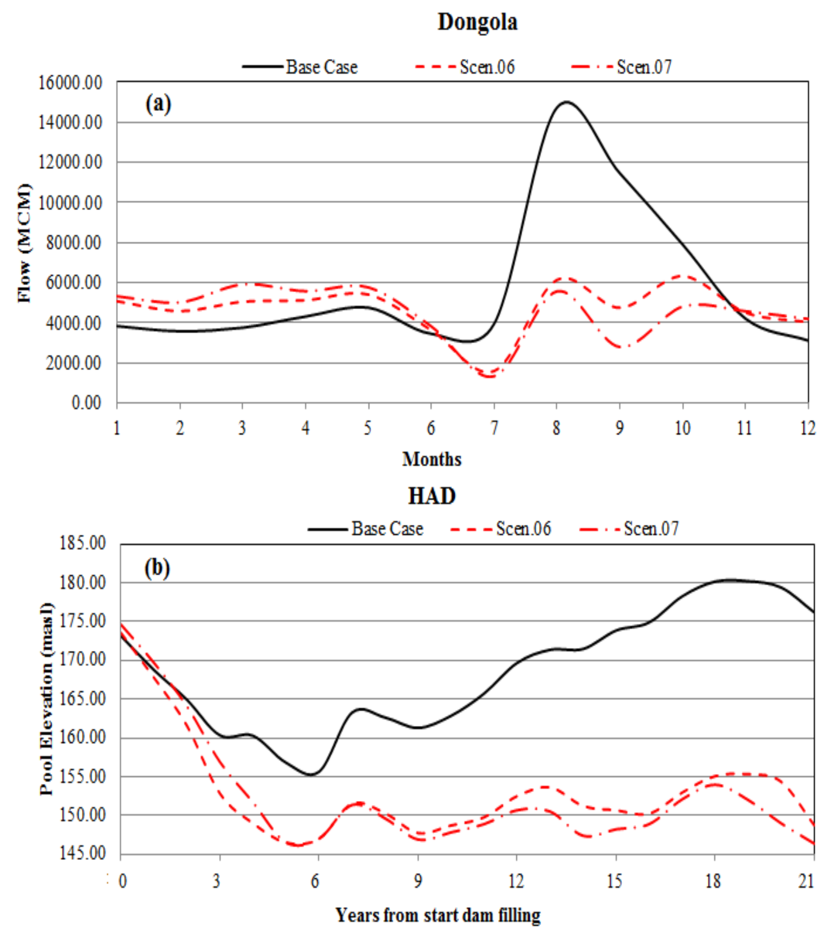

Figure 8: (a) Dongola Station Mean Monthly flow, (b) HAD Annual Pool Elevation flow for combined (Hydropower + Irrigation) Scenarios

Table 4: Reductions at HAD due to the upstream development scenarios.

Scenario No.	Reduction at HAD					
	Flow (BCM)		Pool Elevation (m)		Power (%)	
	Max	Mean	Max	Mean	Max	Mean
1	16.67	**8.54**	19.95	10.97	**23.01**	17.37
2	21.01	9.19	22.21	12.89	29.51	22.41
3	22.58	8.99	21.21	12.60	30.21	22.03
4	23.85	9.70	23.21	13.29	30.37	23.27
5	30.37	**10.69**	26.57	13.86	**32.24**	25.09
6	33.06	**12.82**	27.42	15.45	**40.48**	30.09
7	35.96	**14.34**	30.38	16.21	**55.32**	33.29

Conclusion

In this paper an offline coupled calibrated / validated SWAT-HecResSim models for BN basin was developed to simulate the current conditions of the BN and to simulate and assess the impacts of the potential water resources-based development scenarios in the BN basin on the Nile River inflow at HAD. Development projects in the BN basin were divided into two main scenario types. First is the hydropower scenario including the construction of four proposed major dams in the BN basin which are GERD, Karadobi, Beko Abo, and Mandaya dams. Second is the combination of hydropower and irrigation projects development scenarios. In case of the hydropower scenarios, the construction of GERD only will have a significant effect on the Nile inflow and pool elevation at HAD by an average annual reduction in the inflow of 8.5 BCM and maximum power reduction of 23 % . In case of combined hydropower and irrigation scenarios, these reductions will be increased (due to the increase of water abstraction in the upstream to satisfy to the demands of the irrigation schemes) to be 12.8 BCM, and 40.4% for the average annual reduction in the inflow and maximum power reduction, respectively. The worst case for the hydropower scenarios comes from the construction of the four expected dams in the Blue Nile. At this case, The Nile River inflows at HAD will face an annual average reduction of 10.7 BCM and maximum power reduction of 32 %. For combined scenarios, these reductions will increase to 14.3 BCM, and 55.3% for the average annual reduction in the inflow and maximum power reduction at HAD, respectively.

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Consideration of Soil Salinity Mapping in Hydrological Drought Indices Evaluation in Saudi Arabia

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Abstract
Vegetation indices are mostly described as crop water derivatives. Normalized Difference Vegetation Index (NDVI) is one of the oldest remote sensing applications that widely used to evaluate crop vigor directly and crop water relationships indirectly. Recently, several NDVI derivatives are exclusively used to assess crop water relationships. Four hydrological drought indices are examined in the current research study. Water Supply Vegetation Index (WSVI), Soil Adjusted Vegetation Index (SAVI), Moisture Stress Index (MSI) and Normalized Difference Infrared Index (NDII) are implemented in the current study as an indirect tool to map the effect of different soil salinity level on crop water stress in arid environments. In arid environments; such as Saudi Arabia, water resources are under pressure especially groundwater levels. Groundwater wells are rapidly depleted due to the heavy abstraction of the reserved water. Heavy abstractions of groundwater; which exceed crop water requirements in most of the cases, are powered by high evaporation rates in the designated study area because of the long days of extremely hot summer. Landsat OLI-8 data were extensively used in the current research to obtain several vegetation indices in response to soil salinity in Wadi Ad-Waser.

Keywords: Arid Environment, Remote Sensing techniques, Soil Salinity Mapping, Vegetation Indices.

1. Introduction

Spectral vegetation indices are mathematical combinations of different spectral bands mostly in the visible and near-infrared regions of the electromagnetic spectrum. Vegetation activities can be measured comprehensively through semi-analytical methods of spectral band ratios that have been extensively used to detect not only seasonal variability of the vegetation cover but also local scale spatial variability (Broge and Mortensen, 2002; Xiao *et al.*, 2002).

The generic principle of utilizing vegetation indices is to improve the interpretation of the spectral data reflected from a vegetation cover. Spectral reflectance variabilities tend to differentiate between different vegetation characteristics based on crop water relationships and other surrounding features of soil components and atmosphere based on the maximization of vegetation characteristics over the surrounding environments (Moulin and Guerif, 1999; Boegh *et al.*, 2002).

Implementations of vegetation indices are varied from a local leaf scale to continental vegetation scale. Moreover, certain indices tend to be site and/or species specific (Clevers, 1989; Elhag 2014a) and it can't be applied not only to different species but also different leave structure and canopies geometry (Xiao *et al.*, 2002). Scholarly work of Kerr, and Ostrovsky (2003), Pettorelli et al. (2005), Huete et al. (2008) and Elhag (2014b) reported that several vegetation indices used to estimate different vegetation parameters extensively includes: Leaf Area Index (LAI), Fractional Vegetation Cover (FC), Crop Water Shortage Index (CWSI), Drought Severity Index (DSI) and Water Supply Vegetation Index (WSVI).

Soil salinization is a dynamic process arises basically when an excess of irrigational water is frequently used in the drainage capacity of the fields (Wardlow and Egbert, 2010). Implementations of remote sensing techniques in soil salinity mapping achieved comprehensive results on the regional scale (Montandon and Small, 2008). Brightness Index (BI), Normalized Differential Salinity Index (NDSI) and Salinity Index (SI), are widely distinguished in soil salinity mapping in an arid environment (Douaoui *et al.*, 2006; Jiapaer *et al.*, 2011).

Current research aims to evaluate the suitability of different vegetation indices for a different level of remotely sensed soil salinity with contrasting to crop water relationships in Wadi Ad-Wasser.

2. Materials and methods

2.1. Study area

The study area, Wadi Ad Dawasir town is located in the plateau of Najd at Lat 44o 43' and Lon 20o 29'; about 600 km south of the capital city Riyadh (Figure 1). This study area comprised of gravelly tableland disconnected by insignificant sandy oases and isolated mountain bundles. Wadi Ad Dawasir and Wadi ar Rummah are the most important pattern of the ancient riverbeds remains in the study area. Wadi Ad Dawasir and Najran regions are the major irrigation water abstraction from Al-Wajid aquifer. Agriculture in Wadi Ad Dawasir area consists of technically highly developed farm enterprises that operate modern pivot irrigation system. The size of center pivot ranges from 30 ha to 60 ha with farms managing hundreds of them with the corresponding number of wells. The main crop grown in winter is wheat and occasionally potatoes, tomatoes or melons. All year fodder consists of alfalfa, which is cut up to 10 times a year for food. Typical summer crops for fodder are sorghum and Rhodes grass, which is perennial, but dormant in winter. The shallow alluvial aquifers could not sustain the high groundwater abstraction rates for a long time and groundwater level declined dramatically in most areas. Meteorological features of the area are speckled. Five elements of meteorology are constantly recorded through fixed weather station located within the study area. Temperature varies from 6^{o} C as minimum temperature to 43^{o} C as maximum temperature. Relative humidity is mostly stable at 24 %. Solar radiation of average sunrise duration is generally 11 hrs/day. Average wind speed is closer to 13 km/hr and may reach up to 46 km/hr in thunderstorm incidents. Finally, mean annual rainfall is about 37.6 mm (Al-Zahrani and Baig, 2011).

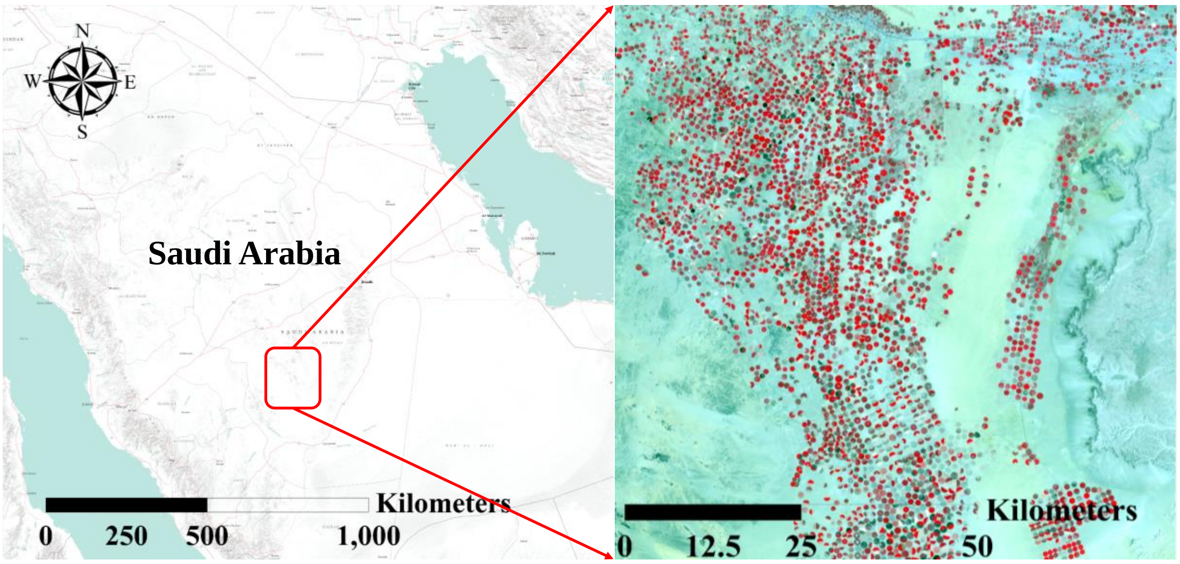


Figure 1: Location of the study area (Elhag, 2016)

2.2. Methodological framework

The current research work is based on assessing a regression correlation between different vegetation indices and their spatial corresponding soil salinity values conducted from satellite images. Principal Component Analysis is the undertaken tool to envisage the impacts of Soil Salinity on the current vegetation.

2.3. Estimation of vegetation indices

2.3.1. Water Supply Vegetation Index (WSVI):

$$WSVI = NDVI/T_s$$

Where

T_s is the brightness temperature channel or related remote sensing imagery estimated. The smaller this index is, the more severe the drought is.

2.3.2. Soil Adjusted Vegetation Index (SAVI):

$$SAVI = \frac{(NIR - R)}{(NIR + R) * (1 + L)}$$

Where,

NIR is the Near Infrared band

R is the Red band

L is the is the soil brightness correction factor, commonly *L* = 0.5, (Huete, 2008)

2.3.3. Moisture Stress Index (MSI):

$$MSI = \frac{SWIR_1}{NIR}$$

Where

$SWIR_1$ is the Short-wave Infrared band 1

NIR is the Near Infrared band

2.3.4. Normalized Difference infrared Index (NDII):

$$NDII = \frac{(NIR - SWIR_1)}{(NIR + SWIR_1)}$$

Where

NIR is the Near Infrared band

$SWIR_1$ is the Short-wave Infrared band 1.

2.4. Estimation of soil salinity index

Soil salinity indices are principally adjusted to detect salt mineral in soils based on the different responses of salty soils to various spectral bands. The following equation to map soil salinity was used after Elhag (2016):

$SI = (G \times R)/B$

Where,

B is the Blue band

G is the Green band

R is the Red band

2.5. Regression Analyses

The purpose of the regression analyzes is to envisage the regression potentials between soil salinity index from one side and the rest of the hydrological drought indices from the other

side. Principle Component Analysis (PCA) and Artificial Neural Network (ANN) were the implemented approaches. The PCA is to transform a set of likely correlated with unlikely correlated variables. Principal components number is less/equal to the variables original number. Following Lorenz (1956), PCA fundamental equations are:
First vector W $_{(1)}$ has to be answered as following:

$$w_{(1)} = \arg max_{\|w\|=1} \left\{ \sum_i (t_1)^2_{(i)} \right\} = \arg max_{\|w\|=1} \left\{ \sum_i (x_i \, . w)^2 \right\}$$

The matrix form of the above equation gives the following:

$$w_{(1)} = \arg max_{\|w\|=1} \{\|Xw\|^2\} = \arg max_{\|w\|=1} \{w^T X^T Xw\}$$

W $_{(1)}$ has to be answered as following:

$$w_{(1)} = \arg max \left\{ \frac{w^T X^T Xw}{w^T w} \right\}$$

Originated $w_{(1)}$ suggests that first component of a data vector $x_{(i)}$ can then be expressed as a score of $t_{1(i)} = x_{(i)} \cdot w_{(1)}$ in the transformed co-ordinates, or as the corresponding vector in the original variables, $\{x_{(i)} \cdot w_{(1)}\} \, w_{(1)}$.

The neural network regression model is written as:

$$Y = \alpha + \sum_h w_h \phi_h(\alpha_h + \sum_{i=1}^{p} w_{ih} X_i))$$

Where
$Y = E(Y|\boldsymbol{X})$. This neural network model has 1 hidden layer but it is possible to have additional hidden layers.
The $\phi(z)$ function used is hyperbolic tangent activation function. It's used for logistic activation for the hidden layers.

$$\phi(z) = \tanh(z) = \frac{1 - e^{-2z}}{1 + e^{-2z}}$$

It is significant that the final outputs to be linear not to constrain the predictions to be between 0 and 1. A simple diagram of a skip-layer neural network is illustrated in Figure 2. The equation for the skip-layer neural network for regression is shown below.

$$Y = \alpha + \sum_{i=1}^{p} \beta_i X_i + \sum_h w_h \phi_h(\alpha_h + \sum_{i=1}^{p} w_{ih} X_i))$$

It should be clear that these models are highly parameterized and thus, will tend to overfit the training data. Cross-validation is, therefore, critical to make sure that the predictive performance of the neural network model is adequate.

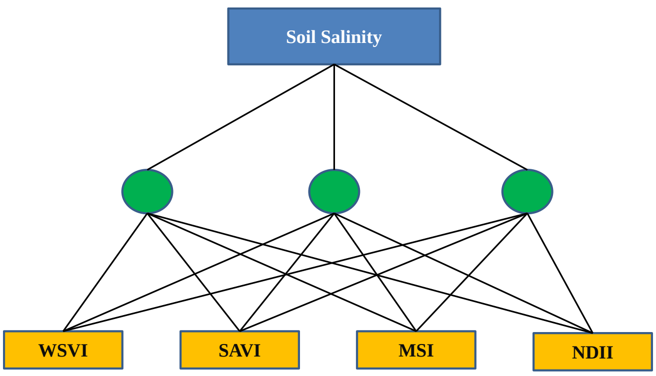


Figure 2: Artificial Neural Network scheme with 1 hidden layer and 3 nodes

Recall the skip-layer neural network regression model looks like this:

$$Y = \alpha + \sum_{i=1}^{p} \beta_i X_i + \sum_{h} w_h \phi_h(\alpha_h + \sum_{i=1}^{p} w_{ih} X_i))$$

However, this model most likely overfits the training data. Consequently, determination of the adequate performance of the ANNs model is a must. Five different criteria are used: the Pearson coefficient of correlation (R), the root mean square error (RMSE), the mean absolute Deviation (MAD), the negative log-likelihood and the unconditional sum of squares (SSE). Basically, RMSE is the examined parameter for comparability reasons. RMSE can be computed as:

$$RMSE = \sqrt{\frac{1}{T_0} \sum_{t=1}^{T_0} (y_1 - \acute{y}_1)^2}$$

Where t is the time index, and $\hat{y}_t$ and y_t are the simulated and measured values. Principally, the higher value of R and smaller values of RMSE ensure the better performance of the model.

3. Results and Discussion

Realization of the hydrological drought indices was exercised after a comprehensive remote sensing data correction. Basically, atmospheric correction and spatial enhancement were practiced utilizing Landsat 8 data acquired over the designated study area. The four hydrological drought indices were shown in Figures 3 to 6. Stochastic algorithms of WSVI and SAVI mapping (Figures 3 and 4) showed spatial coherence with a higher drought indices value within the agricultural area rather than the surrounding (Ceccato *et al.,* 2001; Daughtry *et al.,* 2004).

On the contrary, MSI exercised as a deterministic drought index, it's nearly unaffected by changing water content. Conducted results showed two classes of stresses, stressed and no stress. The no stress class located within the agricultural area and the stressed area represented along the agricultural peripheral areas (Figure 5) where higher values indicate greater water stress and less water content. This could be explained rationally by the presence of irrigational sprinkles (Hunt *et al.,* 1989; Ceccato *et al.,* 2001). NDII is also a stochastic algorithm and was exercised in the current research due to the higher sensitivity of Infrared band to detect changes in water content of plant canopies (Hardisky *et al.,* 1983). Spatial distribution of NDII (Figure 6) was mapped accordingly with WSVI and SAVI indices, in which higher NDII values means higher water content (Jackson *et al.,* 2004). There are several algorithms to map soil salinity based on utilization of different remote sensing data as well as different ecological systems. An adequate NDSI algorithm was carried out according to Elhag (2016) findings in arid ecosystems. In Figure 7, NDSI was mapped in the designated study area showed spatial variation of salted soils, especially the new agricultural expansion at the southern west part of the designated study area due to the sprinkle movement drove the accumulation of excess waters at the peripherals of the agricultural areas (Gobon *et al.,* 2000; Konukcu *et al.,* 2006).

Further statistical analyzes were carried out to construe the correspondences between salted soils and different horological drought indices. Regression analysis demonstrated in Figure 8 showed that salinity increases with lower WSVI and SAVI (Figure 8 a, b) which explained due to salt accumulation in soils. Under salinity stress conditions, there is no enough available water in soils for proper vegetation growth (Gobon *et al.,* 2000; Yang *et al.,* 2011).

Generally, MSI values (Figure 8 c) are high in the study area because of the excess irrigation regime adopted to overcome the high evaporation rates (Elhag, 2014b; 2016). Excess irrigation regimes in poor drain soils lead to waterlogging problems and salts accusation (Elhag, 2016).

Due to NDII higher sensitivity to water, NDII values increases with higher NDSI values. Salts accumulation caused by excessive irrigation is the driving force behind the proportional increment of NDII values in conjunction with NDSI values demonstrated in Figure 8d (Jackson *et al.*, 2004; Pinty *et al.*, 2009).

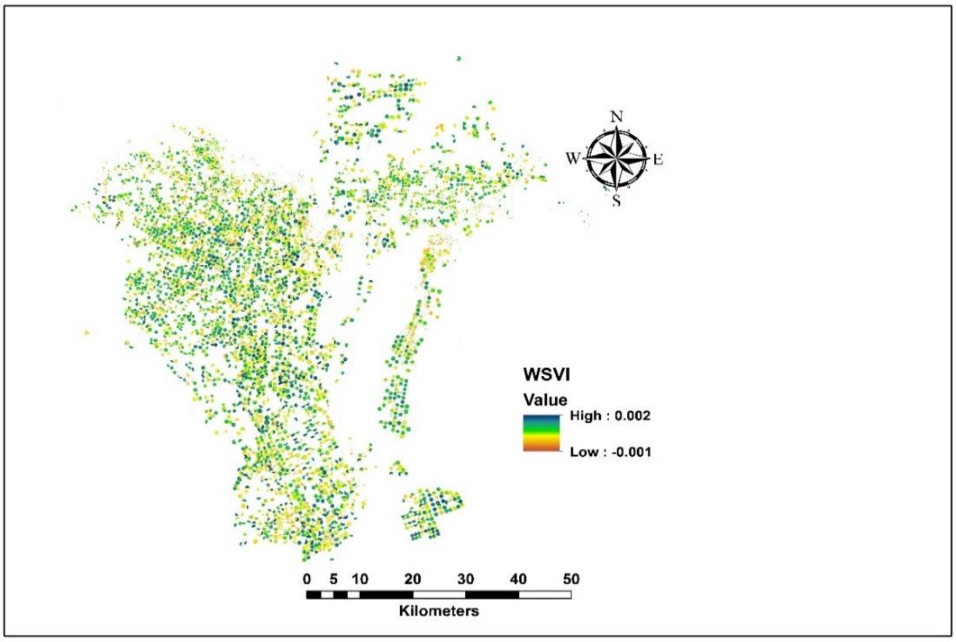


Figure 3: WSVI map

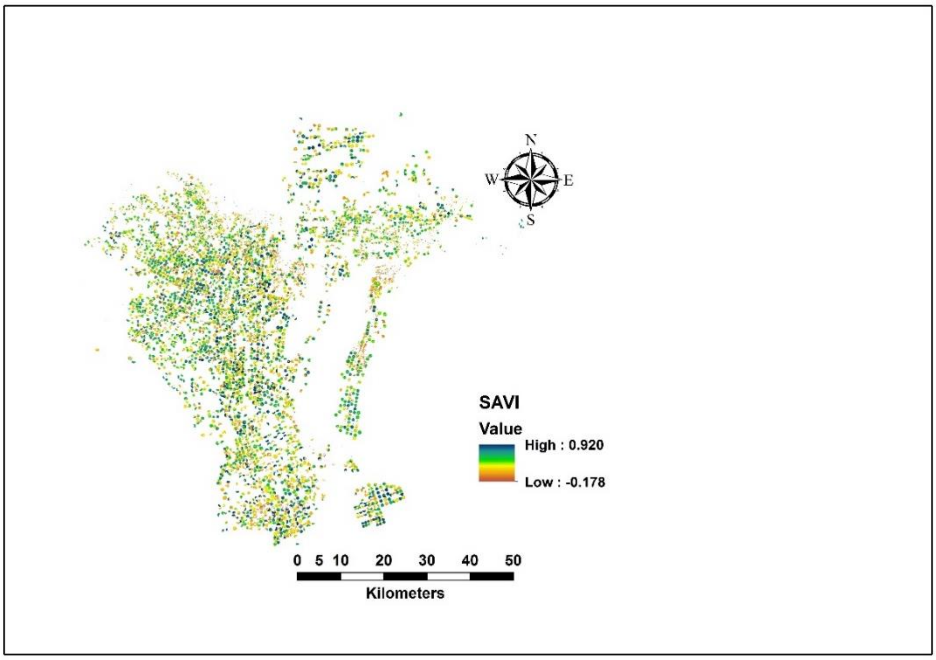


Figure 4: SAVI map

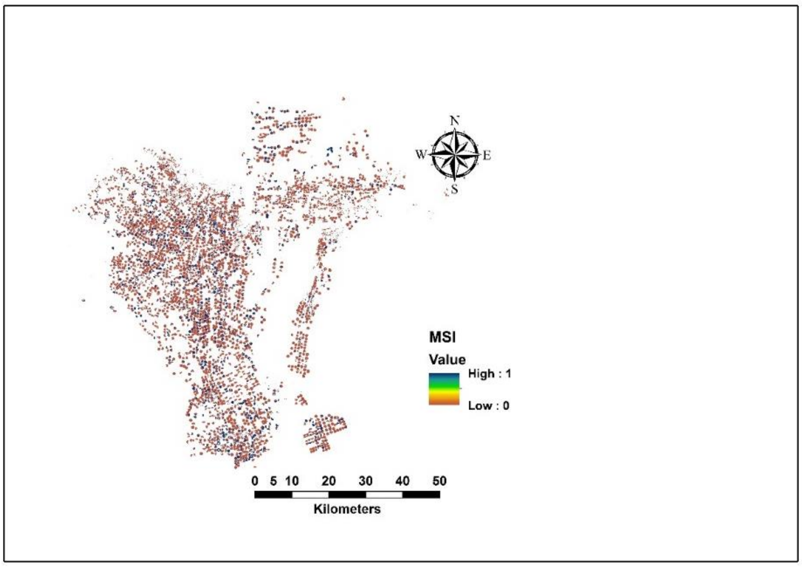


Figure 5: MSI map

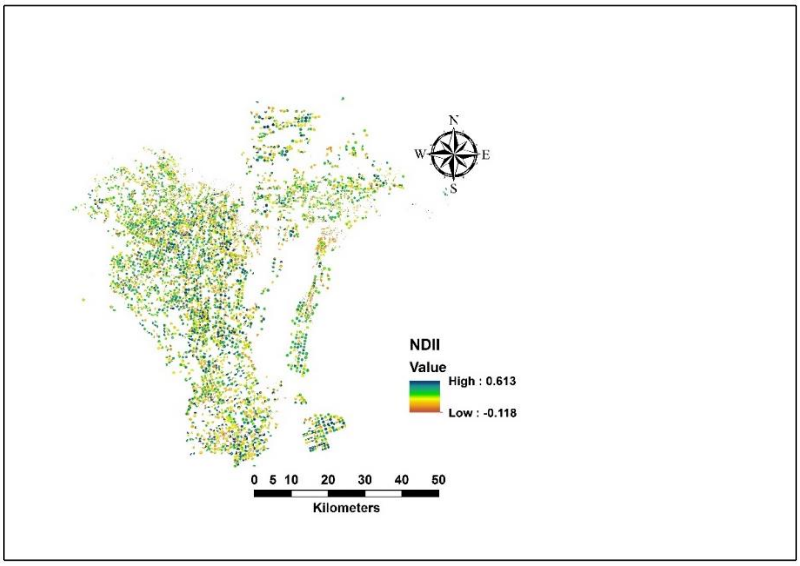


Figure 6: NDII map

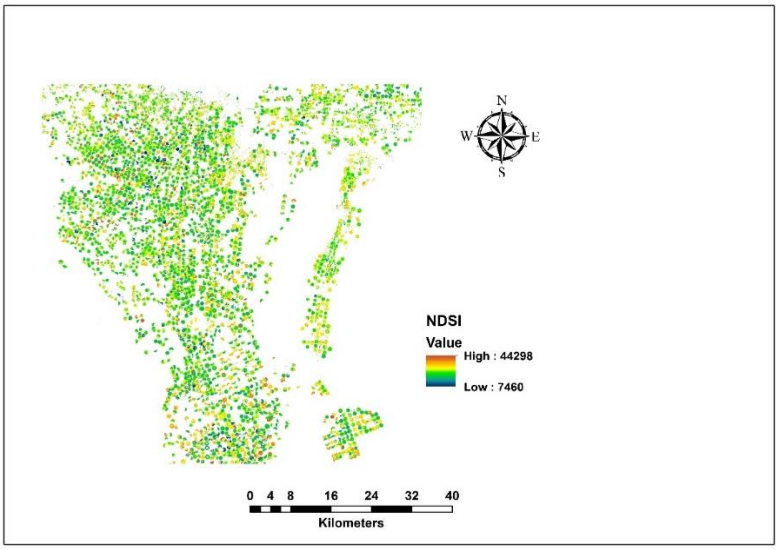


Figure 7: NDSI map

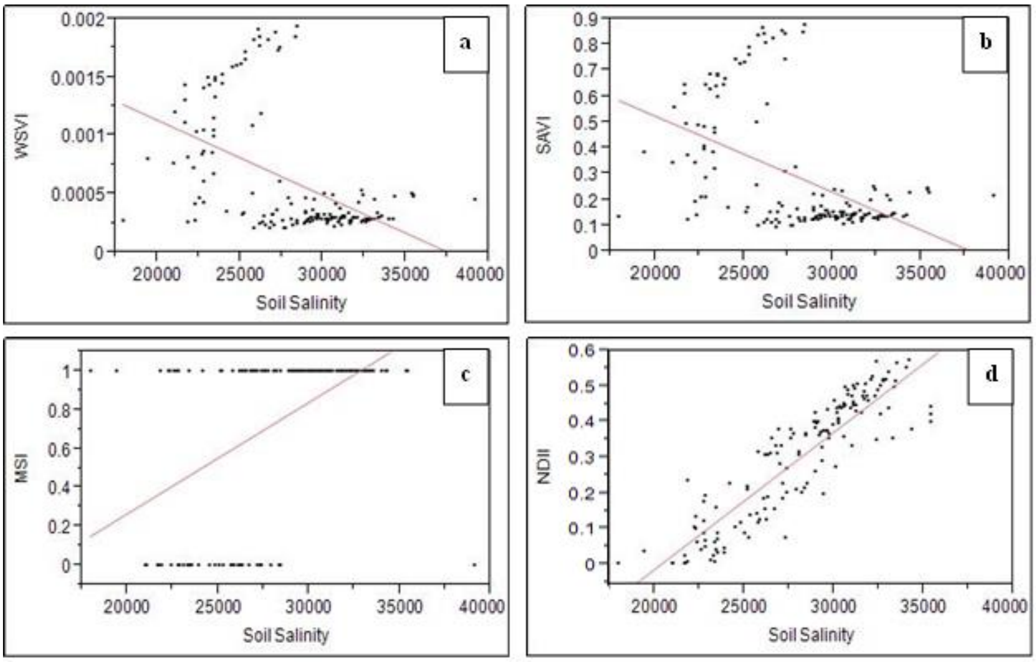


Figure 8: Regression analyzes pf NDSI (ppm) against horological drought indices

Figure 9 demonstrated the Principal Component Analysis along with the Factor Analysis. Moreover, eigenvalue decomposition is also demonstrated. WSVI and SAVI were grouped together. On the other hand, NDII and MSI were individually plotted against the former indices.

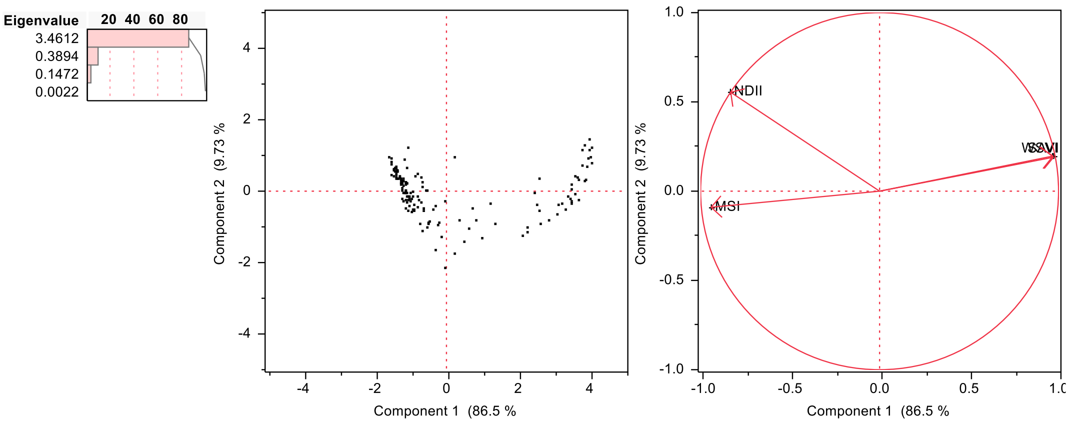


Figure 9: Principle Component Analysis

Similar results conducted from the Scatter Plot Matrix and the companion correlation matrix shown in Figure 10 and Table 1. A high correlation is distinguished between WSVI and SAVI while negative correlation noted between WSVI and SAVI from one side and MSI AND NDII from the other side.

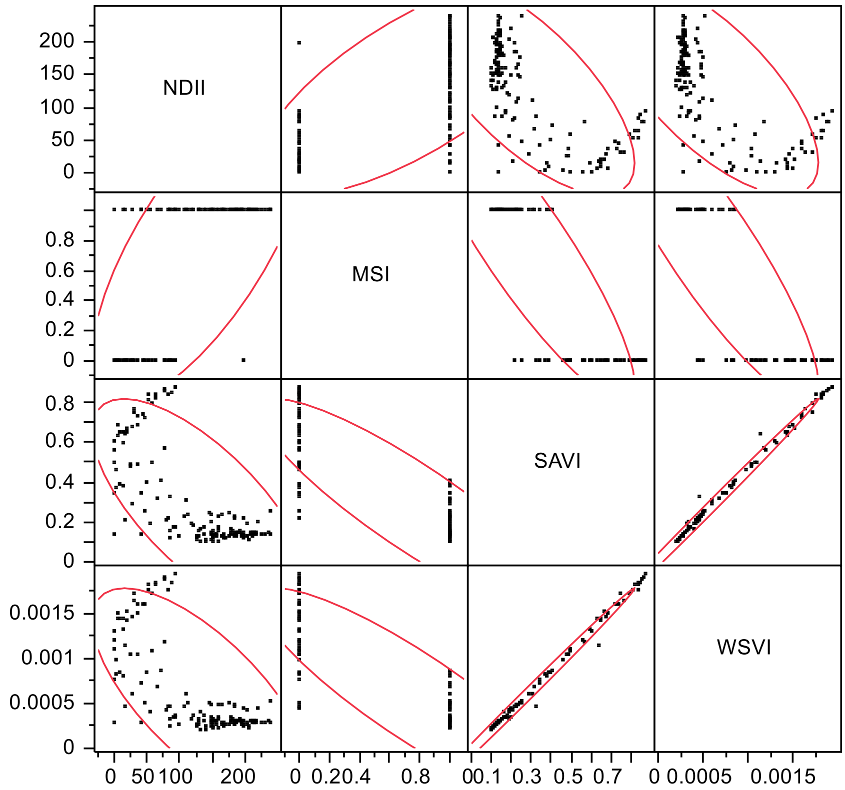


Figure 10: Scatterplot Matrix

Table 1: Correlation matrix

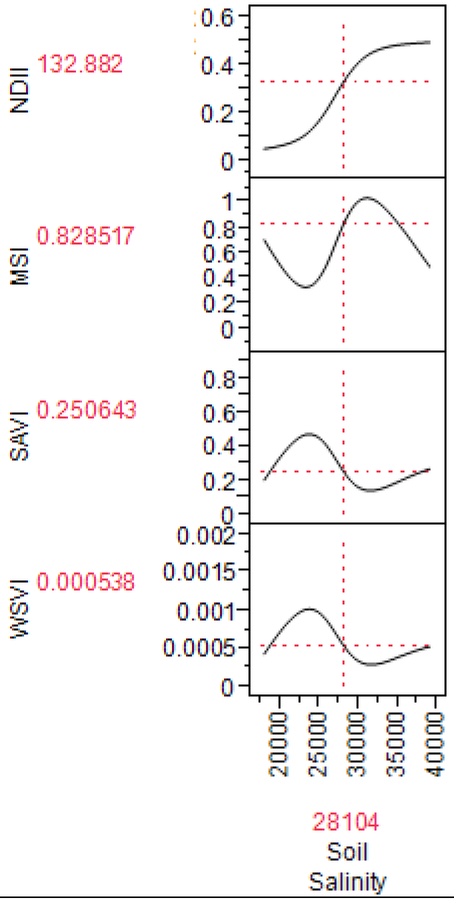
	NDII	MSI	SAVI	WSVI
NDII	1	0.7182080406	-0.708975719	-0.703572559
MSI		1	-0.888156103	-0.88249756
SAVI			1	0.9977255509
WSVI				1

The ANN analysis was carried out under 1 hidden layer, 3 nodes, and hyperbolic tangent activation function conditions. These conditions were carefully exercised to prevent the algorithm overfitting, ANN analysis is demonstrated in Table 2. NDII expressed the highest RMSE which indicates that NDSI and NDII are statistically the best fit (Jiang, 2013). SAVI comes at the second best fit followed by WSVI. MSI failed to fit NDSI values comprehensively like the former hydrological drought indices (Jones and Marshall, 1992; Jiapaer et al., 2011).

Table 2: Neural Network Analysis

		Training Measures	Validation Measures
NDII	RSquare	0.7574526	0.6698156
	RMSE	0.0999530	0.0972931
	Mean Abs Dev	0.0571881	0.0436599
	-LogLikelihood	-88.411680	-45.554430
	SSE	0.9990600	0.4732975
	Sum Freq	100	50
MSI	RSquare	0.3032101	0.0893892
	RMSE	0.2388872	0.1869959
	Mean Abs Dev	0.1203075	0.0628425
	-LogLikelihood	-1.2825260	-12.886510

	SSE	5.7067096	1.7483727
	Sum Freq	100	50
SAVI	RSquare	0.7565419	0.6698155
	RMSE	0.1499295	0.1459397
	Mean Abs Dev	0.0857822	0.0654899
	-LogLikelihood	-47.865170	-25.28115
	SSE	2.2478847	1.0649203
	Sum Freq	100	50
WSVI	RSquare	0.7533827	0.6619429
	RMSE	0.0003280	0.0003226
	Mean Abs Dev	0.0001876	0.0001451
	-LogLikelihood	-660.35100	-331.01460
	SSE	1.08E-05	5.20E-06
	Sum Freq	100	50



4. Conclusion

The findings of the current research emphasized on the importance of the horological drought indices to envisage the adverse effects of salts accumulation in poorly drained soils. Remote Sensing techniques were satisfactory implement and interpreted in term of soil salinity mapping in consort with hydrological drought indices. Normalized Difference Infrared Index was statistically proved to be the Normalized Difference Salinity Index profound, followed by Soil Adjusted Vegetation Index and Water Shortage Vegetation Index respectively. Principal Component Analysis and Artificial Neural Network Analysis are complementary tools to understand the regression pattern of the hydrological drought indices in the designated study area. Further work needs to be considered towards the restrictiveness of the drastic effect of salts accumulation within the study area.

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Combining Remote Sensing, Geo-Statistics and numerical Hydrologic Models to Assess Vulnerability to Erosion and Landslide: a Moroccan High Atlas Case Study

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Abstract
The main goal of this study is the development of a new methodology combining the use of remote sensing, geostatistics and numerical hydrologic modeling to assess and map the vulnerability to water related landslides and erosion for Oued El Abid watershed in High Atlas Moroccan Mountains. In fact, soil resistance, faults and discontinuities, land slope and geomorphology, land cover and land use has been evaluated and mapped. The resulting thematic maps have been combined to hydrologic flow models. The created documents can be considered as references of great help for decision-makers and planners to adapt their policies and activities to landslide risk, and for land users to mitigate the negative impact of climate change on landslides and erosion as a water related hazard. Five factors have been characterized and mapped in the studied area: soil resistance, faults and discontinuities, land slope and geomorphology, land cover and land use. The derived thematic map shows five classes of landslide and erosion vulnerability: very high, high, medium, weak, very weak. The very high and high classes of landslide and erosion vulnerability cover more than 65% of the mountain area uphill from the 8th National road bridge on Oued El Abid. Those zones have been observed and field verified. Hence, hydrologic models have been calibrated for the zones with very high landslide and erosion vulnerability. Those models are tested to predict landslide actual occurrence, and to study scenarios of climate change impact on landslide and erosion as a water related hazard. The methodology used in this study can be reproduced for many other regions in the world where landslides, erosion and climate change impacts are a serious threat to human being activities and infrastructures.

Keywords: Landslides, Water Related Hazards, Climate Change, High Atlas of Morocco; Remote Sensing; Geostatistics, Hydrology Modeling.

Introduction

Recent studies on natural hazards related to climate change show a worldwide increase of those hazards, meanly for those related to water dynamics. It is well known that rainfall and runoff induce soil erosion and transfers under different kind of climate and geologic context. When the geologic, tectonic and structural contexts are suitable this erosion can be resulting or activating mass movements landslides. Consequently, a great amount of surface rocks are moved, especially where land slopes are high, soils are unconsolidated and easily erodible or weakened by unsuitable human activities like agricultures on tilted soils. The situation becomes much more dramatic when regions were suffering from a long time droughts and brutally receive high amounts of rainfall water in a short period of time. This induces flash floods and inundations that results in many loss of human lives and properties, and many damages in fertile soils, siltation of dams, destruction and degradation of roads bridges,…etc. Hence, this work is a first attempt to locate those zones in a mountains area with high vulnerability to erosion, landslides and mass movement in general. The methodology of this work is based on satellite remote sensing images interpretation combined to geostatistical modeling under GIS environment. The resulting documents, maps and products of this work are essential for planners and decision-makers to evaluate the vulnerability the studied region to erosion, landslides and mass movement in order to find the suitable solutions for sustainable land management practices.

The studied area contains different kinds of geological contexts where rocks react differently to water actions. Consequently, it's difficult to map the vulnerability to erosion and landslides in such heterogeneous region especially when climatic data are scarce and non-continuous.

Even if Moroccan climate is arid to sub-arid, many of its regions experience floods, inundations and landslides inducing many loss in human lives and many economic and social and environmental damages (Aresmouk, 2005, DGH, 2005, El Hajjam, 2006). Among those damages one can mention the silting of Bin El Ouidane Dam located down-stream of Oued El Abid and Oued Ahençal watersheds. Water of this dam is used for irrigation, drinking water and production of hydroelectricity. It is well known that siltation of this dam is related to erosion and mass movements up-stream of it (Lahlou, 1994, Sherif and Doumani, 2012).

The main purposes of this work can be summarized as an attempt to:

- Aware stake holders of zones where inundations, landslides and erosion are more likely to take place
- Find any causality between the previous hazard, land cover changes and siltation in Bin El Ouidane hydropower and irrigation Dam.
- Find any correlation between all the previous phenomenon and climate change.

To reach those goals, the present work is made of a multidisciplinary approach using GIS method, Remote Sensing Image Analysis (Landsat), hydrological Modeling (HEC-RAS) and field observations and geotechnical studies.

General characteristics of the studied area

The studied area is located in the eastern part of the High Atlas Mountains in central Morocco (Figure 1). Precisely the region is at the latitudes 32° 37' 10.56" N and 31° 42' 36" N and longitudes 7° 05' 57.12" O et 5°13' 37.92"O. In this zone these are many interesting mountainous cities like Azilal, Wawizeght, Demnat and Ait Attab and many villages, Ouzoud falls, Bin El Ouidane Hydroelectropower and irrigation Dam, Tisli and Isli lakes,…etc. The watershed corresponding to this zone has an area of about 8000 Km2 with a perimeter of about 655 Km and it is located on the left of Oum Er'Rbia River. The region is governed by three provinces: Béni mellal, Azilal and Midelt.

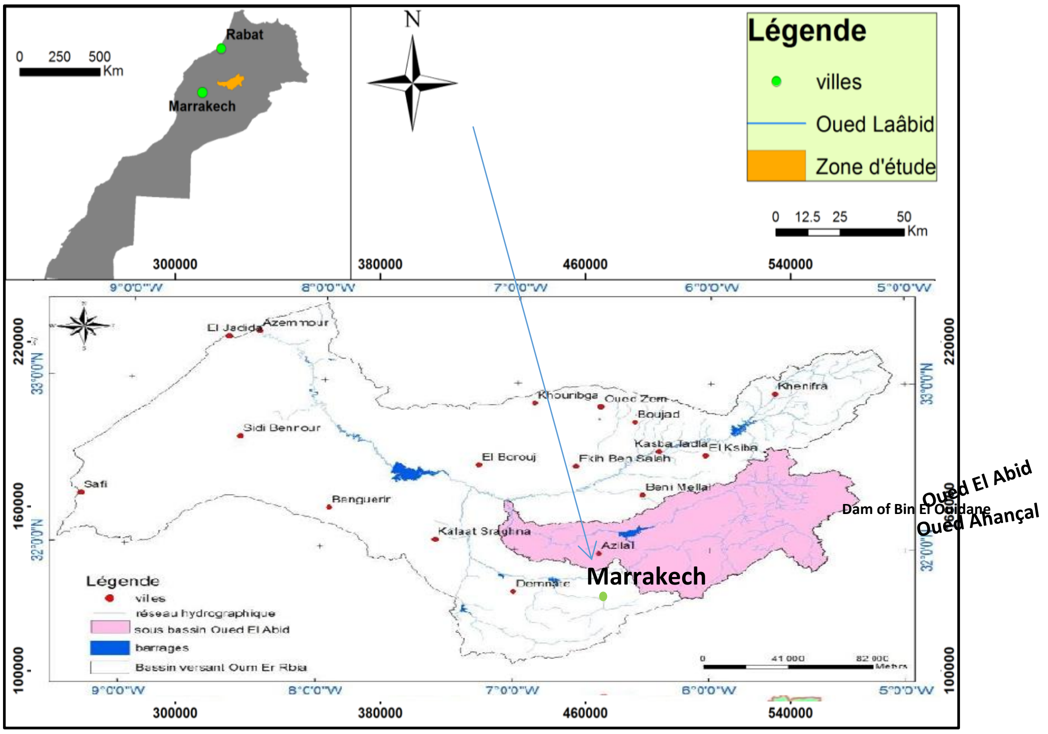

Figure 1: The location of the studied watershed: about 200 Km South-East of Rabat, the capital of Morocco

The studied region is dominated by mountainous geomorphological contexts but one can observe the piedmont context (the Dir) and the plain context downstream. The surface soil topography is fluctuating from about 300 m to 3688 m above the general sea level (Figure 2). Soil surface slopes are fluctuating from 1° to 80 °. In the piedmont and the plain there are many agricultural activities irrigated not only by a dense network of channels bringing water from many springs and from Bin El Ouidane Dam but also by pumped groundwater wells (Figure 3). The aquifers there are generally unconfined and take place in Miocene and plio-quaternary alluviums.

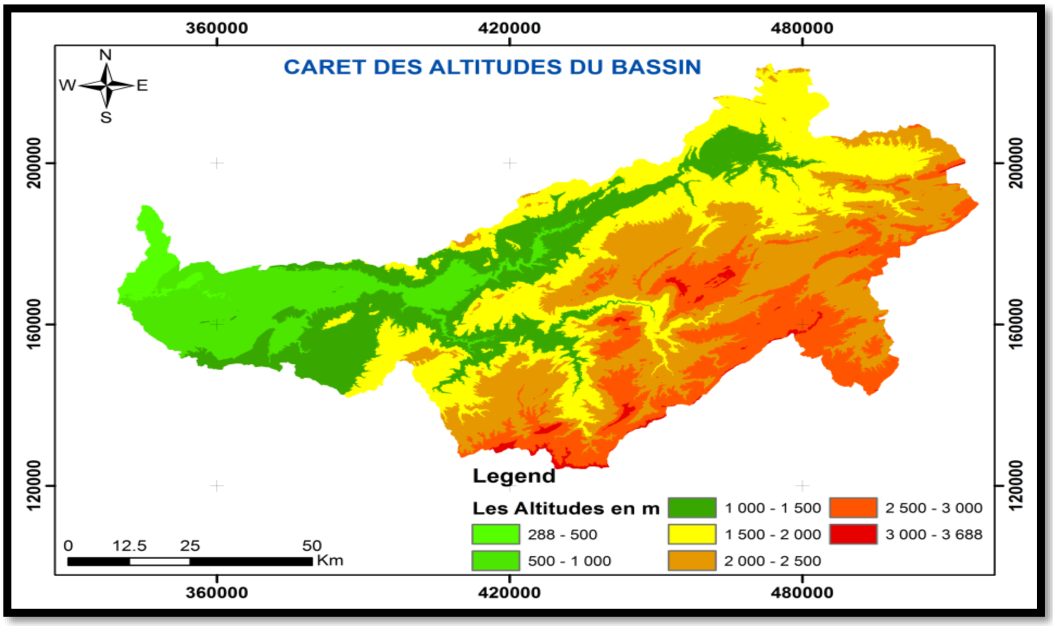

Figure 2: Digital elevation model of the studied watershed

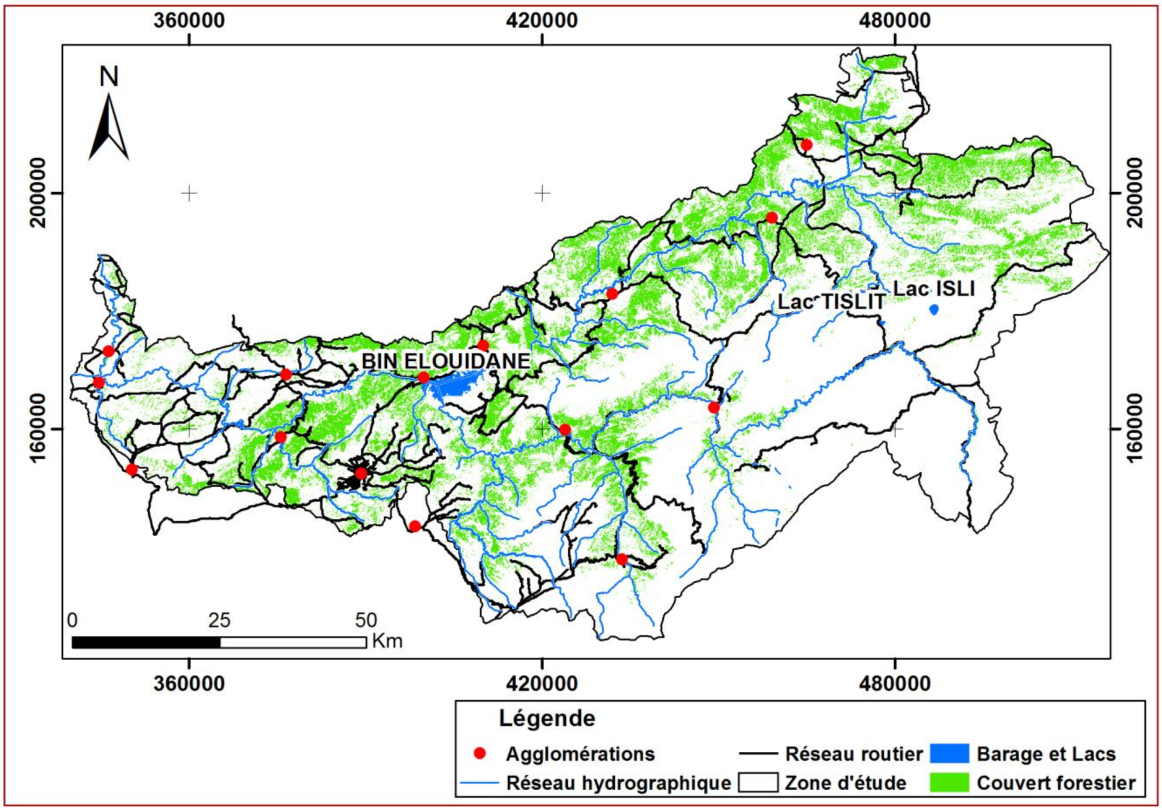

Figure 3: Roads, Hydrologic network, Land use and vegetation cover map as deduced from Landsat Oli 8 image of August 2015

Geological formations in the mountainous part of the region are generally made of limestone and mudstones. The geological formations in the piedmont and plain parts are made of Miocene, plioquaternary conglomerates, silts and sandy alluviums covering a thick Cretaceous and Jurassic limestone (Figure 4). A network of tectonic faults plays also a great role in geodynamic behavior of the region. This network can be observed along the region especially in the piedmont part but it is covered by recent soils in the plain.

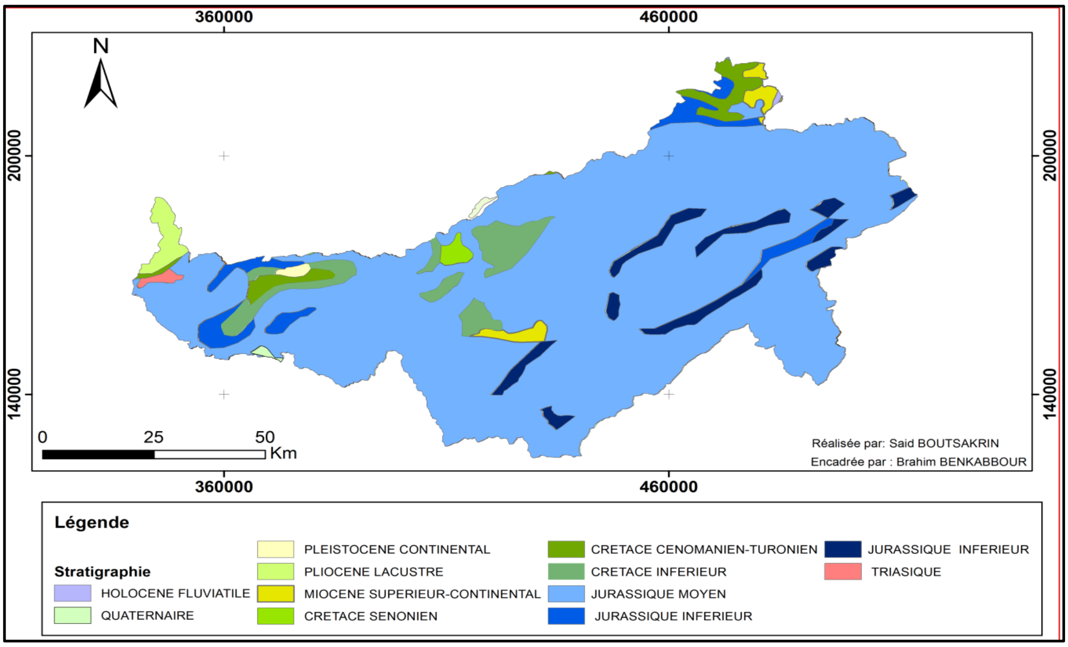

Figure 4: Geologic map of Oued Laâbid watershed dominated by Jurassic caronated rocks

The climate of this region is characterized by a mean annual rainfall of 432 mm for Tilouguite climatic station and 460 mm for Azilal climatic station. Unfortunately rainfall is badly distributed in time and gives birth many flush floods, mass movements, landslides…etc (Photos 1, 2, 3).

Methodology
The methodology followed during this study is as follows: First of all, satellites data and images are used to assess land cover and land use and its variation in time. Secondly, Digital Elevation Models (DEM) and classic topographic maps are also used to study the soil elevation, exposure and slopes. Geological maps are used to study the lithology, the friability and the petrography of rocks and soils. When the most vulnerable sites to landslides, mass movement and erosion are detected, they are hydrological analyzed and modeled by HEC-RAS code to assess and monitor risks of floods and inundations. Maps and tools used in this work can be detailed as follows:

- Landsat 8 Images with 30 m resolution of the date 08/2015 is used to study land cover. ENVI (Environment for Visualizing Images) code is used to make atmospheric and radio-metric corrections
- QGIS   elaborated by ESRI (Environmental Systems Research Institute) is used as a GIS environment to generate DEM and DAM and to analyses and generate all the maps needed for the study: Spatial Analyses, 3D Analyses…etc.
- A Digital Elevation Model with a resolution 90 m is a SRTM model (Shuttle Radar Topography Mission at http://srtm.csi.cgiar.org/)
- Many geological (1/100000 and topographic (1/50.000) maps were used
- HEC-RAS code is used for hydrological modeling and mapping of sites with high floods and inundation risks.
- Field and sites visits were programmed to acquire date and to verify the results


Photo 1


Photo 2


Photo 3


Photo 4

Data acquisition
Data used in this study can be summarized as follows:

Land cover and land use analysis

Those criteria have been deduced from Landsat 8 Satellite Images analysis. ENVI and ERDAS codes were used to analyses a LANDSAT Image of the date 08/2015. Many special geo-referencing, corrections and treatment were made. For correcting spatial resolution topographic maps (1/50000) were used. In those later maps many well referenced points are chosen as a reference to calibrate the Landsat image to less than one pixel error.
Land use and land cover has given the results in table 1 as follows:

Table 3: Land use statistics in Oued Laâbid watershed

Component	Area (Ha)	% of the total watershed area
Lacs and hydrographic network	3736.308043	0.005%
Buildings	1192.554884	0.002%
Végétation cover	179388.95	20.75%
Bare soil	680088.27	78.67%
Watershed total area	798500.28	100%

Those criteria have been summarized in four classes and for each class an index was given respecting the enhancement of erosion and mass movement. Table 2 summarizes those criteria as follows:

Table 2: Land occupation and cover and corresponding indexes.

Land use	Index
Very dense vegetation	1
Medium density vegetation	2
Agricultural lands	3
Bare soil	4

Soil and rocks friability

This parameter is deduced from 1/100000 geologic maps of the region. It was difficult to conclude about the friability just from those maps, then many on-sites analysis were required to estimate friability and to conclude about the reality of soil and rocks. Four classes of rocks taking into account their friability (Table 3).

Resistant rocks with index 1 of friability, rocks with medium resistance with index 2 of friability, Friable rocks with index 3 of friability and highly friable rocks with index four of friability. Friability means the degree of exposure of rocks to erosion, mass movement and landslides according to their petrography only.

Table 3: Rocks friability and corresponding indexs

Rocks Facies	Friability	Index
Lime stones	Résistent	1
Pedogenetic lime stone	Medium resistance	2
Mudstones, Sandstone, dolomite	Friable	3
Alluvium, clays, silts, recent soils	High Friability	4

Soil slopes

Soil slopes are deduced by the vectorisation of levels curves from topographic maps under a GIS environment. A slopes map has been produced and shown four slope classes that can be described as follows:

Table 4: Soil slopes classes and corresponding indexes

Soil Slope in Degrees	Index
0-5	1

5-15	2
15-35	3
35-80	4

Results

As it is previously mentioned the method used in this work consists in quantifying and weighting four parameters that influence mass movements, landslides and erosion: land cover and land use (Figure 3), rocks friability (Figure 5), rainfall distribution (Figure 6) and slopes distribution (Figure 7).

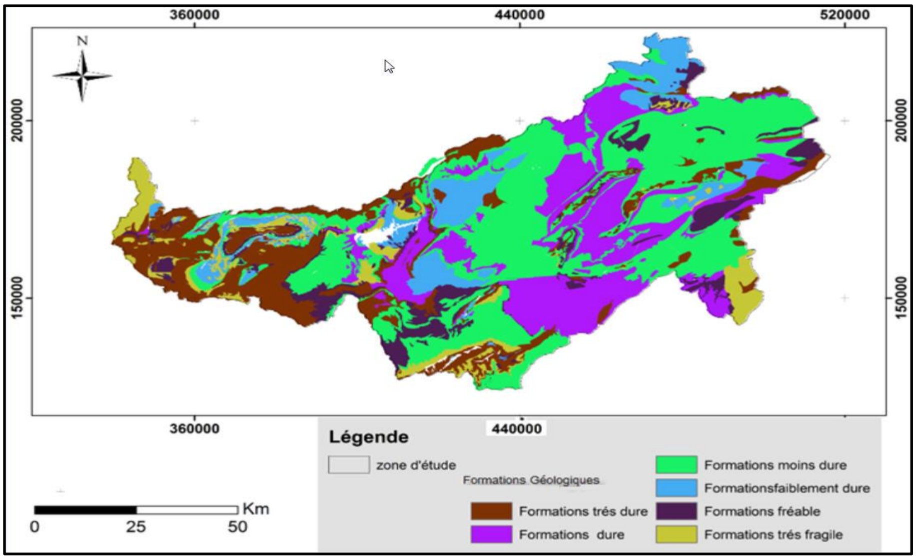

Figure 5: Rocks friabiliy map

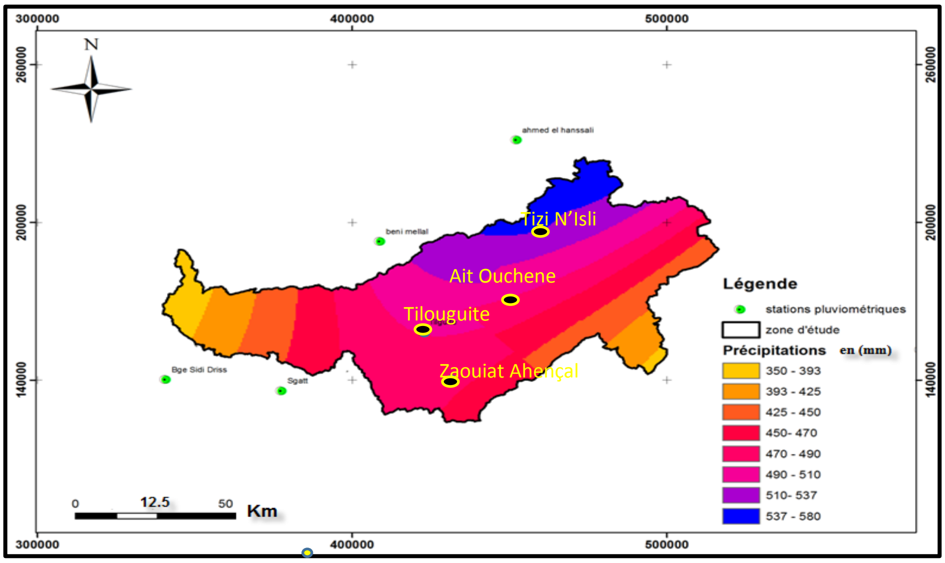

Figure 6: Rainfall distribution in Oued El Abid watershed

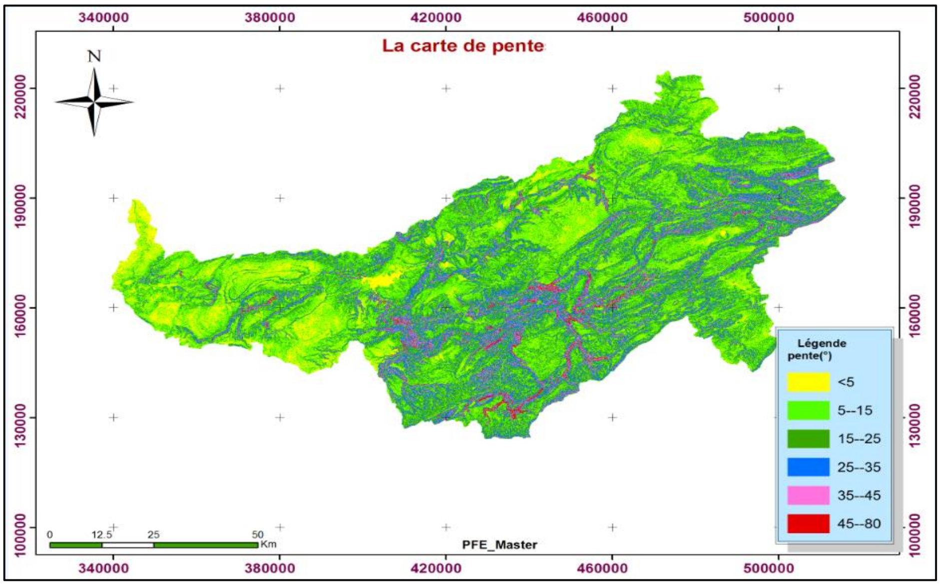

Figure 7: Slopes distribution map for Oued El Abid watershed

All maps and corresponding data are integrated in a QGIS environment and combined according to the weighting method called Analytical Hierarchy Processing (Cheng, 2001) and resulted in a thematic map of the total vulnerability to mass movement, landslides and erosion (Figure 8). This final map shows four degrees or classes of vulnerability: low vulnerability, medium vulnerability, high vulnerability and very high vulnerability. Low vulnerability zones are located down-stream of Bin El Ouidane Dam. The zones with high and very high vulnerability are located meanly along Oued Ahençal sub-watershed south east up-stream of Bin El Ouidane Dam (Figure). Those later zones are characterized by high slopes, bare soils and very friable rocks.

Discussions and prospects

This work has shown the high vulnerability zones are characterized high slopes, friable soils (clays, alluviums, silts …) with no forest or vegetation. Agricultural activities on soils with slopes of more than 10° can be considered as initiating and activating erosion, landslides and mass movement. Those high vulnerable sites are located at the south eastern part of the region up-stream of Bin El Ouidane Dam, precisely along Oued Ahançal River. Not only infrastructures and human properties and activities are threatened by the studied natural hazards but also the mean Dam of the region is threatened by increasing siltation ratio. Consequently, it is well advised for land manager of the region to think about solutions to reduce those hazards. For example, in those highly vulnerable sites at the intersections between roads and rivers (Figure 9) one can suggest the construction of strongest road crossing bridges, reforestation and forest protection, construction of supporting walls. For those highly vulnerable sites in rural and agricultural areas or where buildings are neighboring hydrographic network (Figure 10) it can be suggested to forbid construction in the immediate water stream flow and to forbid any agricultural activities on soils with more than 10° slopes.

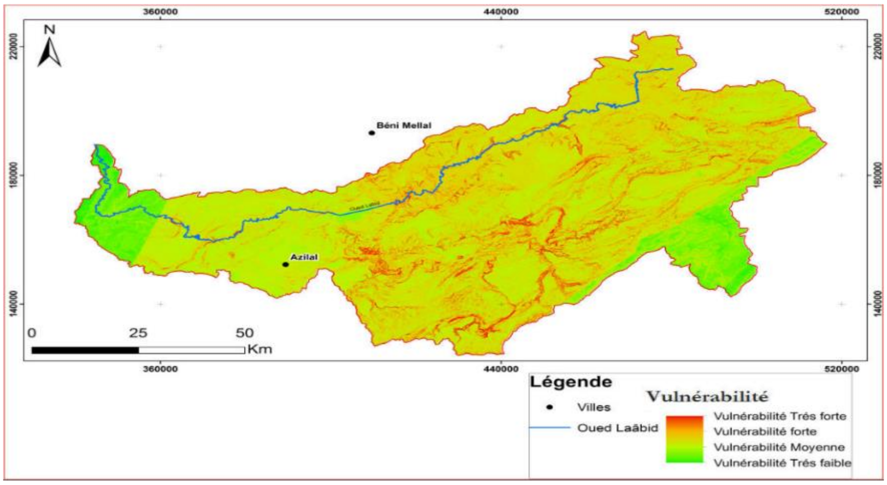

Figure 8: Vulnerability to mass movements, landslides and erosion

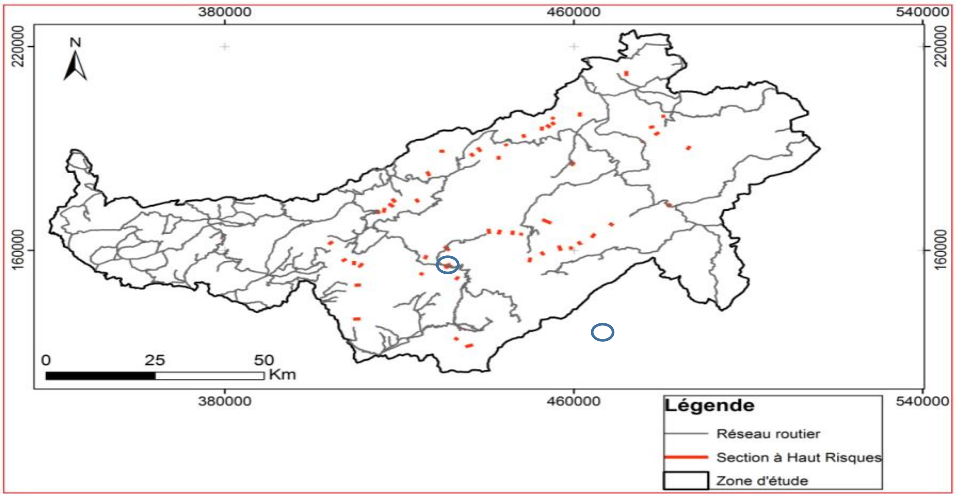

Figure 9: Sections at the intersections between roads network and hydrographic network where the vulnerability is the highest

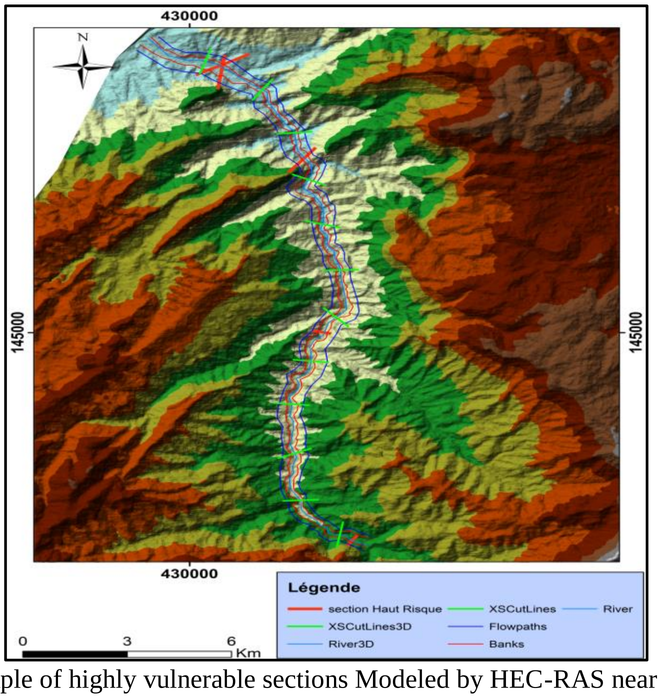

Figure 10: example of highly vulnerable sections Modeled by HEC-RAS near Tilguite village

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Runoff Collection Potential in Abha, Saudi Arabia: An Analysis with Watershed Modelling System Software

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Abstract
In Saudi Arabia, 449 dams with 2017 million cubic meters (MCM) capacity were constructed to control floods, recharge aquifers, and supply for domestic and agricultural uses. However, the country often experiences flash floods in the central and southwestern regions, due to heavy rainfall. In this study, location of a new dam was identified in Abha, Saudi Arabia using the Watershed Modeling System (WMS) software. The WMS software and HEC-HMS hydrologic model were used to delineate watershed and quantify surface runoff. Fuzzy rule based modelling was applied to incorporate uncertainty. This study demonstrates that the rainfall events with 25, 50 and 100-years return periods may generate 3.6 (range: 0.12–15.4), 5.5 (range: 0.4–19.5) and 7.7 (range: 0.8–24.6) MCM surface runoff respectively. Appropriate use of this runoff can save US$ 0.2–28.3, US$ 0.7–35.9 and US$ 1.4–45.3 million respectively. Such a use of runoff can reduce CO_2 emissions by 1.8–231, 6–292.5 and 11.6–369 million kg respectively through reducing the production of desalinated water.

Keywords: Dam Location, Runoff Collection, Runoff Use, Cost Saving, CO_2 Reduction, Uncertainty Analysis.

1. Introduction

Saudi Arabia is a semi-arid country with low annual rainfall. About 90% of the country is covered with deserts and plain lands (Al-Yamani and Zekai, 1993). The population is about 30 million, which is growing at the rate of 2.6%/year (SSYB, 2014). In 2009, total water demand was 18500 million cubic meters (MCM), in which 84% was used for agriculture. The total water demand was reduced to 16300 MCM in 2014, due mainly to the reduction of agricultural water demand (MOEP, 2010; MOWE, 2014). During this period, domestic and industrial water demands were increased by 2.1% and 5.5%/year respectively (MOEP, 2010).

The water demands are satisfied by the groundwater, surface water, desalinated water and treated wastewater sources. The contributions from non-renewable ground water (NGW), surface and renewable groundwater (RGW), desalinated water (DW) and treated wastewater (TWW) sources were approximately 55%, 28.5%, 12.7% and 3.8% respectively (MOEP, 2010). Past studies have reported limited reserves of groundwater sources. In the 1980s, the proven, probable and possible reserves of non-renewable groundwater was estimated to be 353, 405 and 705 billion cubic meters (BCM) respectively (MAW, 1984; FAO, 2009). Significant fraction of this water might have been used in the past (FAO, 1998). There is no natural surface water system in the country. The rainwater is stored as the sources of surface water (SW). The long-term average annual rainfall in the country was estimated to be less than 100 mm (FAO, 2009). However, in the southwestern region, up to 500 mm/year of rainfall is not uncommon (FAO, 2009), which is the main contributor of runoff. Approximately 60% of the total runoff occurs in western region, while the remaining 40% occurs in the extreme south of the western coast (FAO, 2009). The total runoff was estimated to be 2.2 BCM/year, part of which recharges the shallow aquifers while significant fraction is evaporated (FAO, 2009). The country produced approximately 1600 MCM of desalinated water in 2014, which satisfied more than 60% of the domestic water demand (MOWE, 2014; SWCC, 2016). The Saline Water Conversion Corporation (SWCC) produced about1108 MCM of desalinated water and the remaining was produced by the private plants (SWCC, 2014; MOWE, 2014). The country has started reusing TWW (MOEP, 2010). A total of 81 sewage treatment plants with capacity of 1730 MCM/yr treat domestic wastewater (MOWE, 2013). However, 1260 MCM of wastewater was treated while only 325 MCM TWW was recycled for reuse (MOEP, 2010).

The data indicate that augmentation of water sources is essential for Saudi Arabia. Collection of runoff may provide significant support toward this direction. There are several approaches of runoff collection. Infiltration is the natural way of recharge into the groundwater aquifers. In Saudi Arabia, a total of 449 dams with the capacity of approximately 2017 MCM (MOWE, 2013) are available to collect, store and recharge aquifers and to control floods. In the southwestern region, there are 126 dams with capacity of 760 MCM (MOWE, 2013). Despite the large number of dams, frequent flash floods in the southwestern region indicate the needs for additional dams (Al-Zahrani *et al.*, 2015). Al-Zahrani *et al.*, (2015) demonstrated the loss of significant amount of runoff in this region, due mainly to inadequate capacities, locations and lack of maintenance of the dams. Further, the silt and clay carried by runoff is deposited at the bottom of stagnant water (Missimer et al., 2014). Moreover, up to 80% of the stored water could be lost through evaporation from free surface (Missimer et al., 2014). Immediate recharge following the runoff collection can be one option (Al-Othman, 2011).

Past studies have modelled floods in Saudi Arabia using the WMS software (Ewea, 2010; Sharif *et al.*, 2014; Al-Shareef *et al.*, 2013). The HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) hydrologic model was used in the main channel of Wadi Fatimah watershed in the western Saudi Arabia to monitor hydrologic responses through dividing the watershed into seven sub-basins (Al-Yamani, 2004). The rainfall return periods were 10, 25, 50 and 100 years and rainfall durations was 1 hour. Flood simulations were performed using the WMS software for several return periods in the Almisk Lake stretched along the Wadi Bani Malek in Jeddah. The HEC-HMS software was employed to compute the peak flow (Ewea, 2010). Another study evaluated flash flood hazard in the Wadi Qanunah basin, which is located in the southwestern coast of Makkah, Saudi Arabia. The basin was divided into 13 sub-basins using WMS software. The HEC-HMS software was used to generate hydrographs for two sub-basins of Wadi Qanunah. The rainfall events with return periods of 5, 10, 25, 50 and 100 years were considered. Total volume of discharge in the Wadi Qanunah sub-basins were in the ranges of 66 - 138 MCM (Masoud, 2016).

In this study, WMS software was used to identify the watershed and the dam location in Abha, Saudi Arabia. The HEC-HMS model was used to quantify the runoff and hydrograph. The rainfall events with 25, 50 and 100 years of return periods were considered. The uncertainty was incorporated through varying input parameters in the fuzzy rule based modeling system. Overall water collection potential, cost savings and the reduction of CO_2 emission in comparison to the use of desalinated water were estimated.

2. Methodology

2.1 Study Area

The southwestern region of Saudi Arabia is mountainous, relatively high in elevation and experiences the maximum yearly rainfall (FAO, 2009). The Abha area is the capital of Asir province. The rainfall in this area is influenced by the subtropical and orographic conditions (Subyani, 2004). The weather is influenced by the southeastern moist air and it receives the maximum rainfall through half of the year, due possibly to increase of rainfall in leeward side of the mountain (Al-Zahrani *et al.*, 2015). The annual average rainfall in Abha is 215.3 mm (Furl *et al.*, 2014). The highest rainfall occurs during Mar-May and July-August (Al-Zahrani *et al.*, 2015). There is an existing dam at the west side of Abha (e.g., Abha Dam) (Figure 1), which has the capacity of storing 213 MCM of water (Al-Zahrani *et al.*, 2015). This water is used as the main source of drinking water for the city (Al-Zahrani, 2009).

Figure 1: Location of study area with existing and suggested dam site.

2.2 Data Collection

2.2.1 Rainfall data

Using the historical rainfall data from 1985-2009, Areeq *et al.* (2016) developed the IDF curves for Abha and four other areas (Khamis-Mushait, Bisha, Al- Baha and Gizan) in the southwestern region of Saudi Arabia with return periods of 2, 5, 10, 25, 50 and 100 years respectively. The IDF curves were developed using different methods of daily rainfall depth conversion, and a range of rainfall depth was obtained for each return period. Table 1 shows the rainfall variability for different methods of daily rainfall data conversion. The ranges of rainfall depths in different return periods allow the prediction of surface runoff with rainfall variability. As such, uncertainty related to rainfall depth is incorporated. In this study, the SCS (Soil Conservation Service) Hypothetical Storm - Type II are used to represent the storm pattern in the arid/semi-arid regions (USDA, 1986).

Table 1: Rainfall intensities (mm/hr) for different durations (T_d) at various return periods (T_r)

T_r / T_d (minute)	2 years		5 years		10 years		25 years		50 years		100 years	
	min	max	min	max	min	max	min	max	min	max	min	max
10	45.5	75	79.6	131.4	102.3	168.8	130.9	215.9	152.1	250.9	173.2	285.7
30	25.8	42.4	45.1	74.3	58	95.5	74.2	122.2	86.2	142	98.1	161.6
60	16.7	25.8	29.2	45.1	37.5	58	48	74.2	55.8	86.2	63.5	98.1
120	10.8	15	18.9	26.2	24.3	33.7	31.1	43.1	36.1	50.1	41.1	57

2.2.2 DEM data

The Digital Elevation Model (DEM) data were obtained from the Shuttle Radar Topography Mission (SRTM) Worldwide Elevation database as 3 arc second, with approximate resolution of 90 meter in the equator, which is provided in mosaiced 5º×5º tiles. The SRTM Digital Elevation database was developed by the National Aeronautics and Space Administration (NASA).

2.2.3 Soil type and land use data

The soil type data were obtained from the Harmonized World Soil database (version 1.1). The soil was classified into four groups depending on infiltration characteristics or runoff potential

(FAO, 2009; IIASA, 2009). The classifications are Hydrologic soil group A, B, C and D with the highest to lowest infiltration capacities respectively. The land use pattern data were obtained from the Global Land Cover database using the WMS software.

2.3 Software Use

The WMS software was used to delineate the catchment area. WMS is widely used in delineating watershed and computing hydrologic parameters, such as, CN (Curve Number), lag time, time of concentration, etc. (Aquaveo, 2016a). WMS includes several hydrologic and hydraulic models, including the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). WMS software works through the following steps: delineating the watershed, single/multiple basin analysis by selecting a specific model, computing the curve number using land use and soil data and computing lag time. Further details on the software can be found in literature (HEC-HMS, 2000).

2.3.1 Computation

2.3.1.1 Delineating basin

The watershed was delineated using the Topographic Parameterization Program (TOPAZ) function. TOPAZ processes the DEM data, and delineate and order the basins and streams. It assumes that all depressions in DEM are function of poor resolutions (Aquaveo, 2016b).

2.3.1.2 Curve number, lag time and runoff computation

The Soil Conservation Service (SCS) method, developed by the United States Department of Agriculture (USDA), Natural Resources Conservation Service has been used in this study. The SCS method needs the Curve Number (CN) for estimating runoff from rainfall excess (USDA, 1986). The CN varies in the range of 30 - 100, where lower CN indicates high soil permeability and low runoff potential while the higher CN indicates high runoff potential. The Technical report (TR-55) of SCS method contains the detailed classifications for the CN (USDA, 1986). CN is computed as a function of soil type, land use and existing soil moisture. The watershed is unlikely to be in uniform condition, which warrants the composite CN. This was computed using these TR – 55. The lag time is calculated using the SCS method. The surface runoff was calculated in HEC-HMS software

2.4 Uncertainty Analysis

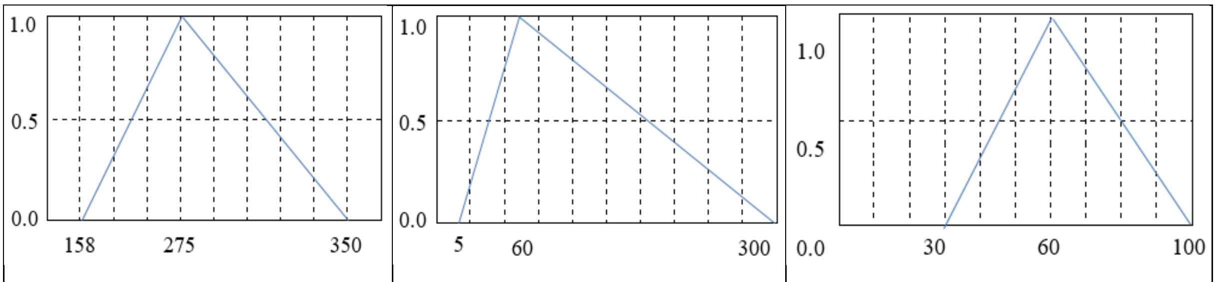
The input data and model parameters are likely to have uncertainty, which deserves further attention. In this study, uncertainty associated with rainfall depth, rainfall duration and CN were incorporated through their ranges. These ranges were used as input parameters and the runoff were estimated. The fuzzy set theory was used to evaluate the scenarios of rainfall-runoff relationships. The fuzzy rule-based modeling technique was employed. The fuzzy rule approaches with the *if-then* logic. *If* is used for representing antecedents while, *then* is for the consequences. Fuzzy data are aggregated through *if-then* logic by the linguistic model as:

$Rule_i\!: If\ a\ is\ A_i\ then\ b\ is\ B_i;$ (1)

Where, 'a' and 'b' are input and output variables, respectively; A_i and B_i are qualitatively defined function for 'a' and 'b', respectively. For multiple input parameters with single output, fuzzy rule is expressed as:

$Rule_i\!: If\ a_1\ is\ A_{1i}\ and\ a_2\ is\ A_{2i}\ and\ a_3\ is\ A_{3i}\ then\ b\ is\ B_i;$ (2)

The parameters A_i and B_i are fuzzy data, which are obtained after fulfilling the predefined conditions, such as poor, moderate and severe. The linguistic model is formed with $Rule_i$ and sets of A and B. The fuzzy relation is formed from each rule; thus $Rule_i$ $(X \times Y) \rightarrow [0, 1]$. Using conjunction (minimum operator) and disjunction (maximum operator) functions, individual fuzzy relation is computed. Figure 2 depicts input variables for predicting runoff.



(a). Rainfall depth (mm/year). (b). Rainfall duration (minute). (c). Curve number.

Figure 2: Fuzzy input variables for runoff estimation.

The parameters are characterized by minimum, most likely and maximum values for a triangular fuzzy number [TFN]. The most likely values for rainfall depth (Figure 2a), rainfall duration (Figure 2b) and Curve Number (Figure 2c) were assigned the membership grade of unity. A total number of $3^3 = 27$ rules were generated using all possibilities.

2.5. Analysis

2.5.1. Selecting dam location

The watershed in Abha area was located using the Earth Map Locator in WMS software. A suitable location for dam was selected by trial and error using Google Earth Pro along with WMS software (Figure 3). Figure 3 shows the locations of the existing dam (A) and the proposed dam (B). The overall area of the watershed was estimated to be 290 Km^2.

Figure 3: Tentative location of dam; using Google Earth & WMS.

2.5.2. Computation

2.5.2.1. Computing flow data and delineating basin

The flow direction was computed and the thalweg was accumulated using the DEM data. Thalweg is the connecting line of the deepest points over a river or a valley (NWS, 2016). The thalweg in a valley acts as stream during rainfall. After that, an outlet point was selected on the accumulated streamlines (Figure 3). The selected outlet was checked whether it was in the wadies using the wadi lines in the Google Earth File (as KMZ file). The WMS software delineated the watershed into a basin of 290 km^2 area.

2.5.2.2. Curve number and lag time computation
To compute CN for the watershed area, it is divided into 10 sub-basins using one outlet in each basin. Using the land use pattern and soil type shape files, WMS software computes CN for each sub-basin (Figure 4). The CN for all sub-basins are tabulated in Table 2. Using these CN values, the composite CN was calculated as:

$$\Rightarrow \mathrm{CN}_{\text{composite}} = \frac{19572}{290} = 67$$

The most likely CN is assumed to be 65, which is fairly consistent to the calculated value and the minimum and maximum CN were assumed to be 50 and 80 respectively. The lag time was calculated to be 6.51 hours.

2.2.1 Rainfall data input

The precipitation method was selected as SCS Hypothetical Storm - Type II, which is representative to the semi-arid regions (UPMD, 2016). Precipitation data from Table 1 was used for 25, 50 and 100 years return periods. The maximum precipitation depth was observed for 2 hours rainfall. The values for 25, 50 and 100-years rainfall events were 86.2 mm, 100.2 mm and 114 mm respectively. For each rainfall depth, 20% variability was considered to incorporate uncertainty in the rainfall depths. This value is somewhat arbitrary. With availability of reliable data, the minimum and maximum values can be obtained (Table 3).

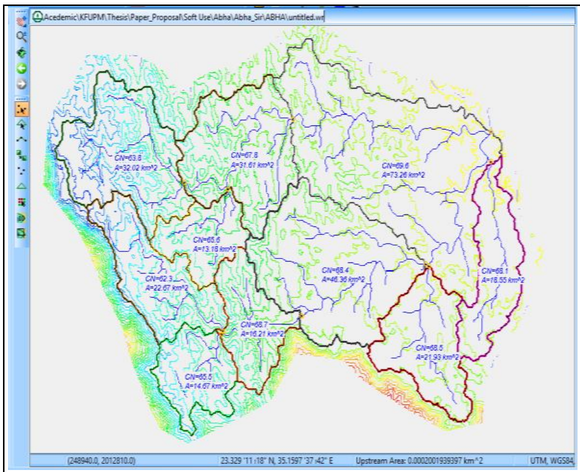


Figure 4: Computed curve numbers for 10 sub-basins.

Table 2: Calculating composite CN.

Basin no.	Area, Ai (km^2)	CN_i value	A_i*CN_i
12B	31.61	67.79	2142.59
13B	13.18	65.59	864.65
14B	32.02	63.77	2042.20
15B	73.26	69.61	5099.80
16B	18.55	68.13	1263.51
17B	46.36	68.39	3170.73
18B	21.93	68.53	1502.62
19B	16.21	68.70	1113.64
20B	14.67	65.52	960.92
21B	22.67	62.28	1412.21
∑	290		19572

Table 3: Rainfall depth (mm) at different return periods (T_r).

Return periods T_r	25 years	50 years	100 years
Minimum	69	80	90
Most likely	86	100	115
Maximum	103	120	140

3. Results and discussion

The delineated basin file, obtained from the WMS software was opened in the HEC-HMS (Version 3.5) software for simulating runoff with varying parameters. For 100-year return period having rainfall depth of 115 mm, the CN value of 65 and for the simulation duration of 48 hour, the peak discharge was estimated to be 231.2 cumec. The runoff volume was found 9.9 MCM and the lag time was more than 6 hours (Figure 5). Variation of runoff volume for other return periods and for different parameters are presented in Tables 4-6.

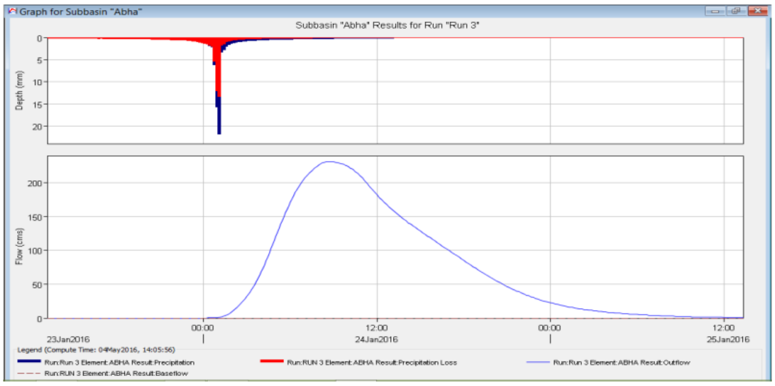


Figure 5: Hydrograph for 100-year return period.

The maximum runoff volume for 25-year return period was estimated to be of 15.36 MCM, which was observed for 103 mm rainfall in 48 hours with the CN value of 80. The minimum runoff volume was estimated to be 0.124 MCM for 69 mm rainfall in 24 hours with the CN value of 50. For 69 mm of rainfall depth, the runoff volume was estimated to be in the range of 0.124 – 7.66 MCM, with an average of 1.57 MCM. For 86 mm of rainfall depth, this range was 0.61 – 11.38 MCM, with an average of 3.47 MCM. For 103 mm of rainfall depth, the runoff volume range was estimated in the range of 1.42 – 15.36 MCM, with an average of 5.75 MCM.

Table 4: Runoff variations in Abha for 25 year return period.
4a: A total of 27 combinations for parameters and runoff

Rule (R_i)	*If*	Rainfall depth (mm)	and	Rainfall duration (hour)	and	Curve number	*then*	Runoff volume (mcm)
R1	*If*	69	and	24	and	50	*then*	0.124
R2	*If*	69	and	24	and	65	*then*	1.69
…								
….								
…..								
R26	*If*	103	and	48	and	65	*then*	7.8
R27	*If*	103	and	48	and	80	*then*	15.36

Table 4b: Variation of runoff for different curve numbers.

Curve number	Runoff volume (mcm) Low	Geo. mean	High
50	0.124 (R_1)	0.79	2.58 (R_{25})
65	1.69 (R_2)	4.09	7.8 (R_{26})
80	5.2 (R_3)	9.68	15.36 (R_{27})

Table 4c: Variation of runoff for different rainfall depth.

Rainfall (mm)	Runoff volume (mcm) Low	Geo. mean	High
69	0.124 (R_1)	1.57	7.66 (R_9)
86	0.61 (R_{10})	3.47	11.38 (R_{18})
103	1.42 (R_{19})	5.75	15.36 (R_{27})

Table 5: Runoff variations in Abha for 50 year return period.
5a: A total of 27 combinations for parameters and runoff

Rule (R_i)	*If*	Rainfall depth (mm)	and	Rainfall duration (hour)	and	Curve number	*then*	Runoff volume (mcm)
R_1	*If*	80	and	24	and	50	*then*	0.4
R_2	*If*	80	and	24	and	65	*then*	2.63
….								
…..								
R_{26}	*If*	120	and	48	and	65	*then*	10.84
R_{27}	*If*	120	and	48	and	80	*then*	19.53

Table 5b: Variation of runoff for different curve numbers.			
Curve number	Runoff volume (mcm)		
	Low	Geo. mean	High
50	0.4 (R_1)	1.64	4.29 (R_{25})
65	2.63 (R_2)	5.95	10.84 (R_{26})
80	6.9 (R_3)	12.53	19.53 (R_{27})

Table 5c: Variation of runoff for different rainfall depth.			
Rainfall (mm)	Runoff volume (mcm)		
	Low	Geo. mean	High
80	0.4 (R_1)	2.76	10.03 (R_9)
100	1.26 (R_{10})	5.32	14.64 (R_{18})
120	2.52 (R_{19})	8.33	19.53 (R_{27})

The maximum runoff volume for 50-year return period was estimated to be of 19.53 MCM, which was observed for 120 mm rainfall in 48 hours with the CN value of 80. The minimum runoff volume was estimated to be 0.4 MCM for 80 mm rainfall in 24 hours with the CN value of 50. For 80 mm rainfall depth, the runoff volume was estimated to be in the range of 0.4 – 10.03 MCM, with an average of 2.76 MCM. For 100 mm of rainfall depth, this range was 1.26 – 14.64 MCM, with an average of 5.32 MCM. For 120 mm of rainfall depth, the runoff volume range was estimated in the range of 2.52 – 19.53 MCM, with an average of 8.33 MCM. The maximum runoff volume for 100-year return period was estimated to be of 24.6 MCM, which was observed for 140 mm rainfall in 48 hours with the CN value of 80. The minimum runoff volume was estimated to be 0.77 MCM for 90 mm rainfall in 24 hours with the CN value of 50. For 90 mm of rainfall depth, the runoff volume was estimated to be in the range of 0.77 – 12.29 MCM, with an average of 3.98 MCM. For 115 mm of rainfall depth, this range was 2.17 – 18.29 MCM, with an average of 7.54 MCM. For 140 mm of rainfall depth, the runoff volume range was estimated in the range of 4.1 – 24.6 MCM, with an average of 11.67 MCM.

Table 6: Runoff variations in Abha for 100 year return period.
6a: A total of 27 combinations for parameters and runoff

Rule (R_i)	If	Rainfall depth (mm)	and	Rainfall duration (hour)	and	Curve number	then	Runoff volume (mcm)
R_1	If	90	and	24	and	50	then	0.772
R_2	If	90	and	24	and	65	then	3.625
….								
R_{26}	If	140	and	48	and	65	then	14.74
R_{27}	If	140	and	48	and	80	then	24.6

Table 6b: Variation of runoff for different curve numbers.			
Curve number	Runoff volume (mcm)		
	Low	Geo. mean	High
50	0.77 (R_1)	2.76	6.71 (R_{25})
65	3.63 (R_2)	8.11	14.74 (R_{26})
80	8.54 (R_3)	15.66	24.6 (R_{27})

Table 6c: Variation of runoff for different rainfall depth.			
Rainfall (mm)	Runoff volume (mcm)		
	Low	Geo. mean	High
90	0.77 (R_1)	3.98	12.29 (R_9)
115	2.17 (R_{10})	7.54	18.29 (R_{18})
140	4.12 (R_{19})	11.67	24.6 (R_{27})

For 25, 50 and 100-years return period, the output location can have 0.124 – 15.36 MCM, 0.4 – 19.53 MCM and 0.77 – 24.6 MCM of runoff, respectively depending on the rainfall depth, duration and CN values. The three return periods render a range of 0.124 – 24.6 MCM of water. Appropriate use of this water can save cost and reduce carbon emissions into the environment. Use of one m^3 of desalinated water needs approximately US$ 1.84, meaning that similar amounts of desalinated water needs US$ 0.23 – 45.26 million. Further, in producing 1 m^3 of desalinated water, the plants emit 15 kg of CO_2 to the environment (average). Use of the estimated amount of surface runoff can reduce CO_2 emissions by 1.86 – 369 million kg.

3.1 Comparison of cost savings with desalination process

Saudi Arabia produces approximately 4.44 MCM of desalinated water per day (SWCC, 2014; MOWE, 2014). The SWCC produces 3.07 MCM of desalinated water per day, which is 69% of the country's total desalinated water (SWCC, 2016). Desalinated water is costlier than the groundwater sourced supplies (SSWM, 2010). The cost of desalinated water depends on several factors, including; process cost, transportation cost and maintenance cost. Three common processes (reverse osmosis (RO), Multi-effect distillation (MED) and Multi-stage flash (MSF)) are typically used for desalinating seawater in Saudi Arabia. The MSF processes are mostly used (62%), followed by the RO processes (22%) (ECRA, 2014). The overall cost of using 1.0 m^3 of desalinated water varies in the ranges of US$ 1.31 - 2.37 with the most likely vale of US$ 1.84 (Chowdhury and Al-Zahrani, 2013). In contrast, the cost of artificial recharge for 1 m^3 of water into groundwater aquifer is around US$ 0.12 (Kalantari et al., 2010), and the total cost of groundwater extraction and supply is approximately US$ 0.49 per m^3 of water (Chowdhury and Al-Zahrani, 2013). Through considering the fixed cost and maintenance, the total cost becomes approximately US$ 0.61 per m^3 of water. The above information infers, replacement of 1 m^3 of desalinated water by 1 m^3 of runoff water can save 1.23 US$ and for the present study the range of cost saving becomes US$ 0.15 – 30.26 million.

3.2 Carbon emission from desalination plants

During desalination, carbon dioxide is emitted. Whenever desalination process is preceded by electricity generation (as cogeneration), a fraction of CO_2 emission is excluded from the total CO_2 in the cogeneration process. Table 7 presents the summary of CO_2 emissions from desalination plants. It shows that the CO_2 release varies in the range of 3.4 – 25 kg/m^3 with the most likely vale of 15 kg/m^3 of desalinated water. The surface runoff can be used to substitute the costly desalinated water, which can reduce the cost of water uses and lower CO_2 emissions into the environment.

Table 7: CO_2 emissions for different methods desalination [Source: Banat and Qiblawey (2006); Darwish (2006); ESCWA (2009)].

Desalination methods	CO_2 (kg) in producing 1.0 m^3 of desalinated water
Multi-stage flash (MSF)	20.4-25.0
Multi-stage flash cogeneration (MSFcogen)	13.9-15.6
Multiple-effect distillation (MED)	11.8-17.6
Multiple-effect distillation cogeneration (MEDcogen)	8.2-8.9
Reverse osmosis (RO)	3.4-6.0

4. Conclusion

This study estimated the runoff potential from the rainfall events in Abha, Saudi Arabia. Despite the availability of one large dam in Abha, it appears to be inadequate to collect the entire amount of runoff generated during the rainfall events with different return periods. A comparative study was performed using different combinations of rainfall intensities, durations and curve numbers. This study demonstrates that additional amounts of runoff can be collected through creating new dam in Abha, which can also reduce the probability of flash floods and intensity of property damage. Future study may further investigate the cost and feasibility of creating a dam in this location.

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Flood Forecasting of Medjerda River in the Context of Water Resource Management of Tunisia

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Abstract
In Tunisia, the control of surface water lies within what can broadly be described as a water resource management framework, which may encompass conservation and enhancement of the aquatic environment, ecology and nature conservation, water supply, water quantity, water quality, and surface water collection, treatment and disposal. In addition, it notes some of the broad linkages between surface water management systems and those of spatial planning and flood risk management, where relevant. The available water resources in Tunisia are mostly concentrated in the north, particularly in the Basin of Medjerda River, representing approximately 80% of total surface water resources while it covers 10% of the national territory. Wadi Medjerda originates from the Atlas Mountains of eastern Algeria, cross Northern city of Tunisia to flow in the Mediterranean Sea. Its watershed covers 24,000 km^2 which 2/3 is in Tunisia. It extends for 460 km including 350 in Tunisia. Since 1973, Wadi Medjerda has been subjected to periods of intense floods that have been devastating on both sides of the river and submerging villages including Boussalem region in the governorate of Jendouba and many other areas around Medjerda Wadi. Given the high speeds and sharp, dams such as Sidi Salem (downstream of Bousalem) and Mellegue (flow in Bousalem) required flood of releases volumes of up to 750 m^3/s causing an overflow of the river beds of which was accompanied by the large volumes transport of sediments along the river bed thus contributing to increased flooding. Faced to flood risk, a system of flood management is created and will be implanted in the two Tunisian Directions of Water Resources and Majors Dams. This system needs an efficient model in order to get a real time flow forecast. In this context a research is realized which its results are presented in this paper. So that a platform is created with Matlab for flow forecasting based in two propagation model: Muskingum and Regression. In fact for a big river like Medjerda which is heterogeneous in its land use and soil texture, the suitable models for flow forecasting are the propagation models. Those models require only the discharges in the upstream and downstream stations. The area interested in our research is the plain of Bousalem that is the most touched by Medjerda inundation. The stream is divided in two sections which are limited by gauging stations. The calculation delay varied from 2 to 8 hours with a pitch of 2. The created platform announces the flood status; alert or overflow in each station based on the peak discharge.

Keywords: Tunisia, Medjerda River, Flood Risk, Forecasting, Propagation Model.

Introduction
Water scarcity has long been a challenge in the North Africa region, but climate change combined with rapid urbanization has made the problem even more acute. A growing urban population, along with demands from industry and agriculture, has put immense pressure on Tunisia’s water resources. In fact, Tunisia is characterized by a space and time variability of water resources. That does belong to its climate type which is Mediterranean in the north and Saharan in the south. The precipitation varied from 50 mm in the south to 1500 mm in the extreme north.

Tunisia is a country lacking in water resources that is distributed unequal from the North to the South (Figure 1). The potential volume of available water, 4,864 million m^3 per year, is less than 500 m^3 per inhabitant per year.

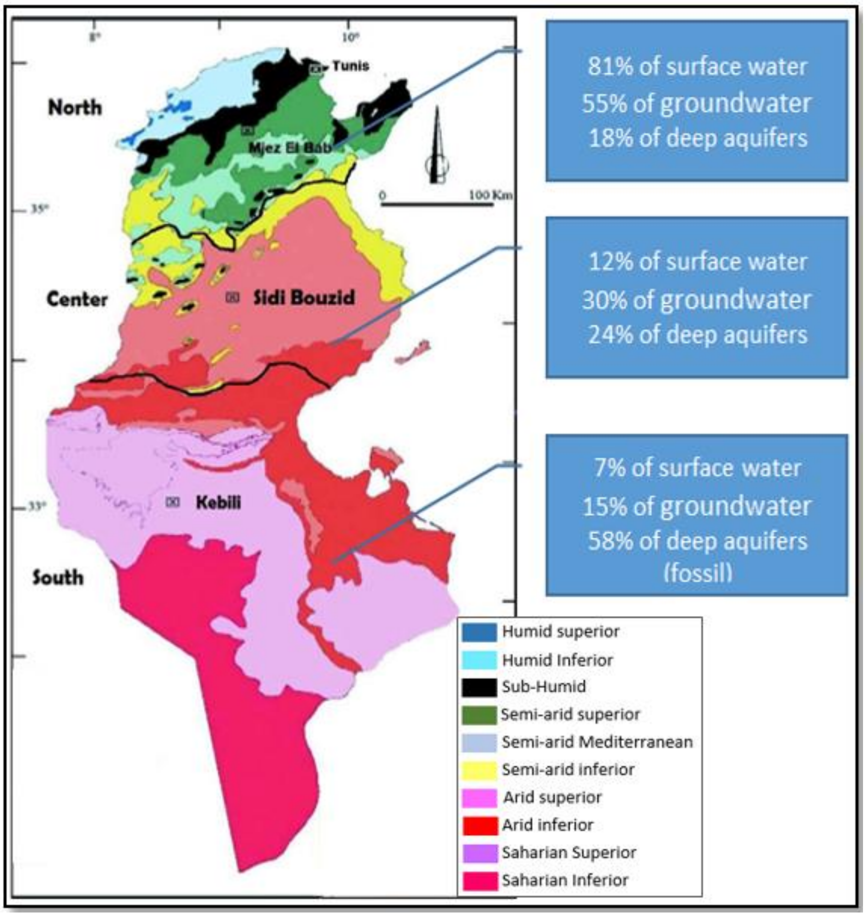


Figure 1: Distribution of water resources in Tunisia

Tunisia's economy is based on Agriculture field as the first level after the industry. So that the demand of water for Agriculture is higher 82% of Tunisia's water resources (Figure 2).

The flood risk management strategy adopted must meet present needs whilst providing an adjustment path to the future.

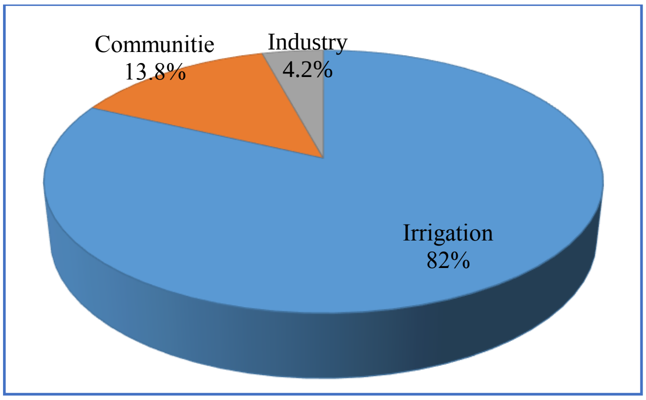


Figure 2: Water uses in Tunisia

Channel flooding is a complex dynamic process characterized by spatial and temporal variation in the flow parameters. Generally, information on water levels is collected at critical locations, as well as at existing stream gauging stations, for analyzing flood movement. Development of flood forecasting model characteristics based on only an observed stage is a difficult task because of recharge over the reach, spatial variability of rainfall, and varying channel characteristics influence river flow in a highly nonlinear manner. These issues become more complicated for large river systems, thus, requiring detailed distributed information for routing the flood along the river reach. Deterministic flood forecasting models can be divided into two general categories: flood routing models and real-time rainfall– runoff models. Models of flood routing are varied; there are a big number of algorithms from simple statistical receipt to the partial differential equations of SaintVenant (Bentura, 1996). The Muskingum model is numerically equivalent to the Saint-Venant equations via the diffusion equation of a wave. It is a classical flood routing method. However, the representation of lateral inflow contributions, as well as the discharge forecasting at the outlets of upstream sub-catchments cause problems. Muskingum model is improved to incorporate multiple sources of inflows and single outflow to route the flood in the reach. In Tunisia, the flood problem arises the only perennial river, Medjerda, in particularly the reach of Ghardimaou-Jendouba-Bou Salem. Muskingum model was applied to reconstitute flood hydrographs of the main stations of Medjerda River in the upstream Sidi Salem dam and the results were satisfactory (Abidi, 2011). In this paper, Muskingum model will be used for flood forecasting using the results of flow reconstitution. The consideration of lateral flow in the hydrograph reconstitution ameliorated the results (Abidi, 2014). Lateral flow will be considered in the upstream discharge for the forecasting. The first part of the paper presents the models and the performance criteria, the second section illustrates the study area and in the third part the results are presented.

Study area

The Medjerda, the major Tunisian river, originates in the semi-arid Atlas Mountains of eastern Algeria. In Tunisia, the western part of the catchment is delimited by the south facing slopes of the Tell region and in particular the Kroumir Mountains, and at the south by the north facing slopes and piedmonts of the semi-arid Dorsal Mountains. The river then flows east, through the tectonic depression of the Ghardimaou basin, characterized by an 8–10 m thick Holocene floodplain sediments. The Medjerda catchment covers approximately 24,000 km², of which 16,100 km² located in Tunisia and extends for 460 km including 350 in Tunisia (Zielhofer, 2002).

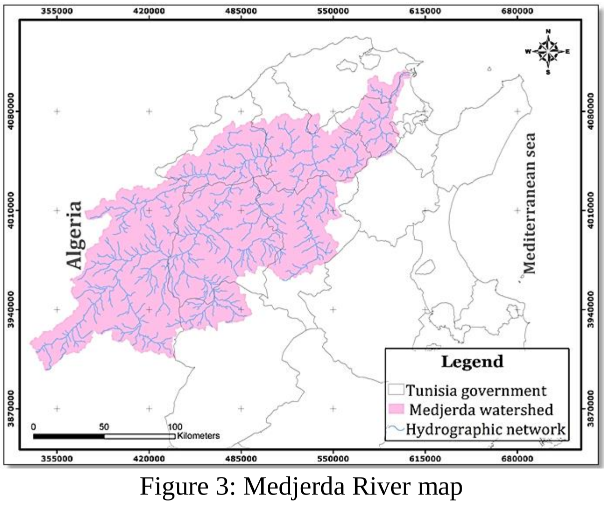


Figure 3: Medjerda River map

The area under study covers partially the height valley of Medjerda river basin and is defined as the area draining between the gauging subwatershed of Ghardimaou and Bou Salem, just before reaching Sidi Salem Dam (Figure 4), the largest dam in North Africa.

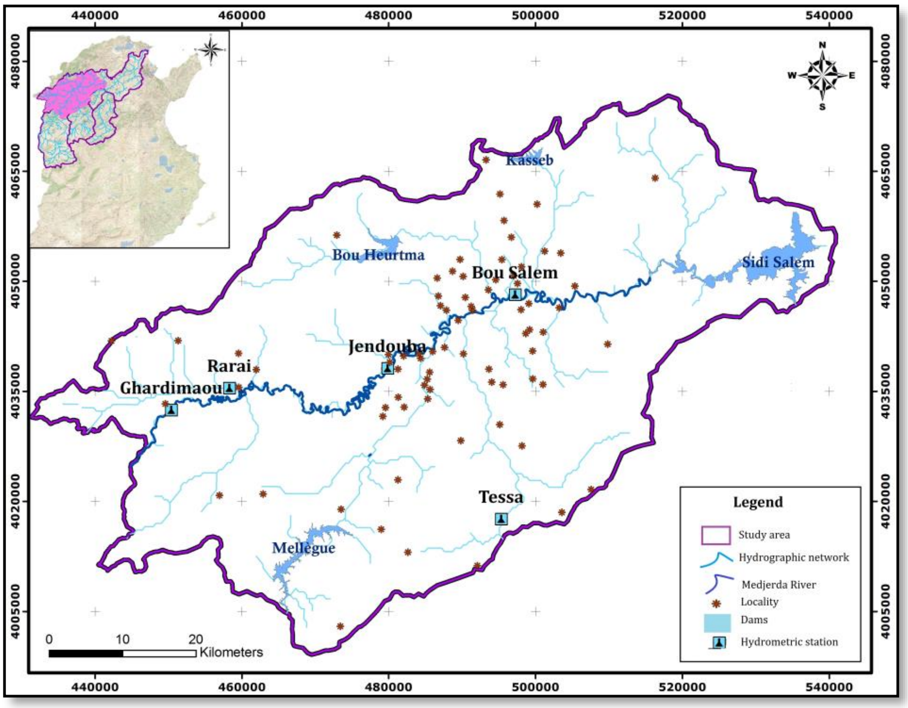


Figure 4: Study area

The area of the studied basin is about 4645 km². The basin is drained by a series of rivers of varying sizes (table 1) which two tributaries are conducted by dams.

Table 1: Tributaries characteristics

Tributaries	Area (km²)	Length (km)
Rarai	750	14
Mellegue	10700	317
Tessa	2450	143
Bouheurtma	550	30

The rugged terrain overlooking the plain on the north side and south side slopes are generally high, which promotes surface runoff. The catchment lies in the sub-humid to Mediterranean humid bio-climatic region. The rainy season extends from September to May, with intense precipitations in autumn.

Flow forecasting methodology

There are a multitude of flood propagation models in the literature. Among these models, two simple mathematical models are chosen: Muskingum and Regression. Indeed, these models require only upstream and downstream flows of a given stations and the propagation time. The choice of this models that are simple in application, that Medjerda basin is heterogeneous in soil characteristics and cover.

The forecasting method is composed in 4 steps as shown in figure 5. After the data collection and the choice of the events, the reconstitution is done by the two models in different delay (2, 4, 6 and 8 hours) and in two stations (Jendouba and Bousalem).

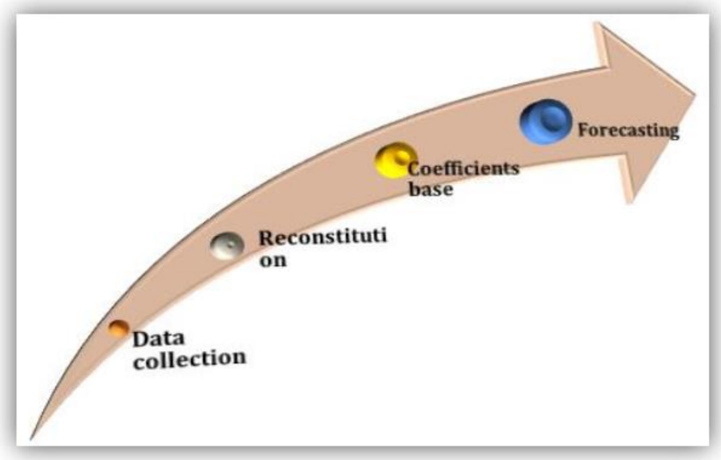


Figure 5: Forecasting methodology steps

The third step consists on the construction of coefficients base which are collected from the second step and organized by season. Finally, the forecasting is achieved by choosing the suitable coefficients from the same season.

Models description

As said above, two models are applied: Muskingum and Regression. A simple description of these models is presented. One of the simplification of Saint-Venant equations derived Muskingum model (Cunge, 1969). This model is a popular localized flow routing technique. In its research Habaieb (1992) establish a relationship (equation 1) between the inflow (upstream) Q_u(t) and outflow (downstream) Q_d(t) for a given station:

$$\boldsymbol{Q_u(t+d) = a_1 Q_u(t) + a_2 Q_u(t+d) + a_3 Q_d(t)} \qquad \textbf{(Eq.1)}$$

Where "t" is the calculation time, "d" represent the calculation delay and "a_1, a_2, a_3" are the coefficients of Muskingum model calculated by least squares method.
Muskingum takes account two data from the upstream and one from the downstream station.

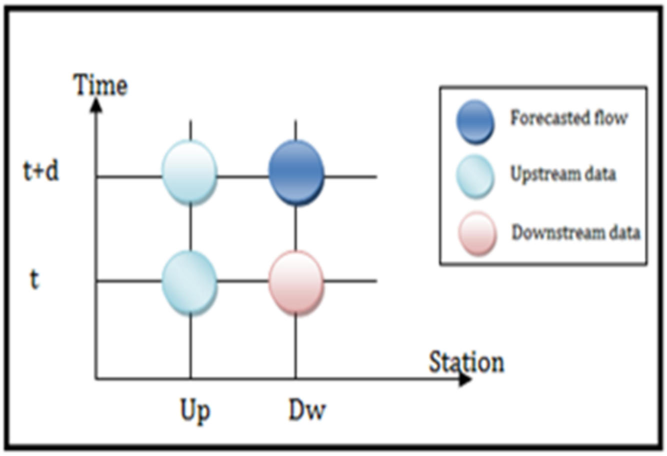


Figure 6: Comparison between Muskingum and Regression models

Flood Forecasting with propagation models selected using the coefficients from reconstitution phase. The upstream flow at time "t + d" is calculated based on upstream flows at the time "t" and "t-d".

$$\boldsymbol{Q_u(t+d) = 2Q_u(t) - Q_u(t-d)} \qquad \textbf{(Eq.2)}$$

Performance measures

Graphic criteria used to optimize the results are observed and simulated hydrographs, peak flows observed and simulated correlations between observed and calculated rates. Numeric criteria chosen to test the effectiveness of the models are the Nash–Sutcliffe model efficiency coefficient (Eq.3), the peak relative error (Eq.4) and the peak time error (Eq.5).

$$CNash = 1 - \frac{\sum_{i=1}^{n}(Qo - Qc)^2}{\sum_{n=1}^{n}(Qo - Qm)^2} \quad \textbf{(Eq.3)}$$

$$PRE = \frac{Qc\,max - Qo\,max}{Qc\,max} \quad \textbf{(Eq.4)}$$

$$PTE = t_{Qc} - t_{Qo} \quad \textbf{(Eq.5)}$$

Where ‘*Qo*’ is the observed flow, ‘*Qc*’ is the calculated flow, ‘*Qm*’ is the average observed flow, ‘*Qc*max’ and ‘*Qomax*’ are the maximum calculated and observed flow, t_{Qc} and t_{Qo} are the calculated and observed peak time.

Results and discussion

25 floods were reconstituted by Muskingum model. The model coefficients were used to forecast these floods. Forecast periods range from 2 to 8 hours, with a pitch of 2 hours.
The flow of Jendouba upstream is the sum of Ghardimaou and Rarai flow. The flow of Bou Salem upstream is the sum of Jendouba flow and the tributaries flows (Mellegue, Tessa, Bouheurtma). To analyze the results, the distribution functions of the different criteria in each section were dressed.

Section Ghardimaou-Jendouba

The following figures show the repartition function of the Nash coefficient, the Pic relative error and the pic time error for all forecasted time:

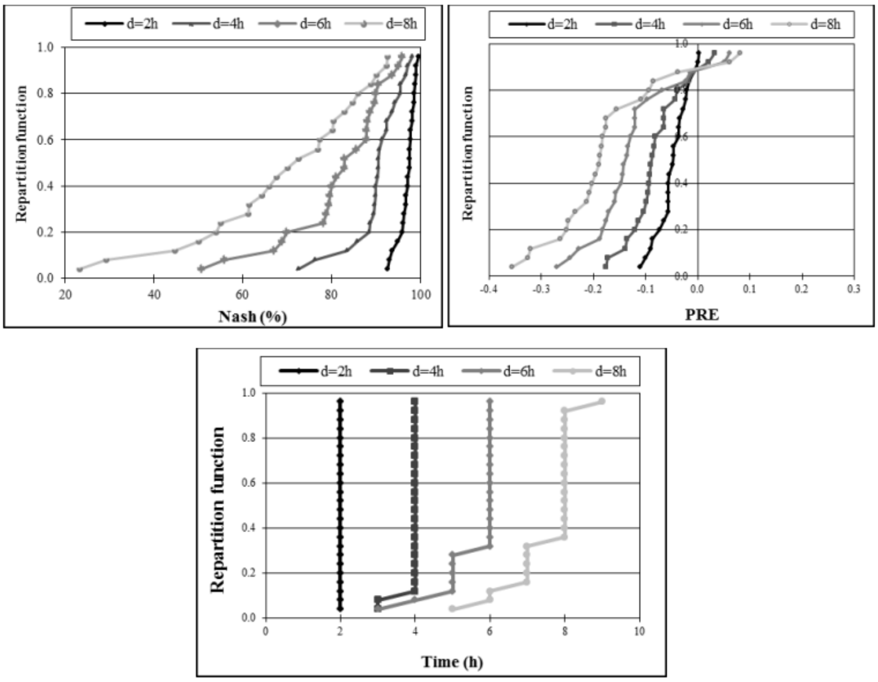


Figure 7: Repartition function of Nash coefficient, Pic relative error and pic time error of forecasting Jendouba flow

The variation of three criteria is proportional to calculated time: the criteria value increase with the forecasting delay.

The Nash coefficient varies between 23 and 92.6% for the forecasting delay of 8 hours, between 50 and 96 for the forecasting delay of 6 hours, between 72.5 and 98 for the forecasting delay of 4 hours and between 93 and 99.6 for the forecasting delay of 2 hours. So, the highest value is found by forecasting delay of 2 hours. The values of the pic relative error (PRE) are very low: the lowest absolute values are found by forecasting delay of 2 hours (0 and 11%). The pic flow is underestimated for 22 flows. The pic time error varies from 2 to 9 hours, but the lowest values are given by the forecasting delay of 2 hours.

One conclude that forecasting results depend on the applied time; over time decreases more than the forecast will be best. The highest values are given by the flow forecasting in two hours. These criteria show that the Muskingum model provided adequate Jendouba flow forecasting.

Section Jendouba – Bousalem
For this section, the repartition function of the Nash coefficient is presented, the Pic relative error and the pic time error for all forecasted time:

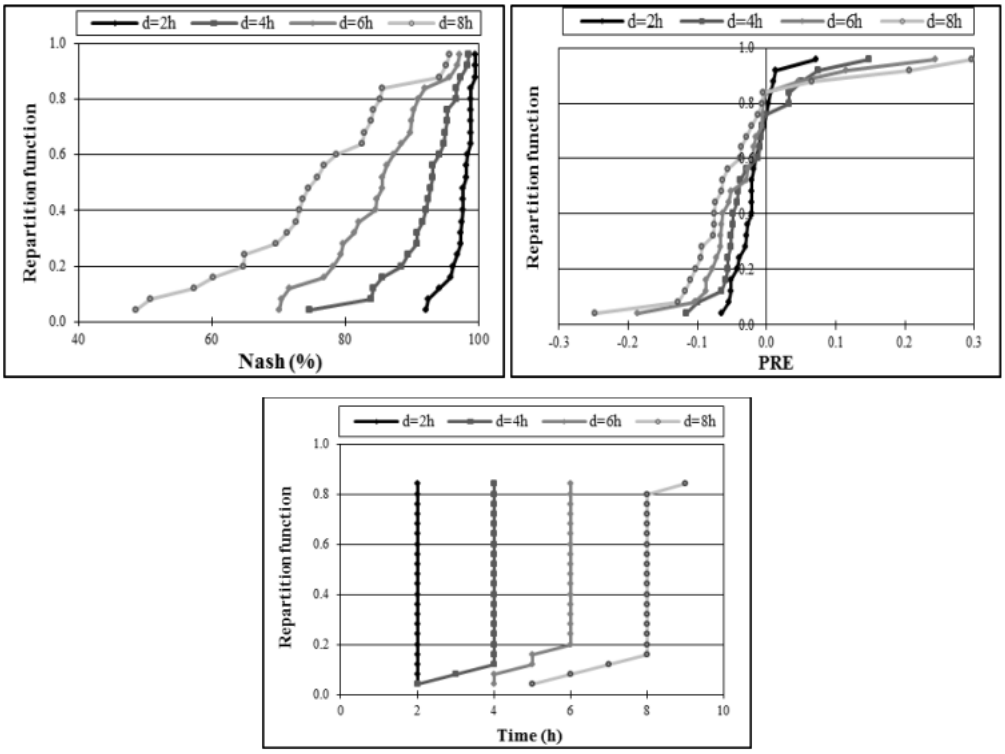


Figure 8: Repartition function of CNash, PRE and PTE of forecasting Bou Salem flow

One note that all the criteria increase when the forecasting delay increases.
For the forecasting delay of 8 hours, the Nash coefficient range from 50 to 95.6%, the pic relative error varies between -24 to 29% and the pic time error is in average equal to 8 hours. For the forecasting delay of 6 hours, the CNash range from 70 to 97%, the PRE varies between -19 to 24% and the PTE is in average equal to 6 hours. While, for the forecasting delay of 4 hours, the Nash coefficient range from 75 to 98.6%, the pic relative error varies between -13 to 15% and the pic time error is in average equal to 4 hours. Finally, for the forecasting delay of 2 hours, the Nash coefficient range from 92 to 99.6%, the pic relative

error varies between -6 to 7% and the pic time error is constant equal to 2 hours. The pic relative error is underestimated for 19 floods for the forecasting delay 2 and 4 hours and for 21 floods for 6 and 8 hours.
One conclude that the forecasting in two hours had the best value of the three criteria. The Muskingum model provided satisfactory forecasting of Bou Salem flow.

As an example, the forecasting of Jendouba flow is presented, the predicted flood of November 2010 at the calculated delay of 2 hours. This flood is classified 24 by Nash coefficient and 20 by pic relative error.

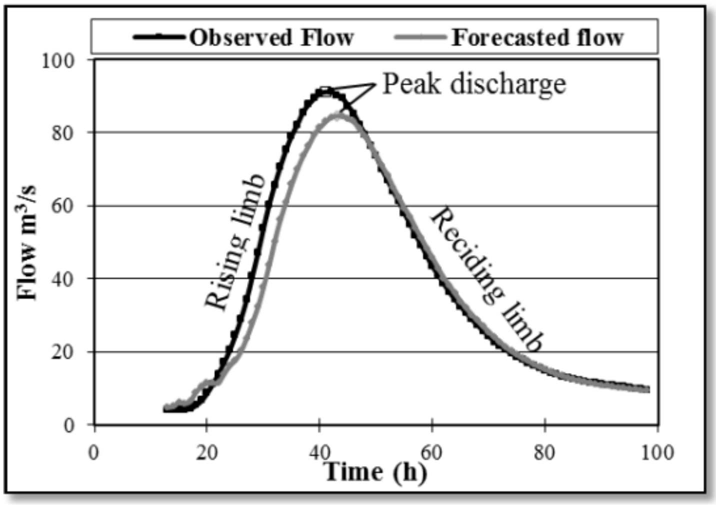


Figure 9: Observed and forecasted hydrograph of the flood November 2010 at 2 hours

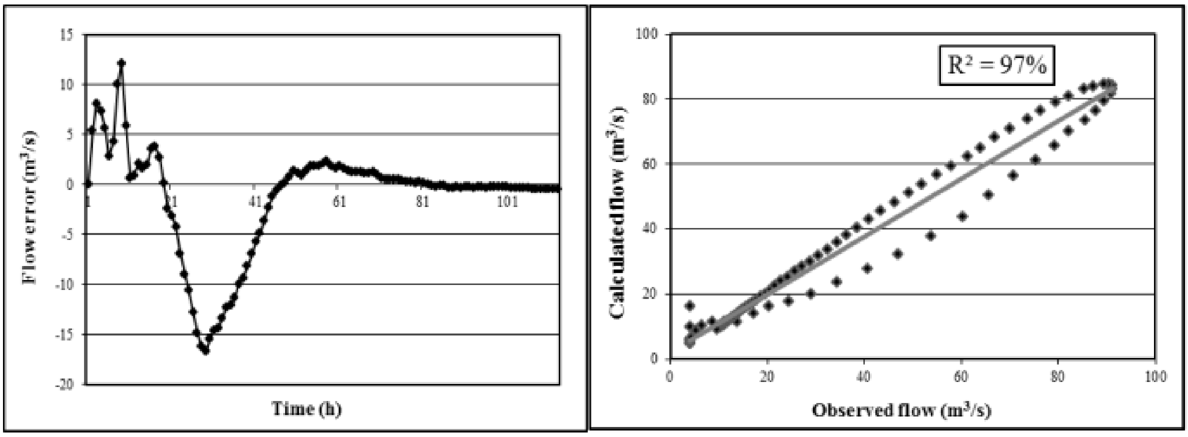


Figure 10: Error and correlation between observed and forecasted flow of the flood November 2010 at 2 hours

The shape of the hydrograph is reproduced, the rising limb is underestimated and the receding limb is confused with the observed hydrograph. The form of the pic is reproduced; it appears after 2 hours with an error of its value of -7%. The error differences between observed and calculated flows are low, between -16 and 12 m^3/s. The scattered point is close to the first bisector with a coefficient of correlation equal to 97%.

One conclude that the routing model of Muskingum give satisfactory results of forecasting of the flow of Jendouba at 2 hours with a Nash of 96%.
An example of forecasting of Bou Salem flow is dressed, the predicted flood of February 2011 at the calculated delay of 4 hours. This flood is classified 14 by Nash coefficient and 12 by pic relative error.

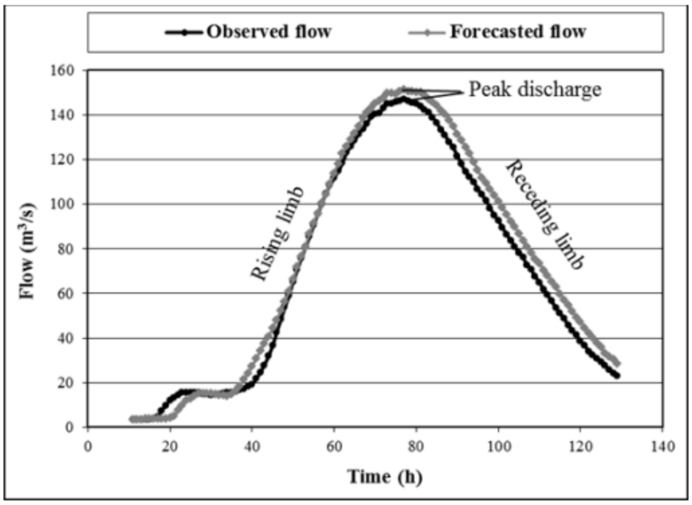


Figure 11: Observed and forecasted hydrograph of the flood February 2011 at 4 hours

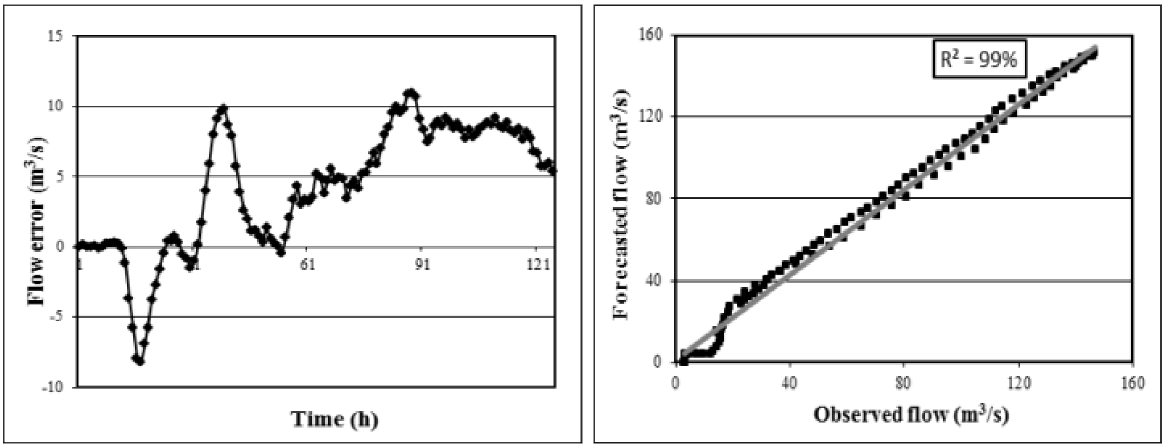
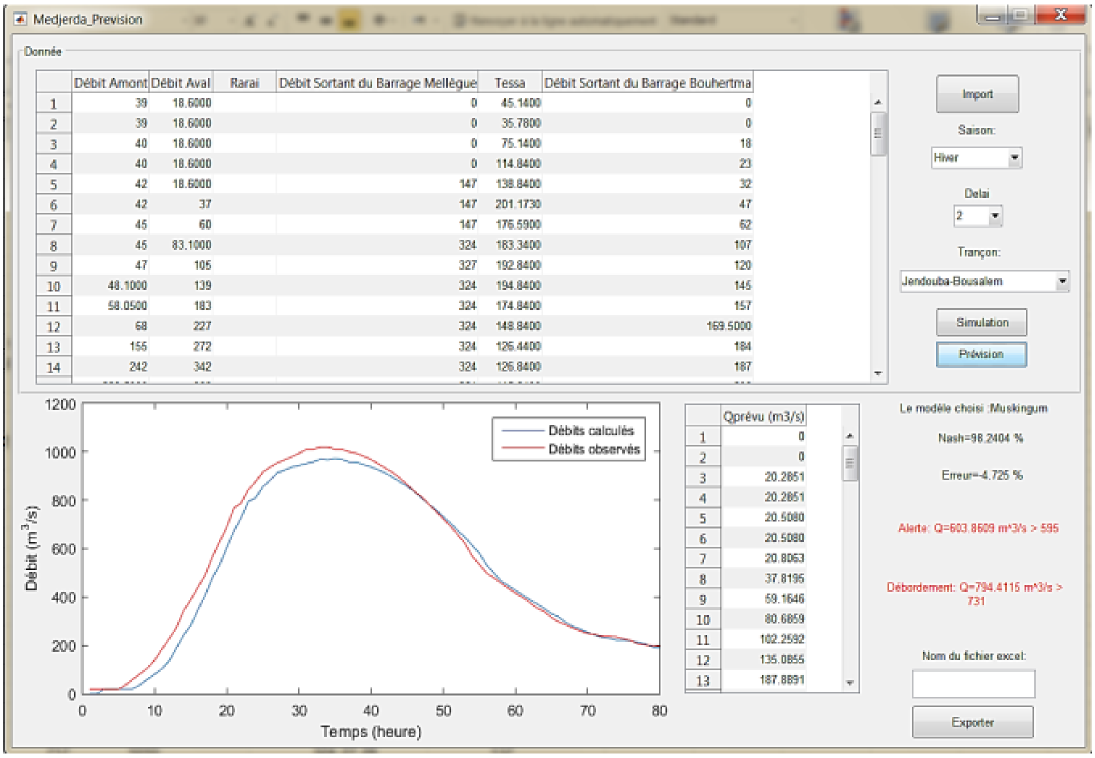


Figure 12: Error and correlation between observed and forecasted flow of the flood February 2011 at 4 hours

For this flooding, one note that Muskingum model reproduces the shape of the hydrograph. The rising limb is confused with the observed hydrograph and the receding limb is overestimated. The model reproduces also the form of the pic; which appears after 2 hours with an error of its value of 3%. The difference between observed and calculated flows is low, between -16 and 12 m3/s. The scattered point is close to the first bisector with a coefficient of correlation equal to 99%. One conclude that the routing model of Muskingum give satisfactory results of forecasting of the flow of Bou Salem at 2 hours with a Nash of 96%. The forecasting results with Muskingum model are satisfying. To facilitate the use of this model during floods, an application under Matlab language is created.

To run the application, the following step must be done:
- Copy the data of instantaneous flow rates and click on "import"
- Choose the time of calculation,
- Define the flood season
- Specify the section to be worked on,
- Launch the forecast.

The application is programmed to provide flow rates with or without tributaries flows. Knowing the warning level and overflow at each station, a message will be displayed if the calculated peak flow exceeds both state. The following figure present an example of flow forecasting by the application of 11 January 2003 at 2 hours.



The peak flow exceeded the warning level 595 m^3/s and overflows 731 m^3/s. Indeed, there has been flooding in this flood. The use of this application may be easier if there is a connection with the base data flows of the general direction of water resources DGRE and that of the DG / BGTH about data dams.

Conclusion

The Muskingum method is examined in this study for its applicability as flood forecasting method for the case study of three main station of Medjerda River in Tunisia. Twenty-four floods from 1973 to 2013 are analyzed for this purpose. Mean squared method is employed to determine the values of the coefficients required for the Muskingum method. The method of forecasting depends on the upstream station flow and models coefficients of antecedent floods. Forecast periods range from 2 to 8 hours, with a pitch of 2 hours. So 192 operation of flow forecasting are analyzed.

It is observed that Nash coefficient, pic relative error and pic time error decreases systematically with decrease forecasting delay. In addition, it is observed that the pic flows predicted by Muskingum method are underestimated for 22 floods (for all forecasting delay) in the section Ghardimaou-Jendouba and 19 floods (for 2 and 4 hours) and 21 floods (for 4 and 6 hours) in section Jendouba-Bou Salem. From these results, it can be concluded that the Muskingum model can be explored for similar watershed such as Medjerda. The creation of the application using Matlab language is a tool for decision maker in flood period. It is a simple tool that requires only instantaneous flows and the response is fast. Future directions of the present study are: the integration of rain in flow forecasting and the test of regression method.

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Performance of SWAT Model in Predicting Surface Runoff of Al-Masad Catchment

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Abstract
Surface runoff produced from rain storms is the main resource of water in the Iraqi Western Desert. Investigation of the quantities and frequencies of the surface runoff plays a significant role in the design of water harvesting projects in this area. In this study, the SWAT (Soil and Water Assessment Tool) model was utilized to predict the quantities of the surface runoff of Wadi Al-Masad catchment, within the Iraqi Western Desert, during the period between 1/9/2010 and 1/1/2024. The model was calibrated by comparing the values of the simulated results of the surface runoff that were obtained from the model to the field measurements during the period between 1/9/2010 and 31/12/2011. The statistical standards that were used to evaluate the models are: 1) the coefficient of model efficiency (NSE), 2) the ratio of root mean square error to the standard deviation (RSR), and 3) the percent Bias (PBias). The values of NSE, RSR, and PBias were estimated to be 0.71, 0.58, and 13 percent respectively. The model verification was performed based on the field measurement of surface runoff in the study from 1/1/2012 to 31/12/2013. The estimated values of the statistical standards NSE, RSR, and PBias were 0.74, 0.55, and 11 percent respectively. The results from the calibration and verification of the model indicated that the model was efficient in the simulation of the surface runoff of this catchment. The SWAT model was also applied to predict the daily, monthly, and annually surface runoff values of Al-Masad catchment during the period between 1/1/2014 and 1/1/2024. The results showed that the volume of the annual surface runoff of the study area during the simulation period was from 0.65 to 8.3 million cubic meters with an average 2.622 million cubic meters. This significant volume of water can be utilized in different water harvesting projects such as small dams.

Keywords: Water Harvesting, Surface Runoff, SWAT Model, Wadi Al-Masad.

Introduction
Natural water sources in Iraq, especially in the Western desert region, face many challenges because of some prevailing natural conditions such as the draught, high rates of evaporation due to higher temperature rates, and the breadth of the phenomenon of desertification. These conditions require explore and study the traditional water resources that are available in this area such as seasonal floods and groundwater. In specific, seasonal runoff is one of the main resources of water in the Iraqi Western Desert. The quantities, frequencies and prospects of the runoff must be studied based on the information and data that are available form field measurements during the past few decades and based on the hydrological forecasting. In order to design any water harvesting project, the volume of the annual water should be estimated and amounts of surface runoff of the drainage basin resulted from a certain rainstorm must be calculated.

Many of the solutions and models have been developed to estimate the surface runoff in different basins. Some of these models, such as the SWAT model, were based on mathematical models of continuous simulation. The SWAT model is a hydrological model that is used to estimate surface runoff and sediment transport. The model was developed by using Soil Conservation Service (SCS) equations (1972) and Modified Universal Soil Loss Equation (MUSLE) proposed by (Williams 1995). The application of this model requires many variables such as daily rainfall, temperature, relative humidity, state of vegetation, type and composition of soil, and slope of the ground surface. Some of these variables change from area to another within the basin, which requires the use of remote sensing and geographic information systems (GIS) to determine theses variables. The model has been applied in many countries and at different catchments during the last few years (e.g. Rodreguez *et al* 2005, Xu *et al* 2007, Amatyea *et al* 2008, Alansi *et al.*, 2009, Jeong *et al.*, 2010, Oeurng *et al.*, 2011, Mohammad *et al.*, 2012). The model was showed to be valid to estimate the surface runoff for most of these catchments.

The purpose of this research is to study the spatial and morphological characteristics with water drainage network of Wadi Al-Masad basin by using the SWAT model. The available hydrological data such as rainfall, temperature, relative humidity, soils characteristics, land cover, and land use were utilized by the model to determine the required current and future characteristics. The model was operated under the Geographic information systems GIS in (ArcSWAT) model.

Description of the Study Area

Wadi Al-Masad Basin is one of the sub-basins of Wadi Horan which is located in the Iraqi Western Desert. Wadi Horan is the largest valleys in western plateau that flowing from the west towards the east which empties into the Euphrates River near the city of Al-Baghdadi. Specifically, the study area is located near the city of Rutba between the latitudes 32º 39' 18" and 32º 51' 36" North and longitudes 40º 05' 24" and 40º 21' 36" East with an estimated catchment area of 404 square kilometers as shown in Figure (1).

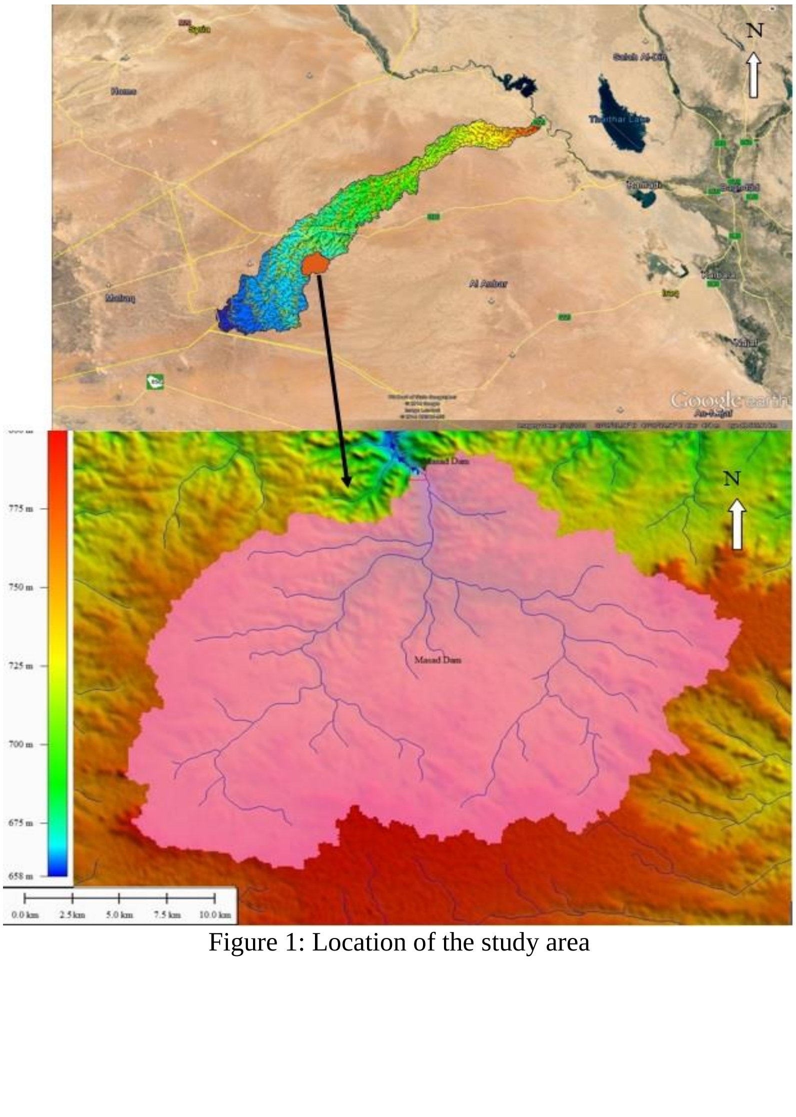

Figure 1: Location of the study area

The data that were used in this study were obtained from Rutba meteorological station which is the closest station to the study area. The climate of the study area is dry in general where temperatures are high, especially, during the months of June, July, and August, with a maximum temperature rate of 41.7 ºC in July and an average minimum temperature of 24.8 ºC. The temperature drops during the months of December, January, and February to about 2.7 ºC. The amount of rainfall that is received by the study area fluctuates during the year with a total annual rainfall of 120 mm. The maximum rainfall occurring is during the months from September to May while extremely rare rainfall is expected during the months from June to August. High rates of evaporation have been recorded in the study area with a maximum rate of 324.5 mm during July and minimum rate of 35.52 mm during January. Laboratory tests performed on six soil samples obtained from the study area showed that the soil was mostly loamy sand and sandy silt with a high percentage of lime up to 151.7 g/kg. The variation in the soil components has a significant impact on the surface runoff after rainstorms.

Previous studies and field visits to the study area have indicated that vegetation density was very low. The density of vegetation highly affected the hydrological conditions. The lower density of vegetation increased the speed of the surface runoff after rainstorms.

Model Description

The SWAT model is a semi-empirical hydrological model that can be calibrated according to the conditions of a given drainage basin. The model was used to predict the amount of surface runoff, sediments transport, and water quality at a drainage basin outlet. The model can be applied on one-day time step. The SWAT model depends on a set of equations and theories to estimate the amount of surface runoff and sediments transported. For example, to estimate the amount of surface runoff when only the daily values of the rainfall are available, as presented in this research, the (SCS) method, also known as Curve Number method (CN), is used as presented in Equations 1 and 2.

$$Q_{surf} = \frac{(P_{day} - 0.2S)^2}{(P_{day} + 0.8S)} \quad \text{Equation 1}$$

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad \text{Equation 2}$$

In Equations 1 and 2, Q_{surf} is the depth of the surface runoff from a rainstorm in millimeters; P_{day} is the depth of the daily rainfall from a rainstorm in millimeters; S is interception coefficient in millimeters; and CN is curve number.

The values of the curve number (CN) can be estimated for each cell of catchment maps by using the chart depending on the type of the soil of the catchment, land use, and soil humidity for several days before the rainstorm. Digital maps were utilized to classify land cover and soil properties. Furthermore, the Modified Universal Soil Loss Equations (MUSLE) were used by the model to estimate the amount of sediments that were transported through the catchment due to the rain and surface runoff according to the procedure proposed by (Williams 1995), as presented in Equation 3.

$$Sed = 11.8(Q_{surf} . q_{peak} . area_{hru})^{0.5}\ K_{USLE} . C_{USLE} . P_{USLE} . LS_{USLE} . C_{FRG} \quad \text{Equation 3}$$

In Equation 3, Sed is the produced sediments in tons; Q_{surf} is the surface runoff in millimeter per hour; q_{peak} is maximum surface runoff in cubic meter per second; $area_{hru}$ is the hydrological area of catchment in hectare; K_{USLE} is soil erodibility factor; C_{USLE} is cropping management factor; P_{USLE} is erosion control practice factor; LS_{USLE} is topographic factor; and C_{FRG} is soil roughness factor.

Model application

In order to obtain the required date for the SWAT model, soil samples were taken from six selected locations within the study area from about 20 cm depth. The Unified Standard Classification was conducted on the soil samples to determine the soil texture. The results indicated that soil samples were sandy loam and silty sand with mostly sandy loam soil. Land use and land cover were also determined based on satellite images and field inspection. Field measurements were recorded at the drainage basin outlet of the valley during the period from 01/09/2010 to 31/12/2013 after a rainfall occurring. The model Arc SWAT and the Geographic Information Systems (GIS) were used to obtain the required data as follows:

1) The digital elevations model (DEM) of the study area was used by the ArcSWAT model to determine the outer boundaries of the Al-Masad basin. The basin was divided into 33 sub-basins as shown in Figure (2).

2) Based on the field data and satellite images, soil type, land use, and distribution of the vegetation cover of the drainage basin were defined as presented in Figure (3).

3) Daily climate data (i.e. depth of rainfall, maximum and minimum temperature, relative humidity, wind speed, and solar brightness) that were obtained from Rutba weather station for the period from 1\1\1995 to 1\12\2013 were input into the model.

4) To calibrate the model, the model was applied to predict the surface runoff of the basin for the period 1\9\2010 to 1\1\2012. The model was calibrated to obtain a better approximation measured and predicted data. The calculated statistical standards NSE, RSR, and PBias for the model evaluation were 0.71, 0.58, and 13 percent respectively as shown in Figure (4).

5) To perform the model verification process, the model was applied on the daily basis for the period from 1\1\2012 to 31\12\2013 to estimate the surface runoff values and compare them to the field measurements. The values of the statistical standards NSE, RSR, and PBias were 0.74, 0.55, and 11 percent respectively, which indicated a good agreement between the predicted and the measured values of the surface runoff as presented in Figure (5).

6) The model was applied to determine a ten-years forecast, during the period from 1\1\2014 to 1\1\2024, of the surface runoff of the drainage basin as shown in Figure (6). This study will help in planning of future water harvesting and dam's projects.

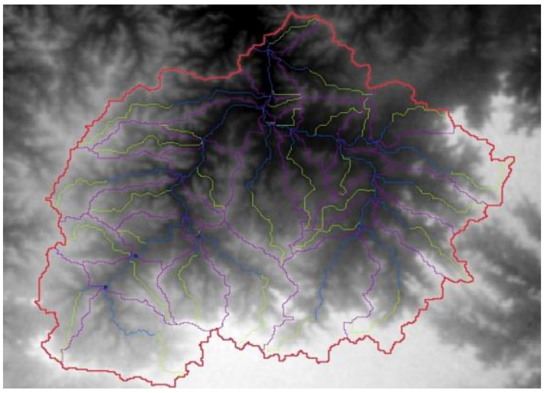

Figure 2: Delineation of sub-basin of the study area.

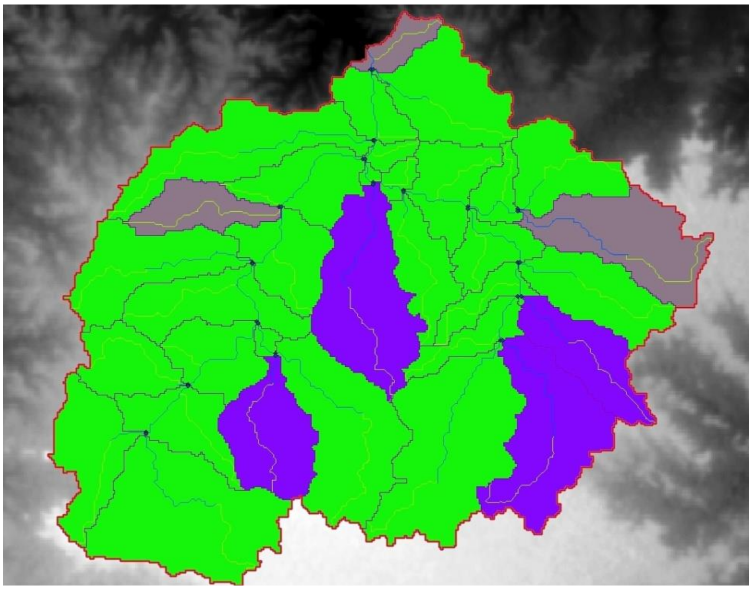

Figure 3: Soil type delineation of the study area.

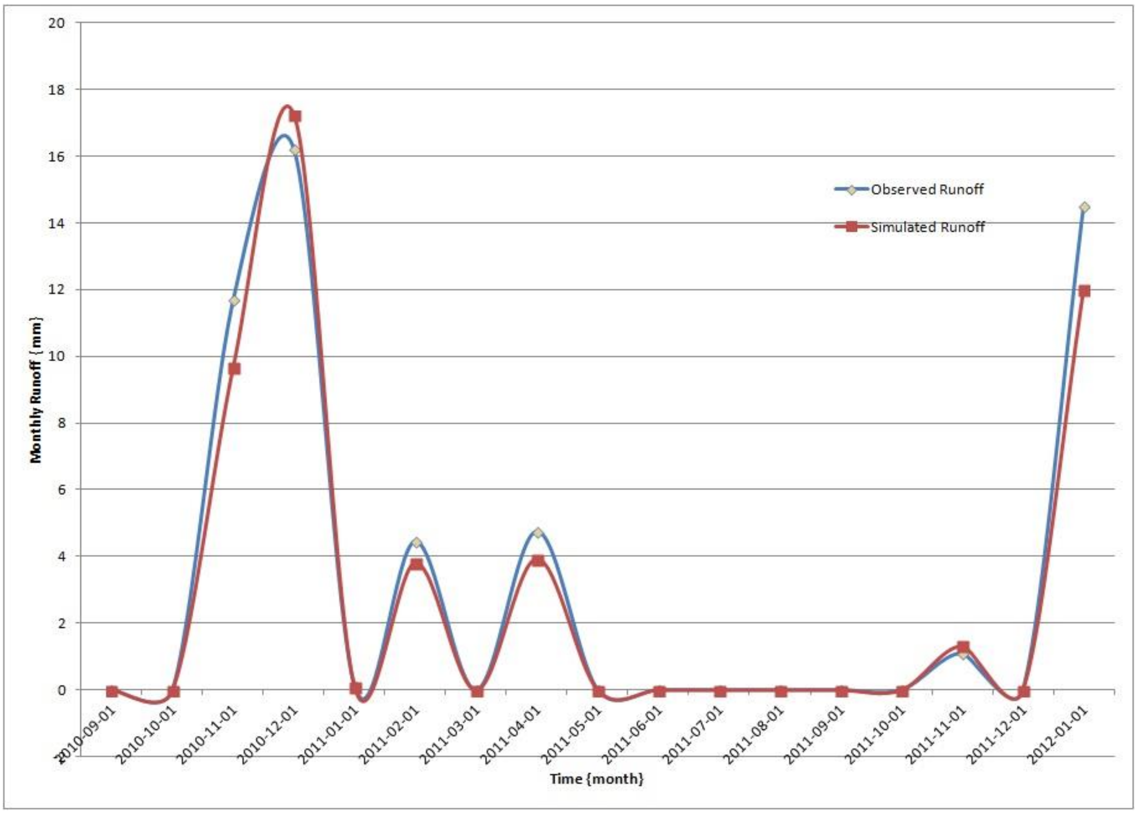

Figure 4: SWAT model calibration.

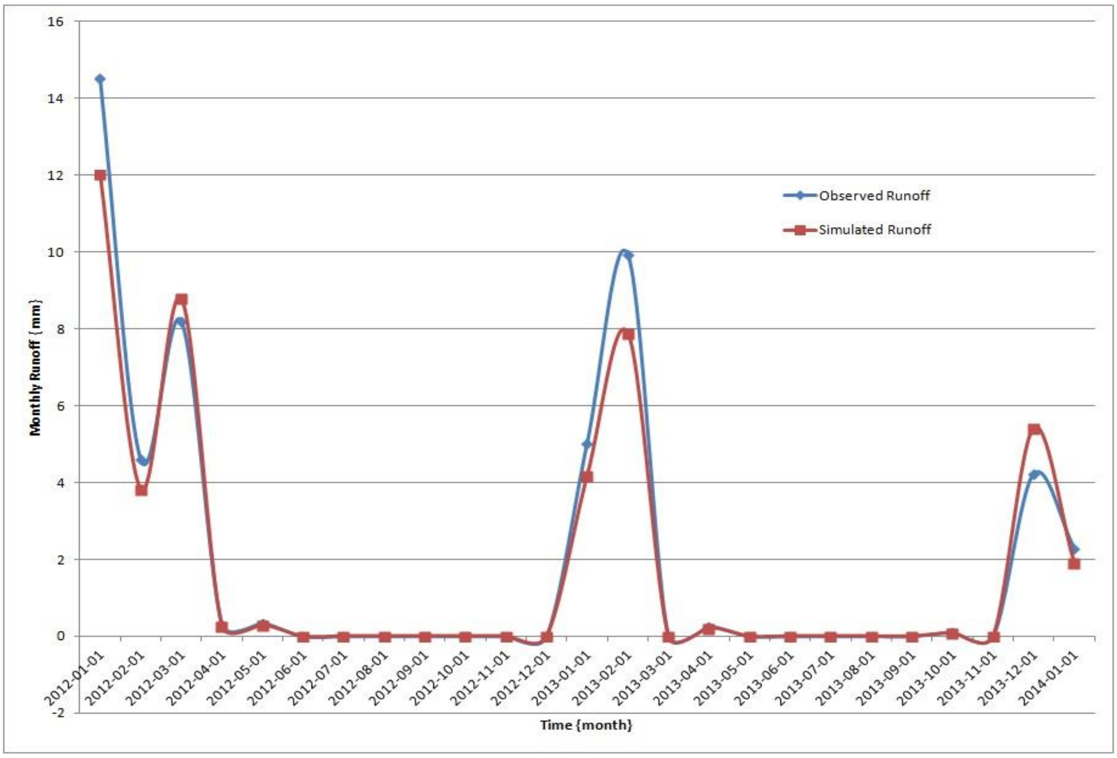

Figure 5: SWAT model verification.

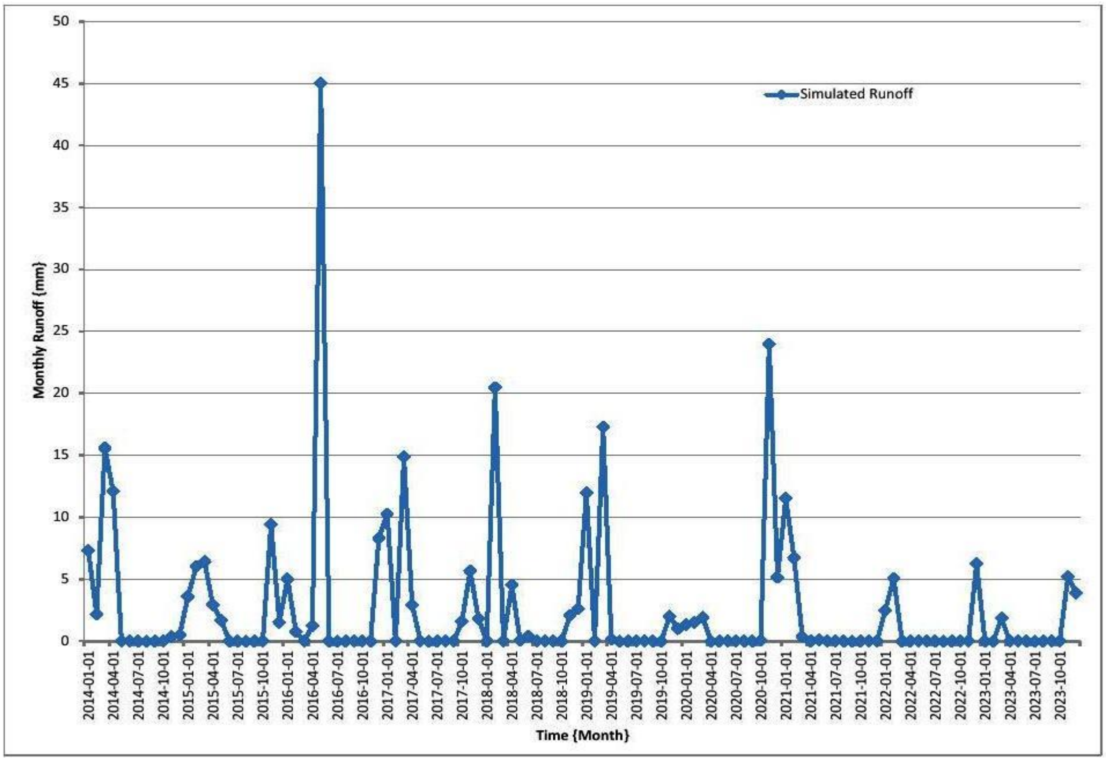

Figure 6: The values of the surface runoff as predicted by the SWAT model.

Results and Discussions

The SWAT model was utilized to study the spatial and morphological characteristics of Wadi Al-Masad basin based on the available climate data and the field measurements. The statistical values NSE, PBIAS, RSR indicated that the model calibration as well as the model verification yielded a good approximation with the measured values of the surface runoff. The prediction of the surface runoff for ten years to come was 36 time occurring of runoff with an average annual volume of water of 6557.2 cubic meter for each square kilometer of the catchment. This significant quantity of water indicated that the study area is adequate for construction of water harvesting projects.

Conclusion

The values of the surface runoff for Al-Masad valley were predicted by utilizing the SWAT model based on the meteorological data and satellite images. Compering the predicted values of the surface runoff to measured values showed that the model was an effective tool to accurately predict the surface runoff with low cost and minimum time. The results of this study will enable to perform time efficient and cost effective designs of water harvesting projects within the investigated area.

To increase the accuracy of the model, it is recommended to use an updated digital elevations model with high resolution because the resolution of the images that were used was only 30 meters. Furthermore, soil samples from greater depths are needed to increase the accuracy of the soil representation. The period of field measurements should also be increased to obtain more time for the model calibration and verification.

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Role of Wadi Emti Dam in Enhancing Water Resources and Reducing Flooding Risks in Ezki Governorate (in Arabic)

دور سد وادي أمطي في تعزيز الموارد المائية والحد من مخاطر السيول بولاية إزكي، سلطنة عُمان

خاطر بن خميس الفارسي[1] وجوخة بنت خميس الهنائية [2]
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2 رئيسة قسم معالجة بيانات موارد المياه –وزارة البلديات الإقليمية وموارد المياه

الملخص
تعتبر سلطنة عُـمان من البلدان التي يتسم مناخها بصيف حار جاف وشتاء معتدل باستثناء محافظة ظفار التي تتأثر بالرياح الموسمية، وتقع السلطنة في نطاق يتميز بأقل معدل للأمطار وأعلى معدل للتبخر في العالم. وتعتبر الأمطار المصدر الرئيسي للمياه العذبة في السلطنة ويبلغ متوسط معدلات سقوط الأمطار على أراضي السلطنة حوالي 85 ملم في العام يذهب منها 80 % بالتبخر و5 % تقريباً إلى البحر وحـوالي 15 % للتغذية الجوفية. ويعود ارتفاع معدل التبخر إلى ارتفاع درجات الحرارة وانخفاض الرطوبة. وفي ظل التنمية الشاملة التي شهدتها البلاد خلال العقود الخمس الماضية وازدياد الطلب على المياه تواجه الموارد المائية بالسلطنة تحديات كثيرة من أهمها: وجود عجز مائي كبير يتطلب سد العجز المائي وإعادة التوازن، محدودية الموارد المائية المتاحة والمتجددة ، توفير الاحتياجات المائية المتزايدة والمتوقعة في المستقبل، استمرار هدر المياه الجوفية في القطاع الزراعي وتدني عائدها الإقتصادي، ظاهرة الملوحة وتدهور جودة المياه ، تعرض السلطنة للعديد من فترات الجفاف التي قد تصل إلى عشرة سنوات متتالية، كما تتعرض كذلك لفترات مطيرة تصل إلى 5 سنوات متتالية ينتج عنها الفيضانات المستمرة والمتكررة بمواقع مختلفة بالسلطنة قد تسبب أضرار بالبنية التحتية والممتلكات. لهذا عملت الحكومة الرشيدة على تنفيذ عدة برامج للمحافظة على الموارد المائية المحدودة في البلاد. ومن أجل تنمية وإدارة الموارد المائية ، كان لابد من مراقبة وتقييم مصادر المياه والمتمثلة في تساقط الأمطار وتدفقات الأودية وجريان الأفلاج والمياه الجوفية. ولذلك فقد عملت الحكومة على إقامة شبكة مراقبة الرصد الهيدرومترية في مختلف محافظات السلطنة وعملت في الوقت نفسه على تحديثها وتطويرها بأحدث الأجهزة كما أولت الحكومة أهمية خاصة لمشاريع حصاد المياه عن طريق إنشاء السدود بمختلف أنواعها والتي أثبتت فعاليتها في تنمية الموارد المائية بالإستفادة من مياه السيول وتعزيز المخزونات الجوفية عوضاً عن ذهابها هدراً إلى البحر أوالصحراء. وتتطرق ورقة العمل هذه إلى جهود السلطنة في إنشاء شبكة مراقبة الموارد المائية وتوزيعها لتغطي كافة محافظات السلطنة، والعمل على تحديثها بصفة دورية بالإضافة إلى تنوع أجهزة القياس المستخدمة لتتوافق مع التقنيات العالمية في هذا المجال. كما تركز الورقة على مشروع إنشاء سد للتغذية الجوفية على وادي أمطي بولاية إزكي بمحافظة الداخلية ، مما كان له أكبر الأثر في تحسن مستويات المياه الجوفية للآبار والأفلاج بالولاية وذلك بمقارنة البيانات الهيدرومترية قبل وبعد إنشاء السد وحماية المناطق السكنية الواقعة أسفل السد من مخاطر الفيضانات. ويتضح من نتائج الدراسة أن تجربة إنشاء السدود في السلطنة بشكل عام وسد وادي أمطي بشكل خاص من أنجح المشاريع المائية فعند مقارنة الوضع المائي بمنطقة السد قبل إنشاء السد وبعده يتضح مدى التحسن بالمخزون الجوفي. كما توفر سدود التغذية درجة من الحماية من مخاطر الفيضانات وتحول دون تعطل حركة السير، كما أنها تساهم بشكل كبير في إستقرار سكان المناطق الزراعية في قراهم وعدم هجرتهم مهنة الزراعة. ويتضح أهمية البيانات المائية فلها دور فعال في تقييم وإدارة الموارد المائية في سلطنة عُمان، لهذا يجب أن تكون ذات قيمة وجودة ومتكاملة وجعل البيانات أفضل لمستقبل أفضل.

الكلمات الدالة: المياه الجوفية، المياه السطحية، عجز مائي، جفاف، تدهور نوعية المياه.

1. مقدمة

تعتبر سلطنة عُــمان من البلدان التي يتسم مناخها بصيف حار جاف وشتاء معتدل باستثناء محافظة ظفار التي تتأثر بالرياح الموسمية ، وتقع السلطنة في نطاق ضمن حزام المناطق الجافة وشبة الجافة يتميز بأقل معدل للأمطار وأعلى معدل للتبخر في العالم . وتعتبر الأمطار المصدر الرئيسي للمياه العذبة في السلطنة ، ويبلغ متوسط معدلات سقوط الأمطار على السلطنة حوالي 85 ملم في العام (المتوســط الســنوي 15.8 مليار م^3) يذهب منها 79 % (12.5 مليار م^3) بالتبخر و5 % (790 مليون م^3) تقريباً إلى البحر وحـوالي 15 % (2.370 مليار م^3) للتغذية الجوفية . ويتباين معدل هطول الأمطار مــا بين أقل من 50 ملم في وسط البلاد إلى حــوالي 300 ملم في الجبال. ويُــقدر معدل التبخر السنوي بما يتراوح بين 3000 ملم في المناطق الداخلية و 2100 ملم في ساحــل البــاطنة بشمال عُمان و1700 ملم في سهل صلالة بجنوب عُمان، ويعود ارتفاع معدل التبخر إلى ارتفاع درجات الحرارة وانخفاض الرطوبة.

وفي ظل التنمية الشــاملة التي تشــهدها البلاد خلال العقود الأربعة الماضــية وازدياد الطلب على المياه ســواء اســتخدامات الزراعة والاســتخدامات العامة واســتخدامات الصــناعة، ومع محدودية الموارد المائية المتمثلة في المياه الجوفية (الآبار والأفلاج)، فقد عملت الحكومة الرشيدة على تنفيذ عدة برامج للمحافظة على الموارد المائية المحدودة في البلاد والعمل على

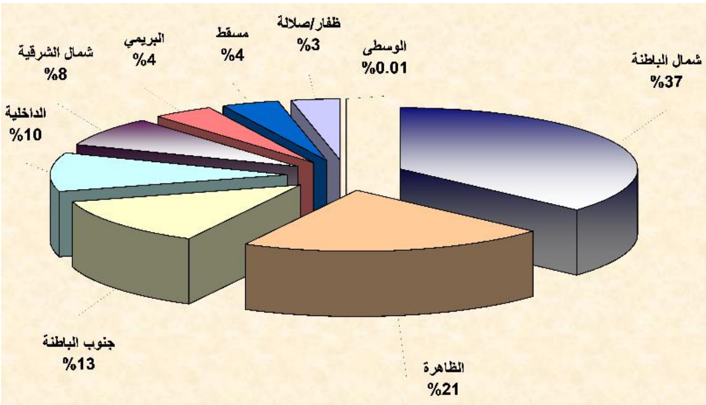
تنميتها وتطويرها ومراقبتها وإدارتها بالأسلوب الأمثل من أجل الاستفادة من الثروة المائية المتاحة.

ومن أهم التحديات التي تواجه قطاع موارد المياه بالسلطنة تحدي لخفض العجز الحالي في موارد المياه وتحقيق التوازن بين الاستخدامات المائية والمياه المتجددة في مختلف محافظات السلطنة بغية توفير المياه للجميع وبشكل كاف. كما يواجه هذا القطاع عدة تحديات أخرى نوجزها في القسم الذي يلي:

2. أهم التحديات التي تواجه قطاع الموارد المائية بالسلطنة

أولاً: محدودية الموارد المائية المتاحة والمتجددة ووجود عجز مائي كبير يتطلب سد العجز المائي وإعادة التوازن

تشير البيانات إلى وجود متوسط عام للعجز المائي يبلغ حوالي (316 مليون متر مكعب) بمختلف محافظات السلطنة وهو ما يمثل حوالي (23%) مقارنة بالموارد المائية التقليدية المتجددة والتي تبلغ (1318 مليون م^3/ عام). وفي بعض المناطق أصبحت معدلات السحب تفوق معدلات التغذية ومن ثم تدنت مناسيب المياه مما يشير إلى تناقص كمية المياه في الخزان الجوفي وفي بعض المناطق الساحلية أدى تدني مناسيب المياه إلى انعكاس التدفق الطبيعي لمياه الجوفية وانسياب مياه البحر نحو اليابسة، حيث يتركز العجز في محافظتي شمال وجنوب الباطنة ويمثل (50%) من إجمالي العجز الكلي ويعود ذلك إلى ارتفاع معدلات الاستخدامات الزراعية حيث يتركز حوالي 50% من الإنتاج الزراعي بالسلطنة في ساحل الباطنة وهو ما يوضحه الشكل (1).



الشكل رقم (1): توزيع العجز المائي في محافظات السلطنة

ثانياً: توفير الاحتياجات المائية المتزايدة والمتوقعة في المستقبل مع وجود تنمية في جميع المجالات

تعتبر المياه من أهم موارد السلطنة الطبيعية وستتزايد أهميتها مستقبلاً نتيجة للتنمية الشاملة في النواحي الاجتماعية والاقتصادية للبلاد ولتوفير متطلبات الأمن الغذائي وضمان متطلبات بناء اقتصاد حديث للأجيال القادمة حيث سيزداد الطلب على المياه نتيجة لارتفاع مستوى المعيشة وتحسين نوعية الحياة والأحوال الصحية. إن كميات الطلب على المياه في العديد من المناطق يزيد عن كمية المياه المتجددة المتاحة وفي مثل هذه الحالات يغطى الطلب عن طريق السحب من المخزون الجوفي الأمر الذي يؤدي إلى تدني مناسيب المياه الجوفية وبالتالي انخفاض تدفق الأفلاج. يوضح الجدول رقم (1) مؤشرات إحصائية للإحتياجات المائية في سلطنة عُمان.

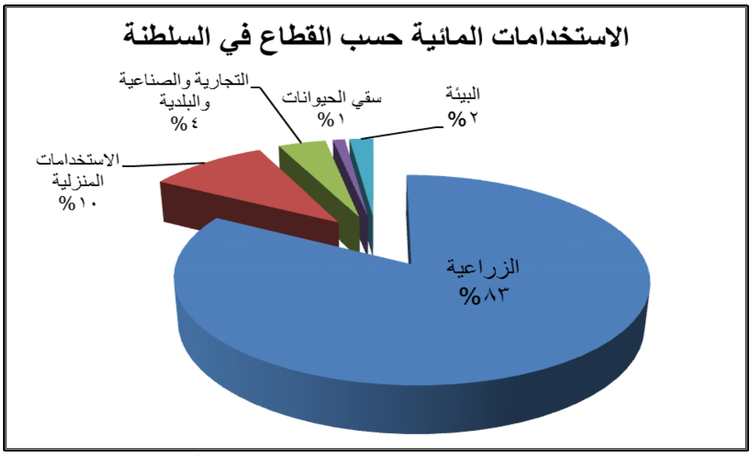
جدول (1): مؤشرات إحصائية للإحتياجات المائية في سلطنة عُمان (2012 م)

المؤشر	القيمة
المساحة	309.832 كم^2 – 30.900 مليون هكتار
تعداد السكان (2017 م)	4.572.949 مليون نسمة
الكثافة السكانية	13.4 فرد/كم^2
مساحة الأجزاء الجبلية	46.425 كم^2 (15% من مساحة السلطنة)
مساحة الأجزاء الصحراوية	232.125 كم^2 (75% من مساحة السلطنة)
مساحة الأراضي الصالحة للزراعة	2.223.074 مليون هكتار (7%)
مساحة الأراضي المزروعة (2012م)	176.000 فدان (73.444 هكتار)
إنتاجية المياه المحلاة (2012م) غير متجددة	196 مليون م^3/عام
نسبة السكان الحاصلين على مياه نظيفة	90 % (4.115.654 مليون)
إنتاجية المياه المعالجة للصرف الصحي	42 مليون م^3/عام

المتوسط السنوي لهطول الأمطار	85 ملم/عام (أقل من 50-350 ملم/عام)
كمية المياه المتجددة (التغذية الفعلية)	1318 مليون م^3/عام
كمية المياه الجوفية المتاحة	1316 مليون م^3/عام
كمية المياه السطحية المتجددة	102 مليون م3/عام
كمية المياه المتوفرة	1556 مليون م^3/عام
إجمالي الاستخدامات المائية	1873 مليون م^3/عام
العجز المائي	316 مليون م^3/عام (36%)
المياه المستوردة	3800 مليون م^3/عام
إجمالي الموارد المائية (المتوفرة + المستوردة)	5356 مليون م^3/عام
نصيب الفرد من المياه المتجددة	314 م^3/عام
نصيب الفرد من المياه غير التقليدية	57 م^3/عام
نصيب الفرد من المياه المستخدمة	446 م^3/عام
نصيب الفرد من المياه المستوردة	904 م^3/عام

ثالثاً: استمرار هدر المياه الجوفية في القطاع الزراعي وتدني عائدها الإقتصادي

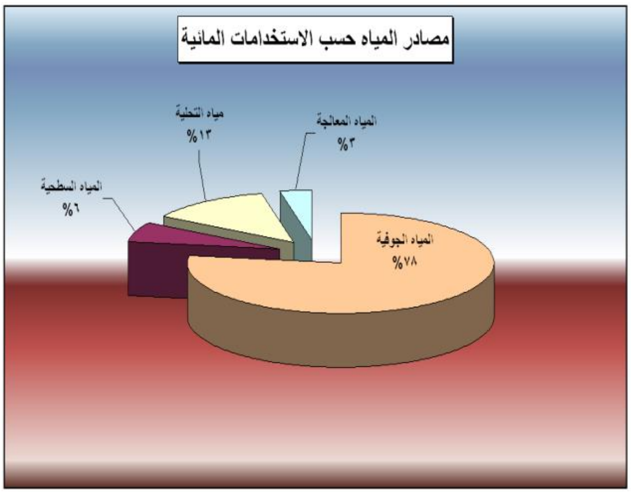
تعتبر معدلات استهلاك المياه في القطاع الزراعي مرتفعة ويستحوذ القطاع الزراعي على أكثر من 80% من المياه الكلية المستخدمة في السلطنة (شكل 2). وستستمر في ارتفاعها ما لم يتم اتخاذ إجراءات معينة مثل التغيير في حجم المساحات المزروعة والتراكيب المحصولية ورفع كفاءة أنظمة الري المستخدمة وتطبيق نظام المقننات المائية وذلك في المزارع المروية من الآبار لتفادي هجر المزارعين لمزارعهم في العديد من المحافظات . حيث أن القطاع الزراعي هو المستهلك الرئيسي للمياه حيث يستأثر بحوالي 83 % من جملة المياه المستهلكة . تمثل المياه السطحية (الأمطار والأفلاج والعيون) حوالي 35 % من إجمالي الاستخدامات المائية أما المياه الجوفية تمثل 65 % من الموارد المائية المتاحة وتعتبر المياه الجوفية المورد الرئيسي للمياه بالسلطنة إلا أن العائد الزراعي من المياه المستخدمة في الزراعة منخفض للغاية ومساهمته في الاقتصاد الوطني قليلة حيث لا تزيد عن 3% من إجمالي الناتج القومي.



الشكل رقم (2): نسب إستخدامات المياه بالسلطنة

رابعاً: ظاهرة الملوحة وتدهور نوعية المياه الجوفية

تمثل ظاهرة تدهور نوعية المياه الجوفية أحد التحديات التي تواجه قطاع موارد المياه حيث يمكن تلخيص أسباب حدوثها إلى ارتفاع ملوحة المياه الجوفية بالأجزاء الساحلية خاصة (سهل الباطنة وسهل صلالة) بسبب تداخل مياه البحر المالحة بالمياه العذبة بتلك الأجزاء نتيجة الإفراط في ضخ المياه بواسطة الآبار بمعدلات تفوق التغذية الطبيعية التي تتلقاها هذه الخزانات الجوفية، وذلك نتيجة الزيادة الكبيرة والمطردة في حفر الآبار خلال أعوام السبعينات والثمانينات، وما رافقه من حفر عشوائي لهذه الآبار وتأثيرها السلبي على بعضها البعض، وانتشار استخدام الآبار العميقة والمضخات الميكانيكية وازدياد معدلات الضخ مما أدى إلى انخفاض مستويات المياه الجوفية . كما يحدث تلوث للمياه الجوفية بسبب تداخل الآبار الخاصة بمجاري الأودية الرئيسية وعدم الالتزام بالمواصفات القياسية لتصريف المخلفات ونواتج الصرف الصحي سواء السائلة أو الصلبة خاصة بالخزانات القريبة من سطح الأرض، كما يوجد بعض التلوث الهيدروكربوني المحدود في بعض المواقع تأخذ فترة طويلة جدا لمعالجتها وبتكاليف عالية.



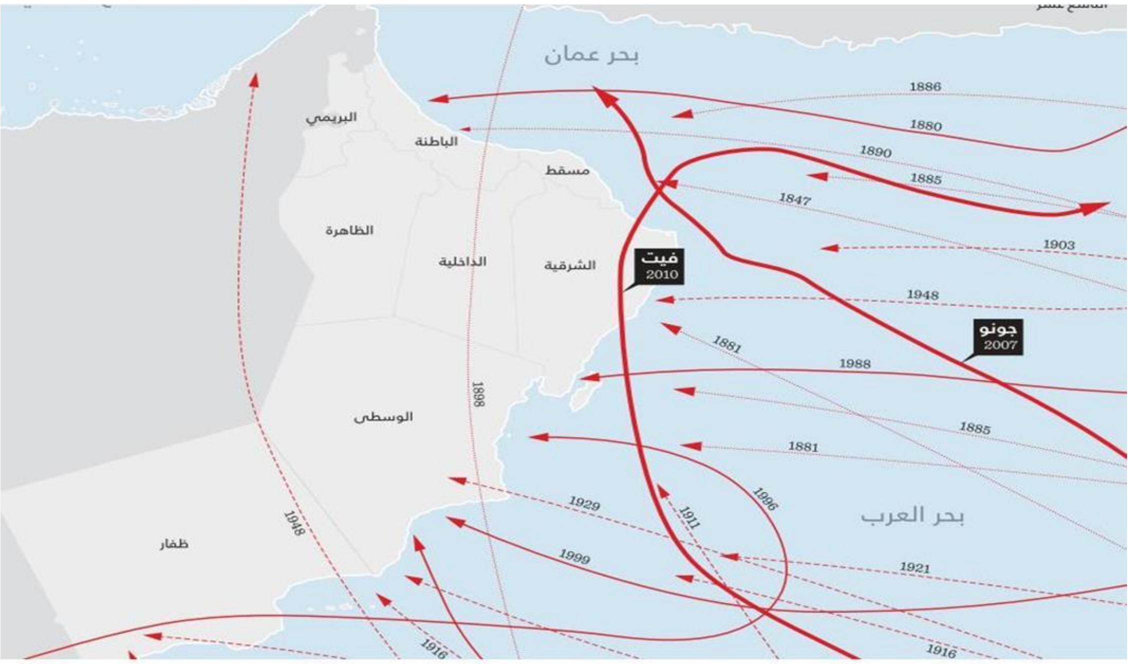
الشكل رقم (3): مصادر المياه حسب الاستخدامات المائية

خامساً: فترات الجفاف والفترات المطيرة بمناخ السلطنة وما يصاحبها من فيضانات مستمرة ومتكررة بمواقع مختلفة بالسلطنة

تتعرض السلطنة كباقي الدول التي تقع في نطاق حزام البلدان الجافة وشبه الجافة إلى فترات جفاف متكررة وأخرى مطيرة قد تستمر لعدة سنوات تبعاً للتغيرات المناخية والهيدرولوجية. ويشير الشكل (4) إلى تعرض السلطنة إلى فترتين من الجفاف الأولي كبيرة قد تمتد مـن (7–10) سنوات والأخرى صغيرة قد تمتد من (5-3) سنوات، كما يشير الشكل إلى تعرض السلطنة إلى فترة جـفاف شديدة منذ عـام 1999م أستمرت إلى 2007 وهي الأعلى خلال فترة رصد البيانات حيث انخفضت معدلات الأمطار بصورة كبيرة.

الشكل (4): معدل انحراف هطول الأمطار لكل عامين بمحافظة مسقط مقارنة بالمتوسط السنوي

وتتأثر أجواء السلطنة بحالات إستثنائية من الاعاصير التي تنشأ في المحيط الهندي وتتحرك باتجاه اليابسة وعادة ما تصيب السواحل الشرقية للسلطنة أو سواحل محافظة ظفار حيث يصاحبها هطول أمطار رعدية غزيرة ورياح قوية قد تبلغ سرعتها أكثر من 140 كم/ساعة كما حدث في أعصار جونو، وتؤدي هذه الأمطار إلى جريان الأودية الرئيسية والفرعية بتدفقات عالية ومدمرة في بعض الأحيان حيث تخلف العديد من الخسائر المادية والبشرية الكبيرة في البنية التحتية والمتمثلة في شبكات الطرق وإمدادات المياه والكهرباء والاتصالات والمباني والمزارع. ومنذ عام 1890 إلى 2002 تم حصر 13 حالة مدارية تعرضت لها أجواء السلطنة ما بين أعاصير شديدة القوة إلى عواصف مدارية ، أما خلال 10 سنوات الماضية فقد تعرضت السلطنة لـخمس حالات مناخية ففي عام 2007 أعصار جونو في 2010 أعصار فيت، وفي عام 2014 العاصفة المدارية نيلوفار، أما في عام 2015 فقد تأثرت أجواء السلطنة لأعصارين أشوبا في شهر يونيو وشابالا في شهر نوفمبر، ونظرا لتوافر عدة عوامل منها وجود الجبال المرتفعة والشديدة الانحدار والعارية من الغطاء النباتي مع مناخ جاف ومعدلات سقوط أمطار متغيرة فهذا يؤدي إلي حدوث معدلات فيضانات عالية الذروة بشكل متكرر بمختلف محافظات السلطنة.



خارطة (1): سجل مسار الأعاصير التي تعرضت لها سلطنة عُمان منذ 1847 م

3. جهود السلطنة في قطاع موارد المياه

سعت حكومة سلطنة عُمان منذ تفاقم أزمة المياه بوضع حلول ملموسة وسريعة ومستدامة لقطاع المياه، فمع إصدار المراسيم السلطانية بإنشاء الوزارات والهيئات التي تعنى بقطاع المياه صاحبها إصدار التشريعات واللوائح التي وضعتها الحكومة في الحفاظ على الثروة المائية، وحماية المصادر المائية من التلوث، وتحسين وتطوير أنظمة الأفلاج وذلك بصيانة الأفلاج وتحسين أنظمة الري بها، تعزيز الأفلاج بآبار مساعدة ، تحديد أحرامات الأفلاج بمنع الحفر والتعميق في محيط التأثير للفلج وتحديد الأنشطة والمنشآت في محيط الفلج ، كما قامت الحكومة خلال السنوات الماضية بدراسات استكشافية مائية متعددة يهدف إلى تقييم الطبقات الجيولوجية الحاملة للمياه والخزانات الجوفية المختلفة وذلك من اجل تقييم مدى امتداد تلك الخزانات وطرق الاستفادة منها، بالإضافة إلى حجم المخزون الجوفي ونوعية الطبقات الحاملة ونوعية المياه فيها نتج عن ذلك إكتشاف خزانات جوفية إستراتيجية، وإعداد الدراسات الهيدرولوجية للتعرف على نمط الهطول المطري ومعدلات تدفقات الأودية، إضافة إلى حساب النمط التكراري للأمطار وتحديد الفترات المطيرة وفترات الجفاف، وإعداد الدراسات المتعلقة بأخطار الفيضانات وتوجيه المختصين لشئون التنمية العمرانية الى الاهتمام بتوفير التصاريف الخاصة بالفيضانات من أجل السلامة العامة والتخطيط السليم للمدن. والقيام بالبحوث والدراسات المائية ومتابعة ما يستجد منها على الساحة العالمية والاستفادة منها بالسلطنة . وتضمنت خطة الحكومة التوسع في مشروعات تجميع مياه الصرف ومعالجتها بإنشاء محطات معالجة مياه الصرف الصحي بالمحافظات بحيث يمكن توفير كميات من المياه المعالجة للاستفادة منها في بعض أنواع الزراعات وتغذية الخزانات الجوفية وبعض الاستخدامات البلدية. وتفعيل دور التوعية والإعلام بتعظيم دور مستخدمي المياه بتعريفهم بأهمية المياه كثروة وطنية وذلك من خلال البرامج التوعوية التي تساهم في رفع وعي المجتمع ، ومن أهم الجهود المبذولة من حكومة سلطنة عُمان في قطاع الموارد المائية ما يلي:

أ. إنشاء شبكة رصد ومراقبة الموارد المائية

تعتمد إدارة وتنمية الموارد المائية بصفة أساسية على البيانات والمعلومات الهيدرولوجية والمائية المتوفرة ، لذلك سعت الحكومة جاهدة على إنشاء شبكة رصد هيدرومترية تغطي كافة محافظات السلطنة. وترتكز إستراتيجية مراقبة الموارد المائية على عدة محاور هي توفير البيانات المائية الهيدرولوجية لكافة الأحواض المائية بمناطق السلطنة المختلفة من خلال مراقبتها الدورية والعمل على تحديثها في قاعدة بيانات متكاملة، بالإضافة إلى القدرة على تحديد المناطق التي تتعرض لنقص في مواردها المائية وإيجاد الحلول السريعة لمواجهة مثل هذه المشاكل . وتتكون شبكة مراقبة الرصد الهيدرومترية بالسلطنة من حوالي 4692 نقطة مراقبة موزعة على مختلف محافظات السلطنة (جدول 2).

جدول (2): يوضح عدد ونوع نقاط المراقبة بشبكة الرصد الهيدرومترية بسلطنة عُمان

	محطات الأودية	ذروة التدفق	السدود	محطات الأمطار: عادية	محطات الأمطار: أوتوماتيكية	قياسات الآبار	الأفلاج	العيون	الخيران	تصريف الآبار	الملوحة: بئر	الملوحة: فلج	المجموع
المجموع	١٣٥	٣٦	٤٢	٧٩	٢٣٦	٢١٠٧	٥٢٤	٦٤	١١	١٧٩	٧٠٦	٥٨٣	٤٦٩٢
				٣١٥							١٢٨٩		

وسعت الحكومة مؤخراً إلى تحديث وتوسيع شبكة مراقبة الموارد المائية وذلك بإستخدام تقنية المراقبة عن بعد وذلك بربطها بنظام الأتصال عن طريق تقنية GPRS بهدف الحصول على البيانات من المحطات آنيه مما يقلل الجهد والوقت، ويصاحبها إستخدام نماذج رياضية لمحاكاة أنظمة الأودية، كما سعت لتحديث قاعدة بيانات المائية وطرح برنامج لمتخذ القرار يربط البيانات المائية وتقييم الوضع المائي، ويصاحب ذلك إعداد برامج تدريب فنية وتأهيلية لرفع كفاءة الموظفين بما يخدم تنفيذ إستراتيجية مراقبة المائية.

ب. التقليل من المياه المفقودة التي تضيع هدراً في البحر أو الصحراء

وتعتمد الفكرة على إعتراض وأحتجاز بعض المياه السطحية والمياه تحت السطحية التي تضيع هدراً وذلك بغرض زيادة كمية المياه المتاحة من الموارد المائية المتجددة. وذلك بإقامة سدود احتجاز أو سدود تخزين أو حقول آبار للاستفادة من المياه قبل ضياعها ، ويأتي دور سدود التغذية الجوفية في تعزيز الخزانات الجوفية والاستفادة من المياه عوضاً عن ذهابها هدراً إلى البحر أوالصحراء . حيث بلغ عدد سدود التغذية الجوفية التي أنشاتها الوزارة (48 سداً) تربو كميات تلك المياه المحتجزة ببحيرات تلك السدود منذ إنشاءها 2 مليار و400 مليون متر مكعب، كما إنشئت السدود التخزينية وبلغ عددها 120 سداً والتي تساهم بشكل فعال في استقرار أهالي المناطق الجبلية في مناطقهم وعدم الهجرة إلى مناطق أخرى بإعتبارها مصدر دائم لتوفر المياه. وفي عام 2010 م إنشأ أكبر سد مائي بالسلطنة سد وادي ضيقة وهو سد تخزيني يبلغ سعة السد 100 مليون م مكعب والهدف من إنشاء هذا السد إستغلال والإستفادة من مياه فيضانات الوادي التي تفقد في البحر، و المحافظة على الإستهلاك الفعلي للمياه المستخدمة في الزراعة بالقرى والمناطق على مجرى الوادي وأسفل السد، وتوفير مياه الشرب والإستخدامات المنزلية الأخرى لولاية قريات ، وتوفير مورد مائي إستراتيجي لمحافظة مسقط، و حماية للقرى الواقعة على مجرى الوادي من مخاطر الفيضانات.

حالة دراسية: دور سد وادي أمطي في رفع مستويات المياه للآبار والأفلاج والحد من مخاطر السيول بولاية إزكي بمحافظة الداخلية

تعرضت ولاية إزكي بمحافظة الداخلية بوسط سلطنة عُمان إلى فترة عصيبة من فترات الجفاف فقد ماتت المزارع وجفت الآبار وفلج الملكي قد أنخفض منسوبه إلى أدنى مستوياته لا يكفي إلا لمزارع قليلة فعلى الرغم من جريان الأودية عدة مرات على مدار السنة بحكم موقع الولاية الإستراتيجي وسط جبال الحجر ألآ إنها تمر بلا تأثير على المخزون الجوفي نتيجة لعدم وجود حواجز مائية تخزن مياه الأودية والامطار فقد ساهم ذلك في حدوث ازمة جفاف بصورة متكررة خاصة بمركز الولاية.

من صور جفاف بولاية إزكي قبل إنشاء سد أمطي

في عام 2014 أنتهت الوزارة من إنشاء سد على مجرى وادي إمطي أحد روافد مستجمع وادي حلفين المائي والذي تقع عليه عدد من القرى والبلدات ، وبه عدد من الأفلاج من أهمها فلج الملكي **الذي سجل ضمن التراث العالمي** ، السعة الكلية للسد

(0.630 مليون متر مكعب) ونتيجة لأمطار عام 2015 م أحتجز السد 2,125 مليون متر مكعب وقد أمتلأ مرتين متتاليتين في عام 2016م . وعن إجراءات السلامة خصوصا مع إمتلأ السد فالسد مزوّد بمفيض خرساني كبير لتصريف المياه الزائدة إلى حوض التهدئة الذي بدوره يمررها إلى مجرى الوادي لتنساب بصورة طبيعية في مجرى الوادي الرئيسي.

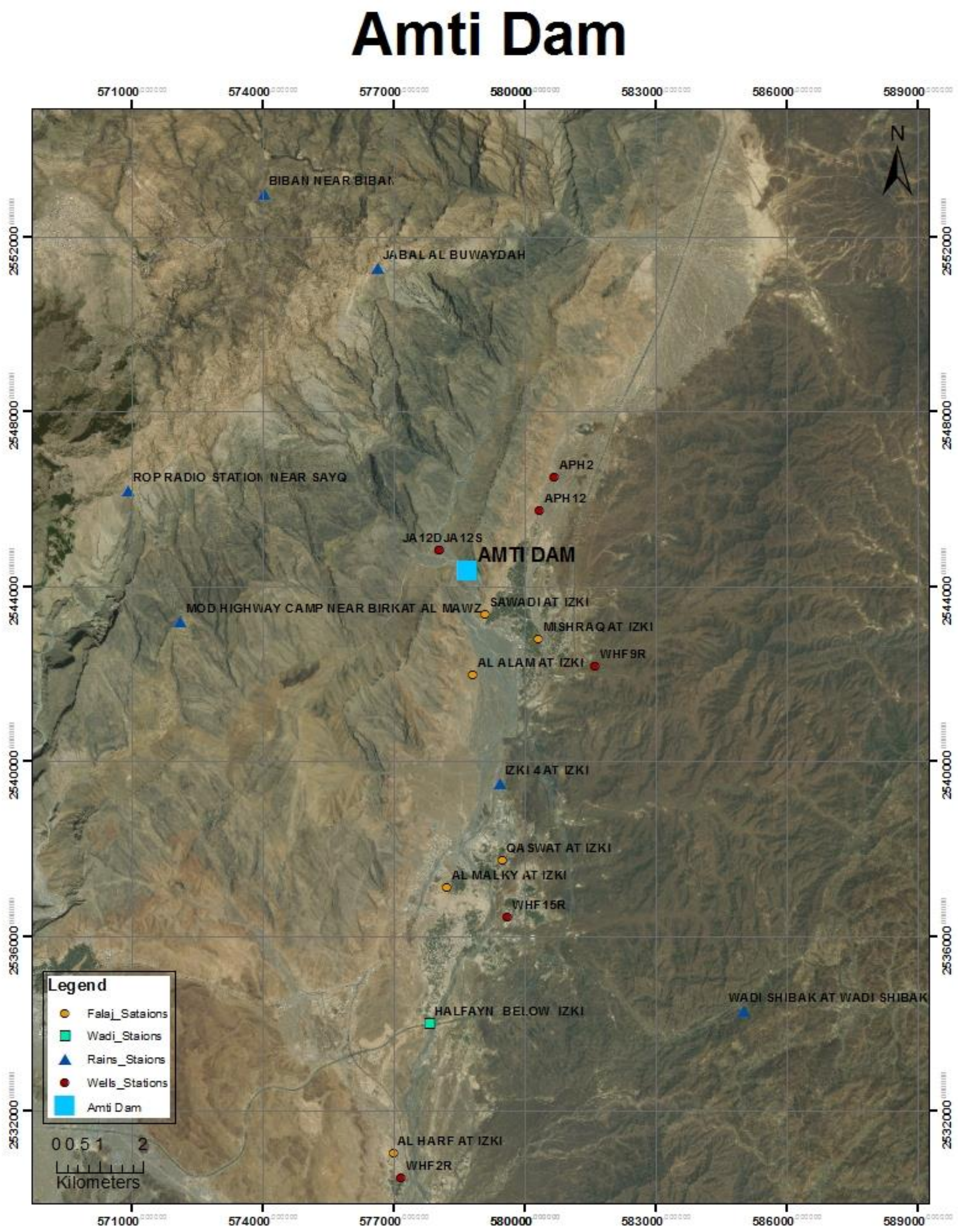
جدول رقم (3): المواصفات الفنية لسد أمطي للتغذية الجوفية بولاية إزكي

Dam	Coordinates		Capacity	Length
	East	North	Million/m3	m
Imti	578672	2544359	0.63	145
Length of spillway m	Max Height m	No# Outlet	Spillway type	Year implementation
100	17.5	1	Concrete Weir	2014


صورة توضح سد وادي أمطي وأمتلائه وجريان المياه في قناة التصريف أسفل السد

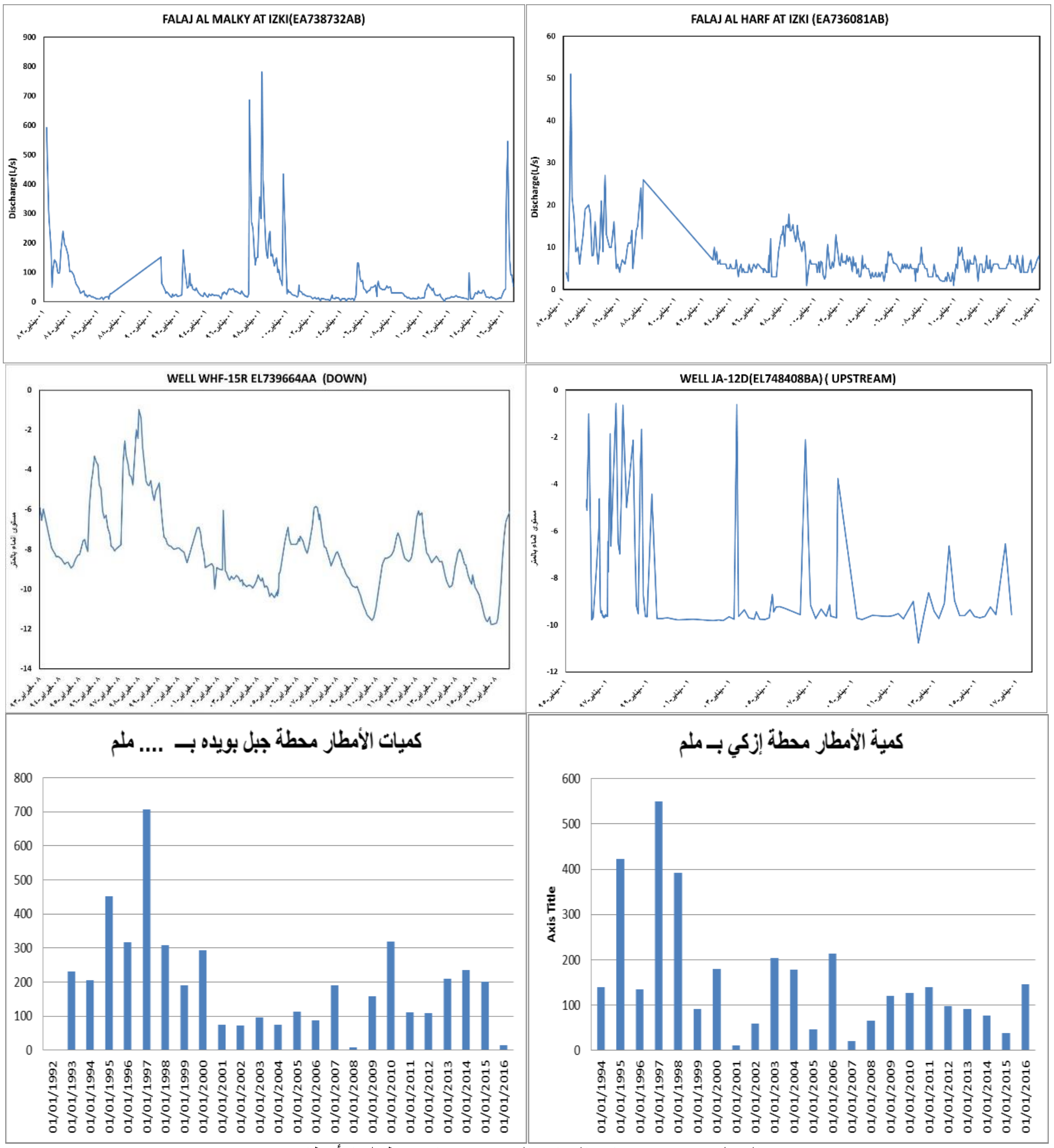

صورة تبين أرتفاع منسوب المياه بقرية أمطي أسفل سد أمطي

بيانات شبكة محطات مراقبة الموارد المائية بولاية إزكي بمنطقة السد



خارطة (2): نقاط مراقبة الموارد المائية بمنطقة سد أمطي بولاية إزكي

نقاط المراقبة في منطقة ســـد أمطي عبارة عن (7 آبار) لقياس مســـتويات المياه و (7 أفلاج) لقياس جريان الأفلاج و (6 محطات) لقياس كميات هطول الأمطار ومحطة واحدة لقياس تدفق الأودية. عند مقارنة البيانات التاريخية لنقاط المراقبة قبل وبعد إنشاء السد من خلال رسومات البيانية نلاحظ ما يلي:



الشكل (5): مستويات المياه والتدفق وكميات هطول الأمطار

النتائج

من البيانات الهيدرولوجية لمحطات الأمطار وآبار مراقبة مستويات المياه الجوفية وجريان الأفلاج ببلدة امطي بولاية إزكي يتضح أن بيانات محطات قياس كميات هطول الأمطار في عامي 2015 و 2016م مقارنة بالسنوات الماضية شهدت المنطقة ارتفاع مستويات المياه الجوفية بصورة كبيرة بلغت (11) متر في بعض آبار المراقبة كذلك الحال وفي نفس الفترة زاد تدفق فلج اللمكي أكبر أفلاج الولاية والذي يقع أدنى سد وادي أمطي ليرتفع من (11 لتر بالثانية) إلى (562 لتر بالثانية) حيث احتجز سد وادي أمطي كمية من المياه بلغت (2.15) مليون متر مكعب خلال عام وهو ما أدى إلى تغذية المخزون الجوفي. وبهذا يتضح أن سد وادي أمطي للتغذية الجوفية بولاية إزكي قد ساهم في زيادة المخزون الجوفي وإبقاءه بصورة مستقرة بصفة عامة وبالتالي ارتفاع مستويات المياه الجوفية بأمهات الأفلاج الداؤودية خاصة تلك الواقعة أدنى بحيرة السد كمأ أرتفع مستويات المياه بآبار المواطنين رغم ان المنطقة لم تشهد كميات أمطار كبيرة مقارنة بالسنوات الماضية، والتي كانت تسجل كميات أمطار عالية مع عدم وجود تحسن مستمر بمستويات المياه، حيث لا تلبث أن تعود للإنخفاض بعد مرور الأودية، وهذا ما تغير معه الحال بالوقت الحالي. كما ساهم سد وادي أمطي بحماية المنطقة السكنية الجديدة الواقعة أسفل السد والمنازل التي أنشئت على ضفاف الوادي، كما سهل للقاطنين بالمنطقة سهولة الحركة بالطرق التي كانت تقطع وتمنع حركة المرور بعد كل فيضان.

التوصيات

إن مناخ السلطنة الجاف وندرة توافر المياه العذبة يجعل الاهتمام بالموارد المائية سواء السطحية أو الجوفية أمراً أساسياً. وهذا

الأمر لا يمكن تحقيقه بدون توفر بيانات دقيقة ولفترات زمنية طويلة عن هذه الموارد، ونظراً للتطور السريع الذي شهدته السلطنة خلال العقود الخمسة الماضية في كافة المجالات فأن على حكومة سلطنة عُمان العمل على توسيع شبكة المراقبة لتوفير بيانات هيدرولوجية تكون قادرة على مواكبة هذا التطور السريع لكافة الأحواض المائية بمناطق السلطنة المختلفة من خلال مراقبتها الدورية والعمل على تحديثها في قاعدة بيانات متكاملة والإستمرار بتوسع وزيادة نقاط المراقبة وتحديث الأجهزة الفنية المستخدمة بالمحطات . بالإضافة إلى القدرة على تحديد المناطق التي تتعرض لنقص في مواردها المائية وإيجاد الحلول السريعة لمواجهة مثل هذه المشاكل وتأهيل وتدريب ورفع كفاءة الكوادر العُمانية لإدارة وتشغيل وصيانة الشبكة الوطنية الهيدرومترية .

وتعتبر السدود من المنشآت المائية الحيوية في السلطنة والتي لعبت دوراً هاماً في تنمية الموارد المائية بالسلطنة وبالتالي أثبتت جدواها على مر الأيام ويجب زيادتها . حيث أظهرت المؤشرات إلى تحسن كمي ونوعي واضح في الموارد المائية في بعض المناطق خلال السنوات الماضية عن طريق المياه التي احتجزتها سدود التغذية الجوفية والتي تغلغلت إلى المكامن الجوفية. كما أدت سدود التخزين السطحي في المناطق الجبلية النائية إلى توفير المياه إلى قاطني تلك المناطق وبالتالي استقرارهم في أماكنهم وتنمية القطاعات الزراعية والحيوانية لتلك المجتمعات.
الجدير بالذكر أن السلطنة قطعت شوطاً كبيراً في مجال إدارة الموارد المائية لإيجاد التوازن بين العرض والطلب من المياه إلا أن موقع السلطنة ضمن البلدان الجافة وشبه الجافة واعتمادها على الأمطار السنوية لتغذية الموارد المائية المحدودة وتنامي الطلب على المياه يمثل تحدياً لقطاع المياه. وهو ما يتطلب إدارة الموارد المائية المتوفرة والمستخدمة في المجال الزراعي (83 % من إجمالي الاستخدامات) بحيث يمكن تطبيق سياسات إدارة الطلب علي المياه وتقليل الفاقد من المياه بهدف سد العجز في الميزان المائي للسلطنة. وعدم زيادته لمواجهة الزيادة المتوقعة في استخدامات المياه للأغراض الصناعية والتجارية والسياحية. لذلك فمن الضروري الاستمرار في تطبيق سياسات عدم التوسع في استحداث أراضي زراعية جديدة خاصة في المناطق التي تعاني من عجز مائي، وتطبيق سياسات الإدارة المتكاملة للمياه في المستجمعات المائية المختلفة بالإضافة إلى التوسع في زيادة الاستثمارات في مجالات توفير مياه غير تقليدية (محطات التحلية ومحطات معالجة مياه الصرف الصحي) وإنشاء السدود.

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Hydraulic Engineering Tools to Model Flood Events and Water Intakes

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Abstract
The semi-arid regions the exploitation and storage of water from flash flood characterized streams for deployment in times of low water availability is a special challenge in the context of design and operation of water abstraction and infiltration structures. The large bed load changes the approaching flow. Furthermore, groundwater formation is strongly limited by clogging. The structural design of water withdrawal from such streams is a classical task. The paper focuses on tools to investigate the flow in a watershed, its stream network and corresponding hydraulic structures. The aim is the hydraulic optimization of design and operation of withdrawal structures.

Keywords: Flash Floods, Semi-Arid, Flow Paths, Hydraulic Structures, Sedimentation.

Introduction

Seasonal and short-term precipitation of high intensity is an important source of water availability in arid as well as in semi-arid areas (Baumgartner & Liebscher 1996). Such areas are spread all over the world. Typical examples are localized in Southern Europe (e. g. Central Spain), both Americas (e. g. North-Eastern Brazil, South-West of the USA), Africa (e. g. Sahel zone), Asia (e. g. Arabian Peninsula, Northern China) and Australia (e. g. Queensland) etc. In such arid as well as semi-arid zones flash floods may occur (UNESCO 1999). Rainfall induced flash floods resulting from high-intensity storms are occurring with suddenness including short time to peak flow and may not be forecasted in a reliable manner. For given watersheds the mean frequency of re-occurrence interval may be years or decades and their areal distribution may be considered to be statistically random. In mountainous regions such flash floods may come along with severe transport of sediments and floating material if present (UNESCO 1999). Under these circumstances the fluvial morphology may change significantly within an event resulting in heavily modified flow paths in the stream bed as well as the flood plain. Further on the fine sediments may cause clogging of the stream bed and limit infiltration and thus groundwater recharge from surface runoff.

For the exploitation of flash flood runoff it is necessary to consider the mentioned effects of suddenness, sediment transport and clogging especially in the design and operation of hydraulic structures used for water abstraction and infiltration. In this context elements of the withdrawal structures (e. g. dam size, spillway, bottom outlet) may be designed also for downstream flood and erosion protection. For this as well as for detailed analysis of flow paths, water depths and flood risk quantification flow simulations form the basis for the investigations. Basis for the selection of sites and detailed design of the withdrawal structures, reservoirs and further hydraulic engineering structures are mainly physical or hydrodynamic-numerical (HN-) model investigations. To achieve the aims there is undoubtedly a demand for reliable modelling including especially HN-modelling-approaches is a fundamental method to apply.

Basic methods of hydraulic modelling

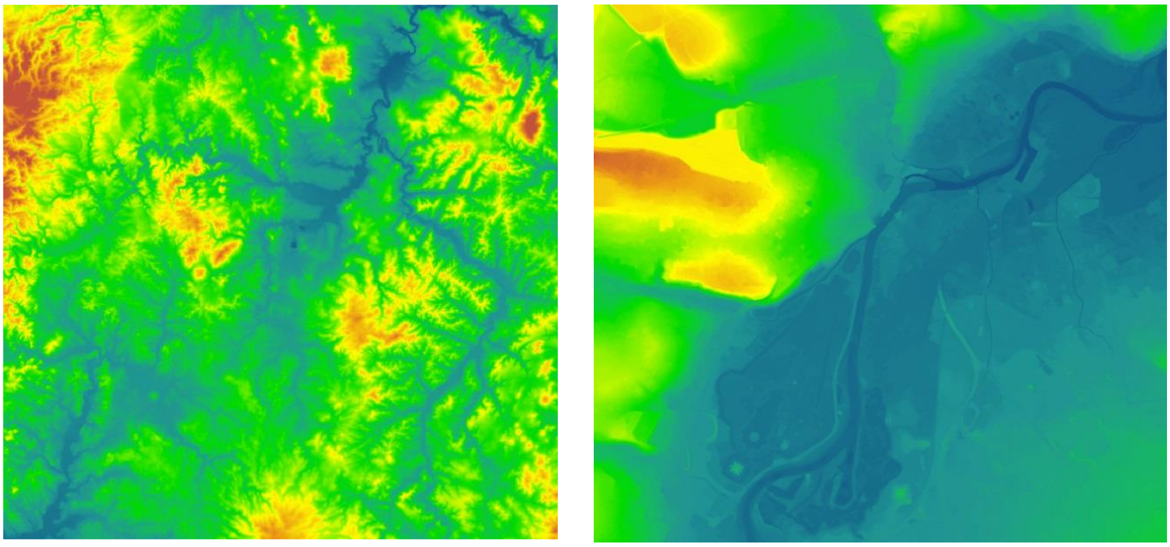
Hydraulic modelling may cover robust analytical approaches, the survey of field situations, physical modelling, hydrodynamic-numerical (HN-) modelling and the most probable a case-appropriate mixture of the mentioned methods. Especially remote sensing field survey methods and physical laboratory models with improved digital measurement devices are of substantial importance as stand-alone-methods as well as in hybrid modelling. Almost all aspects of hydraulic modelling there are continuously enhanced by more and more sophisticated technologies. Nevertheless the main focus of this paper is set to the use of 2D- and 3D-HN-models in finding hydraulic engineering solutions since in engineering practice there still is a rapid increase in the application of such methods in design. However this papers concentration on HN-models does not imply at all that other methods are to be neglected.

HN-models always include the temporal variability of flow processes. They may further be distinguished according to the considered spatial dimensions of flow. The use of HN-models of different spatial regard is widely performed in stream hydraulic investigation. The correct choice of a model to apply on a specific case requires experience in flow hydraulics, approved software and - as far as available - reliable field data. The effects of wall roughness and turbulence may be considered by various approaches and should be carefully cross-checked as far as possible by the use of flow calibration data, comparison to similar cases and experience.

Preparation of extended 2D- and 3D-HN-modelling

In 2D- as well as in 3D-HN-models it is required to introduce the information from stream bathymetry and surface elevation in the watershed. Nowadays remote sensing data is widely available for the use in hydraulic engineering. Where such data is not accessible yet it is strongly recommended to gain these valuable input data before further processing of HN-models for the watershed or the stream networks flood-plains.

To use HN-models to investigate the stream flow for hydraulic engineering purposes there further pre-processing may be needed to achieve a reliable geometry set for the stream bed. This usually has to include the separate definition of break lines which may be rarely executed automatically but still needs a relevant portion of manual work. The result of these preprocessing steps which are commonly provided by the use of Geographical Information Systems (GIS) are cross-checked Digital Elevation Models (DEM).



Left: Watershed (ca. 5000 km²) and stream network

Right: Detailed stream reach (ca. 4 km) including flood-plain and sub-catchments

Figure 16: Results from Digital Elevation Model (DEM) from a watershed and a corresponding stream reach

Data on the geometry of hydraulic structures is taken from any kind of plans like such for design, formworks, implementation or inventory as current as possible. Sometimes older plans are obtainable only in non-digital format and will have to be transformed and aggregated from different sources into a usable digital format. The design and visualization of the hydraulically relevant geometry of hydraulic structures in 3D-HN-models is usually provided by the application of Computer Aided Design (CAD-) methods.

2D-HN-modelling of streamflow and on extended watershed scale
Basic considerations for 2D-HN-modelling

If one out of the three spatial dimensions of flow may be neglected the resulting approach considers the two remaining spatial besides the temporal dimension. Typical 2D-HN-modelling in flash flood investigation may cover shallow water flow when the vertical flow velocity may be neglected in relation to the horizontal flow components in longitudinal as well as lateral flow direction.

2D-HN-models are especially valuable by identifying flood flow paths in flood plains. In the field of flood risk management such models are commonly used since their results simultaneously cover flow depth, direction and velocity in streams beds and flood plains (Figure 17).

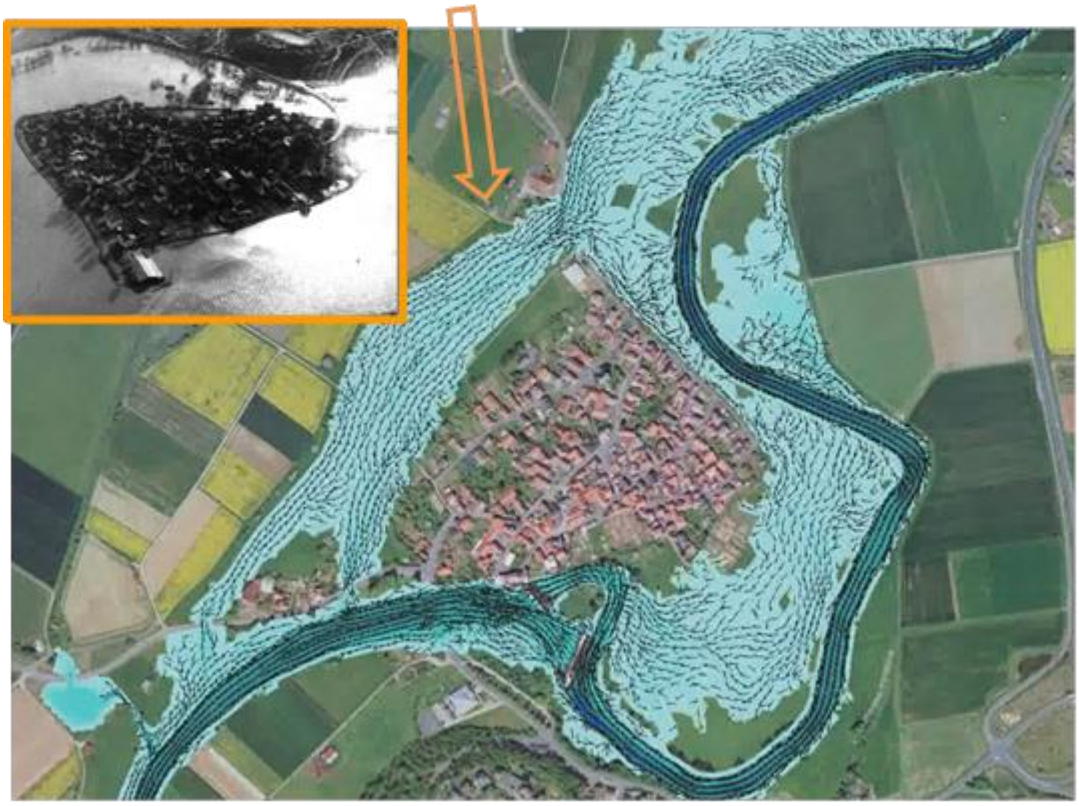
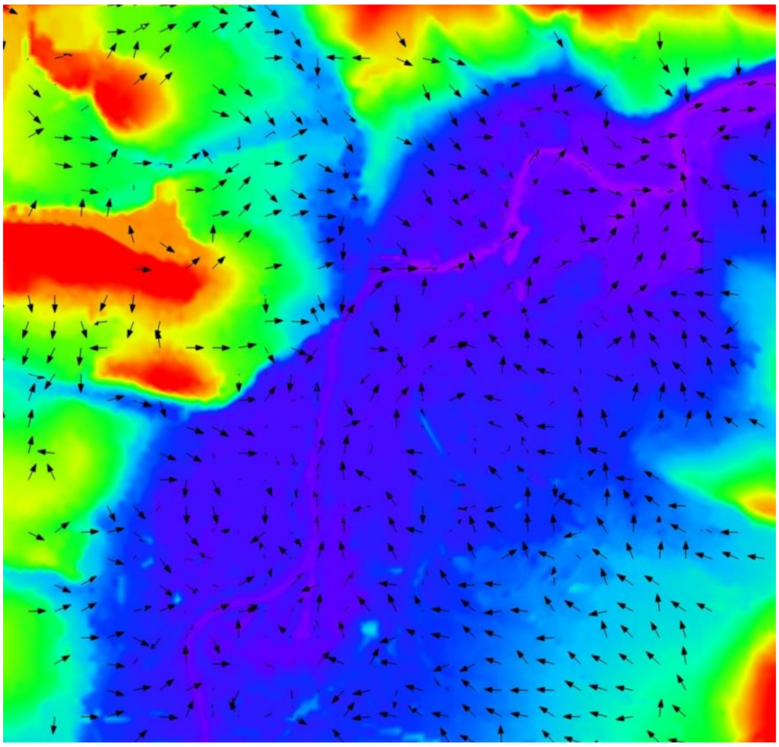


Figure 17: 2D-Floodflow in in different channels, example here is flow path analysis for a stream and its flood plain and a corresponding aerial photograph

Watershed extension approach

A common method to investigate the flow paths in landscapes is the GIS-based analysis of a DEM (Digital elevation Map) to identify the watershed area for selected topographical point and merge this to the stream network. Such an approach does not include the hydraulic effects in the stream network on the hydrological flow curve and usually has to be accompanied by a subsequent step of hydrological modelling of a water sheds sub basins and corresponding streams. 2D-HN-methods in stream hydraulics offer an alternative approach to investigate the watersheds hydrological characteristics including the hydraulic properties of the stream network and surface flow paths (Rötz 2016) including flow depth, flow velocity and corresponding travel times of flash floods (Figure 18). Further on the method may be employed to consider the hydraulic effects on peak flow discharge and the temporal development of a flash flood event. Typical examples of such effects are rainfall respectively discharge depending flow travel times along the stream network inside the water shed or the temporal flow retention in flood plains.



Corresponding DEM see Figure 16: right hand side

Figure 18: 2D-Flow in stream reach and corresponding flood-plain including surrounding catchment surface flows

Since flash floods occur with suddenness, low probabilities and spatial randomness there usually is rare availability of reliable measured data. This commonly is non-satisfactory according to model calibration and verification and requires a modelling approach which allows to study a wide range of simulations to investigate the sensitivity of the results in dependence on input parameters, Obviously 2D-HN-models are a robust and not to computation-time-consuming approach to realize this.

3D-HN-modelling in streamflow at hydraulic structures

Basic considerations for 3D-HN-modelling

3D-HN-models are the most complete approaches which account for all three spatial dimensions of flow. This kind of model is the most costly method in terms of model implementation due to the meshing efforts and model operation because of computation time required. Particularly the choice of an appropriate turbulence model (Ferziger & Peric 2002) may need special attention and might have to be confirmed by varying the model according to its sensitivity on the calculation results achieved.

3D-HN-modelling is usually applied for complicated geometries resulting in relevant three-dimensional flow patterns in the vicinity of hydraulic structures e. g. the approaching flow at hydropower stations water intakes (Figure 19). Other purposes are the investigation of secondary flow patterns induced from relevant curvature or flow separation. Particularly the latter are relevant for the hydraulic design of water withdrawal structures to identify flow zones prone to special phenomena of sediment transport and fluvial morphology like erosion, sedimentation, clogging or channel shifting.

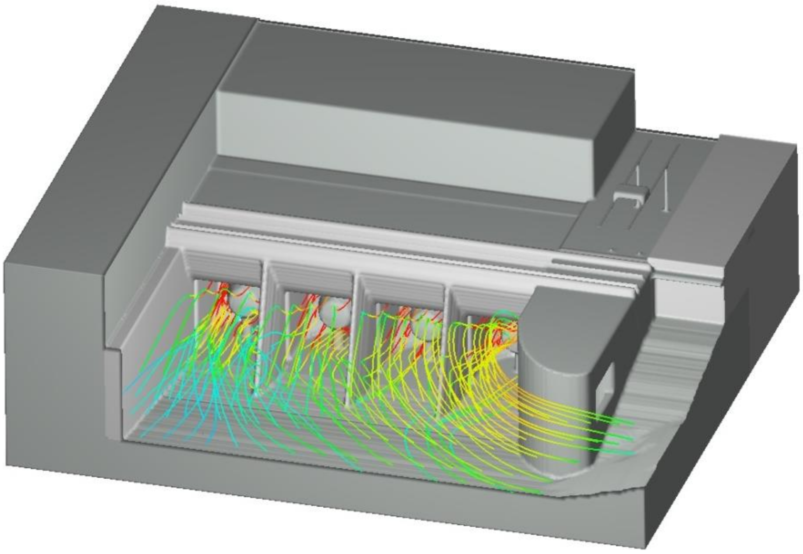


Figure 19: 3D-Flow in the vicinity of water intake structure, example here is hydropower inlet

3D HN-modelling in the context of flash flood exposed hydraulic structures

In the vicinity of hydraulic structures the flow properties are dominated by the manmade geometry and its modifications during operation. Especially water intakes from flash floods may suffer severely from design errors which may easily be avoided if the flow situation would be investigated in a 3D-HN or a physical model. Since the events are very random in space and time it is not only a promising but necessary approach to investigate such ideas first in 3D-HN- or physical models.

Since the reliability of design and operation of water withdrawal is a common task it is possible to use the wide experience that is available on this topic. Concepts have to be developed and examined which take advantage from the long term non-operation in flash flood dominated streams by getting prepared for the next water harvesting event e. g. by arranging withdrawal facilities for proper operation. This will have to be tested and further on developed using modelling methods rather than construct such facilities and evaluate them under very random conditions of natural events.

Conclusion

The proposed application of robust and efficient HN-modelling was experimentally applied on 2D-approaches to watersheds of several hundred km² drainage area as well as by 3D-approaches to small scale flow situations in the vicinity of hydraulic structures. Flash flood modelling will increasingly benefit from continuously declining costs for computational power. Thus the application of HN-models will offer the opportunity for the in-depth-investigation of watersheds and hydraulic structures through studies of variants of rainfall, stream networks and corresponding hydraulic structures e. g. for water harvesting. Nevertheless modelling may always be improved by the use of field data which has to be measured during the spatial and temporal very random events. So besides the use of HN- and physical models it will still be necessary to collect field data. This is also essential to consider future challenges like climate change.

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A Tunisian Strategy of Water Resources Mobilization Evaluation of Water Erosion Risk in Tunisian Semi-Arid (Case of Watershed El Gouazine)

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Abstract
Soil erosion is a serious threat for the agropedological heritage. Water erosion affects, in Tunisia, nearly 3 million hectares of agricultural land, and constitutes a threat to the sustainability of small lakes in the hilly regions. Indeed, this phenomenon is answered in central Tunisia, particularly in this study area of watershed "El Gouazine" that contains several favorable conditions for its release because of the semi-arid Mediterranean climate and its physical characteristics and specific anthropogenic. The objective of this study is to determinate and applicate a quantitative methodology to evaluate water erosion in El Gouazine watershed. In addition, we are conceived to develop the erosion map using Geographic Information Systems (GIS) to properly plan the management actions to protect priority areas from the erosion risk.
Application RUSLE approach's combines the main factors of erosion adapted according to the Tunisian conditions based on the principle of the combination of its main factors related to the natural environment and equipped. To attend this point, the layering on rainfall, soils, topography, vegetation cover and management, provides synthetic card distribution rate to erosion (in t/ha/year). From the results, it can be concluded that the hilly lake is characterized by low erosion with siltation rate1.8 t/ha/year. The evolution of water and soil conservation works has led to a remarkable reduction in soil loss of about 50% at the El Gouazine basin which proves the effectiveness of erosion developments since 1996.

Keywords: RUSLE, Erosion Risk, Water Erosion, GIS, and Tunisia.

Introduction

In Tunisia, during the past two decades, the lakes hillside reservoirs occupy a major place in the national strategies for the Water and Soils Conservation (WSC). In addition to their role of the environment protection, the lakes hillside reservoirs appear as local reserves of water available for agriculture. Nevertheless, these hydraulic infrastructures are quite sensitive to sedimentation because of solid inputs (Hajji *et al.*, 2014). Water erosion affects almost 3 million hectares of agricultural soils in Tunisia, and constitutes a threat to the sustainability of hillside reservoirs intended to mobilize the surface waters; or the dominant economic activity remains agriculture. Therefore, the methods of control are necessary, in order to ensure a sustainable management of soils and secure the agricultural productions. Several studies have been made in the framework of the Water and Soils Conservation (WSC), by resorting to the modeling of the erosion which has become a necessity for the hydrologists in order to be able to limit the areas to major risk and seek appropriate solutions. In this context, this study aims to use the equations RUSLE integrated under a Geographic Information System (GIS) in order to quantify and map the water erosion at the catchment level of El Gouazine.

Material and methodology

After Tahiri *et al.* (2014), multiple equations have been established to link the factors of erosion between them and quantify the losses of soil: Universal Soil Loss Equation (USLE) of Wischmeier and Smith (1978), Water Erosion Prediction Project (WEPP) of Flanagan and Nearing (1995), Soil and Water Assessment Tool (SWAT) of Arnold *et al.* (1998), European Soil Erosion Model (EUROSEM) of Morgan *et al.* (1998). RUSLE (Renard *et al.,* 1997) is an empirical model of the revised USLE equation of Wischmeier and Smith (1978). It is designed for use at the scale of the plot. The RUSLE model allows you to predict the average annual rate of soil erosion of a site of interest for scenarios involving systems of culture, management techniques and practices to control erosion (Custody and Kathyari, 1990).

RUSLE calculates the average erosion expected annual on the slopes by multiplying several factors came together: the aggressiveness of acid (R), the erodibilite soil (K), the slope and length of the slope (LS), vegetation cover (C), and the conservation tillage practices (P).

The values of these factors are determined from measurements of field and laboratory (Renard *et al.,* 1997). The Sedimentation model is based on the results of the RUSLE model to calculate the balance sheet of the erosion in each field elementary. It uses of homogeneous polygons resulting from the calculation of the RUSLE model to assess the net movement of the soil (erosion or deposition) in plots or sub-watersheds (Lewis *et al.*, 2005, El Garouani *et al.,* 2010). It also requires the digital terrain model (MNT) and represents an extension of the incorporation of RUSLE in a framework of GIS (Lewis *et al.*, 2005).

Study Area- El Gouazine Watershed

The catchment area of Lake El Gouazine is about 17.08 km^2. It belongs to the catchment area of the Nebhana in semi-arid Tunisia central (figure 1). It belongs to the syncline and is constituted by marls of intercalated calcareous bars the Lutetien Bartonien. These bars lime have a strong dip. The upstream portion of the watershed is overcome by calcareous crusts sub-horizontal. The interfluves floors calci-magnesic to limestone crust more or less endured; whereas the valleys floors little advanced (Hajji O., 2016).

The land varies from a covered semi-forest plots in the totally devoted to agricultural activity: 32.1 % for the cereal crops in alternations with of fallow land, 35 % for degraded forest and 11.02 per cent the dense forests, 2.1 % for the journey, 4.12 % for the scrublands (carob, lentisks) and the grassy steppe to Alfa, 3.44 % for the arboriculture (olive trees and almond trees), 3 % for the gullies deep and 4 % for the mixed units.

A small dam was built at the outlet of the basin in 1990; the bed of the river and the hilly lake occupy 1.6 % of the surface area. 40% of the area has been landscaped in front benches contours in 1996 and 1997. This development relates to the land of cereal crops and orchards (Mansouri, 2001).

The climate is of the Mediterranean type semi-arid with a hot season of summer and a fresh season of winter. The continentally and terrain accentuate the contrasts thermal and the drought of the summer. The rainfall is on average 400 mm but is experiencing a very high variability space and time. During the observation period (1994 to 2004) the annual rainfall varies from 253 mm to 577 mm. The coordinates of the lake are 35°54'30" in the North, 9°42'13" in the Est. The altitude varies from 383 to 586 m. The index of slope is 11.75 m/km.

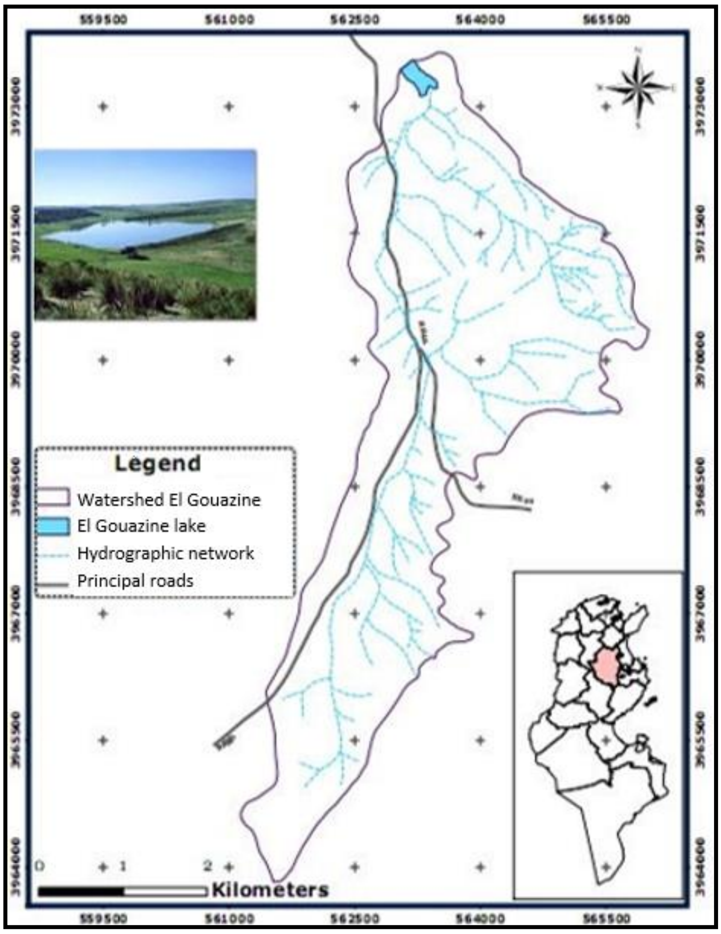

Figure 1: Location map of the study area

The main hydrologic characteristics of the watershed and from its reservoir downstream are listed in the table below.

Table 1: Hydrologic characteristics of El Gouazine

Characteristics of the catchment		**Characteristics of the reservoir**	
Area (ha)	1708	Year of construction	1990
Perimeter P (Km)	26.69	Volume to the spill Vi (m^3)	237030
Index of compactness Ic	1.8	The Surface spill As (ha)	9.597
Length of the rectangle L(km)	11.91	Report Vi/As	2.47
Width of the rectangle l(km)	1.41	Height of the dike (m)	10.63
Maximum Altitude Hmax (m)	590	Length of the dike (m)	232
Minimum Altitude Hmin (m)	383	Nature of the weir	Concrete, trapezoid
Index of slope Ig (m/km)	11.75	Spout height (m)	8.28
Specific Rapids Dsp (m)	48.57	Width of the spillway (m)	20.6

Description of erosion factors

To evaluate water erosion in El Gouazine catchment, empirical models of erosion prediction has been established which the revised universal soil loss equation (RUSLE) developed by Fox *et al.* in 1991.

This model has been integrated under a geographic information system (GIS) in order to quantify and map the risk of water erosion at the watershed level cited in the smokescreen. The digitizations of maps, the analysis, the combination of data and modeling have been carried out using GIS.

Factor of rainfall aggressiveness (R)
The index of aggressiveness takes into account the interactions between the height, the intensity and duration of the rains on the solid transport over a long period (Brown *et al.,* 1987). This climate index is calculated, for a heavy downpour, and is cumulative per episode, per month, or per season. The climatic erosivity of rainfall is considered constant for the whole river basin that is to say it has not used a layer of this factor under a GIS, but it was considered a single value.

Factor of rainfall erosivity R according to RUSLE
R monthly (of Arnoldous 1980): R is called factor rain or index of rain erosivity. The factor R can be defined as the potential capacity of the rain to produce erosion. This potential capacity is often attributed to its physical characteristics to know the quantity, intensity, the dimension of the rain drops, the distribution size of these drops and the speed of the fall which are connected between them.

In fact, several methods are presented for the determination of the factor R in which the one cited in the table below:

Table 2: Factor of rainfall erosivity (R)

Case	**Reference**	**R and P or F relationship**
Case I	Arnoldus-linear (1980)	R= (4.17F-152) /17.02
Case II	Arnoldus (1980)	R= 4.17F - 152
Case III	YU AND Rosewall (1996)	R=3. 82 F1.41
Case IV	Arnoldus-Exponential (1977)	R = 0,302 F1.93
Case V	Renald and FREIMUN -F (1994)	R= 0.739F1.847
Case VI	Renald and Freimun (1994)	R=0.0483 P1.61
Case VII	Roose (1994)	R=P * 0.5
Case VIII	Kassam & al. (1992)	R=117.6 (1.00105^{MAR}) for MAR< 2000mm
Acc IX	Singh & al. (1981)	R = 79+ 0,363 F

Or:

- F: index of Fournier.
- P: annual precipitation.
- MAR: precipitation annual average.
- R: factor of rainfall erosivity.

In reality, it has not used a layer of this factor under a GIS, but it was considered a single value for the entire watershed.
The factor of rainfall erosivity is calculated from several formulas proposed by Weischmeir and Smith (1970), and then by the method of Arnoldus (1980) based on the monthly precipitation or of the index of Fournier.
To calculate this factor, we used the data of the monthly of the rain, and the annual rainfall by using the formula of Arnoldus (1980) which is presented in the form:

$$log\ R = 1.47 * log\left(\frac{Pi^2}{P}\right) + 1.29$$

- R: rainfall erosivity in (MJ/ha.mm/h)
- Pi: rain's monthly i (mm)
- P: annual rainfall (mm)

The data used in this work are from the direction of water resources (1994-2009).

R (15 min) and R (30 min) of RUSLE

This factor is calculated using the data from the instantaneous rainfall which gives the values of cumulative rains every 15 minutes in the same manner for R (30) which presents the values of cumulative rains every 30 minutes. The data used are from the database DGACTA/IRD. This index takes into account the three conditions: energy, intensity of peak and duration of rain. E is a function of:

- The kinetic energy of the rain E.
- Maximum intensity of the rain in duration of 15 minutes I_{15} or 30 minutes at I_{30}.

The R value adopted in the equation of RUSLE is the average of those subpoenaed during a hydrologic year during a multi-year period representative:

$$R = (EI)_{15} = \sum_{j=i}^{n} I_{15j} \left[\sum_{i=1}^{m} (\Delta hij, i) E_{i,j} \right]$$

Has each not of time, measure the height rushed and the kinetic energy (E_i) generated in (MJ/ha.mm) depending on the intensity of precipitation (I) in (mm/h). In the equation of RUSLE, the kinetic energy, for each interval of uniform intensity in the downpour, is given by the following formula:

$$E_i = 0{,}29 * \left[1 - 0{,}72 e^{(-0.05I)}\right]$$

With:

- *I:* Intensity of rain in mm/h.
- *Ei* : kinetic energy of a amounted-phase.
- *Δhi:* height of the amounted phase in mm.

Factor of soil erodibility also occur throughout the ground (K)

The card of the factor K is obtained from the soil map (agricultural map, 2000). A bibliographic study allows us to determine the values of the factor soil erodibility also occur throughout K of each soil unit of the watershed as shown in the following table:

Table 3: Factor soil erodibility also occur throughout K (reported by Cormary, 1964).

Pedological Units	Index K (RUSLE)
Complex of sol	0.05
Rendzines	0.013
Soil raw minerals	0.036
Vertisols	0.01
Little Soil advanced to contribution	0.08

Factor of vegetation cover C

The spatial distribution map of the vegetation cover factor is obtained directly from the card of occupation of the soil made from satellite images from Google Earth. In fact, the indices of C deductions are chosen in referring to:

- The work of Cormary and Masson (1971) in Tunisia,
- The applications of the RUSLE model, especially on the hilly lake Abdessaddok (Zante *et al.*, 2003).

The values of the factor C obtained are represented in the following table:

Table 4: Factor of the vegetation cover C (reported by Masson (1971) & Zante and al. (2003))

Occupation	C (RUSLE)
Dense Forest	0.01
Degraded Forest	0.05
Annual Crop	0.7
Olive Trees	0.104
Journey	0.55

Garrigues	0.3
Mixed Unit	0.37
Vivid Gullies	0

Factor practices of anti-erosive P

This factor reflects the effects of practices that reduce the amount of runoff water and the runoff rate and which reduce to this fact the importance of erosion.

The protection index P used in the USLE model is a report without dimension obtained by comparison of erosion measured on plots where the work is done in the direction of the greatest slope (P= 1) and the erosion of plots variously protected and or P<1, all other factors being equal.

The practices anti-erosive the most used at the watershed of El Gouazine are the benches. The indexing of this factor is derived primarily from experimental results of Masson (1971), Heusch (1970) in Mediterranean area as well as of various compilations (FAO, 1993, WSC Tunis, 1995).

Table 5: Weighting of the index P according to the slope

Slope (%)	Index P (RUSLE)
0 -5	0.1
5 - 15	0.12
15 - 25	0.16
25 - 35	0.18
> 35	0.28

Topographic Factor handset (LS)

This factor results from the combination of the tilt factor S and length L of slope. The action of the angle of the slope on runoff is amplified by the length of the slope, even if the impact of the latter remains limited. The steep slopes with a fast flow are in general at the origin of major erosion whose importance depends on the geology, of the nature of the soil, and the protection by the vegetation cover. The *LS factor* is a function of the length and the angle of the slopes.

Factor of practices LS according to RUSLE

In the framework of our study, we used the formula developed by Wischmeier and Smith (1978) which has been used by several authors (Vezena and Bonn 2006), Park 200, Rodriguez &Suárez 2010, Toumi 2013).

$$LS = (flowaccumulation * \frac{resolution}{22.1})^m \times (0.065 + 0.0045 * S + 0.0065 * S^2)$$

With: S is the slope (%) and m is a parameter such as:

Table 6: Value of ‘m’ relative to each class of slope

Slope (%)	m
>5	0.5
3-5	0.4
1-3	0.3
<1	0.2

Map of soil loss

The crossing of the cards of the major factors involved in soil erosion by water allows you to get the card of losses in soil at any point in the watershed (Fig 2).

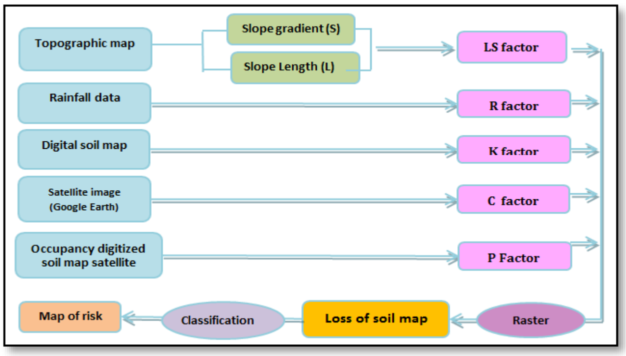

Figure 2: Flowchart methodological

This work has allowed us to characterize the various parameters of the universal equation of the soil loss by consultation of former research and professional studies on the study area. These settings have been distributed on the totality of each watershed. The climatic erosivity of rain is assumed constant throughout the basin for each lake hilly, whereas the other parameters will be presented subsequently in the form of thematic maps (Hajji, 2016).

Assessment of erosion-The application of the RUSLE model

The RUSLE model provided an average estimate of water erosion at the catchment level of El Gouazine at different scales (monthly, 15min and 30 min) mentioned below.

Map of erosion for R (monthly) of Arldous 1980 **-1st scenario: Before the facilities WSC**

The dipped beam maps of factors LS, K, C and P of the RUSLE model with the climatic erosivity of rainfall by the RUSLE model allows you to get the card of losses in soil at any point of the catchment. The results are presented in the following figure:

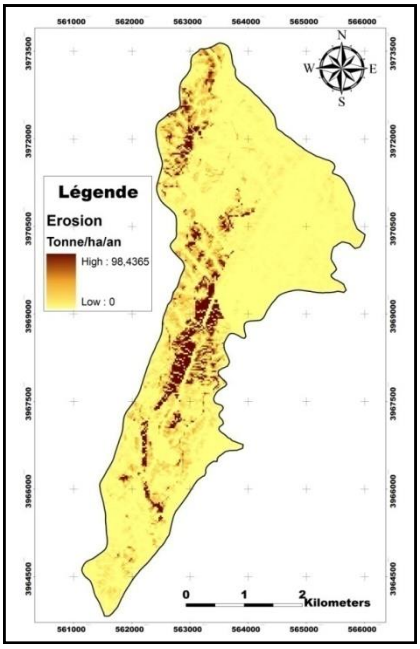

Figure 3: Map of soil loss determined by the model RUSLE R (monthly)

Before the facilities WSC of El Gouazine

The review of the figure above shows that the strong erosion equal to 98.43 t/ha/year is located at the level of highest elevations. While the low erosion (less than 2.5 t/ha/year) is located at the level of areas of low altitude and at the level of the plains. The total losses of the annual basin are of the order of 62730.58 t/year. The average erosion is of the order of 2.38 t/ha/year. The spatial distribution of different classes of soil loss adopted is presented in the following table:

Table 7: Class of soil loss determined by the RUSLE model (R monthly

Class (tonne/ha/year)	Area (ha)	% Surface
0-2.5	1391,8	82.2
2.5 -5	102.55	6.06
5-10	88.3	5.21
10-20	63.6	3.76
20 - 100	47.1	2.78

The table shows that more than 82% of the basin is characterized by a loss of ground low (less than 2.5). While approximately 11 % of the basin have a soil loss average of 2.5 to 10 t/ha/year. While less than 7 % of the basin have a strong loss of soil (greater than 10 t/ha/year).

2nd scenario: After the management WSC

Now we will quantify the rate of erosion on the catchment of El Gouazine after implantation of benches in 1996/1997.

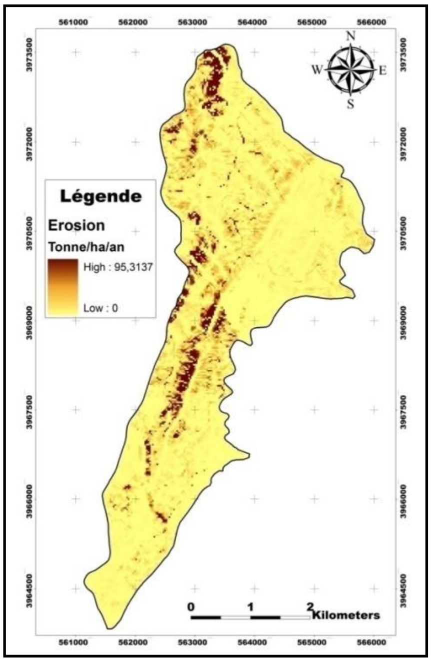

Figure 4: Map of soil loss determined by the model RUSLE R (monthly)

After the management WSC of El Gouazine.

From the figure, above it is found that the average loss by water erosion in tablecloths for all the homogeneous units is approximately 0.86 t/ha/year. The maximum loss and minimum per unit in the watershed are respectively of 95.31 t/ha/year and 0 t/ha/year. The total losses of the annual basin are of 22666.2 t/year. The erosion rate differs from one area to another of the watershed, according to the influence of different factors which control the erosion.

The spatial distribution of different classes of soil loss adopted is presented in the following table:

Table 8: Class of soil loss determined by the RUSLE model (R (monthly)).

Class (tonne/ha/year)	Area (ha)	% Surface
0 2,5	1565,7	92.59
2.5 - 5	60.67	3.59
5 - 10	42.95	2.54
10 - 20	18.58	1.1
20 - 95.31	3.09	0.18

The analysis of the above table shows that more than 92% of the basin is characterized by a loss of ground low (less than 2.5). While approximately 6% of the basin have a soil loss average of 2.5 to 20 t/ha/year. While only 1.28 % of the basin have a strong loss of soil (greater than 20 t/ha/year) after development. By comparing the results obtained by the model RUSLE (R monthly) before the WSC and those obtained by the same model after the WSC management, one finds:

- The total loss of the soil decreases of 62730.58 t/year up to 22666.2 t/year.
- The value the average of the annual erosion decreased from 2.38 t/ha/year (before construction) up to 0.86 t/ha/year (after development), a rate of decline of about 66%; this reflects the effectiveness of these facilities.
- The maximum value of the erosion decreases of 98.43 t/ha/year up to 95.31 t/ha/year.
- While the minimum value remains constant equal to 0 t/ha/year.
- The percentage of surface which contains a strong erosion decreases of 6.54% up to 1.28%, with a decay rate of 80%.
- The percentage of surface which contains a low erosion believes of 82.2% to 92.52%.

Case of the RUSLE model with R (15min)- 1st scenario: Application of the RUSLE model before the WSC management

The dipped beam maps of factors LS, K, C and P of the RUSLE model with the climatic erosivity of rainfall by the RUSLE model at no time of 15 minutes allows you to get the card of losses in soil at any point of the catchment. The following figure illustrates the map of soil loss.

The map of soil loss therefore provides a variety of information concerning the risk of departure of sediment. This information is both quantitative since the results give measures of erosion, expressed in (t/ha/year) for each of the cells of the map, the qualitative result of the allocation of a class of severity of risk and space because of the knowledge of the distribution of the risk of detachment of sediment on the study area. The map of loss in soil has been developed from a classification of erosion rate.

The RUSLE model gives a homogeneous distribution in the polygons more at least uniform. The spatial distribution of soil losses for the whole watershed El Gouazine is very heterogeneous. In effect, the minimum loss in soils is of the order of 0 t/ha/year and the maximum loss is approximately 333 t/ha/year. The total losses of the annual basin are of the order of 212273,4 m^3. The average loss of soils for the whole watershed is of the order of 8.05 t/ha/year.

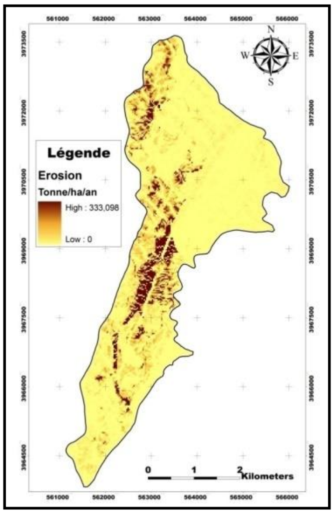

Figure 5: Map of soil loss determined by the RUSLE model (R15min)

Before the WSC management El Gouazine.
The values obtained, despite their apparent heterogeneity, have a spatial structure defined by the location topo-landscape in which they are drawn. The parties of the upstream catchment still suffer an erosion more strong: average values are observed for the slopes; the values the least high are located on the intertidal, in the downstream while depressions and in the alluvial valleys. This last element must be qualified: the downstream concavity is unlike the summits, an area of deposition of sediments and not a zone of erosion (Renard *et al.*, 1997) as evidenced by the filling of gullies of catchment (Revel and *al*, 1990) and the highest thickness of soils in these sectors (Brunet, 1957). The risk map eroding should therefore provide in these places of "negative values of erosion" to include the fact that the sediment is deposited. The method used does not allow us to achieve this type of distinctions or to quantify the proportion of soil likely to remove in these sectors. However, since they appear on the map as low risk of detachment of sediment, the error introduced does not affect the identification of areas to high risk.

The distribution of the surface on the classes of soil loss adopted is presented in the following table:

Table 9: Class of soil loss determined by the RUSLE model (R15min).

Class (tonne/ha/year)	**Area (ha)**	**% Surface**
0 2,5	1169,49	69.1
2.5 - 5	123.4	7.29
5 - 10	109.44	6.47
10 - 20	108.9	6.43
20 - 333	181.4	10.72

From the above table, it can be seen more than 69 per cent of the basin is characterized by a low soil loss (less than 2.5). While approximately 13.76 per cent of the basin have a soil loss average of 2.5 to 10 t/ha/year. While 17.15 % of the basin have a strong soil loss (greater than 10 t/ha/year).

2nd scenario: Application of the RUSLE model after the WSC management:
The results obtained are presented in the following figure:

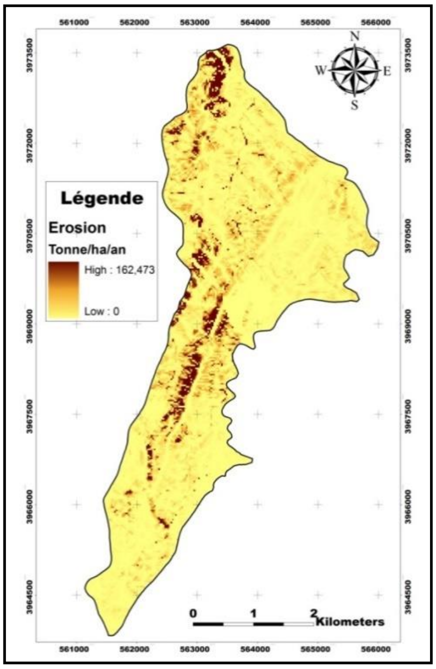

Figure 6: Map of soil loss determined by the RUSLE model (R15min)

After the WSC management of El Gouazine.

The review of the figure above shows that the average loss of soil for the entire catchment area of El Gouazine is of the order of 1.46 t/ha/year. The minimum loss in soils is of the order of 0 t/ha/year and the maximum loss is approximately 162.4 t/ha/year. The total losses of the annual basin are of the order of 38637.22 t /year. The spatial distribution of different classes of soil loss adopted is presented in the following table:

Table 10: Class of soil loss determined by the RUSLE model (R15min).

Class (tonne/ha/year)	**Area (ha)**	**% Surface**
0 2.5	1481.18	87.59
2.5 - 5	96.1	5.68
5 - 10	59.84	3.54
10 - 20	39.4	2.33
20 - 162.47	14.64	0.86

The above table shows that more than 87 % of the basin is characterized by a loss of ground low (less than 5). While approximately 9 per cent of the basin have a soil loss average of (5 to 10 t/ha/year). While less than 4 % of the basin have a strong soil loss (greater than 10 t/ha/year).

- By comparing the results obtained by the model RUSLE in no time of 15min before the WSC management and those obtained by the same model after then, we find:
- The average value of the erosion decreased from 8.05 t/ha/year to 1.46 t/ha/year.
- The maximum value of the erosion decreases of 333 t/ha/year up to 162.4 /ha/year.
- While the minimum value remains constant equal to 0 t/ha/year.
- The total loss of the soil decreases of more than 81% also (of 212273.4 t/ha/year until 38637.22 t/ha/year).

- The percentage of surface area occupied by a strong erosion decreases by 81% (from 17.15 per cent to 3.19 %), in contrast to the percentage of surface area occupied by an erosion low which increased by more than 26% (from 69.1% to 87.59%).

Case of the model of Wischmeier Revised (RUSLE) with R (30min)
Application of the RUSLE model R30min before the WSC management

The following figure shows the spatial distribution of water erosion throughout the watershed of El Gouazine at no time of 30 minutes and before the installation of the WSC management:

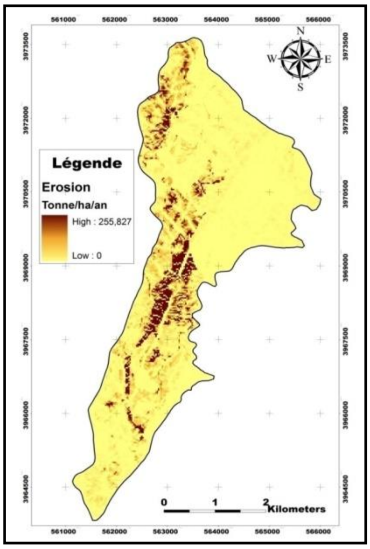

Figure 7: Map of soil loss determined by the RUSLE model R30min

Before the WSC management of El Gouazine.

The review of the figure above shows that the average and the strong erosion greater than 20 t/ha/year is located at the level of high altitude of the catchment. While the low erosion (less than 1.5 t/ha/year) is located at the level of areas of low altitude and at the level of the plains. The average loss of soils for the whole watershed is of the order of 6.18 t/ha/year. The minimum loss in soils is of the order of 0 t/ha/year and the maximum loss is approximately 255.82 t/ha/year. The total losses of the annual basin are of the order of 163031,04 t/ha/year. The distribution of the surface on the classes of soil loss adopted is presented in the following table:

Table 11: Class of soil loss determined by the RUSLE model (R30min)

Class (tonne/ha/year)	Area (ha)	% Surface
0 2,5	1328,45	74.07
2.5 - 5	110	6.13
5 - 10	108.66	6.06
10 - 20	101.12	5.64
20 - 255.82	145.25	8.1

The above table shows that more than 74% of the basin is characterized by a loss of ground low (less than 2.5 t/ha/year). While approximately 12.19 per cent of the basin have a soil loss average of 2.5 to 10 t/ha/year. While 13.74 % of the basin have a strong soil loss (greater than 15 t/ha/year).

Application of the RUSLE model with R30min after WSC management
The dipped beam maps of factors LS, K, C and P of the RUSLE model with the climatic erosivity of acid, by the RUSLE model in no time 30min, allows you to get the card of losses in soil at any point of our watershed.
The figure below presents the losses in soil determined by the RUSLE model at no time of 30 minutes before the WSC management:

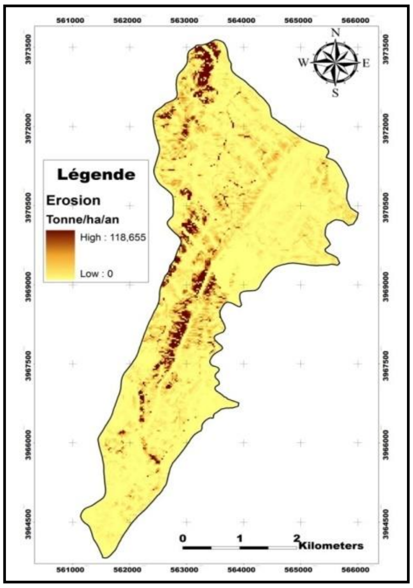

Figure 8: Map of soil loss determined by RUSLE model (R30min) before the WSC management El Gouazine

The review of the figure above shows that the average loss of soils for the whole watershed is of the order of 1.07 t/ha/year. The minimum loss in soils is of the order of 0 t/ha/year and the maximum loss is approximately 118.65 t/ha/year. The total losses of the annual basin are of the order of 28216.89 t /year. The distribution of the surface on the classes of soil loss adopted is presented in the following table:

Table 12: Class of soil loss determined by the RUSLE model R (30min)

Class (tonne/ha/year)	Area (ha)	% Surface
0-2.5	1535,72	90.81
2.5 -5	71.42	4.22
5-10	52.51	3.1
10 - 20	25.08	1.48
20 - 118.65	6.33	0.37

The above table shows that more than 90 % of the basin of El Gouazine is characterized by a loss of ground low (less than 2.5). While approximately 7.32 per cent of the basin have a soil loss average of 2.5 to 10 t/ha/year. Then that 1.85 per cent of the basin have a strong soil loss (greater than 10 t/ha/year).

- By comparing the results obtained by the model RUSLE (R30min) before the WSC management and those obtained by the same model after the WSC management, one finds:
- The average value of the erosion decreased from 6.18 t/ha/year to 1.07 t/ha/year.
- The maximum value of the erosion decreases of 255.82 t/ha/year up to 118.65 t/ha/year.
- While the minimum value remains constant equal to 0 t/ha/year.

- The total loss of the soil decreases as of 163031 t/year until 28216,89 t/year.
- The surface which presents a strong erosion decreases from 13.74 per cent to 1.85 per cent of the total surface area.
- The low erosion increased to a value 74.07 per cent to 90.81 per cent of the total surface area
- By comparing the results obtained by the RUSLE model (monthly); RUSLE (R15min) and those obtained by RUSLE (R30min), we note for the two periods before and after development that:

1st scenario: Before the WSC management

- The application of the RUSLE model shows that the area affected by an erosion tolerated (less than 2.5 t/ha/year) is crueler to the monthly scale; with a value of 82.2 % of the total surface area; that at no time of 30 min (74.07 %) and 15min with a value of 69.1 % of the total surface area of the watershed El Gouazine.
- While the area affected by an average erosion (2.5 to 10 t/ha/year) is more important in the RUSLE model (R15min) (13.76 %) than in the RUSLE model (R30min) (12.19 %) and in the RUSLE model (R (monthly)) (11.27 %).
- However that the area affected by an erosion strong (greater than 10 t/ha/year) is less important in the RUSLE model(R (monthly)) (6.54 %) than that in the model RUSLE(R (30)) (13.74 %) and the RUSLE model(R(15)) (17.15 %).

2nd scenario: After the WSC management

- The area affected by an erosion tolerated (less than 2.5 t/ha/year) is increased for all values of calculated in R. In fact, it is more important for the calculation of RUSLE with R (monthly) with a value of 92.59 % of the total surface area that with R at no time 30 minutes (90.81 %) and not at the time of 15 minutes with a value of 87.59 % of the total surface area of the watershed El Gouazine.
- While the area affected by an average erosion (2.5 to 10 t/ha/year) decreases for the three methods of calculation. It is more important in the RUSLE model (R15min) (9.22 %) than in the RUSLE model in no time 30min (7.32 %) and at the monthly scale (6.13 %).
- Similarly, we found that the area affected by an erosion strong (greater than 10 t/ha/year) presents a decrease distinguishable after the WSC management carried out. In effect, it is less important in the RUSLE model (R (monthly)) (1.28 %) than to calculate with the RUSLE model (R30min) (1.85 %) and the RUSLE model (R15min) (3.19 %).
- The RUSLE model gives a good estimate of the erosion. In effect, it is the most suitable for our watershed by using R(monthly). The results obtained in the application of this model are that of satisfactory values that can help in the planning of activities for soil conservation and a reduction of siltation of dams. They are providing valuable assistance to policy makers and planners to simulate scenarios of future development of the catchment of El Gouazine and especially plan interventions to combat water erosion.

Conclusion and Recommendations

In the news, there are several empirical models that consider soil erosion by water in watersheds, these methods vary from simple to complex. In this context, this work was to mapping and quantification of water erosion on the watershed of El Gouazine the revised universal equation of soil loss (RUSLE) in a geographic information system (GIS). The use of (GIS) has allowed us to build and combine these different factors of erosion, to achieve a synthesis of the loss card in the ground.

Indeed, the erosion map provides synthetic and systematic information on the intensity, spatial distribution of the phenomenon that will be used to identify priority areas of intervention in order to solve many problems of crop, soil and management of watersheds, since it is a major problem in countries with different degrees of severity. In addition, erosion modeling by different models, shows that more than half of the catchment area El Gouazine is affected by erosion or less than 2.5 tonnes/ha/year, second about 20% of the surface is affected by a loss in the soil between 2.5 and 10 ton/ ha/year loss of very high value of the soil is practically negligible, only 4% of the total surface of the basin. This proves, in addition, the weakness of the average value erosion.

In addition, by comparing the results obtained by different models before and after Layouts WSC (1996-1997), we find that there is a remarkable reduction in the loss of land and this is mainly due to the functioning of these practices (mostly benches) which occupies about 43 percent of El Gouazine watershed. Moreover, by comparing the results of each scenario and bathymetric measurements we found that the model RUSLE (monthly) gives the most adequate results for the watershed El Gouazine. Indeed, it leads to a good estimate of erosion. The lakes are very good sediment traps. They play a protective role for larger sizes dams downstream. But their rapid clogging goes against an agricultural development. Located in fragile environments and weak economic activities, they are perceived as an additional resource, vital and scarce: water. To support this resource, watershed management to protect these lakes is a priority. The nature and density of these facilities must balance the reduction of sediment transport without depriving the lake flows into these waters by runoff.
In conclusion, this study suggests more research opportunities that can be applied to the redesign of the same watershed taking into account:

- Learning new CES management scenarios;
- The interconnection of groundwater runoff

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SESSION 7: AGRICULTURAL WATER MANAGEMENT

Keynote

Food and Water Security in the GCC countries (in Arabic)
الأمن المائي والغذائي في دول مجلس التعاون... نحو استراتيجيات متكاملة

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الملخص
تعتبر قضية الأمن الغذائي من أهم القضايا المطروحة على المستوى العالمي، حيث تلجأ بعض الدول المحتكرة لإنتاج وتصدير السلع الغذائية الاستراتيجية إلى الضغط السياسي والاقتصادي على الدول الأخرى. وتسعى دول المجلس إلى تحقيق مستوى معين من الأمن الغذائي، حيث تسعى لتحقيق ذلك عن طريق الاحتفاظ بمخزون استراتيجي من السلع الغذائية يكفي الاحتياجات الاستهلاكية لمدة معينة لمواجهة الظروف الطارئة، خاصة أن المنطقة أصبحت غير مستقرة عسكرياً وسياسياً واقتصاديا. ويتم تكوين هذا المخزون عن طريق الإنتاج المحلي، والواردات الزراعية، والاستثمار الزراعي الخارجي. لكن التّحديات المائيّة تظل تمثّل هاجساً حقيقيّاً لدول المجلس، خاصة في ظلّ طبيعتها الصّحراويّة القاسية، وندرة الموارد المتجدّدة، والاستهلاك المفرط. وهذا يحتمّ جعْل مسألة المياه في أوّل اهتمامات دول المجلس، باعتبارها تحدّياً يُهدّد المنطقة ككلّ، ووضع رؤية واضحة وشاملة مستقبلية لكيفية معالجة الأمر على مستوى المجلس. تقع دول مجلس في نطاق الأراضي الجافة إلى شديدة الجفاف، وتعاني من ندرة الموارد المائية والأراضي الصالحة للزراعة، ويزيد من الضغوط عليها في مجال تأمين الغذاء ارتفاع معدلات النمو السكاني وبالتالي زيادة الطلب على المواد الغذائية وارتفاع أسعارها. وعليه، فأن توافر مخزون استراتيجي من السلع الغذائية يضمن استمرار تدفق السلع للأسواق المحلية، ومن ثم استقرار الأسعار لضمان عدم نشوء أزمات غذائية مستقبلية. إن سياسات تحقيق الأمن الغذائي لأهم السلع الغذائية الاستراتيجية بدول المجلس يمكن أن تتحقق من خلال التكامل بين الإنتاج الزراعي المحلي والاستيراد والاستثمار الزراعي في الخارج، وتفعيل البنى التحتية الخاصة بالتصنيع الزراعي، والتسويق، والتسعير، والعمل على بناء مخازين استراتيجية من السلع الضرورية تساهم في استقرار الأسعار.

الكلمات الدالة: ترابط المياه والغذاء، الأمن الغذائي النسبي والمطلق، الإنتاج المحلي، استيراد الغذاء، الاستثمار الزراعي الخارجي، مخزون استراتيجي.

Keynote

Irrigation Water Management and Conservation using Modern Irrigation Programs

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Abstract

The continued expansion of agriculture and urban development in the Arab Cooperation Council (GCC), (which is located within the arid regions), accompanied with growing demand for water supply in the different sectors, all of this calls for agricultural sector to look for practices that increase the efficiency of irrigation and water conservation and increasing water productivity of crops. In this study, we will explore some of the efforts in the determination of the actual water requirements as an introduction to water conservation with deficit irrigation (DI) programs and partial root drying system (PRD). The crop water requirements of date palm were done on eight different regions of the Kingdom of Saudi Arabia to estimate monthly and annual water needs, and has been estimating these needs by four different methods from the use of Penman Monteith equation to actual water applied. Then calculate the total water requirements, depending on the quality of water used and the salinity of the soil, taking into account the proportion of vegetation. The results showed that the annual irrigation requirements per palm in the eight regions ranged from 86-95 m3, considering that half of the diameter of the Palm equal to 3.5 m and found that the average total irrigation requirements of regions of the Kingdom at a rate of 8342.41 m 3 / ha / yr. for 100 Palm / hectares. On studies of water conservation using deficit irrigation and partial root drying of various crops, including tomatoes, cucumbers, potatoes. All of these studies have shown that reducing water use by 20% did not significantly affects productivity, and water productivity rose much with deficit when compared to traditional irrigation on farms as well as the provision of water, there was also significant savings in fertilizers and pesticides used.

Keywords: Agriculture Expansion, Irrigation, Penman Monteith Equation, Water Conservation.

Keynote

Effects of Drip Subsurface Irrigation System on Date Palm Production and Water Productivity

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Abstract
Subsurface drip irrigation system has been proved to give higher water use efficiency and better water productivity (WP) than other irrigation systems. At Al-Kamil Research Station in Al-Sharqiyah North governorate, subsurface drip irrigation system was used to irrigate date palm trees compared with bubbler irrigation which is currently used for irrigating date palms. Four irrigation treatments were 100% ET_c using bubbler irrigation, 60%, 40% and 20% ET_c using Subsurface irrigation system have been tested on date palm production.
The results show no significant differences in fruit production between date palm trees irrigated by 100% ET_c using bubbler system and those irrigated with 60% of the water requirement under subsurface drip irrigation system. Fruit production was significantly reduced under the irrigation with 40% and 20% of ET_c under subsurface drip irrigation system as compared to that irrigated with 60% ET_c. The highest WP of 4.7 kg/m^3 was obtained at the rate of 20% of the water requirements under subsurface drip irrigation system. All the results proved that subsurface drip irrigation system contributes to 40% water saving without reduction in fruit production of date palm trees.

Keywords: Irrigation, Productivity, System, Subsurface, Palm Tree.

Water and Food Security in Arabian Gulf Countries

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Abstract
The Gulf Cooperation Countries (GCC) consisting of Saudi Arabia, the United Arab Emirates, Kuwait, Oman, Qatar, and Bahrain are located in the very arid Arab Peninsula of severe water scarcity. Water and food securities in the GCC are of great concern due to lack of water required for agriculture. The main and may only natural water resource is groundwater, which is limited, depleted and quality deteriorated due to over-extraction in order to grow low share of food needs. Water consumption for agriculture represents high share of total water demands. The GCC water resources, demands, water use in agriculture, and food production, consumptions, import, self-sufficiency, and price value are illustrated in this paper. The paper shows the role of using GW and treated wastewater to produce food locally, and virtual water imbedded in imported food to augment the locally produced food. The case of over-exhausting fossil water to secure self-sufficient wheat production in Saudi Arabia is given. It shows that GCC's water resources cannot satisfy the need for food self-sufficiency in GCC. The GCC attempts to acquire (or to invest) cultivated land abroad are also discussed. The GCC depends on revenues from exporting primary energy (mainly oil for all GCC, and NG for Qatar) to secure food imports and to produce desalted seawater (DW), that is used for domestic purposes. Steady rising of population and standard of living and urbanization are accompanied with increasing water and food demands, and representing a real challenge to meet.

Keywords: GCC, Water and Food Security, Local and Imported Food, Virtual Water.

1. Introduction

The GCC countries consist of Saudi Arabia (SA), United Arab Emirates (UAE), Kuwait, Oman, Qatar, and Bahrain. The GCC are located in the arid Arab Peninsula of severe water scarcity. The wealth of the GCC (from oil and gas productions) is used to solve the severe water scarcity and its accompanied food production challenges. Desalted seawater (DW) is generated to satisfy mainly municipal water needs. The increasing food demands is satisfied by food import, besides limited agriculture production by overexploiting the limited, depleted, and quality deteriorated groundwater (GW). Moreover, the GCC lack enough areas of cultivated lands. Agriculture (including growing crops and raising livestock) is the main source of food, and largest water consumer. Water availability and cultivated land are key factors to produce food, and their lack is the main obstacles to grow food, especially staple wheat, accounting for 48% of consumed food in GCC in 2012.

In 2013, SA produced 660,145 metric tons (MT) of wheat from 102,613 hectare (ha), or 6.433 MT/ha, and each hectare required 13,713 m^3 of water. This shows that one MT of wheat required 2,132 tons of water, [1] and [2]. Irrigation water requirements in SA for different crops (barely, Fodder crops, dates, melons, watermelons, and fruits) are given in Table 1. This table shows the necessity of choosing crops that need less irrigation water. Excessive use of GW in GCC has resulted in lowering water table, increasing salinity and cropland abandoned in some cases.

Table 1: Irrigation water requirements for 1 ha of land for different types of crops, [2].

Crop	Land under irrigation (ha)	Water use (m^3/ha)	Produced ton/ha	m^3/ton
Wheat	450330	13713	6.43	2132
Barley	4554	13560	7.50	1808
Fodder crops	151301	39000	20.33	1918
Dates	155734	9100	6.98	1304
Melons	11528	13560	19.03	713
Watermelons	19455	13560	21.54	630
Other fruits	229423	10100	7.45	1356
All vegetables	112163	18000	25.72	700

This paper assesses the natural resources for food production, mainly water and cultivated land, and food demands status and trend in GCC.

2. Food Security

One food security definition for a country is to have self-sufficient food production to feed its inhabitants. In 1970s-1980s, one of SA objectives was to achieve food security by being wheat self-sufficient. In Arab countries, wheat is the main contributor to food intake and directly linked to food security. Arabs high wheat intake (up to 130 kg/y.Ca) is about twice that of world-wide average. It represents the major source (33% to 50%) of the calorie and protein intake of population. Wheat production in SA was increased to self-sufficiency in 1984, but on the expense of extracting too much fossil (non-renewable) GW, besides importing fertilizers, equipment, and labor, which are also foreign inputs. So, solving food problem by growing wheat (or other cereals) exacerbates the chronic water problem scarcity. SA and other GCC realized that food self-sufficiency cannot be achieved due to lack of both water resources and enough land areas for cultivation. The GCC limited water resources cannot satisfy its all food growing needs regardless of whatever developed high agriculture usage water efficiency.

Another food security definition for a country is its ability to have enough income to import food from global market to supplement its locally produced food. This definition implies that all presently rich GCC are quite food secured. In 2011, the ratio of total import value of wheat, main crop considered for food security, to total value of merchant export in GCC was very low, about 0.2% for each of Bahrain, Oman, and SA, and about 0.1% for Qatar, Kuwait, and UAE, [3]. Importing food can be seen as a way to import waters that are embedded in imported food. This imported water is known as virtual water (VW). As example, SA imported about 3.5 million metric tons (MMT) of wheat in 2015. This means VW of 7,460 Mm^3 was imported during this period by wheat import only, based on 2,132-m^3/MT, [4].

The United Nation Food and Agriculture Organization (FAO) defined food security as the state in which all people at all times have physical, social, and economic access to sufficient, safe, and nutritious food to meet their dietary need and food preference for active healthy life. This food security concept includes the food availability, access, stability of supply and utilization, [5]. A Global Food Security Index ranks countries by considering three core issues (affordability, availability, and quality) based on 28 indicators. The rank of the GCC on this food security index is high. Out of 113 nations, Qatar, Oman, Kuwait, UAE, SA, and Bahrain were ranked 20, 26, 27, 30, 32, and 33 respectively, [6].

3. Water and Arable Lands Status in GCC

While GCC are rich in primary fuel (oil and natural gas), they have absolute water scarcity, i.e. extremely low natural fresh water resources (NWR), which limits agriculture to grow food. The annual rain fall is low with average annual precipitation (in mm/y) equal to 83 in Bahrain, 125 in Oman, 59 in SA, 74 in Qatar, 121 in Kuwait, and 78 in UAE, [3]; while the annual evaporation is high (in the range of 2500-4500 mm/y), [7]. The annual NWR per capita in cubic meters (in m^3/y.Ca) in the year 2014 was 87 for Bahrain, 6 for Kuwait, 385 for Oman, 26.7 for Qatar, 83 for SA, and 16 in UAE, [8]. Table 2 shows the annual decline of NWR per capita (Ca) due to population increase in GCC, [9].

Table 2: Renewable water resources and per capita share, Ecological foot print (2012), [9].

Country/Sub-region	**Natural Water Resources (million $m^3$3)**	**Average share (m^3/capita)**		
		2010	**2030**	**2050**
Bahrain	116	92	70	64
Kuwait	20	7	5	4
Oman	1400	503	389	374
Qatar	58	33	24	22
SA	2400	87	62	53
UAE	150	20	14	12
GCC	**4144**	**95**	**68**	**59**

The NWR in all GCC, except Oman, is mainly GW formed by rain-fall that infiltrates to shallow aquifers, and some little surface runoff collected behind dams, and equal (in Mm^3/y) to 3210 in SA, 1470 in Oman, 150 in UAE, and 1.4 in Qatar, 0.2 in Bahrain, and 0.1 in Kuwait, [7].

Several definition of water shortages are given in one of FAO publications (FAO), [10] in terms of annual NWR per capita (in m^3/y.Ca) as: absolute water scarcity for less than 500, chronic water shortage for 500-1000**,** regular water stress for 1,000-1,700, and occasional or local water stress for close to 1700. The NWR per capita in GCC is much far below that of world average (6000 m^3/y.Ca), required to raise food (3000 m^3/y.Ca), and marked poverty line (1000 m^3/y.Ca).

The GW (main MWR) in GCC is very limited depleted, quality deteriorated, and over-extracted. In 2008, water used for agriculture, in Mm^3/y, and (its ratio to NWR) were: 159 (1.37) in Bahrain, 492 (24.6) in Kuwait, 20,826 (8.68) in SA, 1,168 (0.83) in Oman, 262 (4.52) in Qatar and 3,312 (22.1) in UAE. The percentage of water used for agriculture to total water usage was 45% in Bahrain, 54% in Kuwait, 88% in SA, 88% in Oman, 59% in Qatar and 83% in UAE, [11]. Even with the low NWR, inefficient irrigation methods are mainly used as shown in Table 3, with less percentages of using modern irrigation methods, [11].

The total area of the GCC countries (~2,673 M km^2) includes 665 km^2 in Bahrain, 1,111 km^2 in Kuwait, 212,460 km^2 in Oman, 11,437 km^2 in Qatar, 2,149,690 km^2 in SA, and 83,3600 km^2 in UAE. The ratio of cultivable land area to total area in the GCC are very limited, e.g. 4.35% in Bahrain, 0.84% in Kuwait, 0.12% in Oman, 1.64% in Qatar, 1.67% in SA, and 0.77% in UAE, [12].

Table 3: Irrigation methods used in the GCC, [11]

	Bahrain	**Kuwait**	**SA**	**Oman**	**Qatar**	**UAE**
Area equipped for irrigation (1000 ha)	4	7	1,730	59	13	227
Area actually irrigated (% of equipped)	100%	100%	69%	NA	47%	NA
Traditional irrigation (%)	84%	63%	34%	79%	75%	12%
Modern irrigation (%)	16%	37%	66%	21%	25%	88%
Drip, bubbler, and other localized (%)	74%	66%	3%	45%	44%	98%
Sprinkler (%)	26%	34%	97%	55%	56%	2%

Arable land is the land capable of being ploughed and used to grow crops. The GCC arable land in 2012, in hectare per capita (ha/Ca) was 0.0012 in Bahrain, 0.0031 in Kuwait, 0.102 in Oman, 0.0063 in Qatar, 0.1117 in SA, and 0.005 in UAE. These are lower than the world average of 0.2 ha/Ca, [3]. The total agricultural area (in 1000 ha) with (% of permanent crop lands) in 2011 were given as: 8 (35.9%) for Bahrain, 152 (3.3%) for Kuwait, 1,770 (2.2%) for Oman, 66 (3%) for Qatar, 173,355 (0.1%) for SA, and 379 (10.5%) for UAE, [13].

Table 4 gives the areas suitable for agriculture, actual cultivated areas, and % of agriculture area to area suitable for agriculture in GCC, [14].

Table 4: The percentage of cultivated agricultural area to the area suitable for agriculture, [14].

Country	Total Area (MKm^2)	Area suitable for agriculture (in 1000 ha)	Actual cultivated agriculture area (in 1000 ha)	Percentage of agriculture area to area suitable for agriculture (%)
SA	2,250	52068.4	4359.5	8.37
Bahrain	0.00760	6.4	3.5	54.94
UAE	0.0836	74.2	68.4	92.27
Oman	0.3095	2300	73.7	3.2
Qatar	0.0116	650	12.3	1.89
Kuwait	0.0178			
Total	2,292	55252.8	4521.3	8.18

Source: Agriculture Development in GCC Countries (2011)

4. Factors Affecting the GCC Water and Food Demands

The GCC water demands are on the rise, [15], due to significant population increase, see Table 5, urbanization, and rising income (standard of living), Fig. 1. These factors drive for more water and food demands. The ratio of urban to total population in 2010 was high in GCC, e.g. 98.4% in Kuwait, 95.8% in Qatar, 88.6% in Bahrain, 83.6% in SA, 78% in UAE, and 71.7% in Oman, [16]. The total GCC estimated population, 50.359 million (M), includes 1.36 M in Bahrain, 4.115 M in Kuwait, 4.24 M in Oman, 30.89 M in SA, and 9.09M in UAE as reported in 2014, and 2.340 M in Qatar, 4.161M in Kuwait, 4.149M in Oman as reported in 2015, [17]. In 2014, the annual population increase was 3.8% in Qatar, 2.71% in UAE, 2.49% in Bahrain, 1.49% in SA, 2.06% in Oman, and 1.7% I Kuwait, [18] and [17]. The 2013 GCC per capita income in GCC was 105 thousand (k) US dollars ($) in Qatar, $48k in Kuwait, $43k in UAE, $26k in Oman, $24k in SA, and $24k in Bahrain, compared to $53k in USA, $44k in Germany, and $39k in both UK and Japan, Fig. 1, [19].

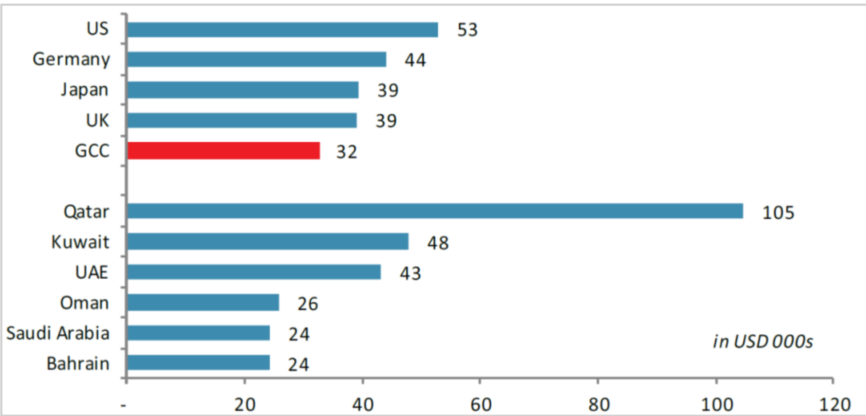

Figure 1: Per capita income (2013E), [19]

Rising standard of living is expressed by increase of gross domestic product (GDP), which was 5.5% in Qatar, 4% in UAE, 4.4% in Bahrain, 3.6% in SA, 5.1% in Oman, and 2.3% in

Kuwait, [18]. Increasing living standards of living move the dietary to high water-intensive animal-based food. Water demands in GCC, Figs. 2, are much higher than NWR.

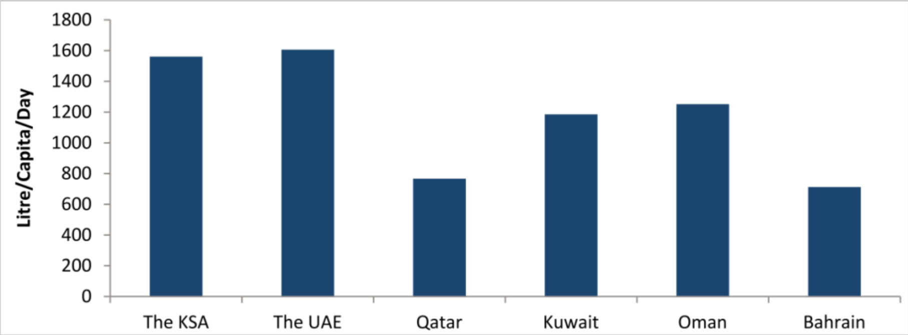

Figure 2: Total per Capita Water Consumption, [15]

Table 5 shows the agriculture large share of water withdrawal, and its low return (very low share in GDP). The GCC have the highest, worldwide, domestic consumed water (liters per capita per day), more than 50% than in the United States, Fig. 2, [15].

Table 5: GCC population in 2000 and 2012, % of population working in agriculture, ratio of total water withdrawal used for agriculture, and agriculture share in GDP, [13]

Country	2000 population in M	2012 population in M	Population % increase	% Population working in agriculture	% of water agriculture consumption	% of Agriculture contribution to GDP
SA	20.045	28.705	43.20	4.4	88	2
UAE	3.033	8.108	167.33	2.8	54	0.6
Kuwait	1.941	2.892	49.00	1	45	0.3
Qatar	0.591	1.939	228.097	0.7	39	0.1
Oman	2.264	2.904	28.27	27.6	88	1.0
Bahrain	0.638	1.359	113.01	0.6	45	0.3
Total	**28.512**	**45.907**	**61.01**			

Agriculture irrigation in GCC depends mainly on GW. The gap between water demands and resources is usually bridged by unconventional water resources, e.g. desalted seawater (DW), and treated wastewater (TWW). Desalting seawater (SW) is a costly and energy intensive process; and over-extracting GW causes its depletion and quality deterioration, and SW intrusion. DW is used only for domestic, and some industrial usage, but it is very expensive to be used for agriculture.

Water demand management can be controlled by conserving domestic water, efficient irrigation methods, etc. In 2012, the GCC annual consumed water (in Mm^3/y) was estimated as: 360 in Bahrain, 460 in Kuwait, 1,780 in Oman, 440 in Qatar, 23,670 in SA, and 4,000 in UAE; with DW percentage share of 79% in Bahrain, 69% in Kuwait, 44% in Oman, 75% in Qatar, 14% in Sa, and 67% in UAE, [20]. In 2016, Qatar water consumptions reached 540 Mm^3/y from DW, 240 Mm^3/y from GW, and 150 Mm^3/y from treated wastewater (TWW). In 2012, the annual water consumption per capita (in $m^3/y.Ca$) was 386 in Bahrain, 441 in Kuwait, 516 in Oman, 337 in Qatar, 928 in SA, and 740 in UAE with average of 816 in GCC. Note that the high per capita consumed water in SA is mainly due to high agriculture production relative to other GCC.

The GCC depends on global market to satisfy its food needs. The GCC's economic strength allows them to import their food needs and create trade-based food security. Moreover, the

GCC are using their wealth to invest in land abroad in countries rich in both NWR and land, but under-invested in their agriculture to grow food.

5. Food Status and Trend in individual GCC

In GCC, food demands are continuously on the rise due to the increases of population and per capita income. The later levels rose to that of developed countries with its average increased from $14k in 2003 to $32k in 2013 (Fig. 2). Between 2014 and 2019, the annual increase in food consumption in GCC is expected be 3.5% in general, and 3% in cereal. The expected annual increase in consumed food is 5.5% in Qatar, and 4.8% in UAE for the same period, [21]. Positive correlation exists between food consumption and per capita income, [11]. The average annual per capita food consumption in 2012 was 852 kg/y.Ca with percentage of 48% for cereal, 13% for fruits, 12% for dairy, 11% for vegetables, 8% for meat, and 8% for others, [21]. The average diet in grams/person per day (g/d.Ca) in GCC are: 513 cereal, 401 vegetables, 269 milk, 240 fruit, 196 meat, 52 starch roots, 96 sugar and sweeteners, 36 vegetable oils, 4 fish and seafood, 23 pulses, and 24 eggs, [16].

The production of wheat, main food of the GCC, is almost zero, Table 6, except in SA in last three decades where wheat was intensively produced, but it was almost terminated in 2016.

Table 6: Cereal production in GCC, [13]

Country/ Sub-Region	Area (1,000 ha)		Productivity (kg/ha)		Production (1,000 Ton)	
	1990-1992	2008-2010	1990	2010	1990	2010
Bahrain	0.0	0.0	0.0	0.0	0.0	0.0
Kuwait	0.3	1.1	3,653	3,415	1.10	3.76
Oman	2.8	3.1 2	2,160	18,987	6.05	58.86
Qatar	1.2	2.1	2,897	4,795	3.48	10.07
SA	1,121.9	317.4	4,245	5,631	4,762.47	1,787.28
UAE	1.4	0.0	2,216	0.0	3.10	0.00
GCC	1,127.6	323.7	4,236	5,746	4,776.20	1,859.97

In 2011, the GCC meat production, in million metric tons (MMT) was 1.878; including 0.99 in SA, 0.415 in UAE, and 0.172 in Kuwait, while importing 0.08 MMT. They also produced (in MMT) vegetables (3.117), fruits (3.257 MMT), eggs, milk and processed milk (0.101), fish (0.0273), sheep meat (0.238), and beef meat (0.0686), [13]. Detailed livestock, poultry, milk, eggs, and fish food productions in GCC in the year 2010 are given in Table 6, [22].

Table 7: Livestock, poultry, milk, eggs, and fish productions in GCC (in 1000 tons) in year 2011, [22]

Country	Cattle & buffalo meat	Sheep & goats	Camel meat	Red meat	Poultry	Red & poultry meat	Milk	Eggs	Fish
UAE	0.8	5.35	5.35	6.73	78.79	85.51	162.24	35.89	77.71
Bahrain	1.4	15.17	-	16.57	6.1	22.67	9.2	2.68	16.19
SA	23.58	37.77	35.41	96.75	447	543.75	1508.38	199.35	100.48
Oman	3.46	4.84	0.56	9.05	227	31.75	74.4	9.24	164.05
Qatar	0.51	12.83	0.77	14.6	7.8	22.41	22.58	2.89	15.11
Kuwait	2.32	39.71	0.54	42.52	37.42	79.94	47.96	22	4.81
Total	**32.07**	**115.67**	**42.63**	**186.22**	**804.11**	**786.03**	**1824.76**	**272.05**	**378.35**

Food consumptions in GCC were increased from 28.9 MMT in 1999 to 30.8 in 2007 to 40.9 in 2012. In 2012, the shares of GCC food consumption were 62% in SA, 18% in UAE, 8% in Kuwait, 7% in Oman, 4% in Qatar, and 1% in Bahrain, [21]. Out of the 40.9 MMT consumed in 2012, only 10.9 were produced in GCC with percentage of 70% in SA, 15% in UAE, 5% in Kuwait, 8% in Oman, and 2% in Bahrain, [21].

5.1. Saudi Arabia (SA) Water and Food Status

SA is the largest country in GCC in terms of population, area, and production and consumption of food. Its population increased from 6.9 M in 1972 to 24.8 M in 2004, and to 30.89 M in 2014. Although SA is mainly a desert with very limited water resources, it has some promising areas for farming, e.g. from Hail in the north to the valleys near Taif in the west. The SA total area is 2.25 M km² (about 80% of total Arab Peninsula), with only 850,000 ha (1.6% of total) cultivated land. Unbelievable high arable lands was reported in one report as 52.68 M-ha (23.4% of total area), [31, 23]. The SA cultivated area in hectares (ha) increased from 15,000 in 1975 to 1,620,000 ha in 1992, and then dropped to 1,100,000 ha in 2005, to 834,989 ha in 2009, and to 694,549 ha in 2013, [32, 24] and [33, 25].

SA total water consumption (in Mm^3/y) was 27,000 in 1990, 31,500 in 1992, 18,500 in 1997, 20,500 in 2000, 20,200 in 2004, and 18,500 in 2010. These are far beyond the NWR of 5,410 Mm^3/y in 2004 and 5541 Mm^3/y in 2009, and were mainly extracted from fossil (non-renewable) GW, [2] and [33, 25]. Consumed GW (in Mm^3/y) was: 2,662 in 1980, and 15,623 Mm^3/y in 1992. Then, it is decreased to 10,471 Mm^3/y (~58.4% of total withdrawal) in 2010 due to stopping cereals production, [31, 23]. Domestic and industrial water demands (in Mm^3/y) increased from 502 in 1980 to 1650 in 1990 to 2603 in 1997 to 2900 in 2000, and 3600 in 2010. Domestic water consumptions (in Mm^3/y) were: 200 in 1970, 446 in 1980, 1,508 in 1990, 1,800 in 2000, and 2,063 in 2010, [31, 23]. Agriculture water demands (in Mm^3/y) increased from 1850 in 1980 to 25,589 in 1990 to 29,826 in 1992, then dropped to 16,406 in 1997 to 11,200 in 2000 and to 14,700 in 2010, [34, 26]. Other reports gave agriculture water demands (in Mm^3/y) as 6,108 in 1970, 9,470 in 1980, 18,000 in 1990, 18,500 in 2000, and 15,040 in 2010, [31, 23]. The SA agriculture sector has the largest water demands. It reached 29,826 Mm^3/y in 1992 before water conservation measures in agriculture which decreased it to 17,350 Mm^3/y in 2004, and was expected to reach 12,794 Mm^3/y in 2014, [2]. In 2006, the GW extraction was 23.905 Mm^3/y (about 10 times the NWR) including 20.919 for agriculture (88%), 2.270 for domestic uses (9.5%), and 0.716 for industrial uses (3%), [35, 27].

In 2010, the produced DW was about 1050 Mm^3/y (~8.5% of total withdrawal); and reused TWW was about 400 Mm^3/y (~ 2.2% of total withdrawal). SA is very active in agriculture (including livestock) productions, and is (or close to) to self-sufficiency in many agriculture products (e.g. eggplant, cucumber, water melons, okra, eggs, fresh milk, grapes, etc.) or even more for export (e.g. potatoes, dates, etc.), [33]. SA pioneered for wheat self-sufficient in 1970-1980, by heavy investment, and over-extracting of GW, a solution proved to be prohibitively expensive due to fossil water over-extraction, and this policy was terminated in 2016.

The extensive agriculture water usage was behind the high consumption of water in 1990-1992. The SA water demands for agriculture were 83-90% of total withdrawal during the period of 2004-2009. The withdrawal of non-renewable GW sources was reported as 13.5 Bm^3/y in 2004 and 11.6 Bm^3/y in 2009, [2]. The GW withdrawals were estimated by 24.5 Bm^3 in 1990, 28.6 Bm^3 in 1992, and 15.4 Bm^3 in 1997, [2]. These were the main reason for terminating the move of self-sufficient cereal production by 2016.

Large shares of cultivated lands were used for wheat, fodder crops, fruits, dates and vegetables productions. The total cultivated land in SA in 2005, 2006, and 2007 were 1.11 M-ha, 1.07 M-ha, and 1.07 M-ha, out of which 0.489, 0.468 and 0.450 M-ha were used for wheat production respectively, Saudi Statistical year book (2008), cited by [2].

Early SA decision to look for wheat self-sufficiency was prompted by several events of banning certain crops by exporters, e.g. in 2008, India export ban on non-basmati rice; export duties and quota on exporting wheat by Russia in 2008, and by Argentina in 2008. Also, the soaring crop prices in 2008 caused inflated food prices in the GCC, e.g. 15% in Qatar, 12.3% in UAE, 12.6% in Oman, 10.6% in Kuwait, [15].

SA wheat production was decreased from the average of 2.52 MMT between 2004-3008 to 1.152 in 2009, 1.3494 in 2010, 1.184 in 2011, 0.8842 in 2012, and 0.6601 in 2013, [1]. Produced wheat would not exceed 10,000 MT in 2015/16, [38, 28]. SA cereals (mainly wheat, barely, sorghum crop, and maize) productions (in MMT) reached 1.804 in 1999, 2.552 in 2003, 2.952 in 2004, 1.986 in 2008, 1.592 in 2009, 1.418 in 2011, and 0.885 in 2013, [1]. The cereal cultivated land areas were reduced from 632,000 ha in 2005 to 328,725 ha in 2009 to 166,005 ha in 2013.

SA is the largest GCC food producer and consumer (70% and 62% of total respectively). SA food consumptions in 2012 reached 25.3 MMT with food retail sale of $B 47.4, and locally produced food 7.6 MMT (30.1% average), and 12.1% of wheat self-sufficiency (drastically decreased in 2016). SA import food cost is 10.3 $B in 2012. SA is strong producer of vegetables, fruits, dairy, and meat, with self-sufficiency of 85.6%, 64.5%, 58.8%, and 44.2% respectively. The case of SA food, especially wheat is given in next section. In 2011, SA produces (in 1000 tons) 1722 of cereal, 2439 of vegetables, 1824 of fruits, and 24.8 of fish. Meanwhile, SA imported (in 1000 tons) 11356 total cereal, 1328 of total sugar and honey, 990 of meat, 2295 of dairy product, and 487b of fish, [13].

5.2. UAE Water and Food Status

The UAE population increased from 231,529 in 1970 to 1,014,825 in 1980, to 3,026,352 in 2000, to 8,441,537 in 2010, and to 9,346,000 in 2013. Fresh water resources in UAE include GW (~4000 Mm^3/y, 70%), DW (950 Mm^3/y, 24%), and TWW (319 Mm^3/y, 6%), with agriculture consuming 83% of total withdrawal. The GW, mainly used for agriculture, is over-extracted and depleted to the extent that it can be dried out and vanishes. All agriculture land are 100% irrigated, [29]. The UAE is the second GCC food consumer and producer after SA, with 18% and 15% of total GCC food respectively, [21]. The UAE is the most food import dependent in the GCC, [16]. In 2012, the average food self-sufficient was 21.2%, [21]. The annual food consumption per capita was 862.2 kg/y.Ca.

In 2011, the annual price per capita for food import in GCC was the highest in UAE (~$1271/y.Ca), followed by Qatar ($1003/y.Ca), Bahrain ($776/y.Ca), Kuwait ($610/y.Ca), Oman ($488/y.Ca), and SA ($418/y.Ca), [16]. In six months (Jan. 2011-June 2011), UAE imported food cost was $B77.6, and are given in quantity and (value) as: 1.484 MMT cereal ($M 943.8), 1.340 MMT oil seeds ($M 697.1), 0.728 MMT edible fruits and nuts ($M 692.5), 0.524 MMT meat and edible meat offal ($M668), 0.247 MM dairy produce ($M585.7), 0.724 MMT vegetables, roots and tubers ($M 471.4), 0.103 MMT coffee, tea, mate and spices ($M429.40), 0.276 MMT animal and vegetable fats ($M 388.6), 0.090 MMT preparation of cereal, milk, etc. ($M273.7), and 0.193 MMT preparation of vegetables, fruits, etc. ($M211.6), [16]. UAE food consumptions in 2012 reached 7.6 MMT with retail sale of $B 22.3 in 2014, with 1.6 MMT (or 21.1% average) locally produced, and 1.1% of cereal self-sufficiency. UAE is producer of fruits, dairy, vegetables, and meat (with 51.1% and 30.5%, 16.4%, and 14.1% self-sufficiency respectively). UAE import food is largely processed for re-export.

5.3. Qatar Water and Food Case

Qatar has the highest GDP per capita world-wide and highest population percentage increase in GCC. Qatar is a small country of 1,149,300 ha with arable land of 65,000 ha including 11,663 ha already cultivated in 2014 and 5333t ha uncultivated. Qatar depends mainly on imports to satisfy its food needs. Qatar NWR is very limited with an average water balance of 47.5 Mm^3/y during 2009-2012. This balance (in Mm^3/y) resulted from 63.3 recharge of aquifers from precipitation, and 2.2 inflows from SA, and these give 65.5 of total renewable water resources, but there is 18 Mm^3/y outflow from aquifers to sea and deep saline, [30]. In 2013, the total water used (Mm^3/y) in agriculture was 285.28 including 230 of GW and 55.23 of treated wastewater (TWW). The water scarcity limits growing of agricultural sector, although the government is encouraging its development, mainly in the direction to secure food. In 2014, the 11,663 ha cultivated land included 6,108 ha with green fodders, 2,290 ha with date palm, 205 ha fruits, 2,681 ha vegetables and 379 ha with cereals. Total cereal grown in 2014 was 2,455 MT including 5 MT of wheat from 2 ha, 706 MT of barely from 235 ha, and 1729 MT of maize from 138 ha. The vegetable production was 50,648 MT from 2379 ha. In 2014, there were growing fruits and dates of 28,244 MT including 762 MT of fruits from 206 ha, and 27,482 MT of date palm. The vegetable production was 50648 MT from 2379 ha, [31].

Qatar food consumptions in 2012 reached 1.4 MMT with retail sale of $B 11.1 in 2014, and locally produced food 0.1 MMT (9.6% average), [21]. Qatar is producer of dairy, vegetables, fruits, meat, and cereal with 25.4%, 16.6%, 14.0%, 6.4%, and 0.5% self-sufficiency respectively, [21]. Qatar has to increase the shortage of the largely imported poultry and the government is working to boost poultry self-sufficient. In 2014, the production of red meat was 7395 T, poultry meat was 8006 T, fish was 16,213 T, eggs were 4338 T, and milk and dairy products were 90803 T. The total value of agriculture productions increased (in million (M) Qatari Riyal (QR)) from 687 M-QR in 2010 to 1,353 M-QR in 2014. The value (in M-QR) of 1,353 in 2014 includes 5.202 for cereals, 198.99 for green fodder, 101.724 for fruits and dates, 157.926 for vegetables, 353.898 for meat, 265.750 for milk and dairy products, 30.156 for eggs, and 241.574 for fish, [29, 31].

In 2010, the cereal consumptions amounts to 0.51103 MMT with 0.52% self sufficiency including (with self sufficiency %): 0.1816 MMT wheat and flour (0.02%), 0.02555 MMT maize (7.32%), 0.16697 MMT rice (0%), and 0.094 MMT barley (076%). Other food items (in 1000 MT) and its self sufficiency (in %) are potatoes 37.23 (0.13%), 31.00 pulses (0.00%), 287.08 vegetables (17.79%), 157.12 (14.08%), 25.45 refined sugar (0.00%), 53.10 fats and oils (0.00%), 48.40 red meat (30.19%), 102.15 poultry meat (7.64%), 32.02 fish (44.07%), 12.54 eggs (23.05%), and 151.66 milk and dairy products (14.89%), [22].

5.4. Other GCC Countries

Kuwait has the second highest per capita income in GCC, after Qatar. Kuwait's consumed food in 2012 was 3.3 MMT of retail sale price of $B 9.5, with 0.5 MMT (15.6% average) locally produced, and 2.5% of cereal self-sufficiency. Kuwait food self-sufficiency is 42.1% in vegetables, 37% in meat, 11.4% in dairy, and 9.9% in fruits (9.9%), [21]. Kuwait food import cost was $B 1.7 in 2012.

Oman food consumptions in 2012 reached 2.8 MMT with retail sale of $B 5.4 in 2014, with locally produced of 0.9 MMT (32.5% average), and 5.5% of cereal self-sufficiency. Oman is producer of vegetables, fruits, meat, dairy, and cereal (with 68.5% and 59.8%, 39.8%, 12.6%, and 5.5% self-sufficiency respectively, [21]. Oman has significant increase in fish industry and food processing.

Bahrain has the smallest population in GCC, and lowest food consumption per capita. Bahrain food consumptions in 2012 reached 0.6 MMT with retail sale of $B 2.0 in 2014, and locally produced of 0.1 MMT (14.6% average). Bahrain is producer of meat, fruits, dairy, vegetables, and no cereal with 32.1%, 32.1%, 20.5%, 13%, and 0.0% self-sufficiency respectively, [21].

6. Looking of land abroad land for cultivation

Water scarcity is behind the GCC inability to grow their food needs. SA tried to have wheat self-sufficiency in the 1980's but this was in 2016. SA stopped support growing crops such as wheat and barley that consume large volume of water. GCC have to rely on food imports, and worried about tightening markets. So, GCC are looking to invest in farm land abroad as long-term strategy to get food with greater security and good prices. Examples of Known GCC Land Investments Abroad, GCC land investment are given in Table 9.

Table 9: Known GCC Land Investments Abroad, GCC land investment (2012), [32].

GCC Investor State	Host Countries	Stated Purposes for Projects	Scale of Deals
Saudi Arabia	Ethiopia, Sudan, Senegal, South Sudan, Russia, Philippines, Argentina, Egypt, Mali, Mauritania, Nigeria, Niger (Suspended by host in 2009), Pakistan, Zambia	Direct export of maize, soybean, fodder, rice, palm oil, prawn, bananas, pineapple, vegetables, wheat, poultry	Of these deals, 16 cover 1,713,357 ha. Of these deals, 5 cover 1,882,739 ha
UAE	Sudan, Algeria, Morocco, Egypt, Ghana, Indonesia, Namibia, Pakistan, Romania, Spain, Sudan, Tanzania	Direct export of potatoes, olives, dairy, olive oil, citrus, fodder, maize, palm oil, rice, sugar cane, dates, alfalfa, cereals, cotton, sunflowers, peanuts, sorghum	Of these deals, 5 cover 1,882,739 ha
Qatar	Cambodia, Sudan, Turkey, Brazil, Vietnam, Pakistan, India, Ghana, Indonesia, the Philippines, Australia	Direct export of sheep, wheat, cereal, rice, barley	Of these deals, 4 cover 642,630 ha
Kuwait	Cambodia, Laos, the Philippines Direct export of rice and maize Bahrain The Philippines	Direct export of rice and maize	
Bahrain	The Philippines	Direct export of bananas and rice	
Oman	The Philippines	Direct export of rice	

The GCC invested in overseas farmland purchases in Sudan, Pakistan, Egypt and Indonesia. The GCC land investments aim to secure food supplies by direct ownership and/or control of foreign farmland, and to exclude traders and other middlemen, aiming to reduce their food import bills by 20–25%, [33]. If hosting countries have food surplus after feeding their own people, land investments would benefit both the investors and hosting countries, and insure stable relations between them. For poor countries needing food for their own people, exporting food to investors' countries can raise many problems. These problems are discussed in details by in the literature, e.g. [34] for the case of Pakistan, [34] and **[32]** for the case of Ethiopia, and, [32] for the Case of Cambodia. In 2013, SA produced 2.666 MMT of alfalfa and 3.978 of fodders crops, 1.318 MMT of other fodders outside the country. SA grows alfalfa hay in both California and Arizona states in USA for shipment back to its domestic dairy herds. It was reported that SA bought 1,790 acres of farmland in Blythe, California for nearly $32 million. Also, a SA food company, Al Marai, purchased another 10,000 acres of farmland about 50 miles away in Vicksburg, Arizona, for around $48 million. So, SA is also looking to produce animal feed overseas in order to save water. An interesting land investment case is Hassad Food Company in Qatar and Australia is reported by Sippel (2013), [35].

7. Use of Treated Wastewater and Agriculture

GW is mainly used for agriculture irrigation in GCC. Recently, reclaimed TWW is used for animal fodder irrigation, land scape plants, trees, and grass in municipal parks. Reclaimed TWW can be a valuable water source for agriculture irrigation, and plays good share in countries with water scarcity, e.g. Singapore reclaimed TWW satisfies 30% of its water demand. Israel treats about 80% of its municipal WW, and reclaimed TWW satisfies about one quarter of its water withdrawal. Table 10 gives WW plants capacity in GCC. Qatar TWW capacity in this table needs to be corrected as 634860 m^3/d (231.7 Mm^3/y) in 2016, [36].

Table 10: Wastewater treatment capacity in the GCC countries[a], [14]

Country	Existing capacity (m^3 day^{-1})	Additional capacity planned by 2015 (m^3 day^{-1})	Estimated cost of additional capacity ($Millions)[b]
Bahrain	221,000	280,000	493
Kuwait	697,000	795,000	1,399
Oman	106,000	230,000	405
Qatar	285,000	437,000	769
Saudi Arabia	1,952,000	2,224,000	3,914
UAE total	965,000	1,607,000	2,828
Abu Dhabi	414,000	875,000	1,540
Dubai	260,000	400,000	704
Northern Emirates	291,000	332,000	584
Total	**4,226,000**	**5,573,000**	**9,808**

[a]Includes municipal projects only and not captive STPs serving real estate developments
[b]Cost is calculated on the basis of an average price of $1,760 m^3 day^{-1}. This was the estimated cost of building STP capacity in Muscat, Oman in late 2008

In 2005, the SA TWW plants' capacity was 778 Mm^3/y, with generated WW of 1460 Mm^3/y. In SA, about 240 Mm^3/y or 38% of the total TWW are used in landscape and crop irrigation. In Riyadh region, about 90,000 ha used to grow dates and forage crops, are irrigated with 146 Mm^3/y of TWW. The reclaimed TWW is expected to reach about 2,430 MCM which represent about 65% of the total domestic water use in 2025, [23]. Qatar TWW in 2013, is estimated by 640,000 m^3/d (233.65 Mm^3/y). Out of these TWW, about 300,000 m^3/d are reused in irrigation (70%), and injection in aquifers (22%), and other industrial uses. The UAE has 284 Mm^3/y treated WW, and reuse 60% of it. In 2012, a farm near Abu Dhabi used 22,500 m3/d used reclaimed TWW.

7.1. Virtual Water Trade

Virtual water (VW), water embedded in food, is exported from water-rich to water-short countries such as GCC, which find it increasingly difficult to grow sufficient staple food crops. In GCC, food security is satisfied by importing food (with its VW) to overcome local water shortage. The virtual water value (VWV) is generally expressed per volume (m^3) which results from multiplying the quantity of product (kg) by the unit value per product, expressed as volume of water per kg of product (m^3/kg). For agriculture product, the VWV is then defined as the quantity of water evapotranspiration at field level (ETa) to the yield (increment or total yield). It is expressed in m^3 of water per kg of crop, i.e. $VWV = Eta\ (m^3)/yield\ (kg)$.

As example, calculations the virtual water imported to SA through the year (2015 is used here) for cereal, namely, 3.486032 MMT of wheat, 10.86297 of barley, 2.904322 MMT of corn, 1.420487 MMT of rice give (3.486032*2132) + (10.86297*1808) + (2.904322*1937) + (1.420487*3702) =37,957 Mm3/y. This is almost twice the SA total withdrawal.

8. Conclusion

Water security in GCC depends on the economic capability of these countries to produce desalted seawater and reclaimed TWW since the NWR is very scarce and depleted. The same holds for food security. The food, in GCC, is mainly imported from international market or through land investments in rich-water countries. All the GCC consume too much per capita water and food. Conservation and preventing wastes in both water and food is the first step for water and security and sustainability. The lack of NWR and cultivated land make food self-sufficiency not achievable. However, food security is not only satisfied by food self-efficiency, but on the affordability, availability and quality of food by a country. Qatar, UAE, and are classified as the first, third, and fifth countries affordable to secure food worldwide, even ahead of the US (rated the fifth). This is based mainly on the per capita GDP, and the low ratio of food cost to the household expenditure. When considering all factors of security index, the GCC are considered high in food security, and ahead of all Arab countries. Waters available for growing food by agriculture are very limited as: Natural GW is very limited, over-extracted, depleted and quality deteriorated; Reclaimed WW is also limited and have many restrictions to be used for edible food; and DW is too expensive to be used. Diversifying the economy is a key issue towards water and food securities in view of the declining price of the exporting primary fuel (natural gas and oil) from the GCC.

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Improving the Livelihood of Small Farmers in the Arabian Peninsula through Increasing Water Productivity: The Case of Buffel Grass as Indigenous Irrigated Forage

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Abstract

In the Arabian Peninsula and more specifically the GCC countries, the need to use less water is critical, as water consumption has significantly exceeded sustainable supplies over the past decades. The result has been declining water tables and increased salinity. The severe rangelands degradation is well reflected on the feed shortages for livestock, Alfalfa (*Medicago sativa*) and Rhodes grass (*Chloris gayana*) are the main fodder crops cultivated by farmers of the region. These exotic species are not adapted to the prevailing conditions of drought and salinity. They require vast quantities of water (up to 48 000m^3/ha/yr) usually derived from a groundwater source which, apart from being unsustainable, has resulted in many areas having to be abandoned due to problems of salinity.

ICARDA with the full collaboration of the different national research and extension systems (NARES) of the GCC countries and Yemen started since more than two decades the development of a particular regional program to address the problems of agricultural production and natural resource management in the harsh environments of the Arabian Peninsula. It aimed at improving the livelihoods of small-scale farmers through the development and adoption of sustainable natural resources management technologies focusing among others, on forage production, within a water use efficiency approach. Some forages and fodder crops were screened and their performance under moderate to high salinity and water stress conditions. Buffel grass (*Cenchrus ciliaris*), the indigenous species has been identified as the forage that offers high-quality feed and high water-use efficiency. It can be harvested ten times a year, with an average dry matter yield of up to 20 t/ha.

Smallholder farms that are essential in the transition towards a green economy were targeted by the project through technology transfer and technical backstopping. The adoption of the developed technologies increased land and water productivity in farmer's fields. In UAE, the adoption of Buffel grass forage resulted in an average of USD 545 gross income increase/ha/year and each ton of dry matter translated into water saving of 850 m^3 compared to Rhodes grass. In Oman, farmers are saving 55% water by adopting Buffel grass over the popular Rhodes grass. The Oman Government and Abu Dhabi Farmers' Services Center in UAE are supporting and educating growers to replace Rhodes grass, the widely used forage species in the past, with the more beneficial and less water consuming Buffel grass.

Keywords: Water Productivity, Buffel Grass, Arabian Peninsula, ICARDA.

Introduction

The Arabian Peninsula (AP) includes the six GCC countries, and Yemen is characterized by extreme aridity and limited renewable water resources. Water resources are dominated by groundwater which is over-used with five of the seven countries extracting water at rates greater than natural recharge, which led to sea water intrusion in the aquifers and subsequent lowering of water tables. Agricultural productivity is reduced substantially.

Pastoral communities of the Arabian Peninsula operate in a harsh environment where the water scarce and soils are often saline. Vast areas of land suffer from some form of desertification, mainly caused by overgrazing of livestock. This situation first came about in the 1960s, when livestock production increased sharply, thanks to better veterinary services and subsidies that enabled farmers to purchase processed feed and baled hay.

Overgrazing reduces the productivity of an ecosystem as well as the nutritional value and relative abundance of plant species. And when rangelands do not provide sufficient rainfed forage, farmers extract groundwater to produce irrigated forage – further exacerbating water shortages. Unless current practices change, water resources will be rapidly depleted, indigenous species and technical knowledge lost, and the natural resource base destroyed.

Rangeland degradation in the GCC countries has resulted in severe feed shortage over the years and obliged the farmers to grow Rhodes grass and alfalfa. Both forages are produced under a high level of irrigation estimated at 48 000 m^3 ha^{-1} per year ([1]). Pumping of ground water for irrigation has resulted in lowering of the water table in the region, increased salinity and in severe cases abandonment of farms ([1]).

Since its establishment in 1977, ICARDA has actively collaborated with the Arabian Peninsula countries through technical backstopping about its mandated crops and areas of research. However, in 1995 this collaboration had entered into an upper level when ICARDA inaugurated its Arabian Peninsula Regional Program (APRP) office in Dubai. Since then, ICARDA with the financial support of International Fund for Agricultural Development (IFAD), Arab Fund for Economic and Social Development (AFESD) and OPEC Fund for International Development (OFID) executed numbers of intense research for development projects. The achievements of ICARDA in the Arabian Peninsula are demonstrated by the useful technology packages in rangeland rehabilitation, irrigated forages, on-farm water management, and protected agriculture.

A joint research effort between the National Agriculture Research Systems (NARS) of the AP countries and ICARDA was focusing on identifying new forages that use less water in the production process. Under this joint effort, collection missions for indigenous plant species were carried out in 6 AP countries (Bahrain, Oman, Qatar, Saudi Arabia, United Arab Emirates and Yemen), where seeds of potential forages were collected ([2]). Most of these species were evaluated for their forage and seed production, feed quality and water use efficiency in the respective countries.

An Indigenous answer

A potential solution to water and rangeland problems in the AP is developing production and rehabilitation systems based on native species because they are already well adapted to the regional environments. With this context, nine collection missions for major indigenous forage grasses, legumes, shrubs, and trees were conducted by ICARDA scientists and its partners from all AP countries. The ultimate objective was to utilize the most promising germplasm for rangeland rehabilitation and irrigated fodder production.

Prioritization of Species

Followed by collection missions, species with potential to be used either for feed production or rangeland rehabilitation were prioritized over a period through the collection of indigenous knowledge, discussions with Bedouin farmers, local botanists, as well as research activities. As a result, a list of 'target species' with 27 high-priority species developed.

Within the high-priority list, Buffel grass or Lebid (*Cenchrus ciliaris*) was identified as forage of high feed quality and high water-use efficiency. The forage can be harvested ten times a year, with an average annual dry matter yield of up to 20 t ha^{-1}. Buffel grass is high-quality forage, which animals find very palatable. And although the annual yield of buffel grass under drip irrigation is equivalent to that of Rhodes grass (20 tons of dry matter per hectare), it uses 50% less water.

Concerning the feeding value, the chemical composition and gas production data are presented in Table 1. Results show that *Cenchrus ciliaris* is comparable with Rhodes-grass in having a similar neutral detergent fiber (which provides an indication of dry matter intake), acid detergent fiber, acid detergent insoluble nitrogen and ash (which gives an indication of the silica content which makes forages less palatable). Also, *Cenchrus ciliaris* had a similar nutritive value to Rhodes-grass as measured by the gas production technique.

Table 1: Comparison of the mean chemical composition (% DM basis) and gas production of Buffel grass species with irrigated Rhodes-grass [1].

Chemical composition	**Buffel grass (% DM)**	**Rhodes grass (% DM)**
Crude protein	9.6	9.4
Neutral detergent fiber	70.1	72.9
Acid detergent fiber	38.6	38.8
Acid detergent insoluble N	0.1	0.1
Ash	10.0	9.6
Gas production (ml)		
06 h	8.9	7.9
12 h	17.8	15.5
24 h	28.0	26.8
48 h	38.8	37.4

Improving water productivity of irrigated indigenous forage

Many research studies were carried out in AP countries to solve the problems that faced the adaptation of the project new technologies by farmers. Several experiments were conducted according to each country specificities and requirements. For example, the project encouraged using drip irrigation system in this region because of water scarcity and its harsh hot, dry climate. However, in some cases and due to the vast areas of forage crops in Oman and KSA where it is difficult and not practical for farmers to use drip irrigation system ICARDA studied the feeds production and water use efficiency under sprinkler irrigation method. In the other countries including Qatar and UAE, drip irrigations are being used where these systems are suitable for small farms, soil and climate conditions of these countries. The followings are some experiments which were conducted during the project period on forage crops.

In UAE, drip irrigation trials for Buffel grass held in pilot farmers' fields during the period 2003-2013. The study resulted in an average yield of 20 t ha^{-1} of dry matter in 10 harvests and a water productivity within a range of 0.53 -1.2 kg DM m^{-3} compared to a lower range of 0.48 – 0.84 kg DM m^{-3} of water for Rhodes grass ([3]).

In Qatar, an on station yield stability trials under drip irrigation for the native Buffel grass species and three exotic varieties (Biloela, Gayanda and USA) conducted during 2011-2013. The results demonstrated that Biloela recorded the highest production in dry matter (16 t ha^{-1}) followed by the local species (13 t ha^{-1}). On the other hand, the native Buffel grass accession obtained the highest yield stability followed by the variety Biloela (Figure 1).

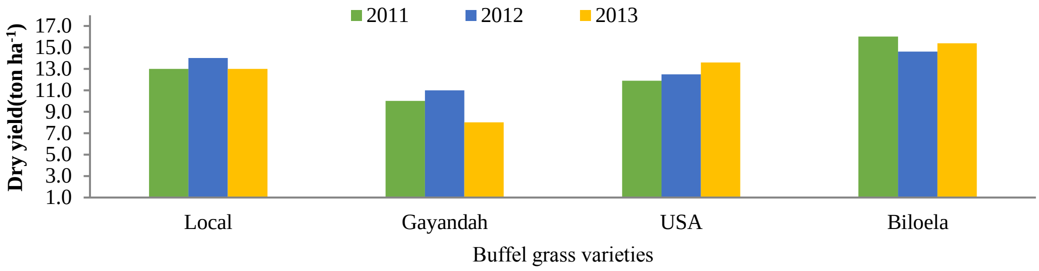

Figure 1: Yield (ton ha^{-1} of Dry Matter) of four types of Buffel grass in Qatar

In Oman and the Saudi Arabia, areas allocated to irrigated forages are colossal, and therefore drip irrigation cannot be used. In Oman, a study conducted to evaluate the response of Buffel and Rhodes grasses to different irrigation levels using line-source sprinkler irrigation system ([5]). The experiment consisted of four irrigation treatments based on the reference evapotranspiration (Eto); 125,100, 65, and 40% of Eto and the two grass species as sub-main treatments in strip plot design with four replications. The Results indicated that Both Buffelgrass and Rhodes grass gave higher dry yield when irrigated with 125% ETo and Buffel grass has a higher yield than Rhodes grass at all irrigation levels. The dry yield of Buffel grass reduced as irrigation quantity decreased with no significant difference between 25786 m^3 ha^{-1} (100% ETo) and 16761 m^3 ha^{-1} (65% ETo) levels. Buffel grass irrigated with 16761 $m^3.ha^{-1}$ (65% ETo) gave higher WUE compared to other irrigation levels and also gave same Rhodes grass dry matter yield irrigated with 32233 $m^3.ha^{-1}$ (125% ETo) (**Error! Reference source not found.**).

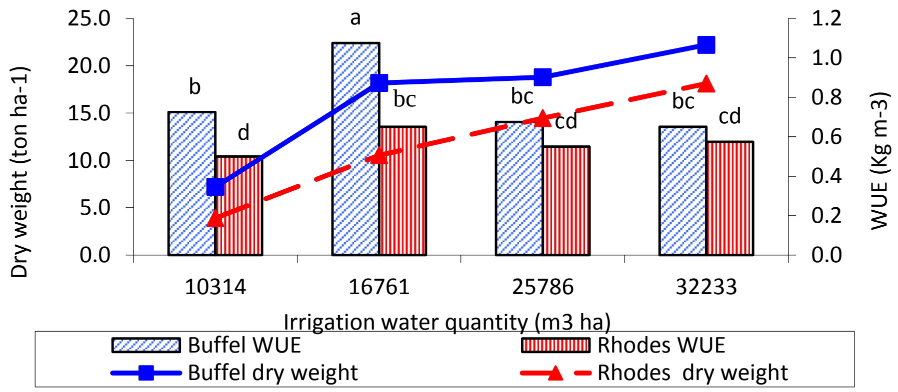

Figure 2**:** Total dry yield (ton ha^{-1}) and average WUE (kg. m^{-3}) under average water quantities per cut different (mm/cutting cycle) for both Buffel and Rhodes grasses

Figure 3 illustrates that for all irrigation levels, buffel grass showed significantly higher water productivity than Rhodes. It also indicates that Buffel and Rhodes grass irrigated with 17454 m^3ha^{-1} (65% ET_o) gave significantly higher water productivity than the other irrigation levels. At 65% ET_o irrigation treatment, Buffel grass water productivity was 31% greater than that of Rhodes grass. These results agreed with the ICARDA previous finding ([3]) that Buffel grass water productivity (kg of dry matter per m^3) was 0.53-1.23 kg m^{-3} compared to Rhodes grass with 0.47-0.85 kg m^{-3} under drip irrigation system.

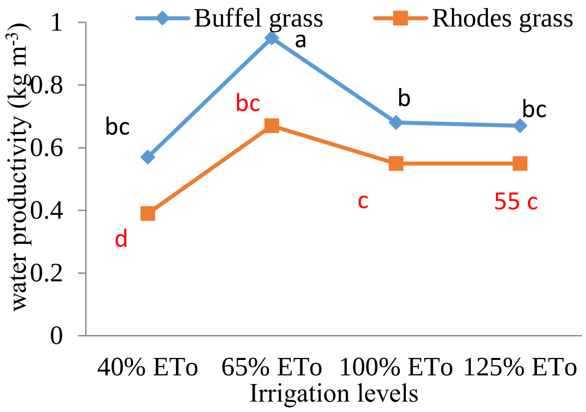

Figure 3: Crop water productivity for Buffel and Rhodes grass under different irrigation regimes at Rumais Research Station–Oman 2013/2014 growing season

It has been concluded that, in vast areas where drip irrigation is very costly and only sprinkler irrigation system can be practically applied, Buffel grass showed higher performances in production and water productivity as compared to Rhodes grass and seems to be more tolerant to salinity and water stress condition. About 50% of applied water can be saved when growing Buffel grass to produce the same amount of dry weight of Rhodes grass.

In Saudi Arabia, a similar study was implemented at the Camel and Range Research Center, Al Jouf. The study aimed to assess the impact of irrigation levels (50, 75 and 100% of crop requirements corresponding respectively to annual irrigation quantities of 4000, 8000 and 12000 m^3ha^{-1}) on the productivity of exotic and native Buffel grass established by seedlings and direct seeding ([4]). The results indicated that applying12000 $m^3ha^{-1}$of crop water requirements gave the highest dry matter yield and the native Buffel grass using seedling planting had the optimum yield when applying 8000 m^3ha^{-1} (Figure).

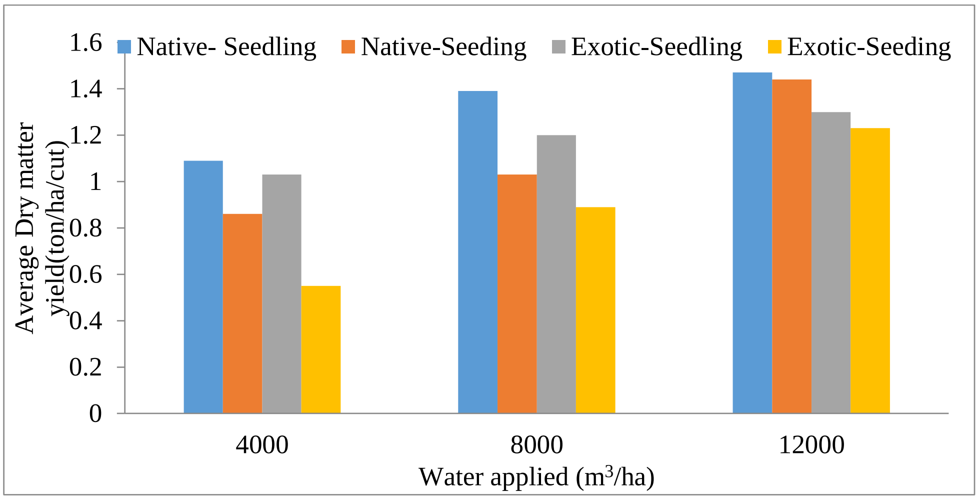

Figure 4: Average Buffel grass dry matter yield (ton ha^{-1} cut^{-1}) as affected by variety and planting methods under sprinkler line source experiment at Al Jouf, KSA during 2013 growing season

The productivity of the native Buffel grass was better than that of the exotic grass at all sprinkler irrigation levels and the dry matter productivity increased by increasing the irrigation rate (Figure 3). No significant differences were noted for the production of seeds or seedlings of Buffel grass below the irrigation of 12,000 $m^3ha^{-1}year^{-1}$. It is recommended to irrigate with

12000 $m^3ha^{-1}year^{-1}$ when planting by direct seeding method until plant reached the root establishment stage and to irrigate by 8000 $m^3ha^{-1}year^{-1}$ level when planting by seedlings method. The highest water efficiency (kg m^{-3}) achieved when planting native Buffel grass using seedling method under 4000 m^3 ha^{-1} irrigation level.

Introduce to growers

To disseminate and introduce the new forage to farmers, some pilot demonstration sites were established in all AP countries by ICARDA in collaboration with National Agricultural Research and Extension Systems (NARES). The growers were provided with seeds and a published field guide on producing the forage and regularly visited by the ICARDA-APRP forage specialists and NARES researchers. Very soon Buffel grass got the attention of local growers and request for adoption of this indigenous species as irrigated forage were increased rapidly. For instance, only in UAE from 2003 to 2016 number of farmers adopted Buffel grass from 1 increased to more than 200. The success stories of the Buffel grass growers in saving water and production high yield has encouraged the policy makers in the region for further support. The Oman Government and Abu Dhabi Farmers' Services Center in UAE are supporting and educating growers to replace Rhodes grass, the widely used forage species in the past, with the more beneficial and less water consuming Buffelgrass. In Abu Dhabi Emirate, all subsidies related to the cultivation of Rhodes grass have already been stopped.

New problem, where to get the seeds?

The constraint of seed availability from the promoting species was addressed in Bahrain, UAE, Oman, Saudi Arabia, and Yemen. UAE have made significant steps in seed production of *Cenchrus ciliaris* and *Lasiurus scindicus*, which allowed for forage demonstrations in farmer fields. Seed production was enhanced by the establishment of Seed Technology Units in UAE, Oman, Qatar, Saudi Arabia, and recently in Yemen. Also, to help the National Agriculture Research Centers to obtain high-quality seed, APRP has established seed multiplication fields together with seed technology units in Oman, Qatar, Saudi Arabia, UAE, and Yemen.

Conclusion and Lessons Learned

The joint effort of ICARDA and NARES to introduce ICARDA-APRP targeted technologies has significantly contributed to increasing in farm income. As average adoption of Buffel grass as an indigenous forage crop increased farmers' income by 540US$ha^{-1}year^{-1}$. Growth in farm revenue generation by adopting these technologies is mostly due to higher yield and water productivity.

Overall, it can be stated that ICARDA targeted technologies in AP, not only have a technical advantage over existing production system (higher yield) but also are more environment-friendly (less water and Hazardous Agro-Chemical) and are matched with the present farming system.

It seems that growers' assets in the farms also positively increased as result of adopting the project targeted technologies. However and beside positive impact on farm income, the adoption rate is still relatively low. Even though the project achieves a higher score than its goals; based on the interviews with the growers and farmers; there are some problems which facing the broad adoption of these technologies. The most important constraint names by farmers as marketing and high initial cost of establishment followed by the lack of know-how and technical backstopping.

Regarding enhancing the technology transfer process, enabling policies in the form of initial matching grants for the creation of on-farm production assets such as irrigation equipment for forage production should be considered.

Acknowledgments

The authors wish to acknowledge the efforts and dedication of NARES researchers and ICARDA scientists in the Arabian Peninsula including Dr. A. Osman, Dr. J. Peacock, Dr. M. Ferguson and Dr. N. Mazahreh. The valuable financial support provided by AFESD, IFAD, and OFID to ICARDA's APRP is highly appreciated.

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SESSION 8: WATER-RELATED ENVIRONMENTAL AND HEALTH ISSUES

Keynote

Regulatory Aspects of Drinking Water and Sanitation

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Regional Advisor on Water, Sanitation, Climate Change and Health
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Abstract

The paper provides an overview of the status of regulatory aspects of drinking water and sanitation across the 22 Member States of the World Health Organization Eastern Mediterranean Region. Water and sanitation is an important determinant of health. Poor water and sanitation conditions account for 842,000 diarrhoeal deaths every year, and contribute to the prevention of management of the vast majority of neglected tropical diseases. WASH deaths have been more than cut in half during the MDG period, with the significant progress on water provision likely playing a key role.

WHO, as the world's guardian of public health, has played a longstanding role providing related technical guidance to its Member States and practitioners. WHO has regularly issued authoritative international standards or guidelines on Drinking-Water Quality since the 1950's; and guidelines on Safe Use of Wastewater since 1989, WHO has performed the function of global water and sanitation monitoring since its inception.

The overview is generated through the WHO's monitoring processes. The regulatory aspects covered in the paper include:

1. Regulation on population access to water and sanitation services including availability, affordability, reliability and quality of these services.
2. Regulation on safely managed drinking water supplies and safe use of wastewater. Regulation include national standards for drinking water, national standards for sanitation services, and national standards for wastewater use. These regulation emphasize the importance of adopting the preventative multi-barrier approaches to safety that are based on risk assessment and risk management often termed Water Safety Planning and Sanitation Safety Planning.
3. Regulation clearly defining the roles and responsibilities of the multiple stakeholders involved in the management of drinking water and sanitation services. These regulations cover: responsibilities for setting up regulatory framework for the water and sanitation services; responsibilities for providing water and sanitation services and operation monitoring and verification; and responsibilities for regulatory surveillance of water and sanitation services to ensure compliance to regulations and to provide feedback to regular updates of the regulations.

Keywords: Regulatory Aspects, Drinking Water, Sanitation, Health, Availability, Affordability, Reliability.

Integrated Approach to Grow Crops with Fish Using Treated Wastewater

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Abstract
Growing fish using treated wastewater is one of the techniques in providing plants with needed nutrients. The objective of the study was to evaluate the effect of treated wastewater on fish life and later on the effect of the produced effluent coming from fish tank on grown crops. Nine tanks with dimensions of 80*40*40 cm were filled either with freshwater or a mixture of freshwater and treated wastewater (50: 50 & 75:25 %) and 25 Tilapia fish were added to each tank. Each tank was connected with another tank of same dimensions that was used to grow lettuce and bean crops on the top layer. Water was circulating between two tanks. No fertilizer was added to all treatments and all tanks got similar amount of fish feed. It was found that tanks with treated wastewater got higher values of dissolved oxygen due to algae growth and more salts content due to minerals added from treated wastewater compared to freshwater alone. Therefore, lettuce and bean growth was much better and got higher values of chlorophyll content compared to control tanks. For heavy metal analysis, all waters got similar values for all measured elements with higher concentrations of Fe, B and Zn which could be supplied by fish food and waste. For the edible part, both crops with all treatments got high values of B and Fe. Whereas, other elements such as Cu, Zn and Ni were found in higher values in lettuce grown in treated wastewater compared to freshwater. In general, the differences in concentrations of all measured elements in different treatments of both crops were small which mean that treated wastewater has low concentrations of heavy metals. Fish analyses showed that all tested heavy metals were within the safe limit. However, applying this technique in the farming system will help the environment by utilizing treated wastewater and reducing fertilizer applications. Moreover, farmer income will increase since both fish and crops will be produced with minimum resources.

Keywords: Tilapia Fish, Aquaponics, Heavy Metals, Lettuce.

Introduction
Aquaponics system incorporate recirculating aquaculture with the soilless production of plants. The recirculating systems are designed to raise large quantities of fish in relatively small volumes of water by treating the water to remove waste products and then re-using it. As water is recycled beneficial nutrients and organic materials accumulate. These are then channeled into secondary crops in an integrated system. Plants grow rapidly with dissolved nutrients that are excreted by the fish or generated by the microbial breakdown in fish wastes (Rakocy *et al.*, 2006). There are a number of benefits linked to aquaponics. These include: 1. Reduced water requirement for intensive fish and plant production, 2. The daily supply of feed to the fish supplies a steady flow of nutrients, which are recovered, after treatment, from the fish tank effluent and used to irrigate crops, 3.

Shared infrastructure and operating costs, 4. Reduced land requirement (Rakocy, 1997).

From other side, in water-scarce regions like Oman, the use of wastewater in agriculture will free up, and prevent the contamination of good quality water resources for the use in urban centers and industry. Although the use of treated wastewater in agriculture is encouraged and promoted (Abdelrahman *et al.*, 2011; Alkhamisi *et al.*, 2016). Therefore, the objective of the study was to evaluate the effect of treated wastewater on fish life and later on the effect of the produced effluent coming from fish tank on grown crops.

Materials and Methods

The study was done in shade house in college of Agricultural and Marine Sciences at Sultan Qaboos University. Tanks with dimension of (80x40x40 cm) were used and each one had either a freshwater or a mixture of freshwater and treated wastewater in ratio of 50: 50 % or 75:25 %. Each tank was filled with 25 Tilapia fishes and each tank was connected with other tank of same dimensions that used to grow lettuce and bean crops (Fig. 1). Constant aeration was provided at fish tank. No water was added or removed during the study. The fish was fed three times a day and water was circulated between each two tanks. Weekly analyses was done for water salinity, dissolved oxygen and pH. Plant growth was monitored and data for chlorophyll using CCM-200 devise was taken. At the end of the study, plants were harvested and different parameters were measured such as: ammonia, nitrate, nitrogen, microbiological analysis and other metal analysis using ICP machine.

Figure 1: Tanks with fish and crops used in the study

Result and Discussion

Water analysis

Dissolved oxygen (DO) is an indicator for how fresh is the water. Whenever the dissolved oxygen get down that mean it may contains some microbes or contaminants and it is un-healthy water for the fish. For Figure 2, it can be seen that dissolved oxygen level was vary with time and almost all treatment got similar concentrations. However, some time it was found that treatments that had treated wastewater got higher values of dissolved oxygen and that due to algae growth that was enhancing production of dissolved oxygen through photosynthesis. From other side and sometimes, high density of algae blocked some pipelines and reduced water circulated between tanks which affect dissolved oxygen values and that was happening in tank with 50% treated wastewater.

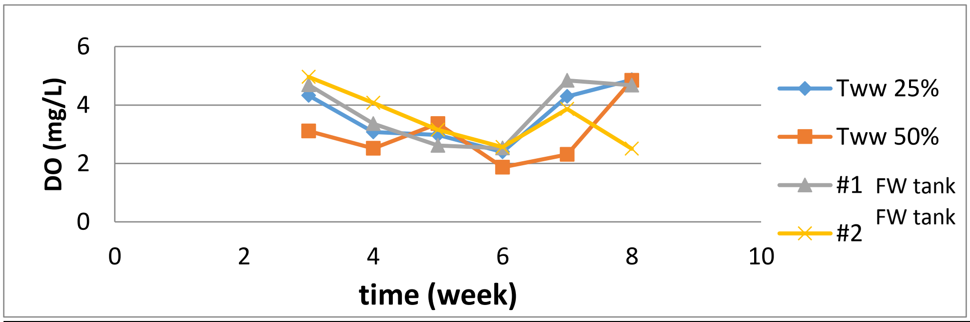

Figure 2: Weekly changes in dissolved oxygen of all treatments

Water salinity should be constant with smal increase due to evaporation process or salts coming from fish food or fish waste. Morover, treated wastwater is rich of many nutrients so it could add some extra salts to the tanks. As it was expected and shown in Figure 3, water salinity was increasing untile plants start to utlize that salts as nutreints for its grwoth.

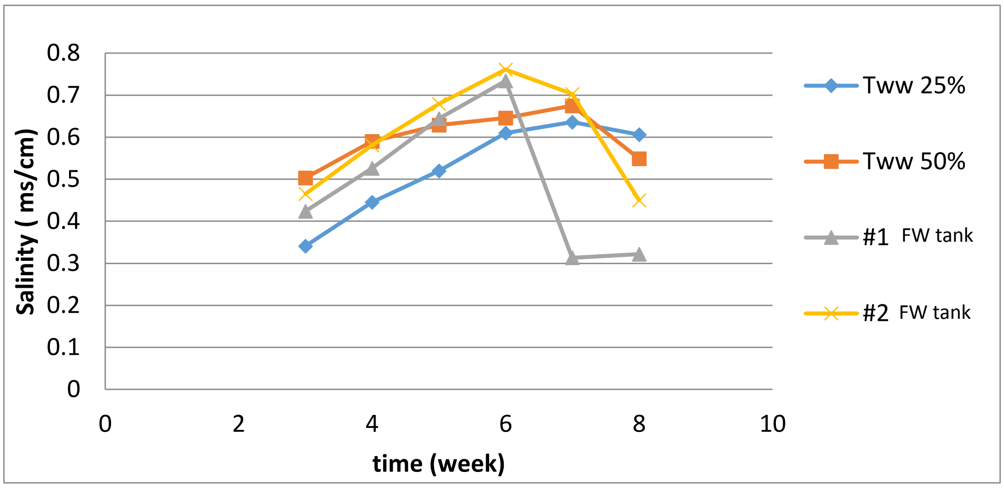

Figure 3: Weekly changes in water salinity of all treatments

High values of heavy metals are not recommended especially in the edible part of the plant. It can be seen in Figure 4 that all measured values had low concentrations except for B, Fe and Zn. There were higher in treated wastewater compared to freshwater. However, all concentrations for all treatments were close from each other which mean the source of those elements could be fish food or waste but not treated wastewater only. Therefore, monitoring is required to make sure that used water is not casing any health problem to fish or grown plants which later will be reflected in human health.

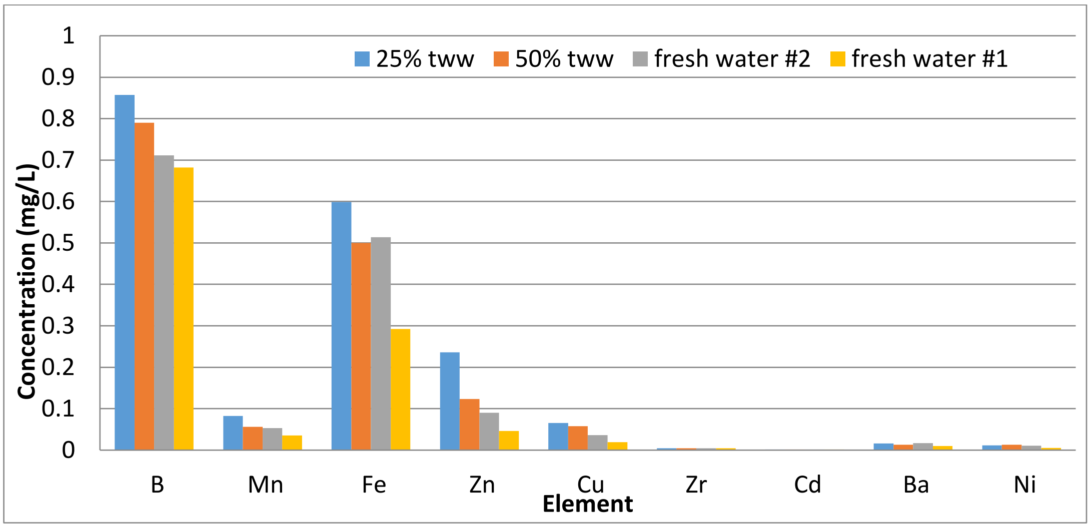

Figure 4: Average elements concentrations of all treatments

Usually microbial analyses are the direct indicators for microbial contamination. In this study, Coliform bacteria was expected to be found because it is existed in fish waste (Table 1). However, E-Coli was not found and that was a good indicator for good quality of all used waters.

Table 1: Microbial analysis

Sample	Coliforms	the Most Probable Number (MPN) of the Coliform bacteria	E-Coli
Tww 25%	50	200.5	0
Tww 50%	50	200.5	0
Fresh water #1	50	200.5	0
Fresh water #2	50	200.5	0

Plants Analysis

Chlorophyll data is a good indicator for nitrogen values in plant tissues. It can be seen from Figure 5 that all measured data for all treatments had a good values of nitrogen and even higher with treated wastewater treatments which also confirmed by measured nitrogen shown in Table 2. This can be explained by nitrogen provided to the plants from fish waste and treated wastewater.

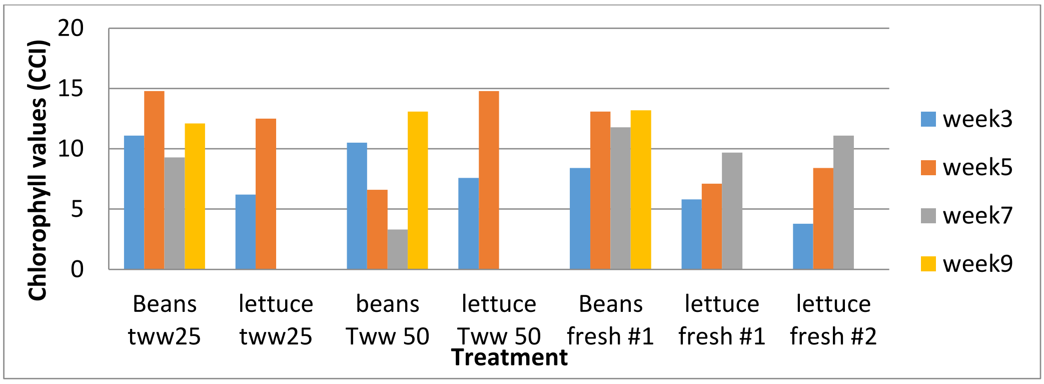

Figure 5: Chlorophyll Content of all treatments

Table 2: Nitrogen values on lettuce plant

Treatment	Nitrogen %
25 % TWW	3.82
50 % TWW	3.70
FW	3.56

Since no chemical fertilizer was add to all treatments so plants were relaying on nutrients coming from fish waste and available in treated wastewater. Therefore, it can be seen from Figure 6 that treated wastewater treatments gave better growth for lettuce plants compared to fresh water treatment.

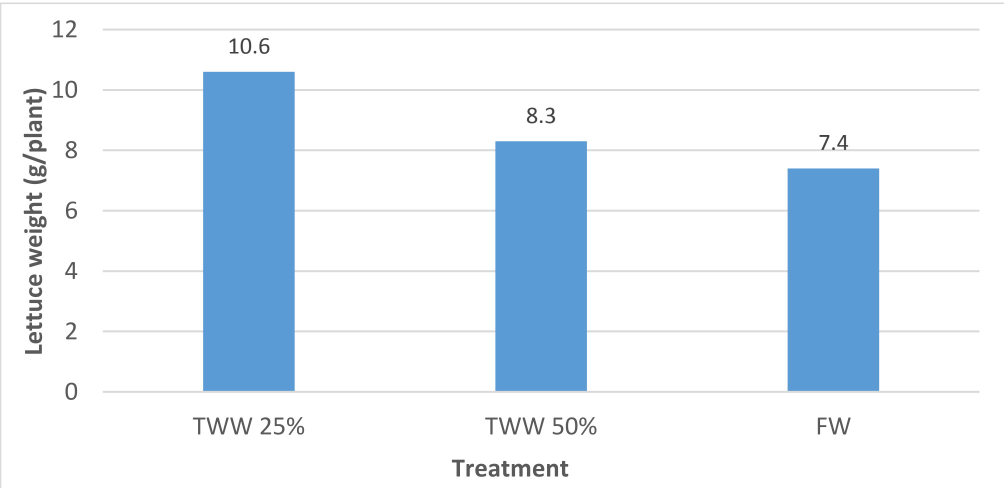

Figure 6: Lettuce growth as affected by different treatments

The most sensitive part for human consumption in each crop is the edible part. It can be seen from Figure 7 that both crops lettuce and bean got similar values for all measured elements which is a reflection for what was found in irrigation waters. Elements of B, Fe were found in high concentrations for all treatments which could be a limited factor for crop consumption. However, other elements such as Ni, Zn and Cu can be found in higher concentrations in treated wastewater compared to freshwater but in general, the difference was small. In Selem et al. (2000) study, they observed an increase in Fe, Zn, Cu, Mn, Pb and Co with land irrigated with treated wastewater as compared to untreated soil. The accumulation of heavy metals in the edible part of some plants could adversely affect human and animal health (Abd-Elfattah et al., 2002). In present study, the increase in heavy metals with treated wastewater was small compared to freshwater and nothing was reflected in plant and fish lives. In addition to that the grown fishes were tested and measured values related to health issues were within the acceptable limit of international standards. However, monitoring is required to avoid any health problems.

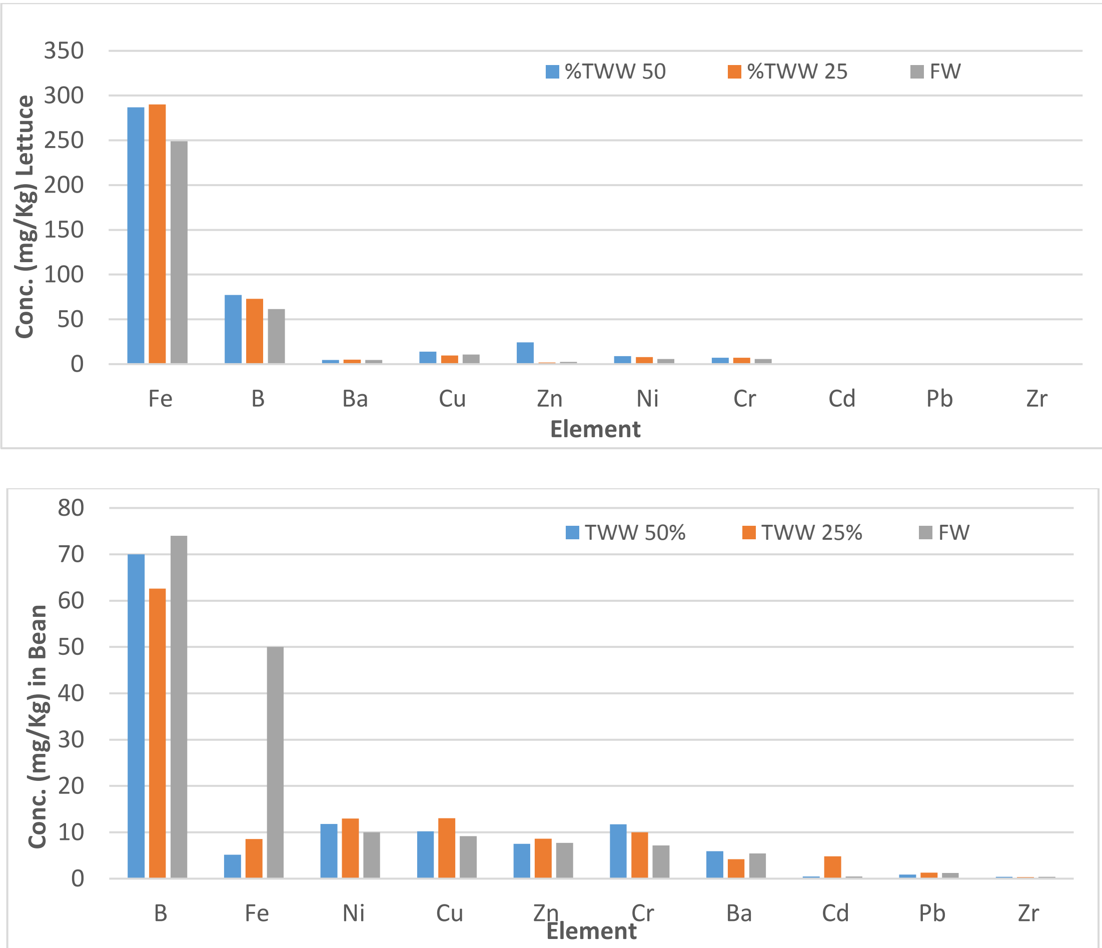

Figure 7: Average elements concentrations in lettuce and bean shoots

Conclusion

The project described the possibility of producing crops in aquaponics system using both fish waste and treated wastewater. Bothe sources enriched the media with many nutrients needed for the plant growth. Some heavy metals were accumulated in the irrigation water which was reflected in grown crops. The concentrations of heavy metals in freshwater and treated wastewater were close from each other indication that diluted wastewater can be used safely in aquaponics system. Therefore, the system used in this study can provide plants with needed nutrients and produce safe crops with minimum risk. The system is simple and can be implemented in small area. It is environment friendly, help in saving freshwater and maximizing the application of treated wastewater with no or minimum need for chemical fertilizers. However, monitoring with good managements is required to avoid any health issues.

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Minerals in Kahramaa Drinking Water and its Importance on Consumers Health and Taste

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Abstract
The state of Qatar depends mainly on sea water desalination to satisfy the nation's need of potable water. A major portion of potable water is produced from sea water by *Independent Power and Water Providers* (IPWPs) through either MSF or MED technology. *Qatar General Electricity and Water Corporation* (KAHRAMAA) is the sole distributor of potable water to the nation of Qatar through its distribution network. KAHRAMAA, with an agreement of terms and conditions with IPWPs, controls the water quality aspects and thereby takes utmost care to provide its customers with a balanced quality of drinking water in terms of clinically important mineral contents and aesthetical aspects. Generally, in developing countries due to changing life style and people's perception most people prefer to consume bottled drinking water rather than tap water. A survey Our Water is Safe conducted in 2014 by Kahramaa Water Quality Section, showed that about only 30% of Qatar's population uses KAHRAMAA water as their main source of drinking water whereas the rest 70% prefers not to use KAHRAMAA water for direct consumption due to different reasons like individual's perception, lack of awareness, lack of confidence and trust. As KAHRAMAA endeavours and ensures the supply of safe and clean drinking water to its customers that complies with national and international standards, therefore to motivate and strengthen the consumers trust and confidence on the tap water quality a research study was conducted. In this study the important chemical constituents related to consumers health and perceptions of taste in KAHRMAA water were reviewed and were compared with the quality of few major bottled drinking water commercially available in the region of Qatar. The review of results shows that the KAHRAMAA water has an equally excellent quality that meets the national and international standards for drinking water quality and fulfils the requirement of consumers' health and taste.

Keywords: Tap water, Bottled Water, Minerals, Water Taste.

1. Introduction
The State of Qatar relies mainly on sea water desalination to satisfy the nation's needs of drinking water. Qatar General Electricity and Water Corporation (KAHRAMAA) is the sole distributes of potable water throughout the State of Qatar through its distribution network. KAHRAMAA, with an agreement of terms and conditions with the water producer companies, controls the water quality aspects following various national and international guidelines and requirements[1,20,21] and thereby takes utmost care to provide its customers with a balanced quality of drinking water in terms of clinically important mineral contents and aesthetical aspects.

Although several researchers[10-12] had proved that minerals are essential nutrients for the human health but the optimal level of nutrients is yet to be determined in drinking water that is necessary to maintain or improve consumer's health conditions. As per World Health Organization (WHO) guidelines for drinking water acceptability aspects, the appearance, taste and odour of drinking water should be acceptable to the consumer. Aesthetically poor or unacceptable water can lead the consumer to switch over to other sources of water that are aesthetically more acceptable. The concentration at which the constituents are objectionable to consumers is termed as taste threshold value and these values may vary significantly. A collective taste threshold values for the minerals that are potential to affect the taste of drinking water are shown in Table#1. WHO established about 14 mineral elements (Calcium, Magnesium, Sodium, Potassium, Chloride, Phosphorus, Fluoride, Zinc, Copper, Selenium, Manganese, Molybdenum, Ferrous and Chromium) as essential for good health[2]. Drinking water supplies may contain some of these minerals in its natural form or due deliberate addition during its treatment process to control the aggressiveness of the water which in terms benefits the consumers in the intake of these minerals to certain extent.

It has been observed as a growing trend that in developing countries due to changing life style and people's perception most people prefer to consume bottled drinking water rather than KAHRAMAA supplied tap water. A survey[4] conducted in 2014 by KAHRAMAA, showed that about only 30% of Qatar's population uses tap water as their main source of drinking water whereas the rest 70% prefers not to use tap water for direct consumption due to different reasons like individual's perception, lack of awareness, lack of confidence and trust. The constituents that may affect the drinking water taste could be of origin from organic or inorganic sources. Organic constituents generally affect the taste intensity lesser than the inorganic constituents of the water[1]. In this study chemically derived constituents that are generally related to the consumers' health and taste of water were analysed in the commercially available bottled drinking water and compared with the characteristics of the KAHRAMAA distributed drinking water.

Table 1: (Taste threshold values for general constituents of drinking water)

Constituents	Taste threshold values	Noticeable effect
pH	6.5 – 8.5	<6.5; Bitter metallic taste >8.5; Slippery, soda taste
TDS*	600 mg/L	Salty taste
Hardness*	100-300 mg/L	Salty taste
Calcium**	125 mg/L	Salty, bitter taste
Magnesium**	100 mg/L	Unpleasant salty taste
Sodium**	30-140 mg/L	Salty, bitter taste
Potassium**	340-680 mg/L	Salty, bitter taste
Chloride*	200-300 mg/L	Salty taste
Ammonia*	35 mg/L	Metallic, blood like taste
Sulfate*	250 mg/L	Salty taste
Copper*	2 mg/L	Metallic taste
Manganese*	0.1 mg/L	Bitter metallic taste
Zinc*	4 mg/L	Metallic taste
Ethyl benzene*	72-200 µg/L	Gasoline taste
Monochlorobenzene*	10-20 µg/L	Sweet taste
1,4-dichlorobenzene*	6 µg/L	Sweet taste
Toluene*	0.04-0.12 mg/L	Sweet taste
Xylenes*	0.3 mg/L	Turpentine like taste

Note: **Chapter-10, WHO guideline for drinking water acceptability aspects[1]; **Canadian guidelines for drinking water taste[18]*

2. Objective

KAHRAMAA endeavours and ensures the supply of safe and clean drinking water to its customers that complies with national and international standards and to motivate and strengthen the consumers trust and confidence on the KAHRAMAA water quality this research study was conducted. The main objectives were to 1) Review the level of chemical constituents in KAHRAMAA water that are potential to affect it's taste with reference to their taste threshold values and 2) Analyse the clinically important constituents like Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Chloride (Cl), Copper (Cu), Zinc (Zn), Manganese (Mn), Selenium (Se), Chromium (Cr) and Fluoride (F) in the commercially available bottled drinking water and compare the findings with the characteristics of KAHRAMAA water.

Design

Drinking water taste can be affected due to organic, natural inorganic, biological contaminants or by synthetic chemicals used during water treatment or due to corrosion of distribution pipelines. In this study few chemical constituents known to have effect on drinking water taste and influence to consumers health were considered. To address the first objective of this study few chemical constituents (as listed in Table 1) commonly known to have influence on the drinking water taste were reviewed in KHARAMAA distributed drinking water for their level of concentration in the last three years and the findings were compared to the taste threshold values for those elements. And to fulfil the second objective clinically important minerals like Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Chloride (Cl), Copper (Cu), Zinc (Zn), Manganese (Mn), Selenium (Se), Chromium (Cr) and Fluoride (F) were reviewed in KHARAMAA distributed drinking water in context with the health based guidelines values for these minerals if any and compared with the bottled drinking water.

3. Methodology

a. Commercially available bottled drinking water

Ten different brands of bottled water were purchased from local Qatari market and the bottles were kept sealed and refrigerated at 4°C until the time of analysis. The bottled water were analysed in duplicates at KAHARAMAA Water Quality Laboratory facility by using various advanced analytical equipment. Ion chromatography (Metrohm 850 professional) was used to determine the concentration of Ca, Mg, Na, K, NH_4, SO_4 and Cl. Gas chromatography mass spectrometry (Thermo 1310) was used to determine the concentration of Ethyl benzene, Chlorobenzene, Toluene and Xylenes. Inductively coupled plasma electrophoresis (Agilent 7500 CE with Octopole Reaction System) was used to measure the concentration of Cu, Mn and Zn. Total dissolved solids (TDS) was derived using mathematical conversion factor from electrical conductivity that were measured by electrical conductivity meter. Total hardness was measured by Metler Toledo T-90 auto titration method. pH was measured by Thermo orion-420A-Plus pH meter.

b. KAHRAMAA distributed drinking water

KAHRAMAA Water Quality Laboratory (KAHRAMAA-WQS) is an ISO17025 accredited facility and is engaged in monitoring of the quality of KAHRAAMA drinking water distributed through its piped network system. KAHRAMAA-WQS follow WHO guidelines for drinking water quality[1] and uses *Standard Method for Examination of Water and Waste Water* or *EPA approved drinking water analytical methods*[3]. To accomplish the water quality monitoring program routinely water samples are collected from Desalination Plants, Reservoirs, Tanker Filling Stations and Fire Hydrants located in different parts of the country and are analysed in the laboratory facility for various parameters. The fire hydrants are sub classified into two categories; fixed fire hydrants and variable fire hydrants. Fixed fire hydrants are selected in a way that those collectively represents the overall quality of the water distributed through the KAHRAMAA network system. There are 140 fixed fire hydrants at present and these are sampled every month and analysed for all the required water quality related parameters. To fulfil the objectives of this study the last three years analytical data for the samples collected from these fixed fire hydrants were reviewed year wise for the minimum, maximum and average concentration level for the minerals of our objective interests.

3. Result and Discussion

The minimum, maximum and yearly average concentration level for the minerals of our objective interests are shown in Table 2 along with their average for the last 3 years. The average concentration for all the constituents considered in this study that are potential to alter or affect the drinking water taste were found to be very well within their taste threshold limit.

Table 2: (Chemical constituents of KAHRAMAA drinking water)

Parameters	**2013**			**2014**			**2015**			**2013 to 2015**
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Avg
pH	7.1	8.3	7.80	7.0	8.2	7.78	7.1	8.3	7.80	7.8
TDS (mg/l)	79	155	111	75	261	117	83	314	124	117
Hardness as $CaCO_3$ (mg/l)	57	114	79	43	97	72	27	93	60	70
Calcium (mg/l)	6	35	30.5	15	39	28.2	8	38	30.4	30
Magnesium (mg/l)	0	3	0.54	0.4	6	0.93	0.1	4.4	0.88	0.8
Sodium (mg/l)	0	16	4.20	1	17	7.52	1	13	7.21	6.3
Potassium (mg/l)	0	0.37	0.07	0	1.8	0.13	0	1.2	0.12	0.1
Ammonium (mg/l)	0	0.5	0.03	0	0.05	0.03	0	1.6	0.02	0.03
Sulfate (mg/l)	0	1.10	1.10	0.13	8.90	0.92	0.09	7.32	1.50	1.2
Chloride (mg/l)	1.1	7.8	7.75	1	62	7.2	3	52	12	9
Copper (µg/l)	0	70	18	0	45	15	0	62	24	19
Manganese (µg/l)	0	101	14	0	33	11	1	67	14	13
Zinc (µg/l)	0	28	7	0	40	6	1.6	51	10	7.7
Fluoride (mg/l)	ND			ND			ND			ND
Selenium (µg/l)	ND			ND			ND			ND
Chromium (µg/l)	ND			ND			ND			ND
Ethyl benzene (µg/l)	ND			ND			ND			ND
Mono chlorobenzene (µg/l)	ND			ND			ND			ND
1,4-dichlorobenzene (µg/l)	ND			ND			ND			ND
Toluene (µg/l)	ND			ND			ND			ND
Xylenes (µg/l)	ND			ND			ND			ND

Note: Min: Minimum; Max: Maximum; Avg: Average; ND: Not Detected

Although foods are the major source of the clinically important minerals in diet, drinking water may also contribute variable fractions of the total intake[22]. The magnitude of the drinking water contribution has not been characterized due to the fact that the contribution is much low or negligible compared to the contribution from food and food supplement. Based on the extent of addition or removal of constituent elements during its treatment process the drinking water may contribute only few selected minerals and electrolytes from 1 to 20% of the total dietary intake[12]. Calcium and Magnesium are the largest proportion of dietary intake in drinking water and it is up to 20% relative to that provided by food. Generally, drinking water provides the majority of the other elements less than 5 % of total intake. People who consume less animal meats may lack the intake of essential elements like Zn, Fe and Cu and these may require to be compensated by metal constituents in food and water. It has been observed in this study that the mineral constituents varied significantly among the tested bottled drinking water shown in Table 3. It also has to be noted that the mineral contents found upon analysis of some of the bottled drinking water has a marginal difference with values printed on their labels.

Table 3: (Chemical constituents of different bottled drinking water)

Parameters	BW1	BW2	BW3	BW4	BW5	BW6	BW7	BW8	BW9	BW10
pH	7.4	7.7	8.0	7.8	8.1	7.5	7.8	7.7	7.2	7.3
TDS	139	119	205	179	209	129	118	118	131	69
Hardness	58	61	76	96	152	41	71	60	67	31
Calcium	12.6	15.7	25.9	22.4	41.8	9.6	25.3	15.4	21.6	10.6
Magnesium	8.4	6.1	3.3	10.7	12.0	5.0	2.8	6.1	3.9	1.9
Sodium	12.2	5.1	28.5	14.7	6.2	18.7	7.2	4.6	4.8	4.3
Potassium	6.5	0.1	1.0	0.4	0.8	0.8	0.4	0.1	0.1	0.1
Ammonium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sulfate	7.2	7.1	4.9	7.7	4.1	19.8	7.5	6.5	0.1	6.7
Chloride	16.0	39.5	50.8	24.3	6.8	25.3	2.6	39.2	51.5	19.3
Fluoride	0.2	ND	ND	ND	ND	ND	ND	ND	ND	ND
Copper	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Manganese	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc	ND	ND	ND	3.4	ND	ND	ND	ND	ND	ND
Selenium	ND	ND	0.73	1.7	ND	0.58	ND	ND	ND	ND
Chromium	ND	0.57	0.61	1.5	0.75	1.6	ND	ND	ND	ND
Ethyl benzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Monochlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,4-dichlorobenzene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Xylenes	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Note: BW1: *Volvic mineral water;* ***BW2****: Almeera natural mineral water;* ***BW3****: Saquee bottled drinking water;* ***BW4:*** *Nestle pure life bottled drinking water;* ***BW5:*** *High land spring water;* ***BW6:*** *Masafi water;* ***BW7:*** *Sirma natural mineral water;* ***BW8:*** *Rayyan natural water;* ***BW9:*** *Dana pure drinking water;* ***BW10:*** *Safa bottled drinking water*

Although no health based guidelines are established for the constituents like Calcium, Magnesium, Sodium, Potassium, Chloride, Zinc and Manganese but they are clinically important in performing various physiological functions[22]. Comparing KAHRAMAA water and bottled water contents analysed in this study, bottled water showed higher levels of mineral content especially for Magnesium, Potassium, Sulfate and Chloride whereas Sodium content in KAHRAMAA water is more or less similar with majority of the tested bottled water. Level of Calcium is more in KAHRAMAA water compared to the bottled water except High land spring water.

pH strongly influences drinking water taste. A pH range of 6.5 - 8.5 is desirable to avoid a bitter or metallic taste. In this study it was found that KAHRAMAA water pH is well within its taste threshold limit and the range varied between 7.0 - 8.3 in the last 3 years with an average of 7.8, which is slightly alkaline. No health-based guideline value is proposed for pH as it has no direct health impact. As several other factors that affect consumers health depends on it therefore WHO recommends pH of drinking water to be maintained within a range of 6.5 to 8.5. All the tested bottled water pH were found within a range of 7.2 to 8.1 along with

KAHRAMAA water that has an average pH of 7.8 for the last three years. Tap water is desirable at a pH level of 7 - 8 dependent on multiple factors like control of disinfection by-products, trihalomethane, corrosion, desired palatability etc…

Total dissolved solids (TDS) is used to assess mineral content and is dependent on water source and treatment process. As per the US drinking water palatability assessments the TDS ratings are as follows; 80 mg/L excellent, 81–450 mg/L good, 451–800 mg/L fair, 801–1,000 mg/L poor and >1,000 mg/L unacceptable (Bruvold and Daniels, 1990). WHO recommends a maximum of 600 mg/l TDS to be maintained for the palatability issue. It has been observed that the value of TDS in KAHRAMAA water varied from a minimum of 79 mg/l to a maximum of 314 mg/l with an overall average of 117 mg/l for the last three years Thus KAHRAMAA water can be considered as good as near to excellent quality in terms of TDS ratings for palatability. TDS varied from a minimum of 69 mg/l in Safa bottled drinking water to a maximum of 209 mg/l in High land spring water and 117 mg/l as an average was observed in KAHRAMAA water. WHO has not provided any guideline value for drinking water hardness.

Hardness also impacts taste and is a measure of multivalent metallic cations[6]. Hardness primarily includes Ca^{+2} and Mg^{+2}. Soft, moderately hard, hard, and very hard tap water contains 0–75, 76–150, 151–300 and >300 mg/L as $CaCO_3$ concentrations respectively. Hardness once found in the year of 2013 at a level of 114 mg/l which is at the range that might affect the taste of drinking water but the yearly average and the overall average has always been below 80 mg/l and therefore KAHRAMAA water could be considered in between soft and moderately hard drinking water. An average hardness of 70 mg/l was found in KAHRAMAA water whereas the highest level of hardness of 152 mg/l was observed in High land spring water which is at the taste threshold limit followed by Nestle pure life bottled drinking water with a hardness level of 96 mg/l which is very near to the taste threshold limit

Calcium can be tasted by individuals on varying concentration level based upon the conditions of their taste buds and textures of saliva. Normally the Calcium concentration in drinking water is same with the level found in human saliva[14]. The Canadian drinking water taste guideline recommends a concentration of 125 mg/l of calcium as its taste threshold limit in drinking water above which an individual with sensitive taste buds may feel offensive taste. Calcium as a primary structural component of the skeleton also performs important roles in regulation of multiple enzymes and hormonal responses, blood clotting, nerve transmission, muscle contraction/relaxation etc. Calcium deficiency leads to bone demineralization that results in a weaker bone structure. Calcium concentration varied from 9.6 mg/l as minimum and to a maximum of 41.1 mg/l in bottled drinking water. In KAHRAMAA water, Calcium was found at minimum of 6 mg/l, maximum of 39 mg/l and an average of about 30 mg/l prevailed throughout the last three years which is considered as the desired level in typical drinking water.

The taste threshold concentration for Sodium lies between 30-140 mg/l. Individual may feel salty taste in drinking water in this range based upon one's taste bud condition. Sodium as an electrolyte has an important physiological role that maintains the extracellular fluid volume. Hypertension has been clearly demonstrated in different species of animals given high levels of sodium chloride in their diet. The American heart association recommends a maximum intake of 20 mg/l Sodium through drinking water for those individuals on sodium restricted diet. In the last three years KAHRAMAA water showed a level of Sodium concentration starting from non-detectable limit to a maximum of 17 mg/l with a yearly average of maximum 7.5 mg/l whereas 6.3 mg/l is the overall average for the last 3 years. Among the bottled water Sodium concentration found at a minimum of 4.3 mg/l in Safa bottled drinking water and a maximum of 28.5 mg/l of Sodium was found in Saquee bottled drinking water. Therefore, Saquee bottled water may not be suitable for those on sodium restricted diet. Based on the findings it is clear that the Sodium content in the KAHRAMAA water is even suitable for those on Sodium restricted diet.

Potassium and Chloride are typically present at low levels at the cellular level of the taste buds. Increased chloride levels in water in the presence of Sodium, Calcium, Potassium and Magnesium can cause water to become objectionable. A concentration of 200 - 300 mg/l of Chloride may give rise to taste in drinking water. Tap water Potassium and Chloride concentrations should be well below the concentrations that cause salty taste problems and levels found in saliva. Potassium is predominantly an intracellular cation and Chloride is the main extracellular anion. These electrolytes have important physiological roles in the maintenance of extracellular fluid volume, extra and intracellular osmolarity, regulation of acid-base balance etc. Potassium level in KAHRAMAA water varied from non-detectable limit to a maximum of 1.8 mg/l with an average of 0.1 mg/l and Chloride level was found in a range of 1 mg/l to a maximum of 62 mg/l with an average of 9 mg/l, which are much below their taste threshold limit. Bottled water also showed very low level of Potassium except Volvic mineral water that showed 6.5 mg/l Potassium as the highest among all the tested bottled water. Sirma natural water found to have 2.6 mg/l as the lowest concentration of Chloride whether Saquee bottled drinking water showed a highest of 50.8 mg/l.

Sulfate that give salty taste has minimum taste impact at a level lower than 200 mg/l. It can suppress Magnesium and reduces the effect of Calcium. Very low level of Sulfate is desirable in drinking water. KAHRAMAA water showed Sulfate level from non-detectable limit to a maximum of 8.9 mg/l with an average of 1.2 mg/l.

Constituents like Magnesium, Copper, Zinc and Manganese can influence taste of drinking water. The concentration of these elements in KAHRAMAA water were found to vary from non-detectable limit to a considerable limit of concentration with respect to their taste threshold limit. Copper, Manganese and Zinc that are responsible for catalytic activity of various enzymes necessary for normal body function. These elements were found traces in KAHRAMAA water in various concentration as shown in Table 2 and are within their WHO health based guideline whether none of the tested bottled drinking water showed their presence except Nestle pure life bottled drinking water that showed 3.4 µg/l of Zn. Although these elements are mostly abundant in animal flesh food, having these trace elements in drinking water may be an added advantage to those on low flesh food diet.

Other potential constituents like Ethyl benzene, Mono chlorobenzene, 1,4-dichlorobenzene, Toluene and Xylenes that are potential to affect the taste of drinking water were not detected in KAHRAMAA water for the period of last three years. This confirms their concentration in KAHRAMAA water below their detection limit and thereby far below than their taste threshold limits.

Selenium which is a key component of several enzymes and Chromium that has a hormonal function in maintaining serum glucose levels were detected in traces in Saquee bottled drinking water, Nestle pure life bottled drinking water and Masafi water whereas only

Chromium was detected in traces in Almeera natural mineral water and High land spring water. KAHRAMAA water did not show these two micro elements in the past 3 years.

Fluoride that plays a role in the development of tooth enamel in young children and possibly in strengthening the bone matrix throughout the life was not detected in KAHRAMAA water whereas only one brand of bottled water "Volvic mineral water" showed a concentration of 0.2 mg/l. It should be noted that Fluoride in drinking water must be maintained carefully as higher intake of Fluoride can contribute to dental fluorosis as well as skeletal fluorosis.

5. Conclusion and Recommendation

This study confirms that the taste causing elements are within their taste threshold limit in KAHRAMAA water. Consumers generally cannot detect or differentiate water taste at these level although there may be exception where an sensitive individual may feel offensive taste at even below the taste threshold limit depending on his/her perceptions, experience, memory, physiological stage of tongue, sensitivity of taste bud and composition of saliva. More research is needed to identify specific drinking water characteristics and concentrations that cause consumers to choose to seek another water source, purchase a household treatment device, or purchase bottled water.

KAHRAMAA water contains a significant concentration of Calcium and a considerable level of Sodium, Magnesium, Potassium and Chloride in comparison to the tested bottled drinking water. Interestingly KAHRAMAA water is also enriched with few trace element like Copper, Manganese and Zinc that are necessary for various physiological functions. Other non-health based constituents like pH, TDS and hardness were found to be almost the same both in KAHRAMAA water as well as majority of the bottled drinking water. As the mineral contents found upon analysis of some of the bottled drinking water has a marginal difference with the values printed on their labels therefore individuals preferring bottled drinking water should be aware of his/her personal requirement before opting for a particular brand. This study results clearly shows that the KAHRAMAA water if not better in all respects but has an equally excellent quality that meets the taste and health standards worldwide.

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The Safety, Quality and Environmental Awareness of Potable Water in the Kingdom of Bahrain: A Consumer Perception

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Abstract

When it comes to food and water, consumers attach a very significant weight to health and safety issues. Thus, assurance of drinking-water safety is an important indicator of how healthy and advanced a society. Though, the Kingdom of Bahrain is investing heavily in the public water supply services and its desalination plants produce drinking water quality, most consumers do not use it for drinking. This research aimed to explore the factors and reasons behind public avoidance of drinking tap water and motivations for consumption of bottled water. An online automated structured survey was used, where 384 respondents from different demographic backgrounds answered 39 questions related to water quality, safety, environmental awareness and willingness to modify their behavior. The majority (75%) of male and female respondents of this study regularly drank bottled water regardless of income, level of education and residential location. Nevertheless, consumers adjust their preference to drink water if household water purification devices are available, since only 44% of the respondents drank bottled water while at home compared to 76% while not at home. A high preference of bottled water (40%) was reported among younger respondents. Furthermore, most respondents (58%) indicated that they have no preference towards a specific commercial brand. When asked to rate the quality and safety of public tap water, 48% and 46% indicated it to be fair, respectively. Respondents were equally divided (~26%) on rating water quality as poor and good, while more proportion (32%) rated its safety as poor compared to only 23% as good. Overall reasons for buying bottled water, in descending order, included safer (27%), healthier (21%), convenience (19), organoleptics (13%), and cost (3%). However, when asked to rank factors of importance for purchasing bottled water, health came first (37%), followed by safety (19%), while brand, convenience and organoleptics were similar (10-11%). About 37% and 27% of the respondents associated bottled water being healthy because it has lower sodium level and possess a balanced mineral content, respectively. Positive correlations were found between drinking bottled water and perception among others, while negative correlations were found with the age. High percentage (90%) of the participants indicated their willingness to support official enhancements in the tap water quality and safety, while a significant proportion (57%) will stop drinking bottle water if the improvements were reliable. About 40% indicated their willingness to pay for any additional charges. Respondents of both genders were, somehow, aware of the environmental impacts caused by drinking bottled water, yet reluctant to reduce their dependency on bottled water. The research conclude that tap water is perceived by the public to be of low quality , safety, and unfit for human consumption, that a change in the consumer perception of the quality of tap water in the Kingdom of Bahrain is needed and essential to minimize its adverse environmental impacts resulted from the water bottling industry.

Keywords: Bottled Water, Potable Water, Consumer Perception, Safety, Quality, Bahrain.

Characterization of Halide Compounds in Groundwater of Kuwait

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Abstract
The halide compounds, especially bromide and chloride, are often used in environmental studies to distinguish between different types of water by estimation of the ratio of bromide to chloride. The objectives of this paper are to investigate the concentrations of bromide and chloride in the groundwater production fields and other natural water resources of Kuwait, to determine the ratio of bromide/chloride and to map their concentrations. The methodology that was utilized in the study is the collection of water samples and analysis of bromide and chloride by using ion chromatography instrument. The results show that bromide was between 0.24 and 9.59 mg/l in the groundwater samples. The bromide in seawater was found at around 55.00 mg/l. The brine water samples have bromide concentrations that are equal to 227.33 and 576.67 mg/l. As for the chloride concentrations, the concentrations in the groundwater were found to be between 176 and 1989 mg/l. The seawater has a chloride concentration of 24440 mg/l. The chloride concentrations of the brine water were found to be equal to 45000 and 122911 mg/l. The estimated ratio of bromide/chloride in all types of water was between 0.0011 and 0.0051. The study recommended an investigation to be carried out on Al-Wafra groundwater field in South Kuwait as the ratio of bromide/chloride was found to be high and similar to the value of the brine water.

Keywords: Halide, Bromide, Chloride, Ratio of Bromide to Chloride.

Introduction

The halide compounds are often found in natural water resources, i.e., groundwater and seawater in variable concentrations (Ali and Riley, 1990). These compounds including bromide and chloride are considered to be conservative and often have been used in the field of hydrology. Bromide is a chemical compound that contains the element bromine bonded with other electropositive or radical elements (Edmunds, 1996); while chloride, which is commonly found as sodium chloride, is very soluble in water and is important for the metabolism of human body (*i.e.,* acts as electrolyte). The Kuwait Environment Public Authority (KEPA, 2001) has issued a guideline for chloride concentration in drinking water to not exceed 250 ppm. As for bromide, there is no guideline limit issued by the KEPA as the compound naturally exists in trace concentration in groundwater of Kuwait and does not pose a health risk.

In literature, researchers have used the ratio of bromide to chloride concentrations in studying the geochemistry of groundwater systems (Samantara *et al.,* 2015; Andreasen and Fleck, 1997; Davis *et al.,* 1998). In addition, the ratio of bromide to chloride is often utilized to assess the interactions between water bodies and also as a tracer to investigate the movement of subsurface water (Bouzourra *et al.,* 2015). In a study conducted by Andreasen and Fleck (1997), the authors have utilized the ratio of bromide to chloride to confirm the intrusion of seawater into the groundwater.

The abstraction of groundwater by the Ministry of Electricity and Water (MEW) is carried out from two aquifers in Kuwait, namely, the Kuwait Group rock and Dammam formation. The Dammam formation is underlined by the Kuwait Group rock. The salinity of the groundwater varies across the country where the groundwater is brackish (less than 10,000 mg/l) in western region and becomes saline in the north eastern region (more than 100,000 mg/l). The fresh groundwater only existed in the Rhaudhatain and Um Aish areas, north of the country, where lenses of fresh groundwater float on the saline groundwater of Kuwait Group aquifer. The design of the production wells adopted by the MEW is different from one groundwater production field to another according to the quality and quantity of groundwater needed. As a result, the current groundwater production wells are either screened in a single aquifer (*i.e.*, Kuwait Group rock or Dammam formation) or across multiple aquifers (*i.e.*, that penetrate both Kuwait Group rock and Dammam formation).

There is little information related to the concentration of bromide in the groundwater of Kuwait. Moreover, no previous research studies were conducted to determine the ratio of bromide to chloride in natural water resources in Kuwait. Therefore, the purpose of this study is to determine the concentration of bromide and chloride and subsequently, the ratio between these compounds in the groundwater production fields and other water resources of Kuwait.

Methodology

The study involved collection of water samples from the main groundwater production fields, oil associated water facilities and seawater to identify the ratio of Br/Cl of such water bodies. During the sampling activity, the water samples were collected from six groundwater fields located around Kuwait (i.e., Um-Qudair, Shigaya B, Raudhatain, Sulaibiya, Al-Atraf, and Al-Wafra). In addition to the collection of groundwater samples, oil associated water samples were collected from Manageesh and Um Gudair oil production facilities. Furthermore, the seawater samples were collected near Al-Sabiyah shoreline. The locations of the collected water samples are shown in Figure 1.

At the site, the measurements of electrical conductivity (EC) were carried out using Orion portable meter purchased from Thermo Fisher Scientific Company. The water samples were collected in 250-ml plastic bottles and transferred directly to the laboratory. The analysis of both bromide and chloride were carried out using DIONIX ICS 3000 instrument following method 4110 in the Standard Method for Examination of Water and Waste Water book (APHA, 2012). As a quality control measure, triplicate water samples were collected during the water sampling activity.

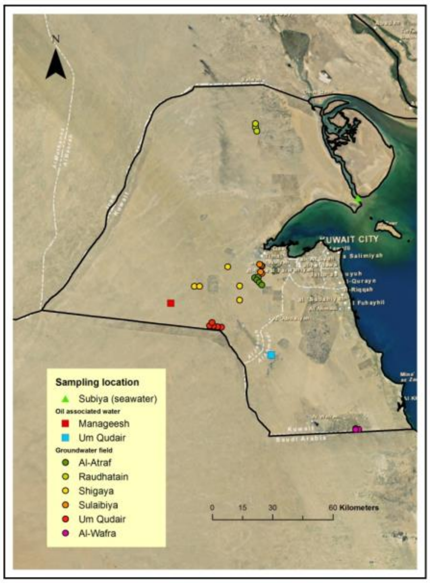

Fig.1: Sampling locations

Results and Discussion

The EC of the water samples collected was measured at the field to assess water salinity. The quality of groundwater in Raudhatain field has the best water quality among the other groundwater fields where the measured EC was between 1399 and 2948 µc/cm. Meanwhile, the quality of groundwater in Al-Wafra and Al-Atraf fields was found to be of less quality and was between 5774 and 7884 µcm/cm. Moreover, the EC of the seawater sample near Al-Sabiyah shoreline was found to be 61100 µs/cm, which is higher than the average EC of the groundwater samples by approximately eight folds. The brine water that is produced during oil production activities has a very high salinity. The salinity of the brine was found to be in the range of 100,000 to 300,000 µs/cm.

The lowest bromide concentrations were found in the groundwater samples of the Raudhatain groundwater field, whereas, the highest bromide concentration was found in Al-Wafra groundwater field. The bromide concentration in the groundwater fields has been increasing in the following order: Raudhatain, Um Qudair, Shigaya, Sulaibiya, Al-Atraf, and Al-Wafra. The bromide concentration of seawater was found to be equal to 55.5 mg/l. Meanwhile, the brine water samples consisted of a high concentration of bromide (i.e., between 200 and 600 mg/l).

In the Raudhatain groundwater field, the chloride was found between 176 and 350 mg/l, which is the lowest concentration found among the other groundwater fields. The highest concentration of chloride was found in Al-Wafra, which was near 2000 mg/l. The chloride in the seawater sample was found to be 24440 mg/l. The brine water samples consisted of a very high level of chloride (i.e., 45000 and 122911 mg/l). Table 1 shows the EC and the concentrations of bromide and chloride of the water samples.

Table 1: EC, Bromide and Chloride Concentrations in the Water Samples

No	Well ID	Electrical Conductivity (µs/cm)	Bromide (mg/l)	Chloride (mg/l)
1	UG59	5363	1.28	1141
2	UG60	5120	1.25	983
3	UG61	5123	1.30	995
4	UG62	5217	1.35	981
5	UG67	5507	1.37	1110
6	AT70	5774	2.04	1272
7	AT71	7884	2.51	1989
8	AT74	7021	2.34	1727
9	AT78	7484	2.37	1830
10	AT82	7080	2.28	1684
11	SU97	5194	1.68	687
12	SU98	5479	1.92	721
13	SU99	5593	1.78	731
14	SU119	4434	1.48	577
15	SU121	4986	1.55	634
16	RA3	2948	0.60	350
17	RA6	1377	0.24	281
18	RA15	1399	0.29	176
19	SH5A	3750	1.30	532
20	SH11D	3760	1.30	508

21	SH12A	3759	1.36	518
22	SH12D	3837	1.26	534
23	SH13A	4919	1.57	964
24	WW02	7480	9.59	1969
25	WW10	7350	9.58	1972
26	Seawater	61100	55.50	24440
27	Brinewater-A	106800	227.33	45000
28	Brinewater-B	275435	576.67	122911

N.B. UG: Um Qudair, AT: Al-Atraf, SU: Sulaibiya, SH: Shigaya, RA: Raudhatain and WW: Al-Wafra.

Table 2 presents the values of the estimated ratio of bromide to chloride. As can be seen in the table, the values of the ratio of Br/Cl in the water samples varied between 0.0007 and 0.0051. The lowest value was found in well FA6 whereas the highest value belongs to brinewater-A sample.

As for the ratio of Br/Cl for the groundwater fields, the Um Qudair groundwater production wells, which are screened in Kuwait Group aquifer, have ratio of Br/Cl between 0.0011 and 0.0014. Furthermore, the production wells of Atraf have ratio of Br/Cl between 0.0013 and 0.0016, which are also screened in Kuwait Group aquifer. Meanwhile, the ratio of Br/Cl for Sulaibiya production wells, which are screened in the Dammam aquifer, were found to be between 0.0024 and 0.0027. In contrast to the previously mentioned groundwater production fields, where nearly all the wells there are screened in single aquifer, the groundwater production wells in Shigaya are screened in single and multiple aquifers. Accordingly, the SH11D and SH12D wells are screened in the Dammam formation, the SH13A is screened in Kuwait Group aquifer, and finally the SH5A and SH12A are both screened across Kuwait Group and Dammam aquifers. All of the Shigaya wells have a ratio of Br/Cl between 0.0024 and 0.0026 except for well SH13A, which has a value of Br/Cl equal to 0.0016. The ratios of Br/Cl in the Rauthatain wells on one hand were 0.0017 for RA3 and RA15, and, on the other hand, RA6 has a value of 0.0008. Lastly, the ratio of Br/Cl of Wafra wells was equal to 0.0049 for WW02 and WW10.

The other natural water resources that the ratio of Br/Cl was estimated for included seawater and brine water. The seawater was found to have Br/Cl ratio equal to 0.0023. The brine water samples have a ratio of Br/Cl equal to 0.0047 and 0.0051.

Table 2: Estimated Ratio of Br/Cl for the Water Samples

No	Well ID	Br : Cl Ratio
1	UG59	0.0011
2	UG60	0.0013
3	UG61	0.0013
4	UG62	0.0014
5	UG67	0.0012
6	AT70	0.0016
7	AT71	0.0013
8	AT74	0.0014
9	AT78	0.0013
10	AT82	0.0014
11	SU97	0.0024
12	SU98	0.0027
13	SU99	0.0024

14	SU119	0.0026
15	SU121	0.0024
16	RA3	0.0017
17	RA6	0.0008
18	RA15	0.0017
19	SH5A	0.0024
20	SH11D	0.0026
21	SH12A	0.0026
22	SH12D	0.0024
23	SH13A	0.0016
24	WW02	0.0049
25	WW10	0.0049
26	Seawater	0.0023
27	Brinewater-A	0.0051
28	Brinewater-B	0.0047

It is clear from the estimated Br/Cl ratios that each water body has a unique Br/Cl ratio, which represents a fingerprint for such water body. It was found that the groundwater of Kuwait Group aquifer has a Br/Cl ratio between 0.0011 and 0.0017. This unique range of Br/Cl ratio of the groundwater of Kuwait Group aquifer was found in Um Qudair field, Al-Atraf field, Rauthatain field (Well ID: RA3 and RA15), and at Shigaya field in well SH13A.

The Br/Cl ratio of Rauthatain groundwater was found to have two different values. The RA3 and RA15 wells were found to have a Br/Cl value equal to 0.0017, whereas, RA6 had a value equal to 0.0008. The Br/Cl value of RA6 represents the fingerprint of Rauthatain groundwater. The RA3 and RA15 wells were drilled deeper than RA6 at the transition zone between Rauthatain fresh groundwater lens and Kuwait Group groundwater. As a result of the interaction occurring at the transition zone between the two types of groundwater, the Br/Cl value of the groundwater of RA3 and RA15 wells became similar to the Br/Cl value of Kuwait Group.

Meanwhile, the groundwater of Dammam aquifer has a value between 0.0024 and 0.0027. This range of Br/Cl values was found in all Sulaibiah and Shigaya wells except the well SH13A. This is because well SH13A at Shigaya field is screened in Kuwait Group aquifer and therefore the Br/Cl was found to be equal 0.0016.

The ratio of Br/Cl of the brine water samples that were collected from the oil production facilities in Um Qudair (Brinewater A) and Manageesh (Brinewater B) were found to be equal to 0.0051 and 0.0047 respectively. This relatively high value of Br/Cl ratio reflects the high salt content of the brinewater.

Although Al-Wafra production wells (WW02 and WW10) are screened in Dammam aquifer, the Br/Cl ratios were found to be equal to 0.0049, which is outside the range of fingerprint of Dammam aquifer. This might indicate interaction or contamination of Al-Wafra field with other water body possibly from a brine water (oil associated water) that has similar ratio (i.e., between 0.0047 and 0.0051).

Conclusion

The determination of the ratio of Br/Cl of the natural water resources in Kuwait is important for developing unique fingerprints of such resources. The fingerprint of the waters could be used to determine the interaction or contamination of groundwater by other water bodies. The study has revealed the following:

- The groundwater of Kuwait Group aquifer in the tested wells has a ratio of Br/Cl between 0.0011 and 0.0017.
- The groundwater of Dammam aquifer in the tested wells has a ratio of Br/Cl between 0.0024 and 0.0027.
- The groundwater of Al-Wafra has a Br/Cl ratio equal to 0.0049, though the tested wells are screened through Dammam aquifer. This might indicate interaction of the groundwater at the site with other water bodies.

Acknowledgments
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Low Cost Materials for Contaminated Groundwater Treatment Using Adsorption Reactive Barrier

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Abstract

Inorgano-organobentonite (IOBs) were synthesized by replacing the metal ions of sodium bentonite with and (1) a cationic alkylbenzyd-methylammonium chloride surfactants (MCB50), formula C12-C16 with the closest IUPAC name is tetradecyl benzyldimethylazanium chloride (2) non-ionic, polypropylene glycol (PPG) surfactant, formula of H-(OC3H6)21)-OH. The IOBs were then pillared using Aluminum chlorohydrate 50% aqueous solution pillaring agent. Thermo-gravimetric analysis, (TGA), SEM and X-ray diffraction (d-spacing changes) were used to confirm the intercalation of the surfactants and bentonite modification. Materials were tested in a batch test for both site groundwater collected from a contaminated site in Yorkshire to the north of the UK and model contaminants, including toluene, ethylbenzene and xylene (TEX). IOB materials showed greatest sorptive capacity to the site groundwater (~60mg/g) with almost three times higher than the affinity to the model contaminants. Materials' sorptive capacity towards TEX corresponded to molecules solubility and octane number with a preference X > E > T. The hydraulic conductivity of IOB-soil mixes was also investigated as for IOB materials to be applied in a soil mixed permeable barriers (PRB). The test was conducted in a separate fixed bed column test where contaminated site groundwater was permeated through the IOB-soil mixes to simulate the site groundwater flow rate.

Keywords: Modified Bentonite, Soil Mix, Batch Sorption, Hydraulic Conductivity.

Suspended Sediment Estimation during Single Rainfall Storms Using Digital Photographs at the Smaquli Catchment, Erbil, Iraq

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Abstract
Soil erosion results in great agricultural, engineering and environmental problems. Land degradation is one of them. The moving sediments and the muddy water also affect the quality of water in many water supply projects along the river systems. This happens mainly by suspended sediment which is provided chiefly during single storm events. Study of suspended sediment during rainfall storms provides essential information for future planning and solutions. This study aims to identify a possible relationship between suspended sediment concentration and reflectance of digital photographs, taken during various events, at two sites on tributaries of Smaquli stream, using the statistical parameters of visible part of the spectrum, namely red, green and blue bands. This work examines application of a special form of remote sensing namely close distance photography of stream flow during storm events using an ordinary digital camera. The study area is located in High Folded Zone in northeastern Iraq. The Smaquli catchment is divided into two sub-catchments namely Sarwchawa and Krozh. They are drained by Smaquli and Krozh streams. Stream flows and suspended sediment concentrations are monitored at Senan and Krozh measurement stations during four rainfall storms of various amount, duration and intensity in March 2014. Simultaneously, at each site and for the same sampling interval, a digital photograph was taken exactly at the same point where the 2 liters of water sample was taken by hand. Digital analysis of selected photographs is done by determination of statistical image reflectance parameters using Arc GIS 10.1 software package. These parameters include minimum, maximum, mean and standard deviation. Bivariate correlations between the statistical parameters and the suspended sediment concentration in *mg/l* with the associated stream discharge in l/sec are developed, using Pearson type. For the data of Senan station, the mean green colour reflectance values demonstrated moderate correlation with suspended sediment concentration (R= -0.74). Furthermore, suspended sediment concentration has demonstrated significant positive relation with stream flow in *l*/sec (R= 0.63). On the other hand, the data of Krozh station showed another type of relationships. The standard deviation of green, red and blue colour reflectance demonstrated very strong relations with suspended sediment concentration with R= -0.80, -0.79 and -0.78 and stream flow with R= -0.76, -0.75 and -0.74 respectively. Nonlinear regression models are developed between suspended sediment concentration and stream water reflectance behavior. Finally, the developed equations for predicting suspended sediment concentration are tested. It is observed that, in time intervals where identical photographs are available, the nonlinear polynomial regression equations at both sites give good results.

Keywords: Digital Photograph, Suspended Sediment, Water Quality, Regression Model, Iraq.

1.Introduction
Remote sensing can be defined as the science and art of gathering information about an object, area, or phenomenon without actual physical contact with observed issue (Lillesand and Kiefer, 2000). Throughout the literature, many researchers have found remote sensing as a suitable means for several water resource applications such as water pollution detection, flood damage estimation and determination of groundwater recharge areas. Several of them

have used remote sensing data in sediment transport studies (see among others, Goel *et al*., 2002; Pavelsky and Smith, 2009; Pick and Simmons, 2012; Wang *et al*., 2012 Alvarez and Ruiz, 2013). In these studies, statistical relationship was developed between the water reflectance and sediment concentrations using various bands of satellite images.

This work examines application of a special form of remote sensing namely close distance photography of stream flow during storm events using an ordinary digital camera in order to establish a relationship between statistical parameters such as minimum, maximum, mean and standard deviation of color reflectance of red, blue and green bands of the photographs with the concentration of suspended sediment and the associated stream flow.

Utilizing of such sophisticated technology but simple in form and use in suspended sediment studies during runoff events helps to develop a regression model through which suspended sediment concentration to be predicted from statistical parameter(s) of reflectance of taken photographs.

2. Study Area

The study area is a 126.674 km^2 headwater catchment. It is located approximately 50 km east of Erbil city in Kurdistan Region of Iraq (Figure 1). The catchment ranges in elevation from 714 to 1478 m. above sea level. The basin outlet is situated nearly 70 m downward of the new constructed Jali Dam.

The study area is bordered by four mountain ridges. The southwestern part of catchment lies across an important topographic / structural boundary between the southwestern Low Lands and the northeastern High Folded Zone. The mean channel slope is 0.05256. The Smaquli catchment is divided into two sub-catchments namely Sarwchawa and Krozh with areas of 80.64 and 34.82 km^2 respectively. These two sub-catchments are representing 63.66 and 27.49 % of the total catchment area. The remaining area 8.85% (11.22 km^2), is representing the draining area from the stations to the catchment outlet.

The Smaquli stream is a perennial stream in the area. It takes its source from several permanent springs. The main stream is formed as a result of confluence of tributaries of Krozh and Sarwchawa. The Krozh stream drains the Krozh sub-catchment at the southern and southwestern parts of the study area, while the Sarwchawa stream drains the Sarwchawa sub-catchment at the northern and northeastern parts of the basin (Figure 1).

Average annual precipitation is 582.8 mm for the period of 13 years (2001-2014) reported by the Koya Meteorological Station. The catchment response to precipitation varies from Krozh to Sarwchawa sub-catchments. It is strongly affected by catchment characteristics namely topography, shape, slope and soil type and precipitation characteristics.

The soil groups are variation of lithosols, rendzinas, shallow and deep chestnut, rankers and brown calcareous (Kahraman, 2004). In the southern part of the catchment, vegetation is dominated by grass and the presence of scattered shrubs and trees namely oak trees.

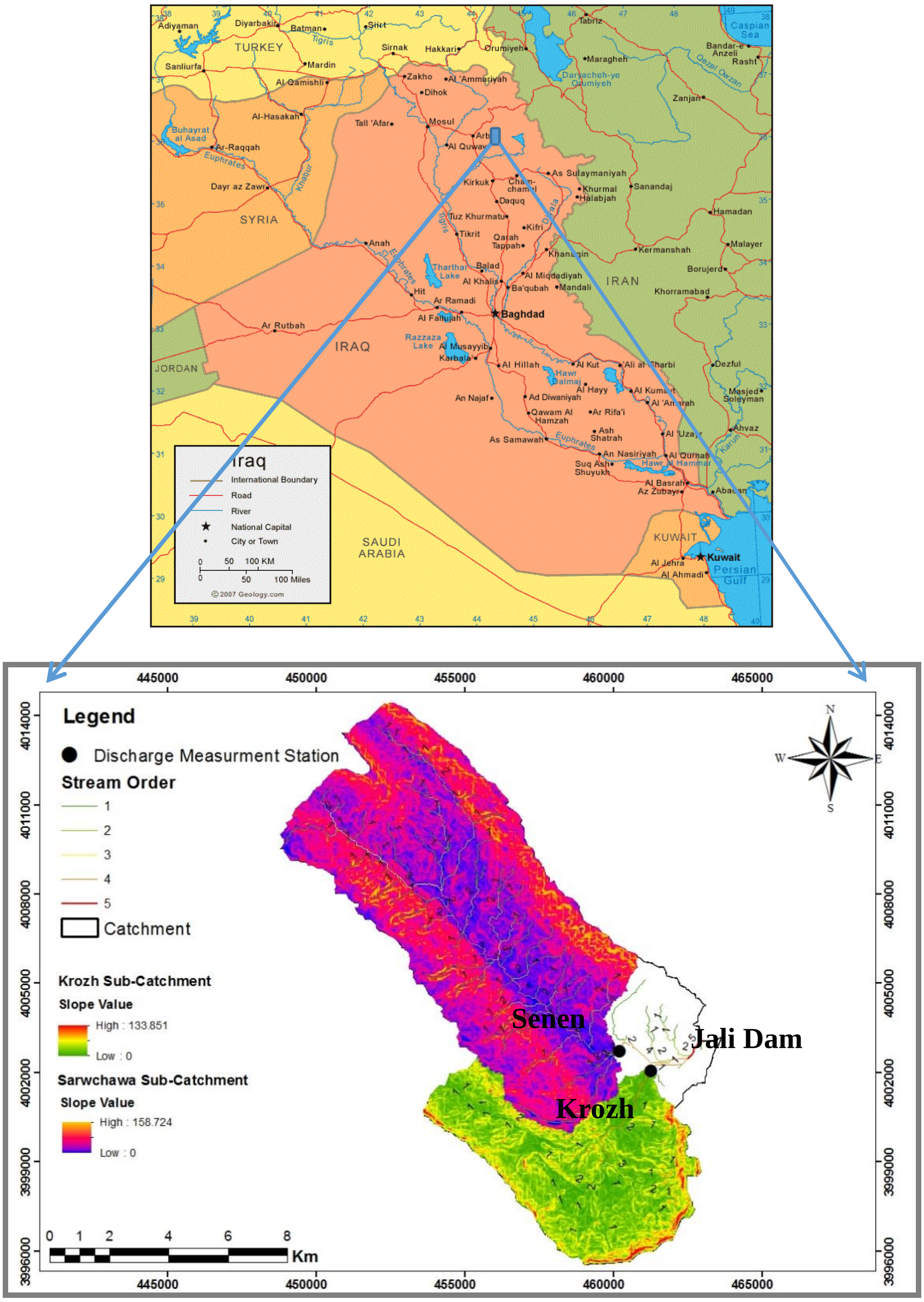

Figure 1: The map of Iraq and the Smaquli catchment

2. Data Acquisition and Methodology

Stream flows and suspended sediment concentrations are monitored at Senan and Krozh measurement stations during four rainfall storms of various amount, duration and intensity in March 2014. Simultaneously, at each site and for the same sampling interval, a digital photograph was taken exactly at the same point where the 2 liters of water sample was taken by hand. This is done from a distance of approximately a meter between camera lens and the stream water level. In order to obtain identical photographs through the course of sampling at each event, many field notes were made. These included the timing, meteorological conditions such as radiation and its intensity (descriptive), stream bed effect, the angle of view of camera and distance between water surface and the camera lens.

Care was taken to take the digital photographs with the same resolution, angle, dimension and distance to the water surface. Each water sampling and photograph needed to get into the stream at a specific location regardless the amount of water during the event. It was indeed not an easy task. The digital camera used in this study was SONY®, Cyber-shot, Digital Still Camera, DSC-TX10-50i, Item No. 2249526.

The system produced images of 16.2 Mega Pixels (4608 x 3456 pixels) with almost the same technical image characteristics, but different contains. The latter is very much depending on suspended sediment material in the water. As the turbidity of water changes due to organic or inorganic materials, transmittance and therefore, reflectance changes dramatically (Lillesand and Kiefer, 2000).

All images are stored as JPG image, this format was selected to keep the storage efficiency. At the end, a total of 33 and 28 digital photographs were taken during four storms of 4, 10, 11 and 30 March 2014 at Senan and Krozh sampling stations respectively. On the basis of the above mentioned field notes, 16 digital photographs for each station were chosen for further phoyograph and statistical analysis.

The filtering procedure of collected water samples is done at the field by pouring the water sample on Melitta®1X4 coffee filter paper (FSC No. C095206). Labeled and weighed empty, dry filter was used by setting it onto a filtering flask. Depending on suspended sediment amount, sometimes up to 5 filters are used per sample.

Drying and weighing of filter paper and sediment were conducted at the laboratory of soil mechanics at Faculty of Engineering in Koya University. The TRiSTAR oven was set at 105 *°C* for one hour. Once filters were dried, they weighed using CONTROLS accurate balance with three decimals. The suspended sediment load afterwards is calculated.

3. Photograph Interpretation and Data Analysis

Digital interpretation of selected photographs is done by using Arc GIS 10.1 software package. The analysis procedure is started by determination of statistical photograph reflectance parameters. These parameters include minimum, maximum, mean and standard deviation for all visible channels namely red, green and blue bands.

Arc Map provides tools to improve the display of a raster. These include providing faster drawing methods, enhancements and retaining calculated raster data set statistics. Normally, the statistics and histograms of raster data are used to render it correctly. Here, we used them to find out any possible relation with the suspended sediment transport rates. During the determination of those statistical parameters, the default value used by the standard deviation on the stretch tab of the image analysis options. The applied resampling method to the selected raster layer was set on Bilinear.

3.1. Correlation and Regression

Bivariate relations are developed using Pearson type at Data Analysis tool in Microsoft Excel 2010. The correlations are between the statistical parameters of minimum, maximum, mean and standard deviation for red, green and blue colour bands and the suspended sediment concentration in *mg/l* with the associated stream discharge in *l/sec*.

For the data set of Senan station, the mean green colour reflectance values demonstrated strong correlation with suspended sediment load in *mg/l* (R= -0.74). The mean blue colour reflectance values also had significant moderate correlation with suspended sediment concentration (R= -0.59). Furthermore, suspended sediment concentration has demonstrated significant positive relation with stream flow in *l*/sec (R= 0.63). Table 1 presents the correlation matrix of Senan station.

These results indicate that as stream flow increases during the event runoff, the quantity of suspended sediment also increases. It could be explained from either the re-suspension of fine channel sediments or from the sediment generated as a result of land erosion due to intense rainfall.

On the other hand, the data of Krozh station showed another type of relationships. The standard deviation of green, red and blue colour reflectance demonstrated strong correlations with suspended sediment concentration and stream discharge having R= -0.80, -0.79 and -0.78 and stream flow with R= -0.76, -0.75 and -0.74, respectively.

Further, for this data, the suspended sediment concentration showed an exceptionally very strong relation with stream flow (R= 0.96). The peak and total suspended sediment concentrations are highly correlated with stream flow (Gardi and Al-Shama'a, 2016). The correlation matrix of Krozh station is given in Table 2. An increase of standard deviation of an image is concluded as more dispersion of the reflectance behavior of different pixels which is occurred as a result of increase of or decrease of suspension material in the water. At the beginning of storm event, this dispersion was high and suspended sediment transport rate was low. As the stream flow and suspended sediment rates approached peak time interval the standard deviation or dispersion is decreased due to the increase of suspended material.

A nonlinear regression model is developed between suspended sediment concentration and stream water reflectance behavior. Figure 2 illustrates the results of Senan station regression analysis between mean green colour reflectance as dependent variable on the vertical and suspended sediment concentration as independent variable on the horizontal axis.

The best nonlinear trend was polynomial order three. Here the model follows the general trend of the data. The model equation is:

$y = 1E\text{-}11x^3 - 1E\text{-}07x^2 - 0.0007x + 134.69$ Nonlinear, polynomial (1)

Where,

x = suspended sediment concentration in [*mg/l*].

y = mean green reflectance value.

Whereas, the nonlinear relation between standard deviation of green colour reflectance and suspended sediment concentration for non-transformed data at Krozh station is significant having the determination coefficient R^2 of 0.71 (Figure 3). The best nonlinear trend was polynomial at order six. Here again the general trend of the data is followed by the model curve. The equation is:

$y = 2E\text{-}19x^6 - 3E\text{-}15x^5 + 1E\text{-}11x^4 - 4E\text{-}08x^3 + 5E\text{-}05x^2 - 0.0304x + 16.848$ (2)

Where,

x = suspended sediment concentration in [*mg/l*].

y = standard deviation green reflectance value.

Table 1: Summary of bivariate correlations between image reflectance statistical parameters, stream flows and suspended sediment concentrations for different observations during four rainfall events in March 2014 at Senan station

Statistical Parameters	**Min. R**	**Max. R**	**Mean R**	**S.D. R**	**Min. G**	**Max. G**	**Mean G**	**S.D. G**	**Min. B**	**Max. B**	**Mean B**	**S.D. B**	**Stream Discharge (*l/sec*)**	**S. Sediment (*mg/l*)**
Min. Red	1.00													
Max. Red	-0.18	1.00												
Mean Red	-0.16	0.42	1.00											
Standard Deviation Red	-0.62	0.64	0.59	1.00										
Min. Green	0.82	-0.32	-0.07	-0.58	1.00									
Max. Green	-0.17	0.99	0.40	0.63	-0.29	1.00								
Mean Green	0.01	0.33	0.71	0.45	0.29	0.36	1.00							
Standard Deviation Green	-0.55	0.67	0.58	0.99	-0.54	0.66	0.46	1.00						
Min. Blue	0.48	-0.36	-0.19	-0.48	0.83	-0.32	0.22	-0.49	1.00					
Max. Blue	-0.25	0.98	0.39	0.69	-0.34	0.99	0.35	0.72	-0.33	1.00				
Mean Blue	-0.35	0.57	0.61	0.72	-0.13	0.57	0.63	0.67	0.13	0.60	1.00			
Standard Deviation Blue	-0.50	0.69	0.51	0.97	-0.51	0.68	0.42	0.99	-0.47	0.73	0.63	1.00		
Gamma	0.04	-0.44	-0.81	-0.57	-0.18	-0.45	-0.98	-0.57	-0.14	-0.45	-0.74	-0.53		
Stream Discharge (*l/sec*)	0.25	0.10	0.01	-0.13	-0.13	0.05	-0.43	-0.06	-0.39	0.01	-0.39	-0.03	1.00	
S. Sediment (*mg/l*)	0.02	-0.05	-0.41	-0.24	-0.41	-0.09	-0.74	-0.21	-0.53	-0.11	-0.59	-0.16	0.63	1.00

Table 2: Summary of bivariate correlations between image reflectance statistical parameters, stream flows and suspended sediment concentrations for different observations during four rainfall events in March 2014 at Krozh station

Statistical Parameters	**Min. R**	**Max. R**	**Mean R**	**S.D. R**	**Min. G**	**Max. G**	**Mean G**	**S.D. G**	**Min. B**	**Max. B**	**Mean B**	**S.D. B**	**Stream Discharge (*l/sec*)**	**S. Sediment (*mg/l*)**
Min. Red	1.00													
Max. Red	-0.43	1.00												
Mean Red	-0.07	0.52	1.00											
Standard Deviation Red	-0.33	0.01	-0.35	1.00										
Min. Green	0.97	-0.50	-0.13	-0.26	1.00									
Max. Green	-0.38	1.00	0.54	-0.05	-0.44	1.00								
Mean Green	-0.05	0.46	0.97	-0.36	-0.09	0.50	1.00							
Standard Deviation Green	-0.30	0.01	-0.36	1.00	-0.23	-0.05	-0.37	1.00						
Min. Blue	0.82	-0.47	-0.08	-0.35	0.92	-0.41	-0.03	-0.32	1.00					
Max. Blue	-0.31	0.94	0.44	-0.11	-0.39	0.95	0.40	-0.11	-0.35	1.00				
Mean Blue	-0.16	0.24	0.14	-0.17	-0.19	0.28	0.15	-0.17	-0.14	0.50	1.00			
Standard Deviation Blue	-0.30	0.01	-0.41	0.98	-0.23	-0.05	-0.43	0.99	-0.33	-0.09	-0.15	1.00		
Gamma	0.09	-0.46	-0.98	0.36	0.13	-0.48	-0.99	0.38	0.06	-0.38	-0.16	0.44		
Stream Discharge (*l/sec*)	-0.14	0.43	0.43	-0.75	-0.23	0.47	0.41	-0.76	-0.09	0.56	0.36	-0.74	1.00	
S. Sediment (m*g/l*)	0.01	0.38	0.56	-0.79	-0.09	0.42	0.52	-0.80	0.00	0.50	0.35	-0.78	0.96	1.00

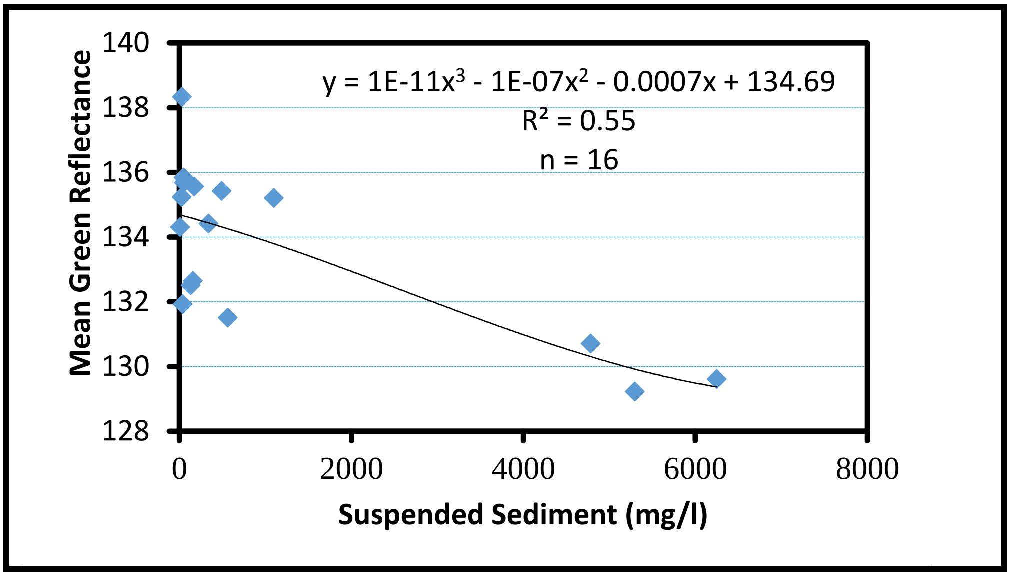

Figure 2: Third degree polynomial regression model of Mean Green Reflectance and Suspended Sediment Concentration at Senan station.

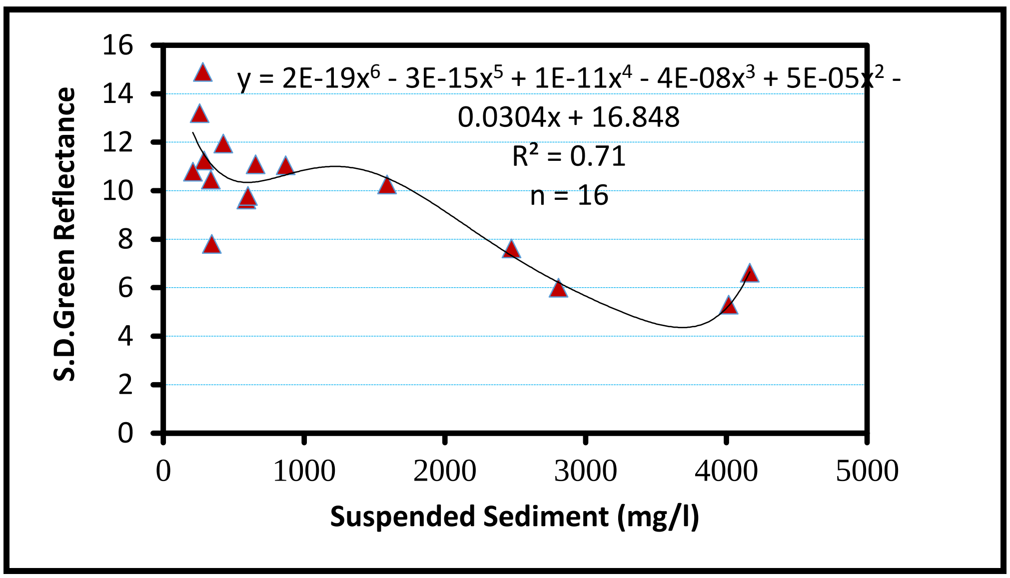

Figure 3: Sixth degree polynomial regression model of Standard Deviation Green Reflectance and Suspended Sediment Concentration at Krozh station.

In order to test the developed equations for predicting suspended sediment concentration, storm of 30 March 2014 was selected. Figures 4 and 5 illustrate the measured and calculated values. It is observed that in time intervals where an identical photographs (similar technical digital photographs in terms of cloud condition, radiation and distance between camera lens and stream water surface) available, the nonlinear polynomial regression equations at both sites give good results.

These identical images are denoted on the graph as blue filled triangles. As far as the photographing conditions are changed, the prediction results will be far away from the measured one. This is a good indication that the accuracy of suspended sediment prediction is very much related to the accuracy of digital images photographing.

After all other points, to have two different digital photograph statistical parameters namely mean and standard deviation for green band and to find correlation with suspended sediment transport rate at both Senan and Krozh monitoring stations reveal a fact that not only the quantity of transported sediment is different but also the quality is not the same at their sub-catchments.

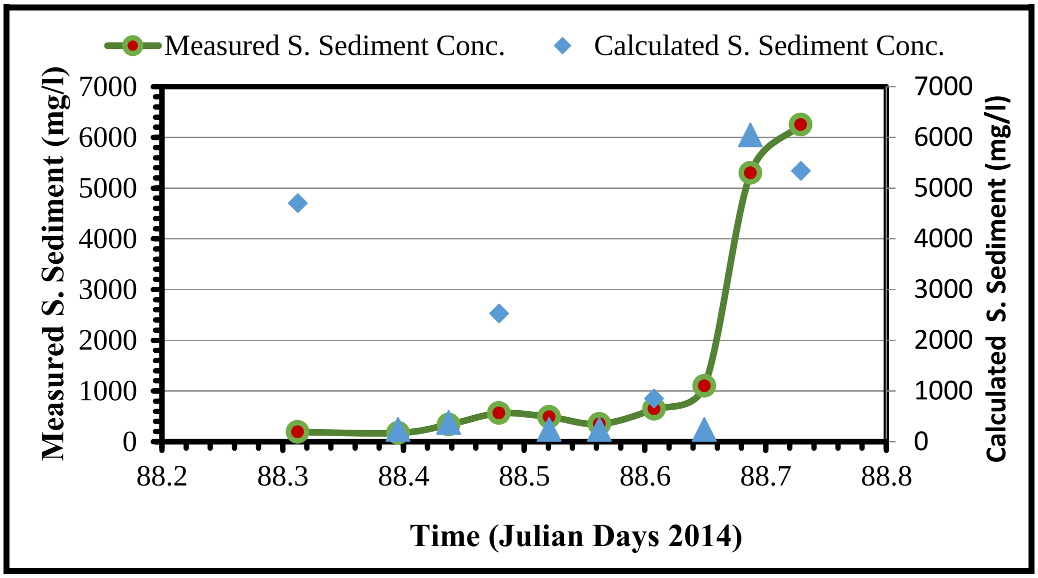

Figure 4: Measured and calculated suspended sediment concentration for storm dated 30/03/2014 at Senan station

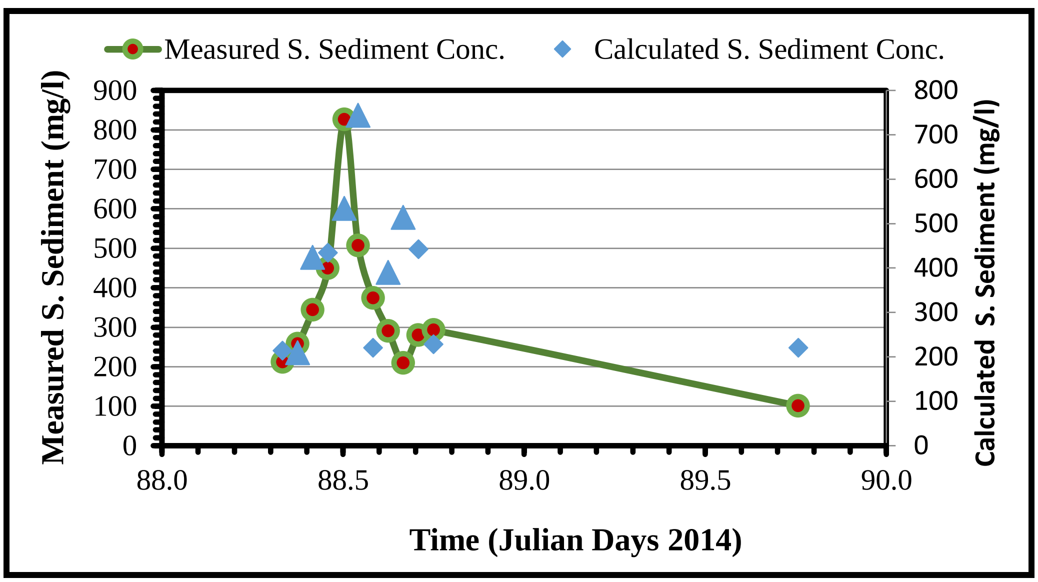

Figure 5: Measured and calculated suspended sediment load for storm dated 30/03/2014 at Krozh station

4. Conclusion

Digital photograph analysis, using the Arc GIS 10.1 of the stream flow photographs, taken during storm events at the Senan and Krozh sub-catchments of the Smaquli catchment, exhibits good nonlinear relationships between statistical parameters such as mean and standard deviation of digital image reflectance at green band in visible portion of spectrum and suspended sediment concentrations. For the data of Senan station, the mean green colour reflectance values demonstrated moderate correlation with suspended sediment concentration (R= -0.74). In addition, suspended sediment concentration has demonstrated significant positive relation with stream flow in *l*/sec (R= 0.63).

On the other hand, the data of Krozh station showed another type of relationships. The standard deviation of green, red and blue colour reflectance demonstrated very strong relations with suspended sediment concentration with R= -0.80, -0.79 and -0.78 and stream flow with R= -0.76, -0.75 and -0.74 respectively. Finally, the developed equations for predicting suspended sediment concentration are tested. It is observed that, in time intervals where identical photographs are available, the nonlinear polynomial regression equations at both sites give good results.

The study also revealed that not only the quantity of transported sediment is different but also the quality is not the same at Senan and Krozh monitoring stations which is directly related to the geological difference and the location of the sediment source in their sub-catchments. It is recommended to do more researches in this field. The method is simple and effective. Any success in this regards leads to easier prediction of suspended sediment concentrations during single storm events.

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Desalinated and Blended Water: An Analysis for Human Exposure and Risk

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Abstract
Saudi Arabia produces the largest amount of desalinated water as a single country. The desalinated water is typically blended with treated groundwater, pH adjusted and chlorinated prior to supply to the communities. The desalinated seawater and/or blended water contains various types of disinfection byproducts (DBPs), some of which may induce cancer risks to human through lifetime exposure. In this study, occurrences of trihalomethanes (THMs) in desalinated and blended water in Saudi Arabia were investigated and their exposure and risks were predicted. The chronic daily intakes of $CHCl_3$, BDCM, DBCM and $CHBr_3$ were estimated to be 8.38×10^{-5}, 7.57×10^{-5}, 2.54×10^{-5} and 4.32×10^{-4} mg/kg-day respectively. The overall cancer risk was 1.78×10^{-5} with the range of $7.40\times10^{-7} – 9.26\times10^{-5}$ and the average hazard index was 3.49×10^{-2} with the range of $1.20\times10^{-3} – 2.34\times10^{-1}$. There are 100, 77.5, 1.2 percent chances that cancer risks can exceed the risk levels of 1×10^{-6}, 1×10^{-5} and 5.0×10^{-5} respectively. The loss of disability adjusted life years (DALY) were estimated to be 25.1 per year and the average cancer risk had 8.48×10^{-7} DALY per person per year. The financial burden was estimated to be US$2.72 million with the range of US$2.52–2.91 million. The findings may assist in better understanding and reducing cancer risks from DBPs in desalinated and blended water.

Keywords: Disinfection Byproducts, Desalinated and Blended Water, Trihalomethanes, Human Exposure and Risk, Disability Adjusted Life Years.

1. Introduction

Desalination of seawater has been in practice for satisfying domestic water demands in many countries in the Middle East, the Mediterranean Basin, as well as in Australia and USA. In the Arabian Gulf, total production of desalinated water was reported to be approximately 11 million m^3/day while Saudi Arabia produced approximately 4.5 million m^3/day, which has made Saudi Arabia as the largest producer of desalinated water as a single country (Al-Zahrani *et al.*, 2016; MOWE, 2013). For desalination, two main processes: thermal (MSF: multi-stage flash; MED: multi effect distillation); and membrane (RO: reverse osmosis) are in practice, and the dominant process is MSF, due mainly to low energy cost in this region. In addition, large-scale plants with advanced technologies are being established in these countries indicating the increase in desalinated water supplies in future.

The desalination plants receive feed water mainly from the open seawater intakes while some plants receive feed water via different intakes and coastal locations. Free chlorine (HOCl/OCl) are often used during pre-treatment to prevent bacterial growth and bio fouling, and to enhance filter performance. The pretreatment is performed using continuous or intermittent chlorination with initial doses of 0.5 – 2.0 mg/L to achieve the target residuals of 0.25 – 0.5 mg/L. Free chlorine is also applied in different stages of desalination process as well as in final disinfection. Consequently, different types of disinfection byproducts (DBPs) are formed in the desalinated seawater, which can pose public health risks. Past studies have reported that seawater could contain bromide and iodide in the ranges of 50,000 - 80,000 µg/L and 21 - 60 µg/L respectively

(Kim *et al.*, 2015), which can increase the formation of brominated and iodinated DBPs. The brominated and iodinated DBPs are much more cytotoxic and genotoxic than the chlorinated DBPs (Richardson *et al.*, 2007). The thermal desalination process removes bromide and iodide to the non-detectable levels in the feed water while the RO permeate reported considerable amounts of bromide (250-600 µg/L) and iodide (< 4 – 16 µg/L), which can increase the formation of brominated and iodinated DBPs in the distribution systems (Kim *et al.*, 2015).

In the past, many studies have focused on human exposure and risk from DBPs in freshwater sourced drinking water. Despite the public health relevance, not much is known about the DBPs in desalinated and blended water, their exposure and risk. In Saudi Arabia, desalinated water supplies more than 60% (~1620 million m^3/year) of domestic water demand (MOWE, 2013), which is likely to be increased in future. The desalinated water is blended with the treated brackish groundwater, pH adjusted and chlorinated prior to supplying to the consumers. The blended water stays in the regional pipelines, storage tanks, blending stations and WDS for several days. In addition, maximum daily temperature during summer often exceeds 40ºC, which can increase the reaction rates by several folds. The water has the environments and constituents conducive to increased formation of DBPs, in particular, the brominated and iodinated DBPs (Chowdhury, 2013). There is a need to understand DBPs concentrations in desalinated and blended water, and the consequent exposure and risk. In this study, formation and distribution of THMs in desalinated and blended water from different desalination plants in Saudi Arabia were investigated. Exposure to THMs were estimated through ingestion, inhalation and dermal absorption pathways. Cancer and non-cancer risks were predicted. Using the predicted risks, the societal burden was estimated in terms of disability adjusted life year (DALY) using the concept of YLL (years of life lost due to premature mortality) and YLD (years of life lost due to disability). Strategy was proposed to reduce THMs in desalinated and blended water and to reduce human exposure and risks.

2. Methodology

2.1. Data collection

Occurrences of THMs (chloroform: $CHCl_3$; bromodichloromethane: BDCM; dibromochloromethane: DBCM; and bromoform: $CHBr_3$) and water quality parameters were investigated in desalinated seawater and blended water (mixture of desalinated seawater and treated groundwater in the ratio of 40-60%) in the WDS in Al-Khobar, Saudi Arabia for a period of one year (Feb, 2014 – Jan 2015). The samples were collected on bi-weekly basis and analyzed in duplicates following the standard methods.

2.2. Exposure and risk assessment

Exposure to THMs occurs through multiple pathways, including ingestion of drinking water, and inhalation and dermal contact during showering, bathing, house cleaning and swimming (Xu and Weisel, 2005). Exposure assessment is associated with uncertainty from variable sources, including rate of water ingestion, life expectancy, temperature of cold and hot water, mixing ratio of cold and hot water, free residual chlorine, DBPs formation kinetics, shower stall volume, water flow, dermal absorption coefficients and shower duration (Xu and Weisel, 2005). To incorporate uncertainty, 5000 random data are generated for each parameter following the statistical distributions. Exposure to THMs through ingestion is predicted using the THMs in cold water. THMs exposure through inhalation pathway is predicted using THMs in the shower air, which is estimated using the partition coefficients and mass-balance equations. In assessing dermal exposure during showering, showering events are divided into the unsteady and steady states and exposure. Further details are summarized below.

2.2.1. Ingestion pathway

The chronic daily intakes (CDI) of THMs through ingestion of drinking water is computed following USEPA (USEPA, 1998, 2005; Chowdhury, 2013) as:

$$CDI_{ing} = \frac{C_w \times EF \times IR \times ED \times CF}{BW \times AT} \tag{1}$$

Where, CDI_{ing} = CDI via ingestion (mg/kg-day); C_w = THMs concentrations in drinking water (μg/L); EF = frequency of exposure (days/year); IR = rate of drinking water ingestion (L/day); ED = duration of exposure (year); BW = weight of the body (kg); AT = averaging time (days); and CF = 0.001 (conversion factor of mass from μg to mg).

2.2.2. Inhalation pathway

The CDI of THMs through inhalation pathway is predicted following USEPA (Chowdhury, 2013; USEPA, 1998, 2005) as:

$$CDI_{inh} = \frac{E_r \times C_a \times t \times R \times F \times EF \times ED \times CF}{BW \times AT} \tag{2}$$

Where, CDI_{inh} = CDI via inhalation (mg/kg-day); E_r = THMs absorption rate in respiratory system; t = shower duration (min/shower); R = breathing rate (m^3/min); F = shower frequency (shower/day); CF = 0.001 (conversion factor of mass from μg to mg); and C_a = concentrations of THM in shower air (μg/m^3). C_a depends on various factors, including water flow rate of shower, shower stall volume, THMs in cold water, mass transfer rate, shower duration and exchange rate of shower air. C_a is be modeled following Chowdhury (2013).

2.2.3. Dermal contact pathway

The CDI through dermal route depends on the thickness of stratum corneum, molecular diffusion of chemical through stratum corneum, partition coefficient between stratum corneum and chemical in the water and concentration gradient between upper and lower layers of stratum corneum (Chowdhury, 2013). Depending on shower duration, dermal exposure often needs unsteady and steady state exposure assessments (Chowdhury, 2013). Past studies reported that the steady state diffusion through stratum corneum was in the order of 10^{-13} to 10^{-14} m^2/s for compounds having low molecular weight and 10^{-15} to 10^{-17} m^2/s for compounds having high molecular weight (Scheuplein and Blank, 1971). However, diffusion of chemicals before reaching steady state can be significantly different from the steady state values. To achieve steady state between the chemicals in water attached to the skin surface (i.e. upper layer of stratum corneum) and lower layer of stratum corneum, there is a need of lag time, which was reported to be in the range of 9.8 - 391.2 minutes for different DBPs (Chowdhury, 2013). The lag time prior to achieving steady state condition, diffusion through skin, octanol-air partition coefficient, CDI during unsteady and steady states are estimated following past studies

(Chowdhury, 2013). Upon estimation of CDI through the unsteady and steady states of exposure, the total CDI through dermal route is calculated as:

$$CDI_{derm} = CDI_{derm\text{-}ust} + CDI_{derm\text{-}ss} \tag{3}$$

Where, $CDI_{derm-ust}$ = CDI of THMs during unsteady-state period (mg/kg-day); $CDI_{derm-ss}$ = CDI of THMs through dermal route (mg/kg-day) during steady-state condition; $CDI_{derm-ss}$ = total CDI through dermal route. Upon estimation of route specific CDI, lifetime cancer and non-cancer risks can be estimated as:

$$CR = \sum_{i=1}^{m} \sum_{j=1}^{n} CDI_{ij} \times SF_{ij} \tag{4}$$

$$HI = \sum_{i=1}^{m} \frac{CDI_i}{R_f D} \tag{5}$$

Where, i = 1,2,3…m represent different THMs (i.e. $CHCl_3$, BDCM, DBCM and $CHBr_3$); j = 1,2,3…n representing different routes of exposure (i.e. ingestion, inhalation and dermal contact); CR = cancer risk; SF = slope factor ($[mg/kg/day]^{-1}$) for specific route; R_fD = reference dose (mg/kg/day). The oral SF for BDCM, DBCM and $CHBr_3$ are 0.062, 0.084 and 0.0079 per mg/kg-day respectively (USEPA, 2016), while for the other routes, SF data are not available. In this study, oral SF from USEPA were used to estimate human health risk. The R_fD for $CHCl_3$, BDCM, DBCM and $CHBr_3$ are 0.01, 0.02, 0.02 and 0.02 mg/kg-day respectively (USEPA, 2016).

2.3. Adjustment factor

According to USEPA (USEPA, 2005), early-life exposure has higher contribution to cancers appearing later in life. To represent such effects, age dependent adjustment factors of USEPA (USEPA, 2005) were used as:
An adjustment factor of 10 fold for exposures up to 2 years of age from birth;
An adjustment factor of 3 fold for exposures between 2 years to less than 16 years of age; and
No adjustment after 16 years of age.

DALY analysis

The disability adjusted life year (DALY) estimates the number of years lost due to premature death and disability because of a disease or injury (Murray and Lopez, 1996). To asses DALY, three possible scenarios are considered: (i) a proportion of affected people will die from cancer; (ii) a proportion will be cured from cancer; and (iii) rest of them will live with cancer sequelaes. The healthy years of life lost in a group of populations is calculated following Soerjomataram et al. (2012) as:

$$DALY = YLL + YLD \tag{6}$$

Where, DALY = total disability adjusted years of life lost; YLL = total years of life lost due to premature death from cancer; YLD = total years of life lost due to disability. YLL is calculated by multiplying the number of death with the years of life expected to live at the time of death. YLD is calculated by multiplying the incidence rate with the disable years caused by the disease and severity of the disease (e.g., disability weight). The calculations of YLL and YLD can be simplified following (Pan et al., 2014) as:

$$YLL = \sum_x n_x d_x e_x \quad (7)$$

$$YLD = \sum_x n_x i_{x,y} DW_y L_y \quad (8)$$

Where, n = number of populations; d = death rate; e = life expectancy at the age of death (year); i = incidence rate; DW = disability weight; L = duration of disability; x = age; and y = disease phase. Equations 7 and 8 were modified to include the age-specific cancer incidence (P_x) and survival rate (S_x) (Pan et al., 2014) as:

$$YLD = \sum_x n_x P_x (1 - S_x)(e_x - T_D) \quad (9)$$

$$YLD = \sum_x n_x P_x \left[(1 - S_x) DW_y L_y + S_x \{DW_y L_y + P_{seq} DW_{seq}\}(e_x - T_D)\right] \quad (10)$$

Where, n_x = number of population for each age group; P_x = age-specific cancer risk. The lifetime cancer risk needs to be converted into age specific cancer risk. However, cancer risks are likely to be different in different age groups. The age specific relative sensitivity parameter (RS_x) is introduced to calculate the age-specific cancer risk. In this study, bladder cancer was considered to be the possible outcome of DBPs exposure (Richardson et al., 2007; USEPA, 2016). The RS_x for bladder cancer is calculated as (Pan et al., 2014):

$$RS_x = \frac{I_x}{I} \quad (11)$$

Where, I_x = cancer incidence rate for age group x, I = cancer incidence rate for total populations. These rates are obtained for Saudi Arabia from the GLOBOCAN database (IARC, 2012). GLOBOCAN is a cancer database, developed by the International Agency for Research on Cancer (IARC). The age-specific cancer estimate is obtained as (Pan et al., 2014):

$$P_x = \frac{IR \times RS_x}{Sp_x} \quad (12)$$

Where, IR = probability of an individual developing cancer; RS_x = age specific relative sensitivity; and Sp_x = age span. S_x = age-group specific survival rate. Sx can be obtained as (Pan et al., 2014):

$$S_x = 1 - \frac{M_x}{I_x} \quad (13)$$

Where, M_x = cancer mortality rate for each age group; I_x = cancer incidence rate for each age group (IARC, 2012); e_x = standard life expectancy, as reported in the Global Burden of Disease Studies (GBDS) (Murray and Lopez, 1996); T_D = median time to die (e.g., 2.20 years for bladder cancer) (Smaastuen et al., 2008). DW = adjusted disability weight (range: 0.0 - 1.0) obtained from GBDS (Murray and Lopez, 1996); L = duration of disability, which is divided into three stages: time for diagnosis and treatment (L_D) times for pre-terminal stage (L_M) and times for terminal stage (L_T). The average values of L_D, L_M and L_T were reported to be 4, 3 and 1 months respectively (Soerjomataram et al., 2012). P_{seq} = proportion of the various sequelaes (Fossa et al., 1992; Hardt et al., 2000; Smaastuen et al., 2008); DW_{seq} = disability weight of various sequelaes; T_c = median time to cure for cancer (average: 4 years for bladder cancer) (Smaastuen et al., 2008).

3. Results and Discussion

3.1. Data statistics

Concentrations of THMs and water quality parameters for the desalinated and blended water are shown in Table 1. The blended water had higher level of organic matter (e.g., DOC, UV_{254}) than the desalinated water (Table 1). Concentrations of THMs in blended water were significantly higher than that in the desalinated water, due mainly to extended reaction period, higher free residual chlorine and higher levels of NOM in blended water than the desalinated water. (Table 1). In this study, average concentrations of THMs in the desalinated and blended water were 10.08 and 19.2 µg/L respectively with the ranges of 0.1-33.6 and 2.1-52.4 µg/L respectively (Table 1). Concentrations of THMs in desalinated and blended water from few other plants in Saudi Arabia, and some Arabian Gulf countries are summarized in Table 2.

In the major cities of Saudi Arabia, THMs in desalinated water were in the range of 0.1 – 41.7 µg/L (Fayad, 1993). In blended water, THMs were in the ranges of 0.1 – 66.7 µg/L (Kim et al., 2015; Le Roux et al., 2015). THMs in desalinated water from the Eastern and Western regions of Saudi Arabia were in the ranges of 0.12 – 28.9 and 4.03 – 41.7 µg/L respectively (Fayad, 1993). The sources water for the Eastern and western regions were the Arabian Gulf and the Red Sea respectively. The RO plants generally had higher THMs than the thermal plants. THMs from the RO and thermal plants were in the ranges of 0.1 – 30.1 and 0.1 – 11.0 µg/L respectively (Ahmad and Bajahlan, 2009; El-Hassan and Al-Sulami, 2005; Le Roux et al., 2015).

Table 1: Summary of water quality parameters and THMs in desalinated and blended water

	Desalinated water		Blended water	
	Average	Range	Average	Range
DOC (mg/L)	0.78 (0.33)	0.39–1.68	1.98 (0.41)	1.27–3.14
TC (mg/L)	0.55 (0.09)	0.33–0.72	1.1 (0.23)	0.69–1.54
FRC (mg/L)	0.44 (0.16)	0.24–0.72	0.82 (0.23)	0.07–1.29
Bromide (mg/L)	0.28 (0.13)	0.1 – 0.64	0.30 (0.21)	0.18 – 0.76
Water temperature (°C)	26.3 (5.8)	20–39	25.4 (6.4)	19–37
pH	6.9 (0.49)	6.6–7.7	7.13 (0.12)	6.7 – 8.1
Turbidity (NTU)	0.21 (0.09)	0.13–0.38	0.33 (0.15)	0.14–0.46
UV_{254} (/cm)	0.015 (0.01)	0.01–0.04	0.04 (0.01)	0.02–0.058
Conductivity (µS/cm)	230.4 (43.9)	149-348.7	415.3(72.4)	266.4-552.5
THMs (µg/L)	10.08 (2.1)	0.1-33.6	19.2 (4.7)	2.1-52.4

DOC: Dissolved organic matter; TC: total chlorine; FRC: Free residual chlorine; Values within brackets are standard deviations

Table 2: Concentration of THMs in µg/L in desalinated and blended water in gulf countries

Country	THMs	Average	Std. dev.	Min	Max
Saudi Arabia	$CHCl_3$	0.6		0	9.3
	BDCM	0.71		0	3.4
	DBCM	1.3		0	2.33
	$CHBr_3$	8.9		0	51.7
Qatar	$CHCl_3$	0.6		0.01	4.96
	BDCM	0.21		0.01	2.66
	DBCM	0.52		0.01	2.74
	$CHBr_3$	20.89	15.2	3.99	72.95
Kuwait	$CHCl_3$	0.81	1.13	0	5.87
	BDCM	2.44	0.84	0.99	7.87
	DBCM	6.63	2.11	2.74	13.73
	$CHBr_3$	30.16	19.6	3.38	77.42
Bahrain	$CHCl_3$				
	BDCM	0.6	0.12		
	DBCM	0.64	0.05		
	$CHBr_3$	5.9	0.15		

Concentrations of THMs in the desalinated and blended water in Kuwait and Qatar were higher (Table 2). THMs in the desalinated and blended water from Bahrain, Kuwait, Qatar and UAE were in the ranges of 0.27 – 6.4, 7.11 – 104.89, 4.02 – 83.31 and 7.0 – 15.0 µg/L respectively (Table 2). Their corresponding averages were 2.95, 40.04, 22.22 and 10.0 µg/L respectively (Al-Otoum, 2014; Al-Saleh and Al-Haddad, 1994; Kim et al., 2015; Latif, 1991). Among the THMs, brominated THMs were much higher than the chlorinated ones (Table 2).

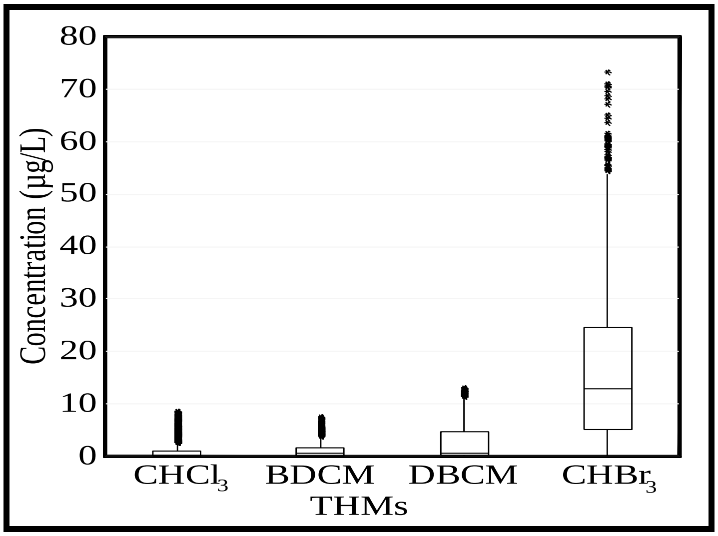

Figure 1: Concentration of THMs in desalinated and blended water in Saudi Arabia. The bottom of the box is the first quartile (Q1) □ 25% of the data values; the top of the box is the third quartile (Q3) □ 75% of the data values; the upper whisker extends to the highest data value within the upper limit: Q3 + 1.5*(Q3 □ Q1). The lower whisker extends to the lowest value within the lower limit: Q1□ 1.5*(Q3 □ Q1); Values beyond the whiskers are outliers; the horizontal bar in the middle of box is the median of the data values.

Figure 1 shows the distribution of THMs in Saudi Arabia. On average, $CHCl_3$, BDCM, DBCM and $CHBr_3$ were approximately 5.2, 6.2, 9.5 and 79.1% respectively. The THMs database obtained in this study was expanded using additional data from the desalinated and blended waters in different desalination plants and WDS in the major cities in Saudi Arabia (Al-Mudhaf and Abu-Shady, 2008; Ahmad and Bajahlan, 2009; Ozair and Al-Shangiti, 2013; Al-Otoum, 2014; Chowdhury, 2013; Kim et al., 2015; Le Roux et al., 2015).

Table 3: THMs concentration in desalinated water in Saudi Arabia

THMs	Average	Range	Distribution
$CHCl_3$	0.71	0.0 – 9.30	T(0.0, 0.76, 9.3)
BDCM	0.86	0.0 – 7.87	T(0.0, 0.98, 7.87)
DBCM	1.46	0.0 – 13.73	Gamma(0.4626, 2.028, 0.0111)
$CHBr_3$	15.74	0.0 – 77.42	Gamma(1.043, 13.77)

Table 4: Proportion and disability weight (DW) for bladder cancer

Sequelae	Proportion (%)	Disability weight (DW)
Incontinence	5	0.157
Impotence	10	0.195
Primary infertility	16	0.18
Secondary infertility	16	0.1

The additional data from multiple desalination plants and cities have explained data variability among different plants and cities, and thus the data variability were incorporated to better explain human exposure and risk. Using the combined data, the best-fit statistical distributions were developed for THMs. In this study, $CHCl_3$ and BDCM followed triangular distribution while DBCM and $CHBr_3$ followed the Gamma distribution (Table 3). For the triangular distribution, 1^{st}, 2^{nd} and 3^{rd} parameters represent the minimum, average and maximum values respectively. In the Gamma distribution, 1^{st}, 2nd and 3^{rd} parameters represent shape, scale and threshold respectively. Following these distributions, 5000 random data were generated using statistical software (e.g., MINITAB™) to incorporate the data variability. These random data were used in estimating the chronic daily intakes (CDI) of THMs. The proportion of various sequelaes and disability weight of various sequelaes are shown in Table 4. The other relevant parameters for exposure and risk assessment are shown in Table 5 (Chowdhury, 2013).

Table 5: Values of the different parameters

Parameter	Group	Symbol	Value	Parameter	Group	Symbol	Value
Water ingestion rate (L/day)	<2 years	IR	0.068, 0.287, 0.735	Molecular weight	$CHCl_3$	MW	119.4
	2 - 16 years		0.224, 0.663, 1.649		BDCM		163.8
	> 16 years		0.74, 1.31, 2.12		DBCM		208.3
Body weight (kg)	<2 years	W_B	9, 11, 14		$CHBr_3$		252.8
	2-16 years		36, 52, 72	Octanol-water partition coefficient	$CHCl_3$	k_{ow}	93
	>16 years		62, 70.4, 81		BDCM		126
Air intake rate (m^3/min)	<2 years	R	0.0026, 0.0034, 0.0043		DBCM		127
	2 -16 years		0.008, 0.011, 0.013		$CHBr_3$		128
	>16 years		0.012, 0.014, 0.016	THMs in cold water (µg/L)		C_w	Table 3
Area of body skin exposed to water (m^2)	<2 years	A_s	0.46, 0.53, 0.59	Exposure frequency (days/year)		EF	330, 350, 360
	2-16 years		1.25, 1.57, 1.94	Exposure duration (year)		ED	65, 77.1, 82.7
	>16 years		1.69, 1.82, 1.94	Averaging time (day)		AT	23725, 28142, 30186
Permeability through skin (m/min)	$CHCl_3$	P_d	$(2.54, 2.67, 2.79) \times 10^{-5}$	Water flow (L/min)		Q_w	8.7, 10.0, 11.4
	BDCM		$(2.87, 3.0, 3.13) \times 10^{-5}$	Shower stall volume (m^3)		V	1.67, 2, 2.25
	DBCM		$(3.25, 3.33, 3.42) \times 10^{-5}$	Shower time (min/shower)		t	5, 10, 20
	$CHBr_3$		$(3.42, 3.50, 3.58) \times 10^{-5}$	Heated water temperature (°C)		T_2	35, 40, 45
Cold water temperature (°C)		T_1	15, 20, 25	THMs absorbance through respiratory system		E_r	0.7, 0.77, 0.84
Air change rate (min^{-1})		k_a	0.018, 0.021, 0.023	Water to air phase transformation rate of THMs (%)		p_v	7.66, 8.76, 9.86
Shower frequency (shower event/day)		F	0.72, 0.74, 0.76	Thickness of stratum corneum (cm)		d_{skin}	0.0015, 0.002, 0.003

3.2. Chronic daily intake of THMs

The CDI for $CHCl_3$, DBCM, BDCM and $CHBr_3$ contributed 13.6, 12.3, 4.1 and 70.0% of total CDI respectively. On average, ingestion, inhalation and dermal routes contributed approximately 63.4, 22.3 and 14.3% of total CDI respectively and their ranges were 65.2 – 86.2, 10.0 – 34.6 and 3.8 – 20.5% respectively. The average CDI of $CHCl_3$, BDCM, DBCM and $CHBr_3$ through all routes were 8.38×10^{-5}, 7.57×10^{-5}, 2.54×10^{-5} and 4.32×10^{-4} mg/kg-day respectively while their ranges were $6.22\times10^{-7} – 3.97\times10^{-4}$, $1.14\times10^{-6} – 3.57\times10^{-4}$, $1.20\times10^{-7} – 5.33\times10^{-4}$ and $7.62\times10^{-8} – 4.92\times10^{-3}$ mg/kg-day respectively. The frequency distribution of CDI through all routes are shown in Figure 2. The CDI of $CHCl_3$ and DBCM followed lognormal distribution. The location and scale of $CHCl_3$ were -10.20 and 0.70 mg/kg-day and for DBCM these parameters were -11.69 and 1.72 mg/kg-day respectively (Figure 2). The CDI of BDCM and $CHBr_3$ followed Gamma distribution. The shape and scale for BDCM were 2.15 and 3.5×10^{-5} mg/kg-day and for $CHBr_3$, these parameters were 1.03 and 4.2×10^{-4} mg/kg-day respectively (Figure 2). The frequency distributions for $CHCl_3$, BDCM, DBCM and $CHBr_3$ showed skewed distributions with right sided long tail, indicating that these fractions of data might pose elevated risk to human.

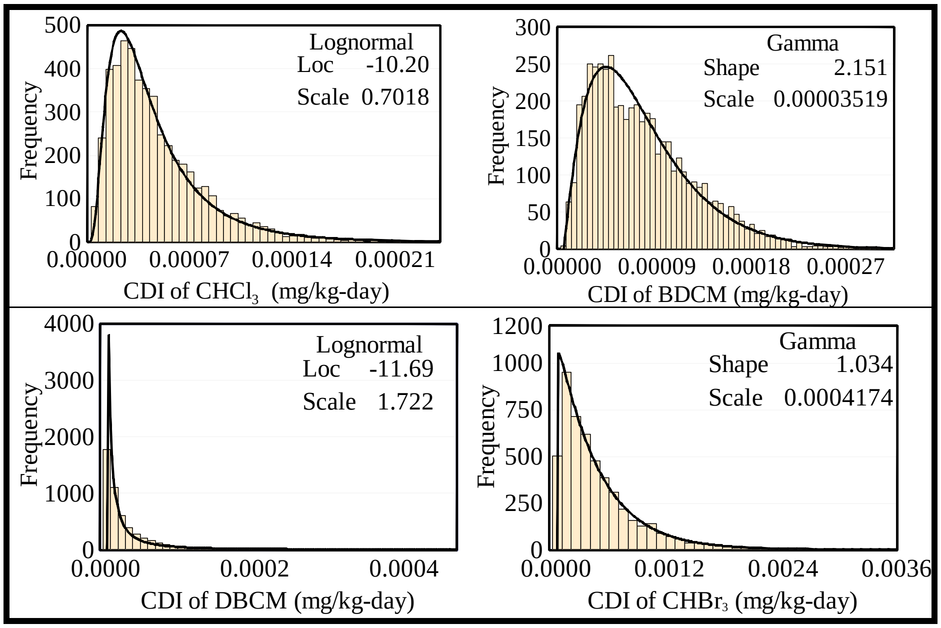

Figure 2: Frequency distribution and fits of CDI of THMs

3.3. Risks of THMs

The lifetime excess cancer risks and hazard indices are shown in Table 6. The average cancer risk considering all age groups was predicted to be 1.78×10^{-5} with range of 7.40×10^{-7} – 9.26×10^{-5}. The ingestion, inhalation and dermal routes contributed approximately 65.4, 23.5 and 11.1% of overall cancer risks. With respect to age groups, average cancer risks during <2 years, 2 – 16 years and >16 years were 4.5×10^{-6}, 5.2×10^{-6} and 8.0×10^{-6} respectively. These three age groups contributed approximately 25.4, 29.3 and 45.3% of total cancer risks respectively. In the early life, despite the exposure was only for 2 years, it contributed 25.4% of the overall risk, indicating that appropriate protection during this period (birth to < 2 years) might reduce the overall risk significantly. The overall hazard index was estimated to be 3.49×10^{-2} with the range of 1.20×10^{-3} – 2.34×10^{-1}. Hazard indices through ingestion, inhalation and dermal routes were estimated to be 2.23×10^{-2} (range: 1.05×10^{-3} – 1.45×10^{-1}), 7.89×10^{-3} (range: 1.21×10^{-4} – 8.18×10^{-2}) and 4.77×10^{-3} (range: 3.84×10^{-5} – 4.53×10^{-2}) respectively (Table 6).

Table 6: Cancer risks and hazard indices for exposure to THMs

Pathways	Cancer Risk				Hazard Index			
	Average	**Std. Dev.**	**Minimum**	**Maximum**	**Average**	**Std. Dev.**	**Minimum**	**Maximum**
Ingestion	1.16×10^{-5}	6.53×10^{-6}	5.76×10^{-7}	5.26×10^{-5}	2.23×10^{-2}	1.45×10^{-2}	1.05×10^{-3}	1.45×10^{-1}
Inhalation	4.17×10^{-6}	3.31×10^{-6}	1.11×10^{-7}	3.54×10^{-5}	7.89×10^{-3}	6.70×10^{-3}	1.21×10^{-4}	8.18×10^{-2}
Dermal Contact	1.97×10^{-6}	1.59×10^{-6}	1.31×10^{-8}	1.35×10^{-5}	4.77×10^{-3}	3.90×10^{-3}	3.84×10^{-5}	4.53×10^{-2}
Total	1.78×10^{-5}	1.02×10^{-5}	7.40×10^{-7}	9.26×10^{-5}	3.49×10^{-2}	2.33×10^{-2}	1.20×10^{-3}	2.34×10^{-1}

3.4. Disability adjusted life years (DALY)

The overall DALY was estimated to be 25.1 with the range of 23.2 – 26.8, meaning that on average 25.1 years are likely to be lost due to cancer risks from exposure to THMs. Among the DALY, the YLL and YLD were estimated to be 18.6 (17.1 – 19.9) and 6.5 (6.0 – 6.9) respectively. The YLL and YLD contributed approximately 74 and 26% of total DALY. Based on the age-specific bladder cancer incident rates in Saudi Arabia (IARC, 2012), the YLL and YLD were estimated for the age-groups of 0-14, 15-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-

69, 70-74 and 75+ ages. In Saudi Arabia, total populations in 2012 were estimated to be 29.5 million (World Bank, 2014). The total number of populations in the noted age groups were obtained from the world fact book of Central Intelligence Agency (CIA) database. The YLL and YLD for different age groups are shown in Figure 3. The largest DALY (5.6) were estimated for 15-39 age group. The age groups of 15-39, 40-44, 45-49, 50-54 and 55-59 were the main contributors of DALY (Figure 3).

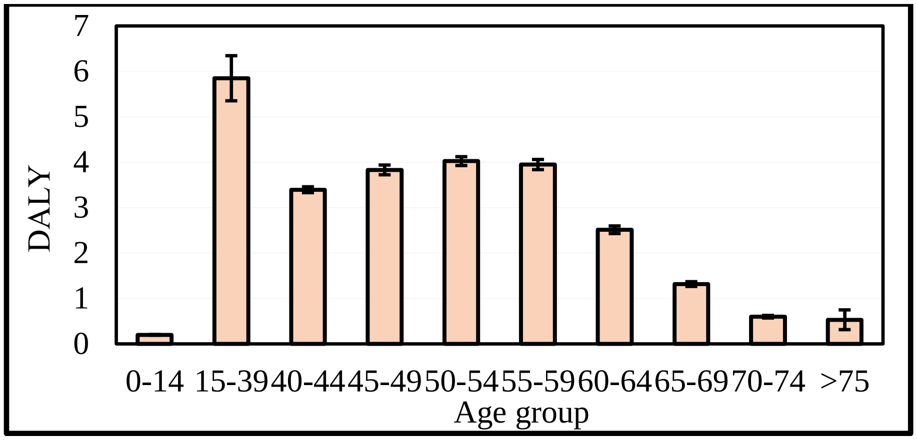

Figure 3: DALYs for different age groups. Error bars represent standard deviation

The total DALY of 25.1 was divided by the total populations (29.5 millions) to obtain cancer risk per person per year (PPPY) in terms of DALY. The cancer risk in terms of DALY was obtained as 8.48×10^{-7} PPPY, which was lower than the USEPA guideline value of 1.0×10^{-6}. The World Health Organization (WHO) has estimated the loss per DALY in terms of monetary value (Lee et al., 2009). One DALY was associated with a loss of US$ 108,600 (Lee et al., 2009), which means one year of healthy human life costs US$ 108,600, indicating that the total financial burden for Saudi Arabia was US$ 2.72 million with the range of US$ 2.52 – 2.91 million per year.

4. Conclusion

This study presented and applied the methodologies of estimating human health risk and DALY from exposure to DBPs in desalinated and blended water in Saudi Arabia. The cancer risks of DBPs in desalinated and blended water was predicted to be 1.78×10^{-5}, which was higher than the minimum risk recommended by the USEPA. Cancer risks through ingestion route was highest (65.4%) followed by dermal (23.5%) and inhalation (11.1%) routes. With respect to age groups, the highest contributor group was >16 years (45.3%), which had the largest lifespan (16+ to death). In contrast, the exposure during the early life (birth to < 2 years) contributed approximately 25.4% of the overall risks. Control of early life exposure can reduce the risk significantly. The cancer risks in terms of DALY was estimated to be 8.48×10^{-7} per person per year, which is below the reference risk level as recommended by the USEPA. The DALY can be used for analyzing financial burden from cancer risks. It can also be used for cost effectiveness analysis, which may help to improve quality of desalinated water and may help to prioritize the hazardous material present in desalinated water. In this study, THMs were used for analyses, which were a fraction of various DBPs present in desalinated water. Few other DBPs with possible cancer risks are HAAs, iodo-THMs, bromate, NDMA while sufficient information on these DBPs are not available to date to conduct risk analysis for desalinated and blended water.

Future study may further look into these DBPs and their risks. Despite these limitations, this study sheds light on possible risks of DBPs in desalinated and blended water.

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Groundwater Quality Assessment in Jazan Region, Saudi Arabia

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Abstract
Jazan province is an arid area, located at the southwestern part of Saudi Arabia along the Red Sea coast. Groundwater is the only resource of drinking water in this area; consequently, its suitability for drinking and domestic uses is of public and scientific concern. In this study, groundwater samples were collected from 23 sites in Jazan area during fall 2014; measurements and analysis of water quality parameters including pH, total dissolved solids, turbidity, hardness, alkalinity, ammonia, nitrite, nitrate, sulfate, calcium, magnesium, chloride, iron and fluoride were carried out with references to World Health Organization WHO and Gulf Standardization Organization GSO. The concentration of total dissolved solids TDS was higher than the desirable limit of 600 mg/l in 30.4% of samples, total hardness values exceeded the desirable limits of 300 mg/l in 34.8% of samples, and nitrate concentration was higher than the desirable limit of 50 mg/l in only one sample. However, the concentrations of investigated parameters in the groundwater samples were within the permissible limits of WHO. The correlation matrices for fourteen variables were performed. TDS and hardness had significant positive correlations among themselves and also with SO_4^{-2}, Cl^-, Mg^{2+}, and Ca^{2+}. Fluoride was not significantly correlated with any of the parameters except nitrite. Calcium and magnesium were positively and significantly correlated with Cl^- and SO_4^{-2}. Furthermore, SO_4^{-2} was positively and significantly correlation with Cl^-. pH was negatively correlated with most of the physicochemical parameters. Our results showed that the water quality of groundwater in Jazan area is acceptable and could be used safely for drinking and domestic purposes. However, a special attention should be paid to the concentration of TDS and nitrate in groundwater in future studies.

Keywords: Groundwater, Water Quality, Physicochemical Parameters, Jazan.

Introduction
Groundwater is the sole resource of drinking water in arid areas, which is also used in domestic consumption and irrigation (Switzman *et al.*, 2015; Kim *et al.*, 2015). Knowledge of the occurrence, replenishment, and recovery of groundwater has special significance in arid and semi-arid regions due to discrepancy in monsoonal rainfall, insufficient surface waters and over drafting of groundwater resources (Hussain *et al*, 2013; Jain *et al.*, 2010). Groundwater quality depends on the quality of recharged water, atmospheric precipitation, inland surface water, and the sub-surface geochemical processes. Temporal changes in the origin and constitution of the recharged water, hydrologic and human factors, may cause periodic changes in groundwater quality (Vasanthavigar *et al.*, 2010). Water pollution affects simultaneously the water quality and threats the human health, economic development, and social prosperity (Milovanovic, 2007). Groundwater chemistry has been utilized as a tool to outlook water quality for drinking and irrigation purposes (Subba Rao, 2006; Edmunds *et al.*, 2002). Groundwater is an important source of acceptable water for drinking in the arid regions and in particular in the Saudi Arabia where it is considered as the first water source for drinking and irrigation. Jazan is the smallest

province in Saudi Arabia covers an area of 13500 km^2 in southwestern part of Saudi Arabia as a part of Tihama plain (Fig. 1), with a population of 1.5 million inhabitants (Department of Statistics and Information- KSA, 2010). The climate of Jazan is hot, windy and arid with high humidity due to the influence of Red Sea, the annual mean temperature 28°C, relative humidity 62%, and annual precipitation of 62 mm (Saudi presidency of meteorology and environment, unpublished data).

Demand on groundwater is increasing in Saudi Arabia due to the population growth and significant economic advancement. Fresh water supply is an important issue worldwide, groundwater contains over 90% of the fresh water resources and it is an important reserve of good quality water (Armon *et al.*, 1994). Water resources assessment represents a major concern of the present world due to the importance of water for human being and society and for implementing sustainable water-use strategies (Oiste, 2014). Moreover, water quality analysis is the most important aspect in groundwater studies, which is always used as a basis to discuss utilizing groundwater in order to avoid associated water illnesses and health problems (Nagarajan *et al.*, 2010). Quality of groundwater depends, to some extents, on its chemical composition. Cations and anions play important roles as indicators of groundwater contamination (Chgue'-Goff, *et al.*, 1997; Sultan, 1998; Matthiesen, 2008). Hussain *et al.* (2013) reported the contamination of groundwater of central Rajastan in India with Fluoride, as consequence, most individuals in the contaminated region suffer from mild and moderate fluorosis.

Information on the assessment of groundwater quality is particularly scarce in Jazan. Within this context, the objectives of this study were, to assess the quality of the groundwater in public wells in Jazan area, and to compare the results with the different standards. Results of this study will be helpful for the decision makers in determining appropriate actions and using integrated water resources management tools to protect groundwater from the possible contamination. The results will be used as a basis for making sustainable groundwater development schemes, understanding the management and future development of groundwater resources in the area. To the best of our knowledge, this is the first work in Jazan area on the assessment of groundwater quality**.**

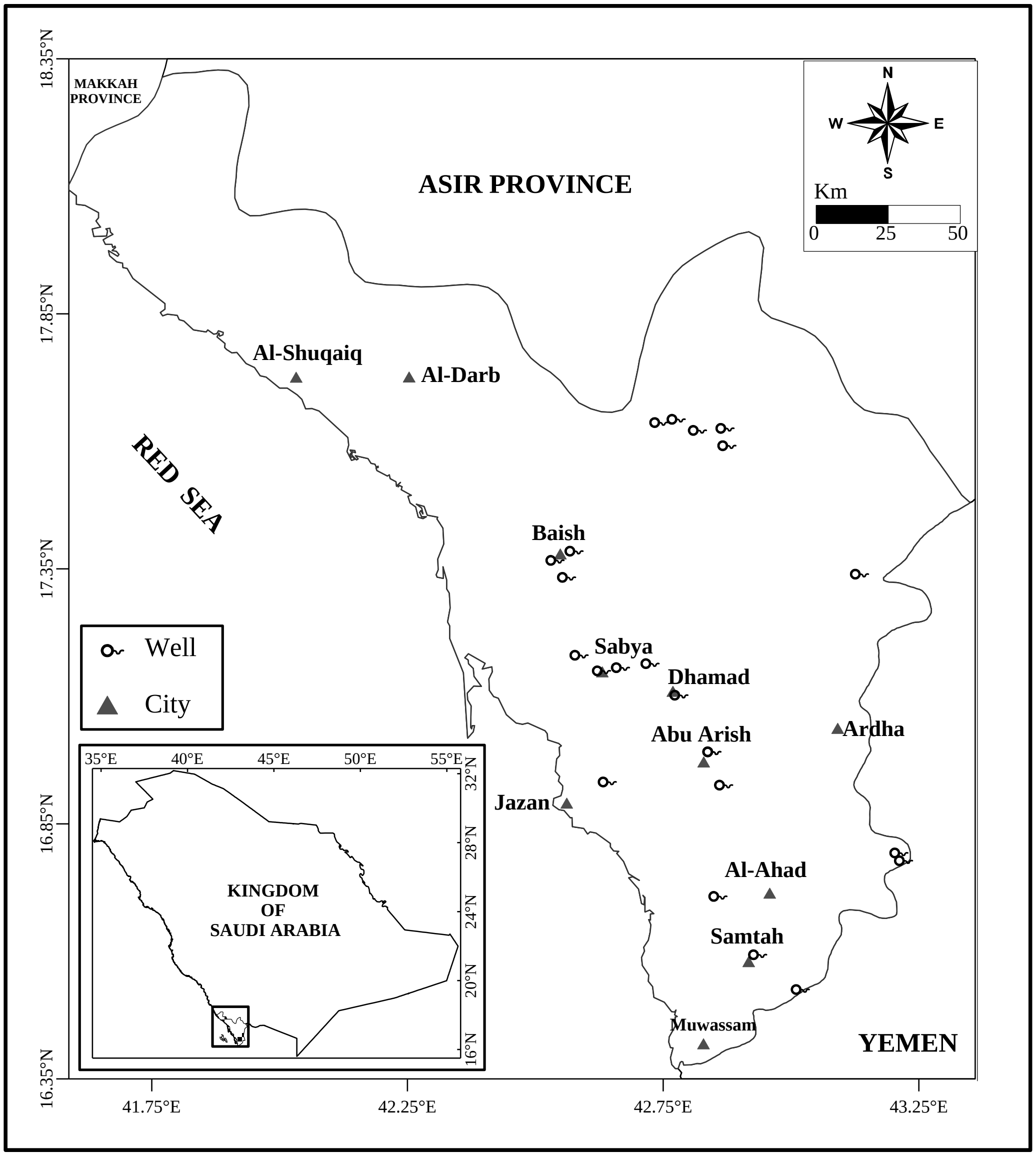

Fig. 1: Location map showing groundwater sampling wells in Jazan province

Methodology

Samples from twenty three groundwater public wells were collected during fall 2014 from different location in Jazan province (Fig, 1). All investigated wells belong to the General Directorate of Water in Jazan. 5L of water were collected from each well in an amber plastic container (Naizak, KSA) washed previously with distilled water. Then, a sub-sample of 100 mL transferred into a 250 mL Erlenmeyer flask (RACCO, KSA) to measure the physical parameters such as pH and Total Dissolved Solids (TDS) directly after sampling using the Multimeter 340/I (WTW) (GeoTech, USA). For each sample, a sub-sample of 20 mL transferred into a 20 mL PE flask for analysis of anions, and another sub-sample was filtered and filled into 20 ml PE flasks for analysis of cations, then some drops of pure HNO_3 were added to the sub-sample for conservation. Samples collected from all wells were identified and transferred to lab refrigerated at 4°C in an ice-chest cooler, then stored at 4°C in the analytical laboratory of General Directorate of Water (Jazan) till analysis within 2 days.

Analytical procedures

The groundwater samples were processed and analyzed for TDS, Turbidity, Hardness, Alkalinity, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Ammonia (NH_3), Nitrite (NO_2^-), Nitrate (NO_3^-) Sulfate (SO_4^{-2}), Chlorine (Cl^-), Iron (Fe^{2+}) and Fluoride (F^-). An ion chromatograph DX500 (Dionex, Thermo Scientific, KSA) with AG9 column was used for analysis of anions. Cations were measured with an atom emission spectrometer ICP-AES (Varian Vista AX, KSA). Ammonia was detected photometrically (PM2DL, Zeiss, KSA). Total hardness was determined by EDTA titrimetric method. Total dissolved solids were measured gravimetrically.

The statistical analysis of data was completed using Microsoft Excel software (version 2010, Microsoft Saudi Arabia), Groundwater quality was assessed based on chemical comparison with drinking water standard from World Health Organization (WHO, 2008) and Gulf Standardization Organization (GSO).

Results and discussion

General parameters

The physico-chemical parameters of investigated samples are presented in Table 1. The pH of water in the samples ranged from 6.70 to 7.70 (mean, 7. 41) indicating that the groundwater of the investigated area is characterized by neutral. The pH values in all water samples in this study were within the safe limits of 8 (WHO, 2011). This result is in accord with (Owamah *et al.*, 2013) who reported pH values of groundwater samples collected from Niger Delta region lower than 8. TDS values in the groundwater samples of our study ranged from 104 to 930 mg/l (mean 473.04 mg/l). In all samples, TDS values are below the WHO and GSO permissible limit of 1000 mg/l (WHO, 2011), and conform to results obtained by (Sharma, 2014). The total hardness caused primarily due to the polyvalent cations (mainly calcium and magnesium) present in water. The hardness of water samples in this study varied from 47.00 to 490.00 mg/l with a mean value of 251.39 mg/l. WHO (2011) mentioned that water samples which have hardness above 200 mg/l may cause scale deposition in the distribution system, pipes and tanks, in addition to increase the soap consumption. The concentration of ammonia (NH_3) varied from 0.01to 0.21mg/l with a mean value of 0.10 mg/l, this value is significantly below the limit of 1.5 mg/l (WHO, 2011). Nitrite (NO_2^-) concentrations in collected water samples were ranged from 0.00 to 0.19 mg/l with a mean value of 0.04 mg/l, this value is below the permissible limit of 3 mg/l (WHO, 2011).

Cation chemistry

The major cations present in most of the groundwater having highest concentrations (all >1 mg/l) are calcium, magnesium, sodium and potassium (Younger, 2007). The concentrations of various cations analyzed in groundwater samples in this study are presented in Table (1).

Calcium and magnesium concentrations in water samples were varied from 31.00 to 360 and 16.00 to 260.00 mg/l, with mean values of 153.35 and 98.39 mg/l, respectively. In groundwater, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks (Jain *et al.*, 2010). Concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) in groundwater samples were significantly higher in the wells located in the west of Jazan province (wells N^o: 9, 11, 18, 21 and 22; table 1) than in other areas due to the rain flow direction from east to west in the mountainous areas of Jazan region.

Anion chemistry

The major anions having highest concentrations (all >1 mg/l) present in majority of groundwater are bicarbonate, sulfate and chloride (Younger, 2007). The concentrations of various anions analyzed in groundwater samples are presented in Table (1). The concentrations of chloride were lows in all groundwater samples, whereas the contents of sulfate were high. Chloride originates from sodium chloride which gets dissolved in water from rocks and soil. Sodium chloride has a little effect on the drinking suitability of water unless it is present in such concentrations as to make the water non-potable or corrosive. The chloride concentrations ranged from 24.85 to 248.50 mg/l (mean, 107.99) which is below the permissible limit of 250 mg/l (WHO, 2011), these results are in accord with data reported by Oiste (2014). The sulfate in groundwater generally presents as calcium, magnesium, and sodium soluble salts. Significant change in the sulfate concentration takes place with time during rainfall infiltration and groundwater recharge (Jain *et al.,* 2010). The sulfate concentrations in the samples varied from 5.00 to 200.00 mg/l (mean, 85.87 mg/l) which is below the permissible limit of 500 mg/l (WHO, 2011) and GSO.

Table 1: Physical and chemical characteristics of groundwater samples in Jazan region, Saudi Arabia.

Well No	PH	TDS	Turb.	Hard.	Alka.	Ca^{2+}	Mg^{2+}	NH_3	NO_2^-	NO_3^-	SO_4^{-2}	Cl^-	Fe^{2+}	F^-
1	7.5	308	3.17	202	70	141	61	0.11	0.029	4.9	45	46.15	0.50	0
2	7.4	437	0.76	218	40	119	99	0.21	0.051	11.8	58	86.3	0.11	0.31
3	7.4	448	1.58	224	40	118	106	0.13	0.032	16.6	62	86.26	0.18	0.46
4	7.3	670	0.49	430	40	170	260	0.02	0.030	4.5	142.5	216.5	0.02	0
5	7.7	105	0.71	47	20	31	16	0.12	0.030	3.8	30	30.17	0.08	0
6	7.3	800	1.22	398	70	210	188	0.02	0.003	7	105	185	0.11	0.38
7	7.4	422	0.29	213	40	190	23	0.09	0.190	11.5	70	70.29	0.09	1.16
8	7.7	104	0.68	49	25	32	17	0.10	0.020	3.4	27.5	28.4	0.09	0
9	7.6	650	0.34	344	40	197	147	0.08	0.058	13.4	147.5	113.6	0.03	1.19
10	7.5	750	7.79	309	65	170	139	0.02	0.030	62.4	140	97.24	0.41	0.09
11	7.4	509	0.78	284	40	221	63	0.06	0.031	4	60	134.9	0.06	0.34
12	7.7	105	0.71	51	25	34	17	0.11	0.020	3.8	30	24.85	0.09	0
13	7.6	483	0.62	178	20	102	76	0.01	0.020	0.8	40	145.5	0.01	0
14	7.2	342	0.59	210	20	136	74	0.16	0.013	3.2	72.5	110	0.03	0.32
15	7.6	381	1.18	171	40	86	85	0.19	0.020	5.6	67.5	67.45	0.06	0.01
16	7.6	337	0.7	190	110	169	21	0.14	0.024	4.6	82.5	75.97	0.03	0.48
17	7.6	367	0.67	166	40	79	87	0.12	0.030	7.2	65	74.55	0.05	0.01
18	7.3	731	0.65	490	40	360	130	0.05	0.015	8.6	195	168	0.06	0.7
19	7.6	423	0.3	209	30	114	95	0.08	0.053	6	75	106	0.03	0.28
20	7.2	750	41	390	90	188	210	0.10	0.060	11.5	200	248.5	0.18	0.12
21	6.8	642	0.47	475	50	290	185	0.07	0.033	3.0	105	82.7	0.10	0.06
22	7.4	930	0.4	425	50	303	122	0.13	0.088	14	150	242.8	0.03	1.3
23	6.7	186	3.96	109	40	67	42	0.07	0.007	2.5	5	42.6	0.12	0.03
Mean	7.4	473	3.0	351.4	45.4	153.4	98.4	0.10	0.040	9.3	85.9	108	0.11	0.31
Median	7.4	437	0.7	213	40	141	87	0.10	0.030	5.6	70	86.3	0.08	0.12
Std. Dev	0.26	235	8.45	134.5	22.5	86.7	67	0.05	0.040	12.3	53.5	66	0.12	0.41

The nitrate concentrations ranged from 0.80 to 62.40 mg/l (mean, 9.31mg/l), its concentration was acceptable in all samples (<50 mg/l; WHO, 2011) except in the water of one well (Nº 10, table 1) with a high value of 62.4 mg/l. The high concentration of nitrate in this location might be due either to a leak in the sewage tanks around the well (absence of complete pipes sewage system in this area), or contamination by chemical fertilizers contain nitrogen. Wastewater represents one of the most important sources of contamination of groundwater with nitrate, especially when sewerage system is not available (Kim *et al*, 2015; Al-Ariqi & Abduljalil, 2010). Pollution of groundwater with nitrate is a worldwide problem, which could limit the water supply and increase health risk at high concentrations (Hernández-Espriú *et al.,* 2013). Nitrate concentration >50 mg/l in drinking water has adverse health effects on human resulting methemoglobinemia commonly known as blue baby syndrome which generally affects the infants (Jain *et al.,* 2010) and gastric carcinoma (Tank and Chandel, 2010). Iron concentrations (Fe^{2+}) ranged from 0.01 to 0.50 mg/l (mean, 0.11mg/l), its concentration was acceptable in all samples (<50 mg/l; WHO, 2011). Fluoride (F^-) is inorganic element present in the subsurface depending on the geology of the region. In this study, chemical analysis showed no significant difference for fluoride concentration in all samples. Fluoride concentrations ranged from 0 to 1.30 mg/l with an average of 0.31mg/l which is below the maximum recommended concentration of 1.5 mg/l (WHO, 2011). This result conforms to other results reported by (Jain *et al.,* 2010; Kim *et al.,* 2015).

Correlation analysis

The correlation analysis of the analyzed parameters was performed and the correlation coefficient is presented by correlation matrix in Table 2. TDS and hardness showed significantly positive correlations among themselves and also with SO_4^{-2}, Cl^-, Mg^{2+}, and Ca^{2+}. The high correlation between TDS and hardness is due to the fact that hardness depends on total dissolved solids and the main constituents of TDS in water are these ionic species (Milovanovic, 2007; Jain et al, 2010). Otherwise, fluoride was not significantly correlated with any of the studied parameters except nitrite (Table 2). Calcium and magnesium were positively and significantly correlated with Cl^- and SO_4^{-2}. Furthermore, SO_4^{-2} was positively and significantly correlation with Cl^-.

Table 2: Correlation matrix for physical and chemical parameters of groundwater samples in Jazan region, Saudi Arabia

	PH	**TDS**	**Turb.**	**Hard.**	**Alka.**	**Ca^{2+}**	**Mg^{2+}**	**NH_3**	**NO_2^-**	**NO_3^-**	**SO_4^{-2}**	**Cl^-**	**Fe^{2+}**	**F^-**
PH	**1**													
TDS	-0.27	**1.00**												
Turb.	-0.21	0.27	**1.00**											
Hard.	-0.44	**0.92**	0.21	**1.00**										
Alka.	-0.14	0.38	0.48	0.36	**1.00**									
Ca^2	-0.40	**0.82**	0.07	**0.91**	0.36	**1.00**								
Mg^{2+}	-0.38	**0.80**	0.36	**0.84**	0.27	0.53	**1.00**							
NH_3	0.19	-0.38	-0.03	-0.38	-0.02	-0.29	-0.39	**1.00**						
NO_2^-	0.06	0.18	0.08	0.11	0.02	0.23	-0.08	0.10	**1.00**					
NO_3^-	0.09	0.40	0.19	0.21	0.25	0.16	0.22	-0.20	0.13	**1.00**				

SO_4^{-2}	-0.16	**0.85**	0.46	**0.86**	0.42	**0.76**	**0.75**	-0.27	0.16	0.37	**1.00**			
Cl^-	-0.23	**0.85**	0.42	**0.78**	0.29	**0.64**	**0.75**	-0.34	0.11	0.08	**0.78**	**1.00**		
Fe^{2+}	-0.04	0.02	0.28	-0.02	0.37	-0.04	0.02	-0.08	-0.05	0.54	0.00	-0.20	**1.00**	
F^-	0.02	0.46	-0.16	0.39	0.09	0.58	0.04	0.07	**0.64**	0.12	0.42	0.33	-0.26	**1.00**

Bold faced values are significant at 0.01 level

Conclusion

Groundwater represents the sole source of drinking water supply in Jazan region, Saudi Arabia. The absence of a complete piped sewage system and the relatively high agricultural activities in this area might present a potential risk of contamination of groundwater. In the present work 23 wells representing Jazan area were selected to define their suitability as drinking water resources in fall 2014. Our results showed that groundwater of all investigated wells were considered suitable for drinking and domestic uses based on the comparison of our results with the standards of the WHO and GSO. However, the concentration of nitrate was above the acceptable limit of 50 mg/l in only one well (N° 10) which should be avoided as drinking water resource, and might be used safely in irrigation. On the other hand, a regular monitoring should be ensured by the concerned authorities. Water supplies and sanitation are crucial to the water sustainability development of Jazan region, and a special attention should be paid to the concentration of TDS and nitrate in groundwater in future studies.

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SESSION 9: WASTEWATER MANAGEMENT

Keynote

Wastewater Recycling and Reuse Practices in the Arab Region: Situations and Perspectives

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Abstract
Treated wastewater has to be reclassified as a renewable water resource rather than waste. It will contribute in augmenting water availability, and at the same time in preventing environmental pollution. More than 85% of the water withdrawn in Arab countries is consumed by agriculture and only 11% by municipal and industrial uses. The alleviation of water scarcity implies the reallocation of freshwater from agricultural to domestic and industrial uses. Demographic growth and economic and social development across Arab countries have contributed considerably to significant increases in water demand and consumption. The total volume of wastewater generated by the domestic and industrial sectors in the Arab region is more than 12 km^3/year, 60% of which are reported to undergo treatment and less than 30% is reused. With the overall objective of securing long-term water supplies while meeting strict criteria for socio-economic, financial and environmental sustainability and public health, there is an urgent need to review water policies of Arab countries, and focus on water conservation and demand management.

Water demand management means that wastewater should be viewed as a resource, and advocates its reuse, after appropriate treatment, in several activities such as crop production, irrigating green spaces and golf courses, groundwater recharge, industrial cooling and domestic cleaning. Exploring water reuse is a smart move. Policymakers have long looked to science to address water shortages, and farmers and Municipalities have long recognized the value of recycled water.

The relative failure to expand reuse in Arab region can be linked to incentive problems in wastewater management. The analysis shows that a variety of constraints inhibit formal reuse of wastewater in the Arab region, including problems related to the cost of reuse, problems associated with low demand for reclaimed wastewater in certain states, the widespread lack of effective price signals and cost recovery in the water sector, and challenges in structuring the financing of reuse.

Treated wastewater resources are valuable in poor Arab countries. However, the associated health and environmental risks mean that the use of untreated or inadequately treated wastewater will need to be curtailed. The cost of treating wastewater in these countries could be more attractive than the option of developing new supplies for different water-use sectors. In addition, wastewater treatment will also lead to gains in terms of environmental conservation. However, because governments allocate few funds to wastewater treatment and with private sector involvement lacking, it will be extremely difficult to enforce the treatment of all the wastewater generated in resource-poor Arab countries. Therefore, steps must be taken to maximize the benefits and minimize the risks involved in wastewater use in agriculture.

In Most North African countries, the absence of strong government enforcement or regulation of wastewater discharges, and do not take account of the externalities associated with wastewater conveyance investments and treatment. Upstream users have little incentive to treat wastewater discharges which pollute downstream water supplies, compromising the ability of downstream locations to use recycled wastewater safely and effectively.

GCC countries have always spearheaded the implementation of advanced technologies and practices to create a more sustainable environment and drive economic growth. As we look toward regulations for recycled treated wastewater, theses states particularly Kuwait and United Arab Emirates have the opportunity to lead once again the reuse of treated wastewaters in agriculture

There is a number of actions that Arab countries can pursue to improve its prospects of reusing treated wastewater. These include improving cost recovery by raising water tariffs, extending wastewater management and treatment, and pursuing targeted or national reuse opportunities that are appropriate given the existing levels of development and sustainability in the sector. National policies for reuse will do little good as long as economic incentives and financing constraints are aligned against them.

Several Arab countries approved in their national water strategy that recycling water must be promoted on a national scale within the framework of an integrated water resources management. This paper identifies the main institutional and regulatory constraints hindering the reuse of recycled water on a national scale; it investigates the major issues inhibiting reclaimed water reuse; it explores techniques and methods on how to improve wastewater reuse; it provides recommendations for promoting this activity, with an emphasis on the fruitful role that public-private partnerships can play in this context. Efforts to promote recycled water reuse in agriculture are sometimes met with reluctance by farmers and the general population. Good communication and awareness campaigns for farmers about the use of this resource and the related health issues will hopefully encourage them to become more involved in recycled water reuse.

Keywords: Treated Wastewater, Reuse, Water Demand Management, Water Regulation, Arab Region.

Keynote

The Unified Water Sector Strategy for the GCC Countries for the Years 2015-2035: the Sanitary Wastewater and its Role in Sustainable Development

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KSU

Abstract
The Gulf Cooperation Council (GCC) Countries are located in area of more severe desertification and drier regions of the world, characterized by a lack of rainfall, high evaporation rates, and the lack of ongoing rivers and freshwater lakes. Recognizing the importance of the water sector to achieve sustainable development for the GCC countries, their Majesties and Highnesses, members of the Supreme Council of the Cooperation Council for the Arab Gulf States, directed the establishment of a unified long-term comprehensive water strategy, in the fourteenth consultative meeting, which was held on May 14, 2012 in Saudi Arabia, Riyadh. The unified water strategy (UWS) was then approved by the Supreme Council in 2016 at the 37th session held in Manama, Bahrain.

Sanitary wastewater constitutes an increasing water source driven by escalating water consumption in urban areas, and is one of untraditional water resources that the UWS considers. Despite the fact that all the GCC countries have provided commendable rates for sanitation services and are operating modern treatment facilities with tertiary and advanced treatment capabilities, the reuse potential of the generated wastewater is not fully developed. The collected wastewater on average in the GCC countries does not exceed 50% of the total domestic water volumes, and the reuse rates are less than 40% of the treated wastewater volumes.

The UWS defines a strategic objective tackling the wastewater sector: "To Maximize Municipal Wastewater Collection, Upgrade Treatment and Increase Economic and Safe Use of Treated Wastewater and Sludge". A detailed integrated implementation plan of the UWS is developed based on the identification of inter-linkages and dependence of the policies within each strategic objective and with other strategic objectives' policies. The developed plan shows the policies, programs and activities against their timelines and associated indicators and key performance indicators (KPIs), as well as the responsible parties (office of strategy management OSM, and country office of strategy management COSM) for the key strategic objectives. Moreover, milestones and targets for each KPI have been set to track future implementation progress and to monitor the success of the GCC UWS implementation with the base line established for the year 2015.

Keywords: The Gulf Cooperation Council (GCC), Unified Water Strategy (UWS), Wastewater Reuse, Implementation Plan, Sustainable Development.

Keynote

The Role of Treated Wastewater Reuse in Water Sustainability in GCC Countries

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Abstract
Gulf Cooperation Council (GCC) countries faces the challenges of freshwater resources scarcity which pose severe constraints on economic, social and environmental development. There are no available permanent surface water bodies and the over-pumping of non-renewable groundwater has resulted in lowering the groundwater table, increase its salinity, depletion, and ecological degradation. In the last three decades GCC countries have witnessed growing water demand which lead to investment more in non-conventional water resources including desalination and wastewater treatment and reuse. This looming crisis, groundwater depletion, and desalination costs have prompted many governments to seek a more efficient reuse of treated wastewater resources to help developing interventions to narrow the gaps between supply and demand in the region. The six GCC occupy a total land area of 2.7 million km², with a combined population over 50 million in 2014. The total water uses in GCC is about 35,100 million cubic meters, out of them over 27,800 million cubic meter is from nonrenewable aquifers, 5,100 from desalination and only 2,200 from treated wastewater. The total present (2015) production of treated wastewater 4,000 million cubic meter and it is increased by 11% annually. The predicted production of treated wastewater will be about 17,000 million cubic meters by 2030. Treated wastewater reuse is believed to be one potential intervention strategy for developing nonconventional water resources. Therefore, the extended reuse of treated wastewater for irrigation and other purposes could contribute considerably to the reduction of freshwater stress and water scarcity in the region as part of an Integrated Water Resources Management (IWRM) approach. For this to be achieved, political will, sound policies, strategies, regulatory framework, financed plans of action and cooperation platforms are urgently needed and extremely essential parameters for future success. Risks due to any environmental impacts should be addressed through cost-effective treatment options and alternatives depending on the end users requirements. This paper will analyze the present and future statues of treated wastewater production and reuse and how can help in long term water sustainability in GCC countries and recommend the future way forward.

Keywords: TSE, Waste Water, Water Quality, Water Stress, Groundwater Depletion.

1. Introduction

GCC countries are located in an extremely arid and hyper arid zones with an average annual rainfall ranges from 70 to 140 mm (total annual volume of rainfall is about 209.93 billion cubic meters) except in the coastal zone along the Red Sea in south-western Saudi Arabia and along the gulf of Oman on the eastern shore (rainfall reaches more than 500 mm). However, the annual total evaporation rate ranges from 2500 mm in coastal areas and dramatically increase to center of Saudi Arabia to about 4500 mm (Dawoud, 2007), making it impossible for a perennial surface system water to exist. At present the water demand in GCC countries are met mainly by groundwater with annual abstraction of about 27,850 Million cubic meter (Mcm) (78%) and desalination with an annual production of 5,900 Mcm (16%), and the annual reuse of treated wastewater of about 2,200 Mcm (6%) (Dawoud, 2015) as shown in Figure (1). The water scarcity in GCC countries is mainly being aggravated by:

- Aridity and lack of renewable fresh water resources and permanent freshwater bodies (rivers, lakes …etc.)
- The highest world population growth rates with an annual average of more than 5% with high demand for domestic and food production as shown in Figure (2).
- The historical explanation in the agriculture and forestry sectors (greening policy)
- The high domestic per capita water use (560 l/c/day) compared with worldwide rate of about 180 l/c/day.
- Accelerated socio-economic development

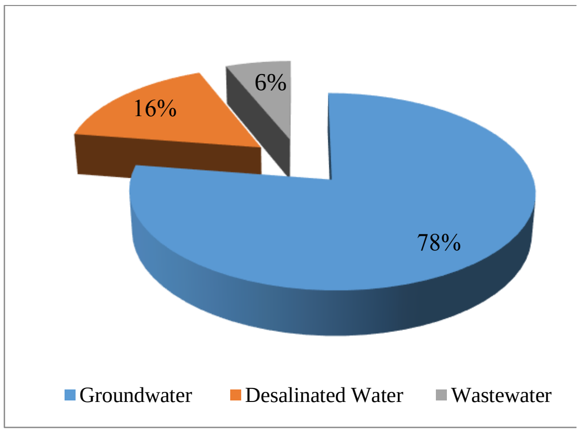

Figure 1: Water resources in GCC countries (2015)

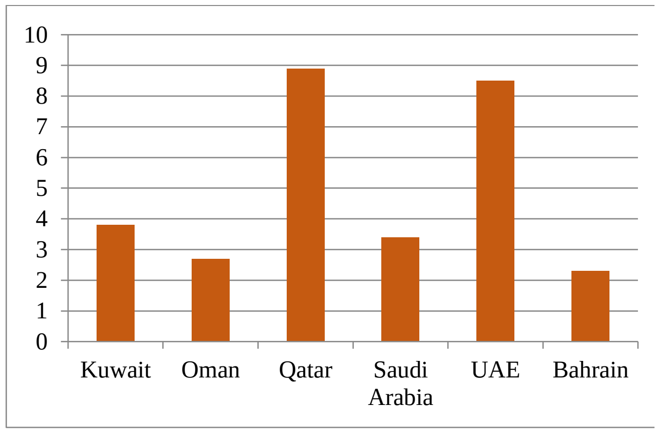

Figure 2: Population growth rate in GCC Countries (2015)

GCC are facing the most severe water shortages in the world. However, the scarcity of renewable water resources is not the only distinctive characteristic of the region, inadequate levels of management and the continuous deterioration of its natural water resources have become during the past few decades equally distinguishing features as well (Al-Zubari, 2008). In the last three decades, water demand in GCC countries increased from less than 5,000 Mcm in 1970 to about 35100 Mcm in 2015. These demands have been driven mainly by agricultural consumptions (agriculture consumes about 78% of the total water use in the region), and by rapid urban expansion (14%). Currently, groundwater aquifers are being over-exploited to meet agricultural and irrigation demands, with continuous deterioration in terms of quantity and quality. In most of GCC countries, unplanned groundwater abstraction and use continues without a clear "exit" strategy. To meet domestic freshwater supply requirements in terms of quality and quantity, GCC countries have turned to desalination since min of 60s in the last century and become collectively the world leaders in desalination productions and capacities, with more than 60% of the world capacity. Desalination technologies improved recently to minimize the cost and energy consumption; however, it needs costly capital investments with negative environmental impacts (Dawoud and Al Mulla, 2012) as shown in Figure (3). In 1990 the annual GCC countries desalinated water production was 1,557 Mcm with a daily rate of about 4.26 Mcm or per capita 30 liters a day at the national average (ESCWA, 2001). In 1995 the total annual desalinated water capacity was about 2012 MCM with a total produced water of about 1548 MCM as shown in Table (1) and Figure (4). In order to meet domestic water demands, which is a function of population and urbanization growth, the GCC countries are going ahead with desalination plants construction, despite their relatively enormous costs, which range between 1-1.5 US$/$m^3$. The total annual desalination capacity of the GCC countries at present (2002) is about 2850 Mcm. MSF are sued seawater and dominates the desalination market by more than 74%. RO is sued mainly for brackish groundwater treatment. A growing trend is toward the application of RO in the desalting of sweater due to the advanced development in membrane technology. Limited numbers of MED plants are used.

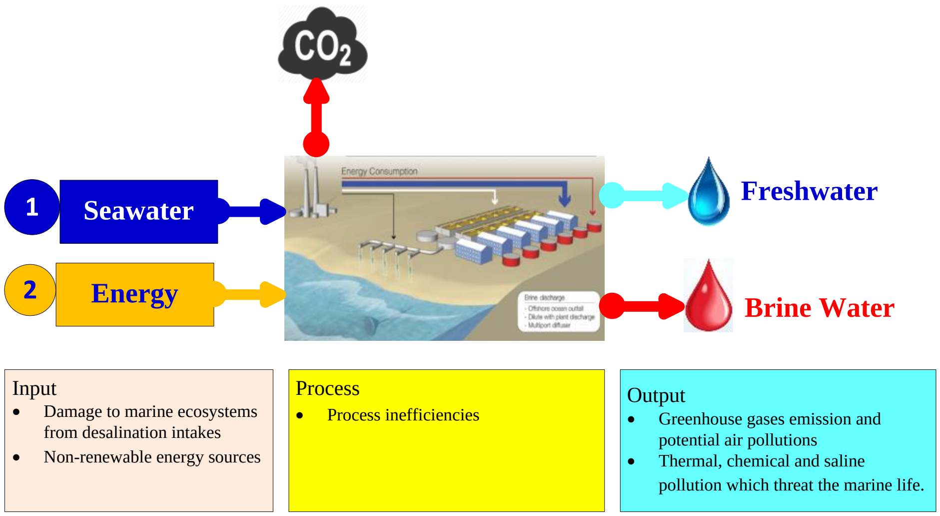

Figure 3: Desalination inputs, outputs and environmental impacts

Table 1: desalination production in GCC countries

Year	Saudi Arabia	UAE	Kuwait	Qatar	Bahrain	Oman	Total
2000	1500	773	476	189	141	71	3151
2005	1624	1243	521	239	148	105	3879
2010	2134	1777	704	390	244	168	5417
2015	2500	1850	750	390	244	168	5902

Desalination industry is a capital intensive project that requires optimization of factors to limit on the cost of the product. Those technologies with lower operation cost (Opex?) options always tend to be responsive to both the operating skills and the quality of the raw material (feed water). Capex is a function of the quality of the raw material, "production capacity, required infrastructure, plant efficiency, material selection and other location factors (Dawoud et al., 2006). For majority plants, the Capex always ranges between $1000 and $2000 per cubic meters. Both the Capex and Opex are vital in determining the final cost of water. Also, the unit (fresh cubic meter produced by desalination) cost is dependent on the technology which is proportional to the cost of oil. At present the average unit cost is about $1.45 in GCC Countries. The capital investment in the desalination sector in GCC countries was estimated to be about $16.0 billion during the last two decades and the estimated needed future investment will be about $60 billion by 2050.

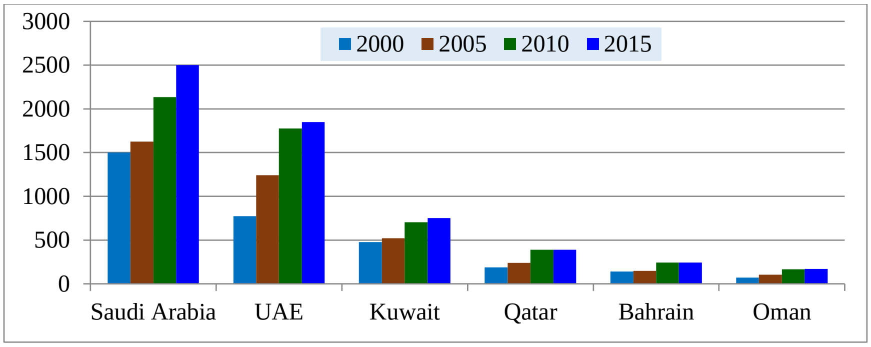

Figure 4: Development in desalination production in GCC countries (2000-2015)

In terms of wastewater recycling, available treated wastewaters are still not being reused to their potential and planning for full utilization of treated effluent is in the early stages. Introduced in the early eighties in most of the GCC countries, treated wastewater represents one of the most important alternatives that can be used to meet some of the present water requirements and to lessen the long term supply vs. demand imbalance faced by these countries. Due to completion of sewage water treatment facilities and urban sewage networks expansion in most of the GCC large cities, relatively large volumes of treated wastewater have become available, and because of environmental considerations, wastewater have been treated completely or partially regardless of its utilization. Some of the issues encountered in wastewater treatment and usage in some GCC countries are the low rate of wastewater treatment due to the limited sewage network coverage (around 60% in the main metropolitan areas) as a result of the rapid rate of population growth; treatment capacity constraints in the major urban centers that require high investment costs; and the high proportion of wastewater that is treated but not used (Al Zubari, 2002).

Table (2) displays the current treated volumes of wastewater produced and the reused volumes in the GCC Countries. At present, all the six countries are operating modern treatment facilities with tertiary and advanced treatment capabilities. The total annual designed treatment capacity of the major facilities is more than 2,400 Mcm, with a present total annual treated wastewater volume of more than 2,034 Mcm as shown in Table (2). The planed future production by 2050 will be about 3,035 Mcm. However, the present annual recycled volumes of these waters are about 1100 Mcm, which represents less than 54% of the total produced treated wastewater. In most of the countries, the remaining unused waters are discharged to environment (desert or sea). Recycling is used mainly in urban uses (irrigating gardens, roads ornamentals, etc.), fodder crops irrigation, and highways landscaping. In the GCC countries, more than one third of treated wastewater is used to irrigate non-edible crops and fodder as well as for landscaping (Choukr-Allah 2010). To reach zero discharge with full utilization of all produced treated wastewater, capital investment in building the main transmission infrastructures (pipes, pumping station and storage tanks) and distribution networks with an estimated cost of about $2,243 million is needed as shown in Table (3). The estimated cost for annual operation and maintenance cost is about 10% of the Capx with a value of $224 million.

Table 2: Treated wastewater production and use in GCC countries

Country	**TSE Production (Mcm)**			**Reused**	**Discharge to Environment**
	2010	**2015**	**Future Planed Capacity (2020)**	**2015**	**2015**
Bahrain	81	102	150	31	72

Kuwait	254	290	420	189	102
Oman	39	84	125	67	17
Qatar	104	160	230	64	96
Saudi Arabia	712	812	1,200	487	325
UAE	352	587	900	264	323
Total	1,542	2,034	3,025	1,101	933

Table 3: Estimated cost to fully utilize TSE in GCC countries

Country	**TSE Production Volumes 2015 (Mcm)**	**Estimated Cost for 100% Utilization (million $)**
Bahrain	102	113
Kuwait	290	320
Oman	84	93
Qatar	160	176
Saudi Arabia	812	895
UAE	587	647
Total	2,034	2,243

2. Sustainable Option for Reusing TSE in GCC Countries

The present uncontrolled TSE discharge to the environment in the GCC countries constitutes one of the most serious threats to the scarce freshwater in the region contributes to global warming. With increasing population and economic growth, treatment and reuse of wastewater is essential to preserve public health and reduce intolerable levels of environmental degradation. In addition, adequate wastewater management is also required for preventing contamination of water bodies for the purpose of preserving the sources of clean water. Effective wastewater management is well established in developed countries but is still limited in developing countries. In most developing countries, many people lack access to water and sanitation services..

Reuse of treated wastewater offers many environmental and economic advantages to arid Arab countries. Options for re-using tread wastewater are manifold, dynamic and strongly depend on a country's economic structure. To reuse the treated wastewater in GCC countries two planning approaches are applied at present (Figure (5)):

- The proposed reuse option determines the water quality needed and thus the treatment technology which should be used. This future oriented approach allows planners a broader treated wastewater management master plan and gives more flexibility for the reuse.
- The existing treatment plants treatment levels and the produced effluent quality define the possible reuse options. Unfortunately, this pragmatic approach is widespread in Arab region, but considerably limits reuse options and the development of any other future reuse options.

The reuse of treated wastewater could play an important role in the GCC countries' water resources management. Present gap between water demands and available freshwater resources is a driving force to consider treated wastewater as an integral part of GCC countries water resources management and plans. GCC countries recycle no more than 54 % of their total produced treated wastewater, which contributes 4.2% of their total water supply, being used mainly for landscaping, afforested areas, fodder crop irrigation, and some industrial uses. However, major plans for water recycling exist in most of these countries. The main handicaps for reuse expansion are both social (psychological repugnance and religion) and technical (microbiological pollutants, potential heavy metals accumulation in irrigated soil, and industrial waste mixing). If all collected wastewater are treated and recycled, recycled waters have the potential to meet more than 11% of the GCC countries total water demands, and this could satisfy more than 14 % of their agricultural sector demands, and reduce fossil groundwater withdrawal by more than 15 % by the year 2020 (Al-Zubari 1997). There are a variety of possible promising options for treated wastewater reuse in Arab countries such as:

2.1 Reuse in Agriculture and Food Production

With the increasing scarcity of renewable freshwater resources in arid and semi-arid regions, and growing needs for food production to meet the demand for expanding populations, intention is being given to reuse wastewater as an important fresh water resource that can be used for irrigation. Irrigation water use is about 80% out of the total water uses in GCC region and wastewater reuse can play an important role into some national water resources management plans in the region (Al Zubari, 2013).

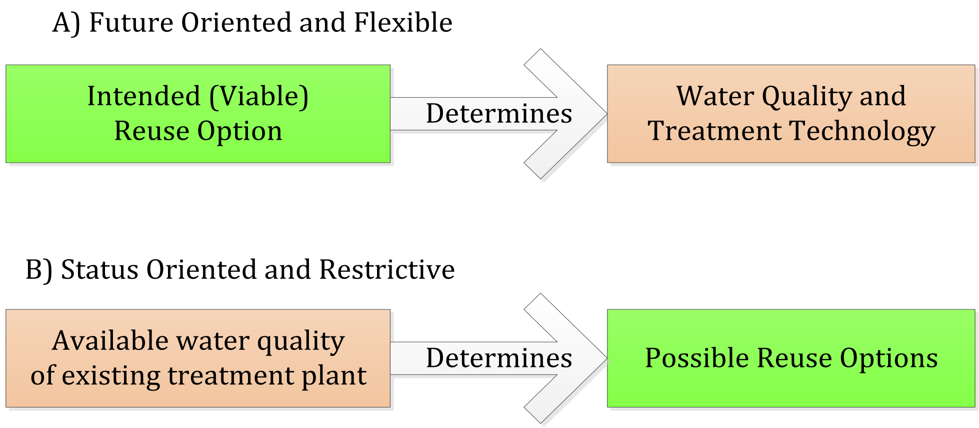

Figure 5: Two approaches for planning and reusing treated wastewater

When considering wastewater reuse for irrigation, an evaluation of the advantages, disadvantages and possible risks has to be made. The advantages include improvement of the economic efficiency of investments in wastewater disposal and irrigation, conservation of freshwater sources and use of the nutrients of the wastewater (e.g., nitrogen and phosphate). Wastewater is normally produced continuously throughout the year, whereas irrigation is mostly limited to the growing season. At present, experiments has shown that the use of treated wastewater in Saudi Arabia as a supplemental irrigation has increased crop production, water use and nitrogen use efficiencies. The use of treated wastewater can save up to 50 % of applied inorganic nitrogen fertilizer if treated wastewater contains 40 mg per liter (Hussain and A-Saati 1999). Many different methods are used by farmers to irrigate crops with treated wastewater. These range from watering individual plants from a can of water to highly automated irrigation by a center pivot system. The success of the irrigation with wastewater is safe when the national regulations for each country regarding its treatment and use are strictly followed and the irrigation method and technology were selected carefully. After irrigation, the wastewater returned to the environment usually will be with higher quality than the wastewater produced by the treatment plants due to the additional treatment provided by the soil through the natural occurring physical, biological and chemical processes. Also, reuse of wastewater for irrigation is considered as an economic and environmental solution for wastewater discharge/disposal option.

For the selection of the most suitable irrigation methods with treated wastewater, many criteria should be considered (Figure 6).

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Box 1: Reuse of Treated Wastewater in Forage Production in Oman

Oman started a research project for reusing treated wastewater in irrigation of different crops, especially forage crops. It has implemented a series of experiments for the use of tertiary treated wastewater on forage crops like barley, maize and sorghum in different seasons (winter and summer) as well as analysis of soil and irrigation treated wastewater for pH, salinity and micro-elements or heavy elements to find out their suitability for animal feeding which will be reflected on human nutrition and health. To ascertain these results and the awareness of the farmers, a joint 'Pilot Project' for reuse of tertiary treated wastewater at Saham Sewage Treatment Plant (STP) was started. The objectives of the project were mainly to take advantage of the quantities of treated wastewater and areas for cultivation and production of seasonal forage crops. Other objectives included evaluation of forage crops for winter and summer cultivation (sorghum, maize, barley). The total area of the site selected was 8 Feddans (1 Feddan = 4,200 m^2). The production of treated effluent of SahamSTP was estimated to be about 200m^3/day. Three cross-sections were selected for soil sampling at the site to examine soil suitability for cultivation. Three crops namely Barley (Hordeum vulagare L.), sorghum (Sorghum bicolor L.) and maize (Zea mays L.) were selected for growing in crop-rotation as fodder crops at appropriate layouts. The economic analysis was carried out on the basis of information made available on input costs, output yield per crop per season and response on sale prices consulted through main fodder markets. With certain assumptions, the economic indicators were worked out for testing the feasibility/ viability of the project and on this basis it was safe to conclude that the project indicated strong economic viability. The practices followed for cultivation, scale of operation and farm management were the critical parameters for obtaining successful results in considering the commercial application of such experimentation. From the above results it can concluded that the forage yield of sorghum and maize was increased by 30% under treated wastewater irrigation in comparison with that using fresh water whereas this increase was 43% in barley crop. The encouraging results of the pilot project directly provided prudent guidelines for sustainable growth of agriculture on reusing treated wastewater for selected crops namely barley, sorghum and maize crops in rotation whose economic analysis showed the positive results indicating the economic viability of the project with average IRR (Internal Rate of Return) as 26%. An average payback period as 2.6 years endorsing the economic viability of the project (MAF 2011).

2.2 Environmental and Recreational Uses

Treated wastewater can be used for many non-potable purposes such as decorative water features (fountains), dust control, and fire protection. Irrigation of landscapes, parks, amenity plantations, road verges, maintenance of natural hydrological regimes and golf courses can also be of potential uses. It also can be used to create manmade wetlands, enhance existing natural wetlands, and sustain or augment stream flows. At present about 40% of treated waste water is used in some Arab countries for environmental and recreational uses such as UAE, Kuwait and Qatar.

Under normal conditions, the following factors should be considred during the selction of any irrigation method:	Other factors that should be carefully considered for the irrigation with treated wastewater (in addition to normal conditions factors)
• Water supply conditions • Climate Conditions • Soil Characteristics • Cost of Irrigation Method • Type of Crops • System operation and management	• Wastewater Quality • Health Risk (Farm Workers) • Protection of Soil and Groundwater • Salinity and Toxicity Hazards • O&M cost • Water application

Figure 6: Selection criteria for irrigation method with treated wastewater

2.3 Industrial

Treated wastewater reuse in the industrial sector is another potential option. Industrial facilities can use treated wastewater for cooling system make-up water, boiler-feed water, process water, and general wash down uses. It can also be used for road maintenance and concrete production in the construction projects. Industrial reuse proposes depend on the effluent quality and in some cases it may require additional treatment.

2.4 District Cooling

At present a huge amount of fresh water –mainly desalination- is used for district cooling in many Arab countries specially GCC countries. District cooling in residential areas could be an optional application for wastewater use in these countries. The used desalination water in district cooling is costly and the economic factor could play an important role for increasing the tertiary treated wastewater in cooling in the future.

2.5 Groundwater Aquifer Recharge

Due to the over abstraction from non-renewable groundwater aquifer systems in many GCC countries, groundwater was deteriorated and depleted in the last two decades. Groundwater recharge with treated wastewater could help to replenish and conserve these aquifer systems from getting dry and keep them used for non-potable uses. Groundwater aquifers artificial recharge with treated wastewater presents a wide range of economical, technical and health challenges that must be carefully assessed and evaluated before starting any project. Some basic challenges that need to be addressed include but not limited to:

- Quality of treated wastewater and its suitability to be injected into the aquifer system.
- Economic aspects (comparing direct reuse with aquifer recharge)
- Quality of the native groundwater and how does wastewater quality change during infiltration into groundwater aquifer unsaturated zone
- Available treatment processes and if there is any additional treatment needed.
- Distance between available produced treated wastewater and the suitable aquifer for recharge
- Aquifer layers and their hydraulic parameters
- Health risk issues
- Existing groundwater recharge, abstraction and use regulations
- Potential environmental impacts

Treated wastewater reuse brings a number of challenges regarding which contaminants must be removed and to what extent the quality of the treated wastewater should be in each case, considering local environmental conditions, economical factors, scientific knowledge, legislations and regulations and requirements. The treated wastewater reuse requires proper planned strategies that incorporate multiple factors and measures to minimize technical, public health and environmental risks. This means that combinations of source control, users' conditions, treatment processes, flow schemes and other engineering factors should be the basis for reclaimed wastewater reuse (Asano and Levine, 1996). Many factors still prevent the increase in reusing treated wastewater including economic, environmental, technical, social, regulatory, institutional and political constraints. Social and public acceptance for reusing of treated wastewater is an important factor. Awareness and education programs are needed also to improve the public acceptance and attitude towards wastewater reuse. Policies, strategies, monitoring and regulatory framework are needed for better wastewater treatment and management in the Arab region to protect human health and environment.

When irrigation is practiced, even though the water quality and conveyance requirements are met, chemical constituents in recycled water should not result in any soil or groundwater quality degradation. Attention should be paid to salinity and nitrate leaching, to pharmaceutically active chemicals, endocrine disrupters, etc. Scheduling of irrigation based on crop water requirements, soil water holding capacity and recycled water quality will prevent groundwater contamination. Selection of crops with high nitrogen requirements will reduce aquifer contamination by nitrates. The success of water reuse projects, and in particular, irrigation with recycled water, depends greatly on good management practices. These are a combination of:

- Policy and institutional measures: the regulatory framework, which is an essential step for the development and social acceptance of water reuse.
- Engineering initiatives: enhancement of water quality, improvement of water use efficiency and removal of polluted water, and
- Agronomic practices: appropriate choice of crops and species that can help to manage water scarcity and salinity, soil fertilization, leveling or amendments that could further improve crop production.
- Finally, the involvement of end users (i.e. farmers) in the management of water reuse systems is essential for project success and efficiency.

For proper selection of appropriate reuse technology, an integrated approach is required, where technological, economical, legal, social, environmental and institutional aspects are considered. While technological and legal issues might be easier to identify and tackle, special attention should be given to market assessment for reuse options and to public acceptance of reuse. The selection process should involve the following steps:

- Inventory of potential sources and demand for wastewater
- Identification of legal requirements and responsible institutions
- Detailed analysis of reuse alternatives
- Economic evaluation
- Financial feasibility check

The process leads from a very broad assessment of potential supply and demand for wastewater to a more detailed evaluation of related benefits and risks and assessment of costs. Table (4) summarizes risks to be considered when selecting reuse applications (Metcalf and Eddy, 1991). Detailed surveys of the local situation will be required to assess actual risks and constraints, and to select the most appropriate technology and applicable risk prevention measures. In the next step, these risks will be compared with the benefits linked with the specific application of wastewater reuse. Many factors decide on viability of reuse projects because such projects require the establishment or adjustment of existing infrastructure, change in water use habits, etc. In order to decide on viability of reuse projects, a more detailed evaluation of applications should cover suitability of soils and crops, environmental and health risks, need for additional infrastructure and public acceptance of reuse.

Table 4: Categories of wastewater reuse and potential constraints

Agriculture and landscape irrigation	
Crop irrigation	Surface-and groundwater pollution, if not properly managed
Commercial nurseries	Marketability of crops and public acceptance
Park/school yards	Effect of water quality, particularly salts, on soils, grasses and crops
Freeways (median strips) courses, Cemeteries Greenbelts, and Residential areas	Public health concerns related to pathogens (bacteria, viruses Golf and parasites)
Industrial recycling and reuse	
Cooling boiler feed	Constituents in reclaimed wastewater cause scaling, corrosion, biological growth and fouling
Pathogens in cooling water	Public health concerns, particularly aerosol transmission of processed water
Groundwater recharge	
Groundwater replenishment and salt water intrusion control	Organic chemicals in reclaimed wastewater and their toxicological effects
Subsidence control	Total dissolved solids, nitrates and pathogens in reclaimed water
Recreational/environmental uses	
Lakes and ponds	Health concerns from bacteria and viruses
Marsh enhancement and stream flow augmentation	Eutrophication due to nitrogen and phosphorus in receiving water
Fisheries	Toxicity to aquatic life
Non-potable urban uses	
Fire protection	Public health concerns on pathogens transmitted by aerosols
Air conditioning and Toilet flushing	Effects of water quality on scaling, corrosion, biological growth Toilet and fouling
Potable uses	
Blending in water supply	Constituents in reclaimed water, especially trace organic reservoirs chemicals and their toxicological effects
Pipe-to-pipe water supply	Aesthetics and public acceptance
	Health concerns about pathogen transmission, particularly viruses

3. Constraints of Wastewater Reuse in GCC Region

3.1 Wastewater Reuse Costs

Treated wastewater can contribute not only in decreasing the gap between water supply and demand, but also to improve social and economic development. Thus the reuse of treated wastewater could play an important role in GCC countries sustainable development. Several studies claim that the optimal wastewater treatment level is affected by costs, hazards and benefits. So, lowering the wastewater treatment level decreases fertilization costs because of the increased levels of available nutrients left in the water, and irrigation costs decrease if water prices reflects the lower treatment costs. Agricultural yields and prices may decrease according to differences between levels of nutrients needed by crops and those available in wastewater (Alkhamisi and Ahmed, 2014). Wastewater collection, treatment, transfer and distribution for reuse are costly especially when the treatment level is tertiary. All GCC countries lack finances for sustainable operation and maintenance of their wastewater treatment systems. At present there are no wastewater tariff systems and even if they exist, they hardly reflect the costs for wastewater collection and treatment, thus resulting in continuous deterioration and depredation in the collection and treatment facilities. Some of the Arab countries depend on international funds for supporting the operation, maintenance and rehabilitation of existing treatment facilities which are in most cases too old and in bad conditions. Such huge investments should be redirected to build new systems in case the existing systems are better managed by skilled and motivated (well paid) staff. Due to the bad reputation of treated wastewater, end users are reluctant or unwilling to pay for the reuse. In some GCC countries (KSA, UAE, Qatar and Bahrain) end users get the wastewater for free. Kuwait charges farmers very low tariffs which does not cover the real costs. On other hand, the absence of the irrigation water tariffs from traditional sources does not give incentive for wastewater reuse.

8.2 Wastewater Reuse Regulations

Guidelines and standards for treated wastewater reuse from the collection to the reuse are missing in many GCC countries. These regulations are very essential to control and ensure visibility and transparency in the whole wastewater cycle from collection, treatment to reuse. However these regulation and standards will help to protect public health and the environment, but the main factor driving wastewater reuse strategies is the cost of collection, treatment, distribution and monitoring. In many countries, treated wastewater quality does not meet the national standards because an appropriate treatment method is not used or the plants are overloaded. On the other hand, monitoring and evaluation of wastewater reuse systems are irregular and underdeveloped because of weak institutions, a shortage of trained personnel, lack of monitoring equipment and high monitoring costs. Table (5) shows the availability of wastewater treatment and reuse regulations in some selected Arab countries. Most GCC countries established conservatively low risk guidelines for wastewater reuse based on a high technology and high cost approach. However, high standards and high cost technologies do not always guarantee low risk because insufficient operational experience, costs, and maintenance costs, and regulatory control can have adverse effects (Choukr-Allah 2010). Oman standards and regulations of wastewater reuse were established under Ministerial Resolution MD 145/93 which regulates treated wastewater reuse and discharge.

Table 5: Available wastewater treatment and reuse regulations

Country	**Regulation**		**Risk Assessment**	**Monitoring**
	Treatment	**Reuse**		
KSA	Yes	Yes	No	No
Oman	Yes	No	No	No
UAE	Yes	Partially	Partially	Yes
Qatar	Yes	No	No	No
Bahrain	Yes	Yes	No	No
Kuwait	Yes	Partially	Partially	Yes

In the Kingdom of Saudi Arabia, for safe reuse, standards have been established by different institutions to control the quality of the irrigation water. The last legislations in Saudi Arabia were issued by Ministry of Water and Electricity (MWE 2006). Regulations identify two types of irrigations: restricted and unrestricted irrigations which depend mainly on kind of crop. Stringent regulations have been set to meet unrestricted irrigation which is intended for any crop and any type of soil without limitations. The regulations and standards for wastewater reuse in Kuwait were established by Environmental Public Authority (EPA) under Decree No (210) in 2001 which stated the criteria for treated wastewater reuse in terms of maximum allowable (WHO 2006) limits. Abu Dhabi emirate has its own guidelines for wastewater and biosolids, called Recycled Water and Biosolids Regulations 2010 issued by Regulation and Supervision Bureau (RSB). These Regulations aimed to provide a clear legal framework for managing recycled water and biosolids. They ensure the safe, environmentally beneficial and economic management of recycled water and biosolids by Disposal Licensees (RSB 2010).

3.3 Institutional Fragmentation

In many Arab countries responsibilities for collection, treatment, transfer, monitoring and regulating of wastewater are fragmented between many agencies and intuitions which make it very difficult to develop an integrated management plan and unique strategy. There are overlapping responsibilities between agriculture authorities and other partners working in the field of collection, treatment, reuse consumer protection, and public health. Many Arab countries need to develop their own comprehensive participatory and multi-stakeholders approach for improving the intuitional framework of wastewater systems and avoid the fragmentation exist.

3.4 Private Sector Participation

Yet there are no incentives in all Arab countries to raise the attention of the private sector in the whole cycle of wastewater from collection to reuse. The private sector would like to know their legal rights and the revenue and the protection of their investments. Getting private sector interests can be made easy by securing the right policy and legal framework that set tariffs rates that are both affordable for end users of treated wastewater and the same time could cover the capital and operational costs of the whole wastewater cycle. The policy and regulatory framework for wastewater system should have the essential elements for a finical viable wastewater reuse projects and initiatives that could be attractive to the private sector.

3.5 Scio-Cultural

The acceptance of treated wastewater must be comprehensively addressed if these resources are to become an integral component of national water budget and sustainable water management strategies. Public awareness efforts based solely on scientific data do not necessarily increase public acceptance of projects. Public policy on wastewater reuse options must include the human dimension since it is the public who will be served by, and pay for, the option. Scio-culture constraints related to farmers willing to switch from traditional good quality and free water resources to treated wastewater still exist in many Arab countries which make a barrier for increasing the reuse. Also, end users perception and their perceived religious reservations about consuming crops irrigated with treated wastewater still high.

However, a successful story from Kuwait indicates that when the quality of treated wastewater is assured, the acceptance by end users will be very high. In Kuwait, Sulaibiya wastewater treatment and reclamation plant is considered by far the largest facility of its kind in the world to use membrane-based purification system (reverse osmosis and ultrafiltration). The plant's daily capacity is 375,000 m^3, which could be expanded to 600,000 m^3/day in the future. Treated wastewater will contribute by 26 % of Kuwait's overall water demand by 2020 (Choukr-Allah

2011). Treated wastewater produced in Kuwait is transmitted from the treatment plants to demand centers for reuse through transmission and distribution networks or tanker trucks to the main farming areas of Sulaibiya, Abdali and Wafra areas. Treated wastewater is stored and disinfected (chlorinated) before distribution to end users. Due to the increasing demand or treated wastewater, six effluent storage reservoirs at a distance of 30 km from the center of Kuwait City with a total storage capacity of 38,000 $m^{3/}$day, their capacity was increased to 68,000 m^3/day by building new additional reservoirs (Al-Anzi *et al.* 2012).

4. Sustainable versus Unsustainable Wastewater Management

The population of GCC countries stood at around 52.6 million by the end of 2015 and is expected to grow by nearly 12 million in 2030, according to official forecasts. Major growth will take place in in urban areas. The production of treated wastewater will alsoincrease which will lead to financial, environmental and social costs dramatic increase unless sustainable wastewater management receives urgent attention. In a sustainable wastewater management system, nutrients in the wastewater are reused to grow food. In this way there is not the need to use as much chemical fertilizer and at the same time, there will bemuch less discharge of nutrients to the environment. The problem of resource depletion and pollution of the river is overcomed by closing the material cycles. Figure (7) also emphasizes the need to treat industrial wastewaters containing toxic substances separately, and not to mix industrial wastewaters with domestic wastewater.

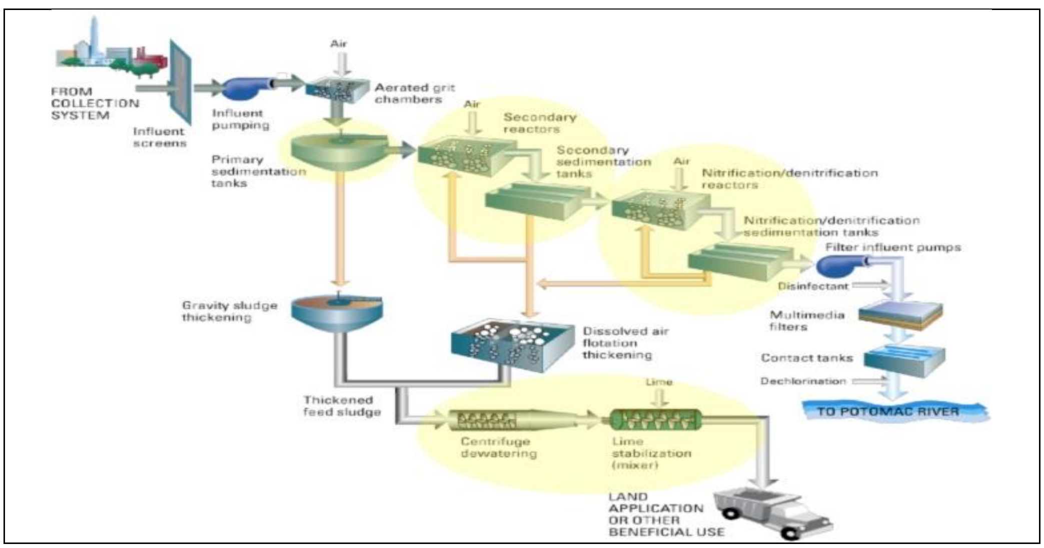

Figure 7: From collection to reuse

Wastewater spent and used water from farms, communities, villages, homes, urban areas or industry may contain harmful dissolved or suspended matter. Unregulated discharge of wastewater undermines biological diversity, natural resilience and the capacity of the planet to provide fundamental ecosystem services, impacting both rural and urban populations and affecting sectors from health to industry, agriculture, fisheries and tourism. In all cases, it is the poorest that are the most severely affected. Managing the wastewater treatment and reuse should be started from the strategic level passing through technical and operational level through an integrated approach (Figure 8).

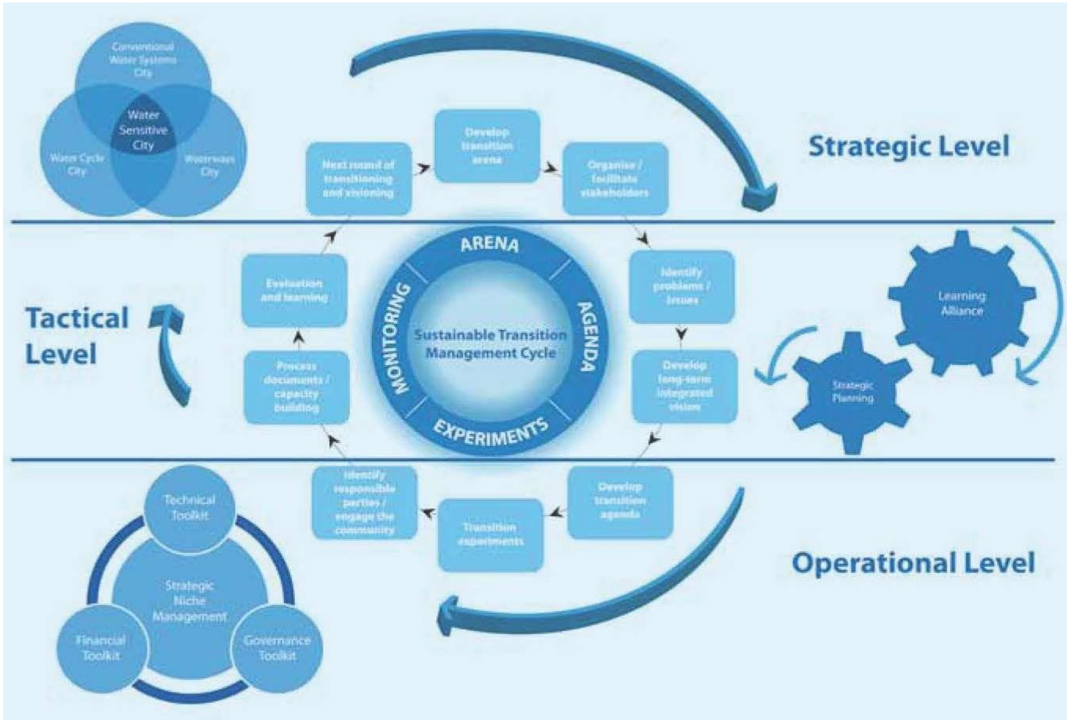

Figure 8: Integrated planning and management of wastewater in GCC countries

5. Conclusion and Recommendations

Water is the major challenge facing most of the arid and semi-arid countries including the GCC countries. Treated wastewater proved to be a very promising source of irrigation water for crop cultivation. Reuse of treated wastewater targets agriculture predominantly especially in GCC countries for irrigation and landscaping. There are economic, institutional, health, and environmental constraints that hamper the sustainable and safe reuse in agriculture. To address these limitations concerted effort and commitment is required to boost the volumes of treated wastewater produced. For maximum utilization of this resource, the cost of water has to be acceptable to farmers. If farmers find free source of water they will not go for treated wastewater. The other challenge is the transportation cost of treated wastewater from Sewage Treatment Plants to agricultural areas, since most of big sewerage treatment plants are located in the cities where the concentration of people is dense. Social issues play a significant role in water reuse initiatives and should be addressed with adequate political will accompanied by awareness programs to overcome cultural, religious and social objections. Acceptance of farmers, retailers and consumers is the most sensitive and important issue. GCC countries face many challenges for securing their fresh water supply and growing food demand. Wastewater reuse can play an important role in food security.

Comprehensive approach for wastewater reuse must be developed from collection, treatment, to land and crop selection and on-farm practices. This approach needs to be built on the basis of stakeholder engagement in all aspects, and a product of this approach should be country-wide strategic plans that take into account the socio-economic-environmental aspects and reflect the interests of the users and consumers. This approach needs also to consider, define and streamline the roles and responsibilities between the different agencies and reflect that in the national plans.

The existing regulatory framework including standards and guidelines need to be revised and updated. These need to be flexible, clear and built on a risk assessment/management approach. The standards and guidelines for reusing treated wastewater should differ according to the level of wastewater treatment to ensure safe and efficient reuse. Extensive capacity building and training for related staff to support appropriate and safe treated wastewater reuse is needed at many levels and in all GCC countries with no exceptions. There is an eminent need to build the expertise of specialized experts and extension staff that could work with the end users of the treated wastewater. Stakeholder engagement, outreach and communications are needed at all levels. There are environmental and public health risks associated with treated wastewater reuse, that need to be precisely defined and mitigated. Hence, more studies and research are needed on the socio-economic-environmental impacts of reuse. Results and lessons learned should be disseminated and shared on a broad base, and projects up scaled.

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Wastewater in the GCC Countries (in Arabic)
مياه الصرف الصحي في دول مجلس التعاون لدول الخليج العربية

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الملخص
تستعرض هذه الدراسة جهود دول مجلس التعاون لدول الخليج العربية في مجال معالجة مياه الصرف الصحي وإعادة استخدامها والتي أصبحت ضرورة ذات أولية ملحة، وخصوصاً في ضوء الاستهلاك العالي للمياه المحلاة بتكاليفها العالية وتأثيراتها البيئية المصاحبة. ومما يزيد من أهمية هذه المياه استنزاف المياه الجوفية والنضوب المستمر لمخزونها في المنطقة والتي تظهر آثاره في تدهور نوعية هذه المياه في العديد من الآبار في المنطقة، بالإضافة إلى ضرورة رفع سعة وكفاءة محطات معالجة مياه الصرف الصحي للحد من الآثار البيئية من تصريف المياه غير المعالجة في الأودية والشواطئ التي تعد من أهم أسباب تلوث البيئة الساحلية في المنطقة. ومع أن التقارير للمشاريع المستقبلية لقطاع الصرف الصحي المتعلقة بالمعالجة وإعادة الاستخدام في دول المجلس تدعو للتفاؤل، إلا أن الفجوة في استغلال هذه المياه تبقى كبيرة، وتمثل فرص ضائعة تحت ظروف الندرة المائية التي تعيشها دول المجلس. ففي الوقت الراهن وبالرغم من أن إمدادات المياه وخدمات الصرف الصحي متاحة لنسبة كبيرة من السكان، لا سيما في المناطق الحضرية، حيث تصل هذه النسبة من 80% إلى 90%، فأن معدل المعالجة لا يزيد عن 56% وسطيا في دول المجلس، ولا تتجاوز معدلات إعادة الاستخدام أكثر من 30% من إجمالي المياه المعالجة وسطياً. وبالرغم من أن الأغلبية العظمى من هذه المياه تتجه نحو الري الزراعي، إلا أن متوسط نسبة المياه المعالجة إلى نسبة المياه الجوفية في القطاع الزراعي لا تتجاوز 9%. ويعود السبب في ذلك بشكل رئيسي إلى نوعية المعالجة وأحياناً تدهور جودة المياه المعالجة في بعض المحطات جراء تحميلها فوق طاقتها الإستيعابية، ونقص شبكات إعادة توزيع المياه المعالجة، بالإضافة للحاجة إلى مراجعة بعض معايير استغلال هذه المياه لتوسعة نطاق استخدامها، والحاجة لرفع وعي العامة بضرورة استغلالها. وفي ضوء كل هذه المبادرات تظل إجراءات الحد من استهلاك المياه في دول مجلس التعاون الخليجي الحل الأول والأهم لمشاكل قطاع المياه فيها وقطاع الصرف الصحي بشكل خاص.

الكلمات الدالة: المياه الجوفية، المياه المحلاة، معدل إنتاج الفرد، إعادة التدوير.

المقدمة
تشير الإحصاءات العالمية إلى أن استخدام المياه ينمو بمعدل ضعف معدل النمو السكاني (WFN, 2015). ونظرا للنمو السريع في عدد السكان، والزيادة السريعة في مجال التنمية الحضرية وأسلوب الحياة، تواجه دول مجلس التعاون الخليجي تحديا في تلبية الطلب على متطلبات مياه الشرب المتزايدة بشكل خاص. ونظرا للنقص المتزايد في الموارد المائية المتجددة، لجأت دول المجلس إلى تحلية مياه البحر لتوفير معظم المياه اللازمة للاستخدامات البلدية والصناعية الماضية (البنك الدولي, 2005). ونظراً للتكلفة المالية الباهظة لإنشاء وتشغيل محطات التحلية فضلاً عن استنزافها لكميات كبيرة من الوقود و أضرارها البيئية المعروفة، عكفت الجهات المختصة إلى معالجة مياه الصرف الصحي وإعادة استخدامها لتخفيف الضغط على المياه الجوفية المحدودة، وتوفير بديل أقل تكلفة مالية واقتصادية من المياه المحلاة والحد من آثارها البيئية ، وتقليل معدلات تصريف مياه الصرف الصحي في المناطق الساحلية أو الصحراوية.

تستعرض هذه الورقة الممارسات الحالية لمعالجة مياه الصرف الصحي البلدية في دول مجلس التعاون مع تسليط الضوء على احصائيات أنواع المياه المستهلكة في المنطقة، وكمياتها، وتكلفتها، والسياسات السعرية لها. وأخيرا، تستعرض الورقة التطلعات نحو توسع وتحسين كفاءة معالجة مياه الصرف الصحي وإعادة استخدامها. وتستنتج الورقة بأنه على الرغم من وجود مشاريع مستقبلية لمعالجة وإعادة استخدام المياه، فإنه على دول الخليج مراجعة السياسة السعرية والدعم العالي للمياه المحلاة للأفراد والمؤسسات وذلك للحد من الاستهلاك أولاً، كما توصي بتطوير محطات معالجة المياه ليتم استخدامها في النطاق البلدي والمحاصيل الزراعية بدلا من اقتصارها على المساحات الخضراء وذلك بدون التضحية بالصحة العامة.

استنزاف المياه الجوفية غير المتجددة في دول مجلس التعاون الخليجي

في إبريل 2015، في دايغو بكوريا الجنوبية دعت العديد من المنظمات العالمية (منظمة الأمم المتحدة للأغذية والزراعة (FAO) واليونسكو والبنك الدولي، ومرفق البيئة العالمي (GEF)، والرابطة الدولية لعلماء الهيدرولوجيا (IAH)) إلى اتخاذ إجراءات على المستوى الدولي لمعالجة النضوب المتزايد والخطير والتدهور المتواصل لموارد المياه الجوفية المحدودة على ظهر الكوكب بشكل عام (FAO, 2015). ولا تختلف دول مجلس التعاون عن هذا التوصيف وخصوصاً أنها تقع في واحدة في اكثر مناطق العالم جفافاً ولا تتلقى مياهها الجوفية التغذية المطلوبة لتجددها. وتعاني المياه الجوفية في المنطقة من الاستنزاف الخطير الذي يتجاوز معدلات السحب منها الحد المسموح به في كل دول المجلس، مما أدى إما لجفافها أو تسرب مياه البحر المالحة إليها في المناطق الساحلية. كما يجرى استغلال المياه الجوفية العميقة غير المتجددة (الأحفورية) بدرجات متفاوتة تصل إلى 50% في المملكة العربية السعودية و أحياناً إلى 100% كما هو حاصل في دولة الإمارات العربية المتحدة (Cisneros et al., 2008). ووفقا لبيانات منظمة الأمم المتحدة للأغذية والزراعة فأن نسبة الاعتماد على المياه الجوفية من إجمالي استخدامات المياه تبلغ حوالي 17% في قطر ، 40% في البحرين، 46% في الكويت، 71% في دولة الإمارات العربية المتحدة، و80% في المملكة العربية السعودية. ويشير آخر تقارير المنظمة (FAO, 2015) إلى أن هذا الاستنزاف غير المبرر يجب أن يدفع إلى العمل الجماعي والمنسق لحماية طبقات المياه الجوفية وإطالة عمرها، وأن تكلفة التقاعس عن العمل واستمرار هذه الممارسات يمكن أن تصبح عالية. ولذا، فأنه لا بد من توجيه دعوة ملحّة إلى صنّاع القرار من أجل المباشرة الآن واختطاط السياسات الملائمة والمساعدة على بلوغ الأهداف المشتركة في التنمية الاجتماعية والاقتصادية.

تعتبر التغذية الصناعية للمياه الجوفية بالمياه المعالجة من أهم تقنيات زيادة مخزون المياه الجوفية في المناطق شحيحة الأمطار. ولقد خططت الكويت لتنفيذ هذه التقنية، حيث شيدت محطة معالجة رباعية للصرف الصحي في منطقة الصليبية لحقن المياه الجوفية المائلة للملوحة المستنزفة والمتركزة في منطقة الصليبية نفسها؛ إلا أن احتجاجات الرأي العام أدت إلى التراجع عن هذه الفكرة بعد تشييد المحطة، وتم تحويل تدفقاتها الناتجة لري المحاصيل الزراعية. كما أن سلطنة عمان قد قامت بتنفيذ مشاريع مشابهة إلا أن المحطات المستخدمة كانت ثلاثية المعالجة مما أدى إلى ظهور بعض النشاط البيولوجي غير المحمود في هذه الآبار (Baawain et al., 2014; SAOC, 2007). وحالياً تقوم دولة قطر ومملكة البحرين أيضا بدراسة تغذية المياه الجوفية بواسطة المياه المعالجة الفائضة عن الحاجة.

تحلية المياه في الخليج العربي حاجة ملحة ولكنها باهظة التكاليف والأضرار

مع ازدياد عدد السكان والتقدم المدني والعمراني وزيادة المساحات الزراعية، بالإضافة إلى تداخلها مع الصناعة والاستهلاك البشري تسارعت مشكلة شح المياه في دول مجلس التعاون، حيث انخفض متوسط المياه المتجددة السنوي للفرد بسرعة، ووصل مستوى ندرة المياه فيها لمرحلة ما يسمى بخط الفقر المائي الحاد[4] (أقل من 500 متر مكعب للفرد بالسنة من المياه العذبة المتجددة) (Cisneros et al., 2008)، كما شكل الطلب المتزايد للمياه عاملاً إضافيا في شح المياه، وتجاوزت معدلات استهلاك المياه الفعلية معدلات تجدد الموارد المائية التقليدية.

من الحلول المعروفة لسد الحاجة المتزايدة للمياه، وخصوصا للأغراض البلدية والصناعية هي تحلية المياه سواء كانت مياه البحر أو المياه الجوفية المائلة للملوحة. وطريقة التحلية المستخدمة بصورة رئيسية حاليا في دول المجلس هي طريقة التقطير الومضي المتعدد المراحل (MSF)، التي ظلت حتى الآونة الأخيرة أكثر الطرق فعالية وقابلية للتنفيذ اقتصادياً ومالياً (البنك الدولي, 2005). واستمرت هذه التقنية لتغطي 78 ٪ من اجمالي تقنيات التحلية في دول مجلس التعاون الخليجي و53% من تقنيات التحلية في العالم(Verdier, 2011). يشكل استهلاك دول مجلس التعاون وحدها حوالي 81 ٪ من إجمالي الطاقة الإنتاجية في العالم من هذه التقنية (Purnama et al., 2005). وتقدر إجمالي الطاقة الإنتاجية الحالية من محطات تحلية المياه في دول مجلس التعاون الخليجي بحوالي4.7 بليون متر مكعب في السنة (GCC Secretariat General, 2015). وعلى الرغم من أهميتها فإن تحلية

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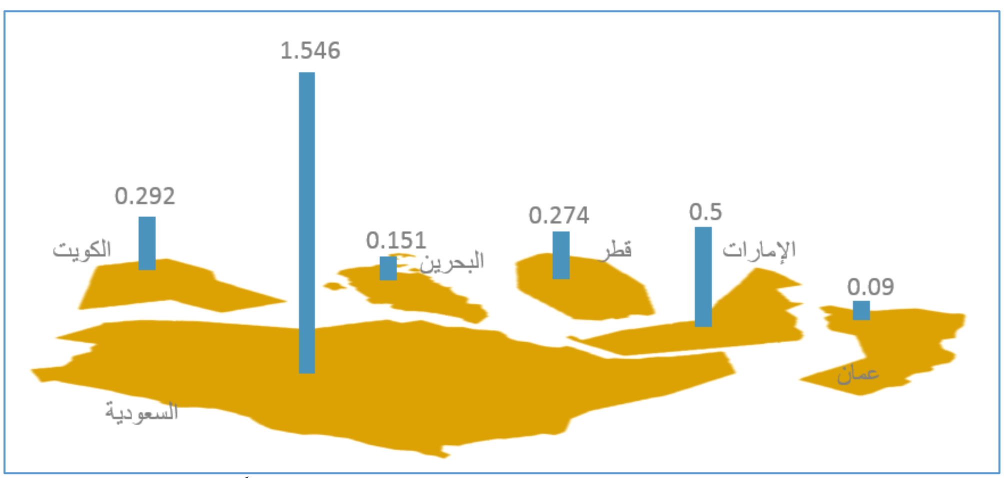
[4] تم استحداث مبدأ حصة الفرد من المياه باعتباره مؤشراً للإجهاد المائي وربطهما بالندرة المائية في العام 1989 بواسطة الهيدرولوجية السويدية مالين فولكنمارك، مقياساً لمقارنة المتطلبات الحالية والمستقبلية في مقابل الموارد المائية المتاحة على مستوى دول العالم. وفي تطوير هذا المؤشر، تم اعتماد المستوى الأدنى لاحتياجات ومتطلبات الفرد السنوية للاستخدام المنزلي (الشرب والصحة والنظافة والاستخدامات المنزلية الأخرى)، وتم تقديره بحوالي 100 لتر في اليوم، وكذلك للزراعة والصناعة وإنتاج الطاقة الهيدروليكية (ما بين 5 إلى 20 ضعف هذا المعدل). وبحسب هذا المؤشر؛ يمثل المعدل 1700 متر مكعب للفرد سنوياً من المياه المتجددة الحد الفاصل بين الندرة والوفرة المائية للدول، حيث يبدأ تصنيف الدول على أنها مجهَدة مائياً إذا قلت حصة الفرد السنوية فيها عن هذا المعدل، وإذا قلت هذه النسبة عن 1000 متر مكعب للفرد في السنة، فتصنف البلدان على أنها واقعة تحت حد الفقر المائي، وسينعكس ذلك سلباً على التنمية الاجتماعية والاقتصادية فيها، أما إذا قلت عن 500 متر مكعب للفرد في السنة (أو ما يسمى بخط الفقر المائي الحاد)؛ فإن المياه تصبح معوقاً رئيساً للتنمية ويمكن أن تتسبب في تدني مستوى المعيشة والصحة والبيئة (Falkenmark, 1989).

المياه تعتبر باهظة الثمن (Al-Zubari, 2014)، وهي مستنزفة للطاقة، حيث تستهلك من 10% إلى 30% من إنتاج النفط في دول مجلس التعاون الخليجي للتوليد المشترك للطاقة ومحطات تحلية المياه (Darwish et al., 2009; Fattouh and Mahadeva, 2014; البنك الدولي, 2005). وبالإضافة إلى ذلك ، فأن عملية تحلية مياه البحر لديها تأثيرات بيئية لأنها تطلق المياه عالية الملوحة والحارة، كما تحتوي على الكلور المتبقي و مضادات التكلس وبعض المعادن الثقيلة التي تصرف إلى البيئة البحرية. ويؤثر هذا سلباً على صحة الحياة الساحلية بما فيه تقليل كمية الأكسجين المذاب مما يؤدي إلى اختناق الكائنات الحية في البيئات الساحلية المهمة (Abdulraheem, 2010). علاوة على ذلك، فأن حرق الوقود لتحلية المياه ينتج عنه غازات أكاسيد الكربون، وأكاسيد النيتروجين، أكاسيد الكبريت والملوثات الضارة الأخرى للبيئة (Aleisa et al., 2011b; Darwish et al., 2009). وبرغم هذه التكاليف المالية والاقتصادية والبيئية فأن سياسة حكومات دول المجلس في بعض الدول هي دعم هذه المياه والتساهل في تحصيل الإيرادات من المستهلك كما هو الحال في دولة الكويت، الامر الذي لا يساعد على ترشيد المياه والحفاظ عليها. ويؤدي إلى نتائج غير مرجوة، حيث أن استهلاك الفرد في دول مجلس التعاون من المياه لا يتناسب البته مع تكلفتها وندرتها في المنطقة. ويؤدي ذلك في النهاية إلى تحمل دول المجلس والمجتمعات الخليجية أعباء مالية واقتصادية عالية، بالإضافة إلى إجهاد البيئة الساحلية والبحرية في الخليج العربي. ولقد استدعى ذلك بعض دول المجلس (البحرين، السعودية وإمارتي أبوظبي ودبي) لمراجعة تعريفة المياه البلدية.

انتاج الفرد من مياه الصرف الصحي في دول مجلس التعاون الخليجي

إن انتاج الفرد من مياه الصرف الصحي هو المقياس الفعلي لزيادة استهلاك الفرد من المياه المنتجة في دول مجلس التعاون مقارنة بدول العالم، بالإضافة الى معدل المياه البلدية من مجموع المياه المنتجة بالمقارنة بتلك المستهلكة في الزراعة والصناعة المذكور سابقاً. وبذلك تعتبر المملكة العربية السعودية ودولة الإمارات المتحدة أكبر منتجين لمياه الصرف الصحي من بين دول مجلس التعاون، إلا أنتاج المملكة منها يعتبر مبرراً نسبةً لتعداد سكانها (أنظر شكل 1). ويعتبر إنتاج مياه الصرف الصحي للفرد في السنة لدول مجلس التعاون الخليجي عالياً جداً عند مقارنته بدول العالم بشكل عام، عدا سلطنة عمان والمملكة العربية السعودية واللتان تنتجانها بمعدلات معقولة بالنسبة لدول العالم (أنظر شكل 2). وتعتبر قطر الدولة الأكثر إنتاجاً لمياه الصرف الصحي بالنسبة للفرد في السنة، يتجاوز انتاج الفرد فيها سبع أضعاف انتاج الفرد في المملكة العربية السعودية، ويساوي انتاجها بالنسبة للفرد ما يوازي انتاج الفرد في عمان والكويت والسعودية والبحرين مجتمعة. ويتبع دولة قطر مملكة البحرين ثم دولة الإمارات ثم دولة الكويت، وجميعها تعتبر عالية جداً بالمقارنة مع دول العالم ولا يتناسب ذلك مع شح المياه في المنطقة. وقد يرجع السبب في ذلك إلى تدني تعرفة المياه للفرد والدعم العالي العام لها.



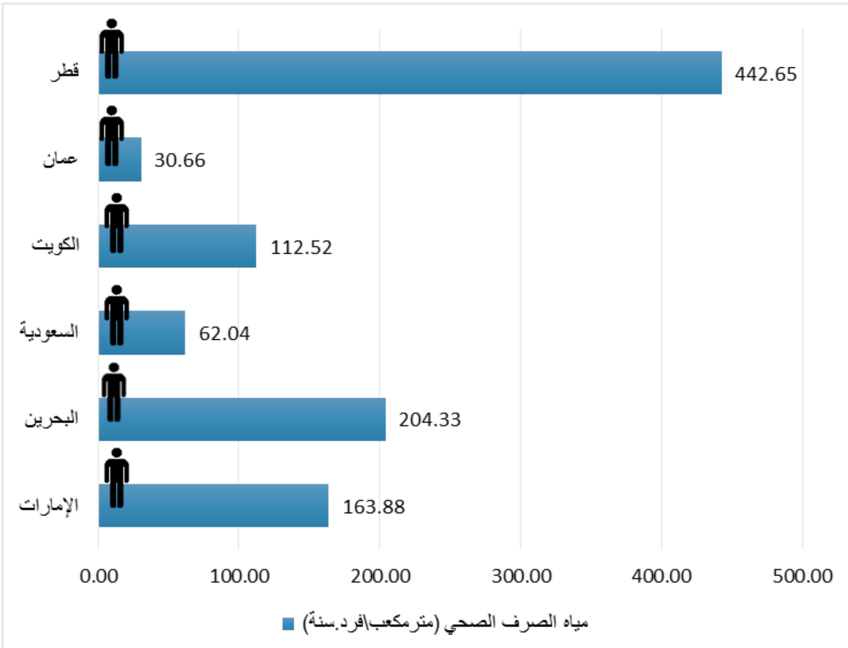
شكل 1: إنتاج مياه الصرف الصحي في دول مجلس التعاون الخليجي بوحدة مليار متر مكعب سنوياً (FAO-AQUASTAT, 2009)

معالجة مياه الصرف الصحي في دول مجلس التعاون الخليجي

تعتبر خدمات إمدادات المياه والصرف الصحي متاحة لنسبة مئوية كبيرة من السكان ولا سيما في المناطق الحضرية حيث تتراوح من 80% إلى 90%، في دول المجلس (البنك الدولي, 2005). وكذلك تشير التقارير السنوية لجميع دول مجلس التعاون أن خدمات الصرف الصحي ومعالجة المياه تشهد تطوراً وانفاقاً واضحاً في مشاريع كثيرة لزيادة التغطية ورفع مستوى جودة المياه المعالجة وكذلك البحث المستمر لاستثمارها في مجالات مناسبة. ويبلغ إجمالي الطاقة الاستيعابية لمعالجة مياه الصرف الصحي

حوالي 2800 مليون متر مكعب في السنة ويصل إجمالي عدد المحطات 241 محطة بين أولية وثنائية وثلاثية، بالإضافة الى محطة واحدة رباعية وهي محطة الصليبية الخاصة في الكويت (الأمانة العامة لمجلس التعاون، 2015) (أنظر

جدول 1).



شكل 2: انتاج الفرد السنوي من مياه الصرف الصحي في دول مجلس التعاون الخليجي (FAO-AQUASTAT, 2009)

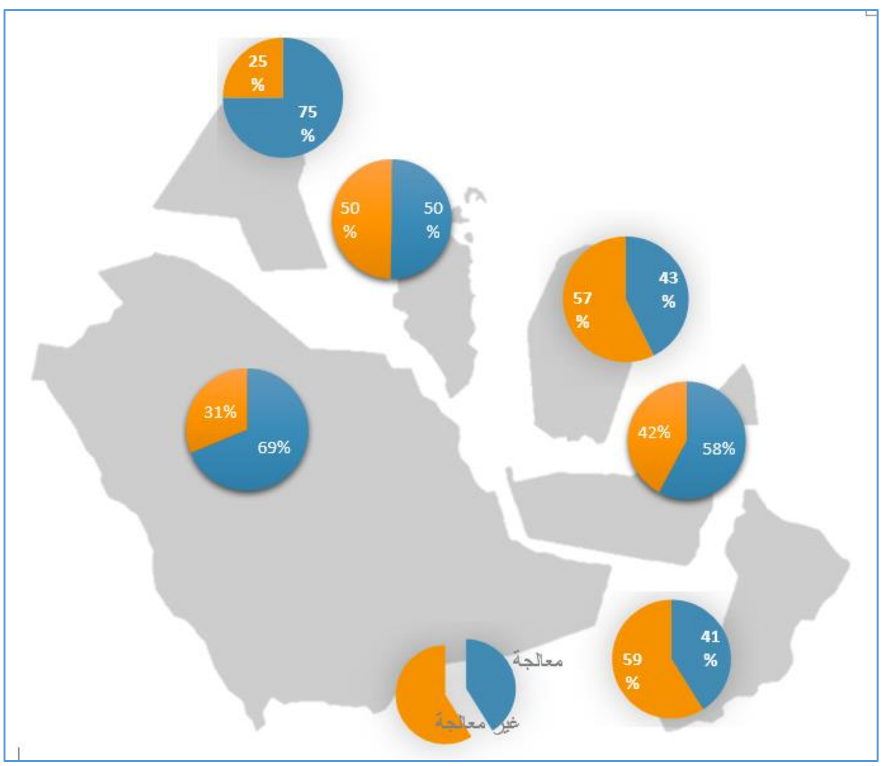
يتفاوت معدل المعالجة من دولة إلى أخرى بمتوسط عام 56% تتصدر فيه دولة الكويت بنسبة معالجة تتجاوز الـ 75%، ثم المملكة العربية السعودية بنسبة 69%، ومن ثم دولة الإمارات العربية المتحدة بنسبة 58% (أنظر شكل 3). ومع أن معدل تغطية خدمات الصرف الصحي الأساسية يبدو عاليا فأن كثير من هذه المحطات قد تجاوزت طاقتها الإستيعابية القصوى منذ أعوام، مما أدى الى تدهور جودة المياه المنتجة الأمر الذي جعل خصائصها الكيميائية والعضوية دون المعايير المسموحة لإعادة استخدامها، ومن ثم تزايدت نسبة المصرفة منها للبحر مقارنة بالمستفاد منها.

بالإضافة إلى ذلك فأن نسبة كبيرة من معدل التغطية يكون عن طريق الشاحنات و الصهاريج (Aleisa et al., 2011a) والتي يمكن أن تحتوي على كثير من المواد غير المسموحة كالمخلفات الصناعية والمسالخ التي تنتهي إلى الصحاري والبحار والوديان بدلاً من محطة الصرف الصحي الملزمة بتغطية منطقة منشأ هذه المياه. وينتج عن ذلك متوسط استفادة تقارب الـ 20% من إجمالي المياه المعالجة؛ وهذا لا يتناسب مع معدل تغطية الصرف الصحي الواسعة. بالإضافة إلى ذلك، فأن عينات مسحية لمياه الخليج كشفت بأن تصريف مياه الصرف الصحي غير المعالجة، أو غير المعالجة إلى المواصفات المرجوة، وتدفق مياه الصرف الصحي المعالجة، وتصريفات المياه العادمة الصناعية، وتصريفات مياه السفن هي أهم أسباب تلوث مياه البحر. ولقد استندت الدراسة في نتائجها هذه على نتائج التحاليل الفيزيائية والكيميائية والميكروبية لعينات من مواقع بأعماق مختلفة، شملت المعادن الثقيلة، البيوض واليرقات، والعوالق الحيوانية والنباتية (عدنان, 2015). ويشير الباحثون فيها إلى مدى خطورة الوضع البيئي في الشواطئ ولا سيما أن الظروف البيئية الطبيعية المحيطة بها المتمثلة في رياح الشمال التي تهب على طول محور الخليج وتلعب دورا فاعلا في نقل جميع الملوثات إلى النظم البيئية البحرية الخليجية (العميري, 2014). كما أن نسبة تلوث التشبع الغذائي (Eutrophication) والذي يبدو على شكل طبقة طحالب خضراء على سواحل مدن مجلس التعاون جراء المخلفات البيولوجية المحتواه في مياه الصرف الصحي المصرفة للسواحل كذلك له تأثير سلبي في سحب كميات من الأكسجين المذاب من المناطق الساحلية. وكذلك تكرار حوادث المد الأحمر على شواطئ دول الخليج العربي والذي يتسبب باختناق ونفوق الأسماك.

جدول 1 : محطات معالجة مياه الصرف الصحي في دول مجلس التعاون الخليجي (الأمانة العامة لمجلس التعاون، 2015)

الدولة	عدد المحطات	السعة الإجمالية للمعالجة (مليون متر مكعب/سنة)	مستوى المعالجة	الإدارة
الإمارات	53	556	ثنائية – ثلاثية	حكومية – شبه حكومية
السعودية	81	1730	أولية- ثنائية - ثلاثية	حكومية
قطر	18	123	ثنائية - ثلاثية	حكوية – شبه حكومية
عمان	73	69.3	ثنائية - ثلاثية	حكومية - خاصة
الكويت	5	239	ثلاثية رباعية	حكومية - خاصة
البحرين	11	81.5	ثلاثية	حكومية

الجدير بالذكر أن جمع بيانات مياه الصرف الصحي وتحليلها لدول مجلس التعاون ليس بالأمر اليسير، أولاً بسبب شح البيانات عن المياه المعالجة وغير المعالجة ومعدلات تصريفها إلى الخليج العربي؛ وثانياً بسبب التفاوت الكبير في البيانات بين المصادر في كميات إعادة استخدام المياه المعالجة الفعلية، حيث يمكن أن تتفاوت هذه الأرقام وفي السنة نفسها للضعف أحياناً للبلد الواحد (FAO-AQUASTAT(FAO-AQUASTAT, 2009 و (Cisneros et al., 2008). ولعل السبب في ذلك هو خطأ في بعض الحسابات في حجم الإنتاج عندما يتم احتساب البيانات رياضياً بدلا من تحصيلها ميدانياً وخاصة لمياه الصرف الصحي غير المعالجة المصرفة إلى البحر. أسباب أخرى يمكن أن ترجع إلى القصور في حساب الكميات المنقولة عن طريق شاحنات وحاويات الصرف الصحي غير المرتبطة بشبكة البنية التحتية والتي تشير الدراسات لاحتوائها على مواد كيميائية خطرة لا يمكن قبولها في مرافق معالجة المياه العادمة البلدية، إلا أنها تنفذ لها. ويمكن أن يعزى سبب آخر لعدم دقة البيانات في كميات المياه المعالجة المعاد استخدامها لأسباب اجتماعية واقتصادية و سياسية أو دينية (Cisneros et al., 2008). وأخيراً بالرغم من أن مستوى المعالجة بين ثنائي وثلاثي ورباعي مدون في الإحصاءات المحلية وكذلك الدولية، إلا أن الدراسات المنشورة عن جودة المياه المنتجة من هذه المرافق وعن كفاءة المعالجة شحيحة للغاية. وباعتبار كل ما ذكر أعلاه، فأن دول مجلس التعاون على علم بمشكلات معالجة المياه العادمة وجميعها تعمل لتطوير مستوى هذه الخدمة. وفيما يلي عرض لبعض المعلومات المنشورة عن نشاط دول مجلس التعاون في معالجة وإعادة استخدام مياه الصرف الصحي.



شكل 3: نسبة مياه الصرف الصحي المعالج وغير المعالج في دول مجلس التعاون الخليجي

التوصيات

في ضوء التزايد السكاني والتطور المجتمعي السريع والواجب المُلح في المحافظة على الموارد والبيئة أصبحت فكرة إعادة تدوير المياه وإعادة استخدامها آلية أساسية ضمن خطة إدارة مياه متكاملة وفعالة، لدول العالم بشكل عام ولدول مجلس التعاون الخليجي بشكل خاص وطارىء. وبالرغم من وجود مخططات لمشروعات كبيرة لمعالجة المياه المستعملة ابتداء من تجميع مياه الصرف الصحي والمعالجة السليمة لها للوصول إلى المستوى الثالث والرابع ومحاولة رفع معدل إعادة استخدام المياه الصحية المعالجة، إلا نافذة العمل لترشيد الاستهلاك وتحسين الأداء في هذا الجانب لا يزال واسعاً ونقدم التوصيات التالية في هذا الصدد:

1. الدعم السياسي والإطار القانوني لتشجيع إعادة التدوير:

- الدعم السياسي والمذهبي والاجتماعي بتعزيز إعادة ضرورة استخدام المياه المعالجة في وجود إطار قانوني وتنظيمي واضح ملزم لا يقف عند الدور الاسترشادي لإنفاذ مشاريع إعادة استخدام المياه المعالجة في إطار مؤسسي واضح المسؤوليات من حيث التخطيط والتمويل الاستثمارات والتنفيذ والتشغيل و صيانة و مراقبة محطات الصرف الصحي.
- توفير طرق تمويلية المبتكرة تشمل البنية التحتية وينبغي أن تتضمن التصميم والبناء، و تشغيل وصيانة والتطوير المستمر لأفضل التكنولوجيا المناسبة لإعادة تدوير المياه.
- عمل دراسات وخطط تخص السياسات الوطنية والتحليلات الاقتصادية بخصوص استغلال معالجة مياه الصرف الصحي وخيارات إعادة استخدامها بشكل متكامل.
- التحفيز في تجهيز البنية التحتية لإعادة استخدام المياه المعالجة واعتبارها مشاريع ذات أولوية في المنطقة.
- توفيرالدعم المالي من الحكومات لتشجيع الخصخصة في مشاريع معالجة المياة وإعادة إستخدامها على سبيل المثال تسهيل القروض وضمانات القروض والائتمانات والضريبية وغيرها.
- التشدد في تغريم تصريف المياه غير المعالجة ومراقبة مجارير مياه الصرف الصحي النافذة للبحار والوديان وغيرها.

2. تقنين الاستهلاك:

- تنفيذ خطط تدريجية للحد من استهلاك المياه المحلاة في المقام الأول وذلك عن طريق مراجعة تعريفات المياه المحلاة وحساب كمياتها وتعجيل تحصيلها بشكل دوري وعملي منظم. حيث ان سخاء بعض دول مجلس التعاون في دعم المياه والتساهل في تحصيل رسوم المياه أدى لفرط عالي في الاستهلاك. فذلك أحرى أن يبرز جدوى إعادة استخدام المياه المعالجة الأوفر تكلفة.
- دراسة فرض رسوم على تجميع مياه الصرف الصحي للمساهمة في الحد من الاستهلاك والتي اثبتت فاعليتها في بعض دول مجلس التعاون الخليجي.
- توفير مياه الصرف الصحي بتعريفة رمزية كما الحال في بعض دول مجلس التعاون للحد من الهدر ولا سيما المعالجة ثلاثياً و رباعياً
- تطبيق طرق الزراعة الحديثة، مثل الزراعة خارج التربة والتي تستطيع التغلب على محددات المياه والتربة وتستطيع تحقيق وفر مائي يصل إلى أكثر من 75 في المئة.
- تركيب أجهزة ترشيد استهلاك المياه في صنابير في جميع المباني الحكومية والتجارية والمنازل والمدارس والمساجد.

3. التوعية والتثقيف:

- أن التثقيف والتوعية يجب أن تلعب دورا مركزيا في تهيئة المواطنين لاستيعاب ضرورة تدوير المياه ولكن يجب أن يكون ضمن خطة مدروسة مدعومة بِسْن قوانين تحتم تدوير المياه كآلية لا تتجزأ من إدارة مصادر المياه العذبة لدول مجلس التعاون الخليجي. فلا يزال لدى الكثير من المواطنين صعوبة في تقبل إعادة استخدام المياه لأسباب دينية ونفسية بالرغم من إصدار الفتاوى الدينية الرسمية التي تجيز استخدامها وفق معايير واضحة و دراسات تسمح بصلاحيتها للشرب كما في المعالجة الرباعية.
- توعية المواطنين بنتائج هدر استهلاك المياه المحلاة ومحاسن استغلال المياه المعالجة على البيئة و الصحة العامة

- إصدار ميثاق للتربية البيئية وإدراجه ضمن المناهج الدراسية من أجل تعزيز الوعي والاهتمام بترابط المسائل الاقتصادية والاجتماعية والبيئية في جميع المناطق الريفية والمدنية الخليجية والقيم وأنماط سلوكية الفرد، وإبراز أعراض ومشاكل تلوث مياه الأنهار وأسبابها وتبصير الناس بغوائل الطبيعة البشرية

4. ما يخص محطات معالجة مياه الصرف الصحي:

- إعداد خطط متكاملة للاستفادة من الحمأة الناتجة عن معالجة مياه الصرف الصحي حيث أن الدراسات تشير بإمكانية استخدامها لأغراض متعددة منها استرجاع عالي للطاقة حوالي ٦٠ - ٨٠ بالمئة.
- شمل الطاقة في القرارات معالجة المياه بحيث تحتاج محطات مياه الصرف الصحي أن تكون مرتبطة مع الطاقة أو على الأقل استعادة الطاقة. و يمكن ايجاد محطات معالجة ذاتية الطاقة باستخدام التقنيات الجديدة مثل خلايا الوقود الميكروبية والتقنيات التابعة لها لاستخدام البكتيريا لإنتاج التيار الكهربائي مباشرة والتي يمكن استخدامها لتشغيل محطات معالجة مياه الصرف الصحي.

5. الدراسات الاسترشادية في إعادة تدوير المياه في المنطقة:

- عمل دراسات ارتفاع ملوحة المياه الجوفية بالأجزاء الساحلية بسبب تداخل المياه المالحة بالمياه العذبة بتلك الأجزاء نتيجة الإفراط في ضخ المياه بواسطة الآبار بمعدلات تفوق التغذية الطبيعية التي تتلقاها هذه الخزانات الجوفية.
- الحرص على فحص المياه الواردة لمحطات الصرف الصحي و تأكيد خلوها من المراد المخالفة التي من شأنها التأثير على جودة عملية معالجة المياه مع الحرص على عدم اجهاد محطات مياه المعالجة بالأحمال الزائدة حتى لا تتسبب تدهور يحول دون استغلال المياه الناتجة حماية للصحة العامة.
- دراسة المواقع المستخدمة لمعالجة مياه الصرف الصحي المستقبلية واتجاهات الرياح للحد من الآثار الجانبية لمحطات المعالجة مع توفير ضخها وإعادة ضخها لمسافات طويلة.
- رفع كفاءة محطات معالجة مياه الصرف الصحي الى ثلاثي و رباعي لتوسعة نطاق إعادة استخدام تدفقاتها.
- مراجعة معايير لاستخدام مياه الصرف الصحي في الزراعة، حيث أن الاستخدام الرئيسي لمياه الصرف الصحي المعالجة هو في ري المحاصيل غير الصالحة للأكل. ولذلك، فإن تطوير معايير أكثر قدرة على التمييز قد يسمح لاستخدام أوسع لمياه الصرف الصحي دون الإضرار بالصحة العامة.
- دعوة دول مجلس التعاون الخليجي لاعتماد نهج متعدد القطاعات لإدارة المياه المستعملة على ربط القطاعات ببعضها البعض وذلك بتخصيص محطات معالجة بقطاعات محددة للاستعجال بجني ثمار معالجة المياه الصحية.

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Photocatalytic Nitrate Reduction over Activated Carbon Loaded with Ag and Pd Nanoparticles.

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Abstract
Photocatalytic removal of nitrate from water was examined using activated carbon prepared from low coast resources (date palm stone) and loaded with silver and palladium nanoparticles under solar radiation. The prepared catalyst was characterized using Scanning Electron Microscope (SEM), Electron Dispersive X-ray Spectroscopy (EDX), X-ray Photoelectron Spectroscopy (XPS), Thermogravimetric analyses (TGA) and surface area measurements. The photocatalytic effect was carried out using 100 ml of 80 ppm nitrate solution and different concentration of acid scavengers. The results of the characterization show massive multi-size granular distribution of silver and palladium nanoparticles on the surface of the prepared activated carbon with 30-80 nm diameter. Apparently the Ag and Pd were present in their zero valent state as evidenced from the XPS analyses. The conversion of nitrate seems to occur through mainly nitrogen gas (N_2) rather than nitrite (NO_2^-) or ammonia (NH_4^+). Among the different scavengers used, formic acid with concentration of 0.05 M was found to be most effective one.

Keywords: Groundwater, Date Palm Stone, Solar Radiation, Formic Acid, Denitrification of Water.

1. Introduction
Nitrate is one of the common contaminant in groundwater of the United Arab Emirates (UAE) and in many parts of the world. Although nitrate ions (NO_3^--N, NO_2^--N, NH_4^+-N) occur naturally, production from extensive agriculture, industry and domestic sources becoming nowadays the major source of contamination. The contribution from these anthropogenic sources results in potential pollution of drinking water. High nitrate (>10 mg/L) in drinking water can be a risk health hazard to human and in particular as carcinogenic and methemoglobinemi (blue baby syndrome).

Removal of nitrate from water presents a challenge due to its high solubility and stability. Many technologies such as Ion exchange, blending, Membrane (reverse osmosis and electro dialyses), biological denitrification, chemical, electrochemical, and catalysis, are currently used for removal of nitrate from water. Catalysis is apparently the best among these methods because it does not generate secondary waste, less energy consuming, and the selectivity for reduction product could be controlled. Nitrate could be reduced to nitrogen by heterogeneous catalysis reduction of nitrate in the presence of hydrogen. Metals such as Pt, Rh, Pd, Ru, Ru, Au, and Ag loaded on supporting compounds as zirconia, alumina, ceria CeO_2, SnO_2, SiO_2, titania and activated carbon were used for catalytic reduction of nitrate using hydrogen [1-4]. Bimetallic catalyst as Pd –Cu, Pt-Cu, Rh-Cu, and Ir –Cu supported on activated carbon and Pd-Cu titania supported were also used for catalytic hydrogen reduction of nitrate in water. Use of formic acid as alternative reductant for hydrogen is also reported [5-10].

Recently photocatalytic reduction of nitrate under UV-radiation in the presence of formic acid without hydrogen was used [3]. Pd supported in alumina was used for reduction of nitrate in the presence of formic acid [2]. Three forms of commercial titanium oxide P25, P90 and Hompicate [11] were used for reduction of nitrate under UV radiation. Also Ag_2O supported onto commercial titanium oxide /P25was used for photocatalytic reduction of nitrate using UV-radiation in the presence of formic acid [12].

To the best of our knowledge using natural solar radiation for nitrate reduction has not been reported in published literatures. Herein, activated carbon prepared from low coast resources date palm stone by phosphoric acid activation then decorated with bimetallic Ag-Pd NPs is used for reduction of nitrate under solar radiation. Together with this new approach, the effect of different scavengers' such as formic acid, oxalic acid, acetic acid and ammonium oxalate on the reduction of nitrate was also investigated.

2. Experimental

2.1. Chemicals and preparation of the catalyst

The chemicals used in the experiment include Silver nitrate, palladium chloride, phosphoric acid, sodium nitrate, oxalic acid, acetic acid, ammonium oxalate and formic acid which all were purchased from Sigma Alderich. Activated carbon was prepared from date palm stone. Date palm stone was collected, washed, crashed and dried at 70^{o}C for 5 hours. Then it is soaked in H_3PO_4 for 24 hours. Finally it is carbonized at 250^{o}C for 20 hour and subsequently crushed and sieved.

Impregnation with silver and palladium was carried out by ion exchange processes. 5 g of the prepared activated carbon was equilibrated with mixture of 500 ml mixture solution of 500 ppm silver and palladium ions. 5 ml of hydrazine hydrate was used for reduction of silver and palladium cations on the activated carbon surface. The quantity of silver and palladium ions impregnated on the surface of activated carbon was calculated by measuring the concentration of the silver and palladium ions before and after equilibrium using Varian 710 ICP-Os.

2.2. Characterization of the prepared catalyst

Composition and surface area characterization of the prepared activated carbon was performed by a variety of methods. These include, Scanning electron microscopy coupled with energy dispersive X-ray analysis (SEM-EDX) using a Bruker instrument, X-ray photoelectron spectroscopy (XPS) using an ESCALAB-250 system with AL-K_α X-ray. , surface area was measured using 90-Quantaqrom Autosorp instrument and thermogravimetric analysis (TGA) using TA-60 Shimadzu thermal analyzer.

2.3. Photocatalytic reduction Experiments

A solution composed of 50 ml of 80ppm nitrate and 0.01M formic acid was mixed with 0.1 g of the prepared Ag-Pd NPs loaded activated carbon in closed glass containers. This mixture was kept in dark for 24 hours and then exposed to sun light in sunny days from 9 am to 5 pm. 1 ml sample of this solution was collected at different time interval. The collected solution was analyzed for nitrate (NO_3^-), nitrite (NO_2^-) and format ions using IC-90 Dionox supplied with column and suppressor and carbonate was used as eluent. Ammonia (NH_4^-) was analyzed spectrophotometrically using HACK 509 spectrophotometer.

3. Results and Discussion.

3.1. Characterization of photocatalyst

The morphological properties of the catalyst surface and distribution of Ag-Pd NPs are shown in figures 1 and 2. The distribution and morphology of palladium and silver on the surface of activated carbon predominantly appear as globules and crystal aggregates that have variable sizes, 30 and 60 nm Fig. 1.

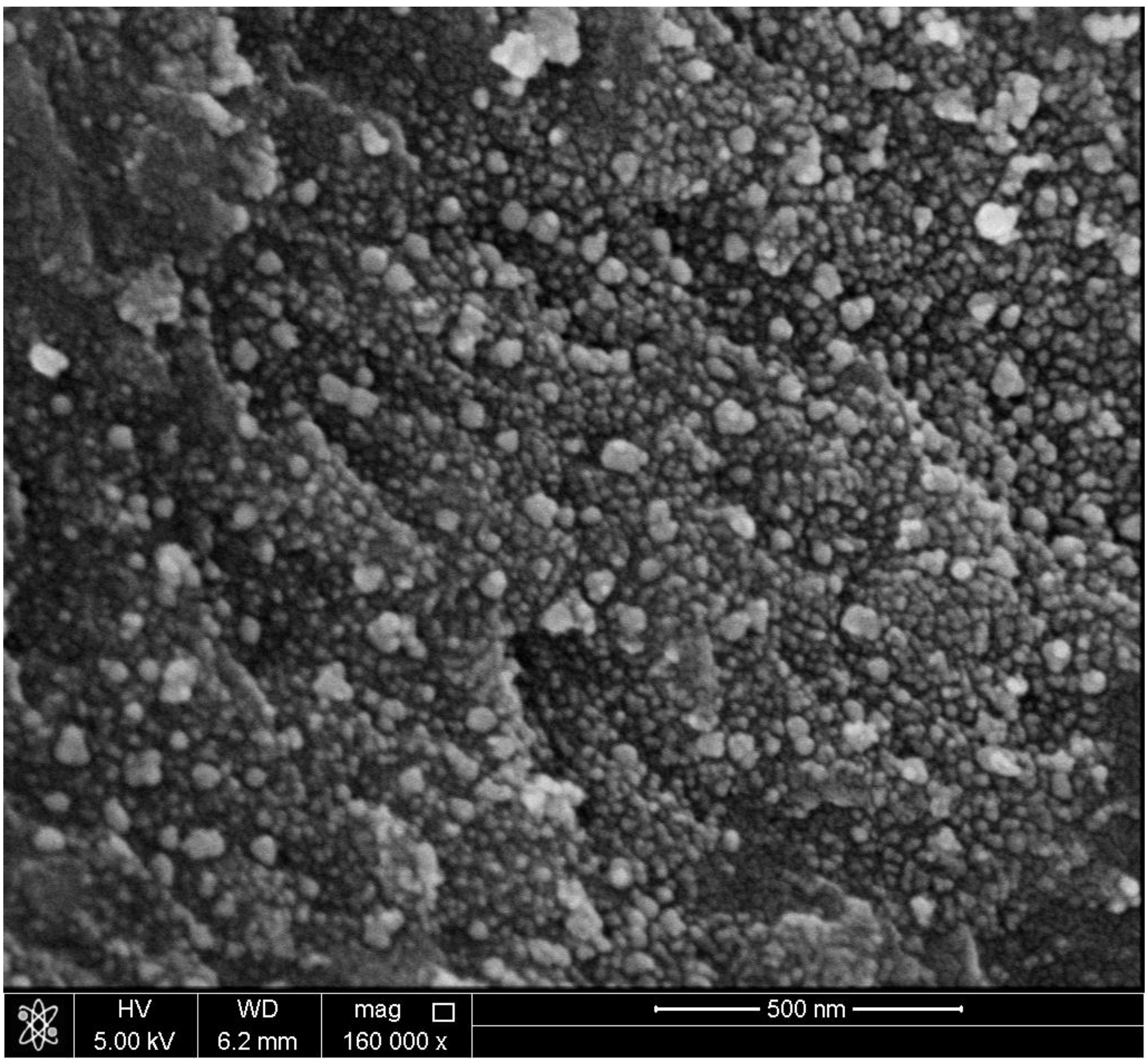
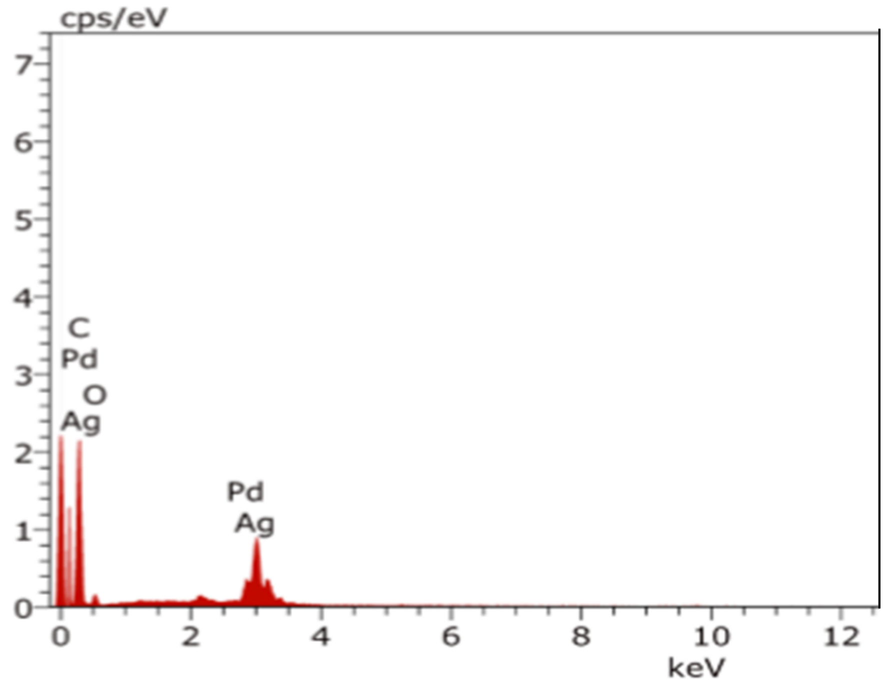


Figure 1: SEM of activated carbon impregnated with Ag-Pd NPs



Spectrum: Pb-Ag-12.spx

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
C	6	K-series	23.52	45.59	76.21	3.23
O	8	K-series	6.58	12.76	16.01	1.49
Pd	46	L-series	5.30	10.27	1.94	0.22
Ag	47	L-series	16.19	31.38	5.84	0.56
		Total:	51.60	100.00	100.00	

Figure 2: EDX of Activated Carbon Impregnated With Ag-Pd NPs

In addition to identification of the elemental composition using EDX (Fig. 2), the valence state of silver and palladium was identified from XPS analyses (Fig. 3).

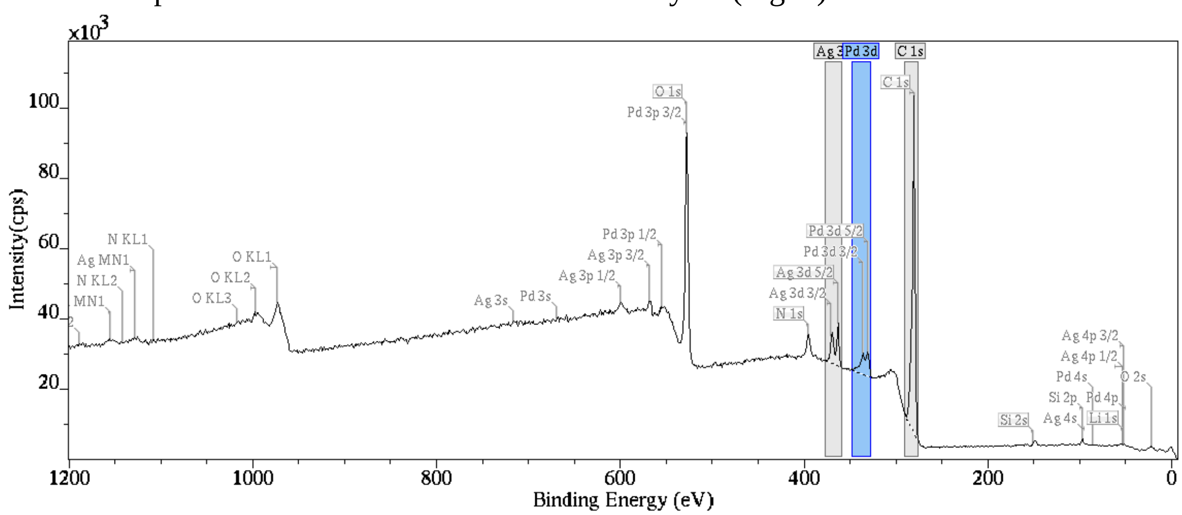


Figure 3: XPS diagram of the elemental scan survey of activated carbon loaded with Ag-PdNPs. Observe the assignment of peaks having different energy level and valance

The deconvolution spectra of the Ag XPS peaks Fig. 4 indicates binding energies at 368 and 374eV of Ag 3d5/2 and Ag 3d3/2 respectively. These peaks and energies suggest that silver is mainly present as Ag^0 [13, 14]. The deconvolution spectra of palladium (Fig. 5) shows peaks at 340 and 335 eV for Pd 3d5/2 and Pd 3d3/2 335 respectively confirming the complete reduction of palladium and formation of metallic palladium on the activated carbon surface [15].

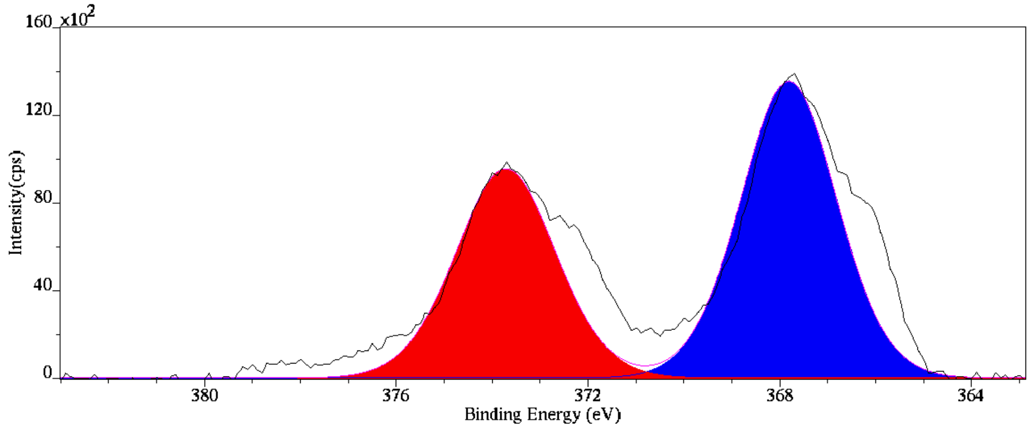


Figure 4: XPS spectra of Ag 3d5/2 and 3d3/2 showing the characteristic Ag^0 binding energy

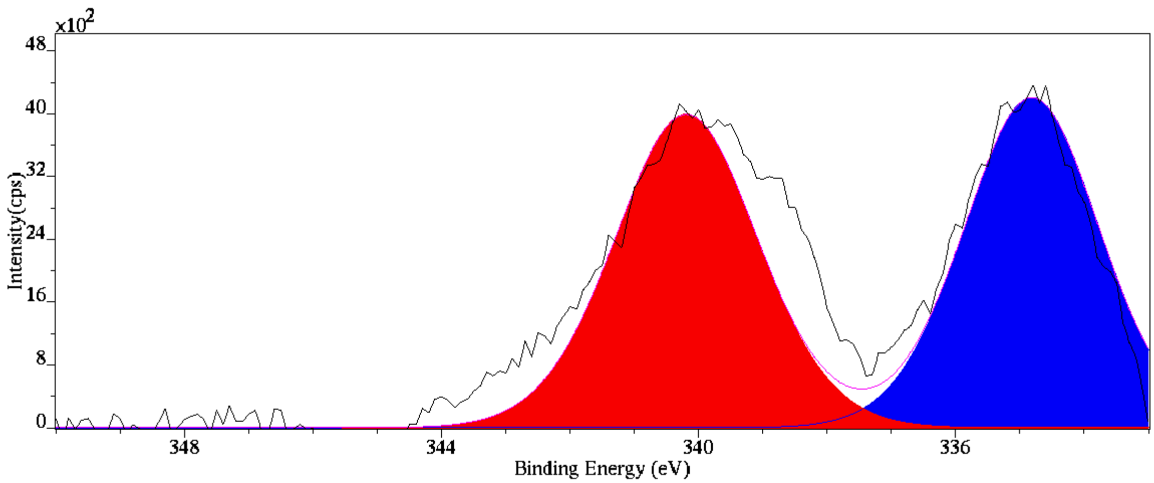


Figure 5: XPS spectra of shows 3d Pd 5/2 and 3d3/2

Depending on the results of XPS analyses, complete reduction and formation of Ag and Pd NPs on the surface of activated carbon was apparently achieved after their loading on the surface of activated carbon as Ag^+ and Pd^{++}. Since, both Ag and Pd have similar oxidation reduction potential [16], they could be reduced by the same reducing agent (hydrazine hydrate (N_2H_2)) according to the reactions presented in Equations 1 and 2 below.

$Ag^+ + e^- \longrightarrow Ag^0$ $\quad E^0_{\text{reduction}} = 0.8$ V (1)

$Pd + 2e \longrightarrow Pd$ $\quad E^0_{\text{reduction}} = 0.82$ V (2)

The thermogravemetic analyses (Fig. 6) indicates stability of the prepared activated carbon loaded with Ag-Pd NPs up to 550°C. The first stage weight loss between 70 and 120°C is attributed to the loss of adsorbed water on the surface of activated carbon.

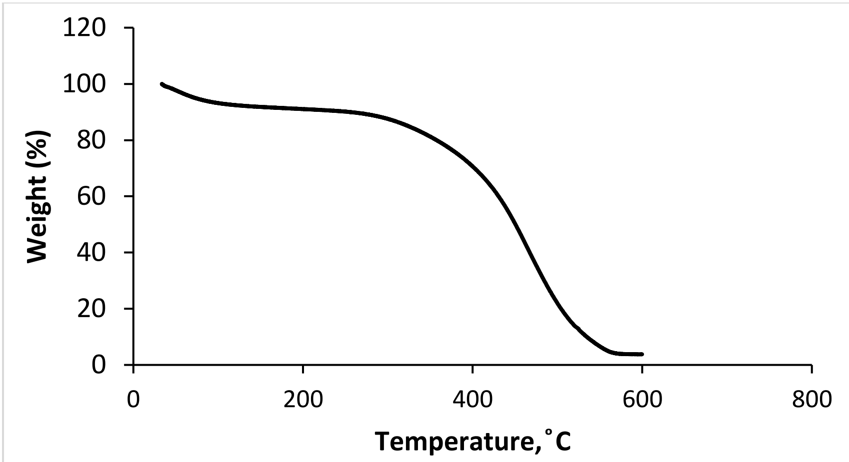


Figure 6: TGA of the prepared Ag-PdNPs activated carbon

The surface area of the prepared activated carbon loaded with Ag-Pd NPs catalyst is 38 m^2/g.

3.2. Photocatalytic reduction of nitrate by Ag-Pd Activated Carbon

When nitrate and formic acid were mixed in dark or exposed to sunlight without catalyst no nitrate reduction was observed. Also no nitrate reduction was observed for samples with activated carbon free from metallic nano particles and activated carbon loaded with palladium only. This confirms that no direct reduction reaction between formic acid and nitrate occur in absence of solar radiation and absence of Ag-PdNPs. In photo catalytic experiment under real solar radiation 50 ml of 80 ppm nitrate were mixed with 100 mg of the catalyst in the presence of formic acid as reducing agent. The result indicates that simultaneous decrease in the nitrate and format concentrations occur in the presence of formic acid (Fig. 7). However, traces of nitrite and ammonia appear in the solution, indicating that nitrate is photo catalytically reduced to nitrite ammonia and nitrogen.

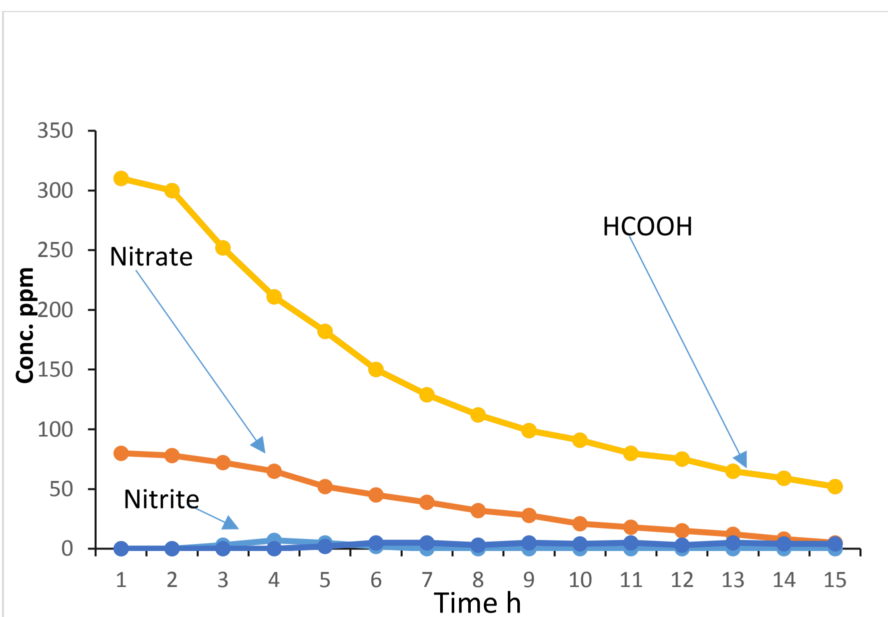


Figure 7: Nitrate reduction under solar radiation in a solution of 25ml of 80 ppm NO_3^- and 200 mg catalyst

The presence of scavengers as reducing agent is essential in photo catalytic reduction processes and different varieties were tested in this investigation including, acetic acid, formic acid, oxalic acid and ammonium oxalate. The results of these tests are shown in Fig. 8 which suggests that formic acid gives the highest rate of nitrate reduction among the studied scavengers. However, it seems that variable formic acid concentration (0.01M to 0.1M) may have different effects on the photo catalytic reduction of nitrate under real solar radiation. The best reduction effect was obtained at a concentration level of 0.05M formic acid which produces the highest photocatalyt reduction rate Fig.9.

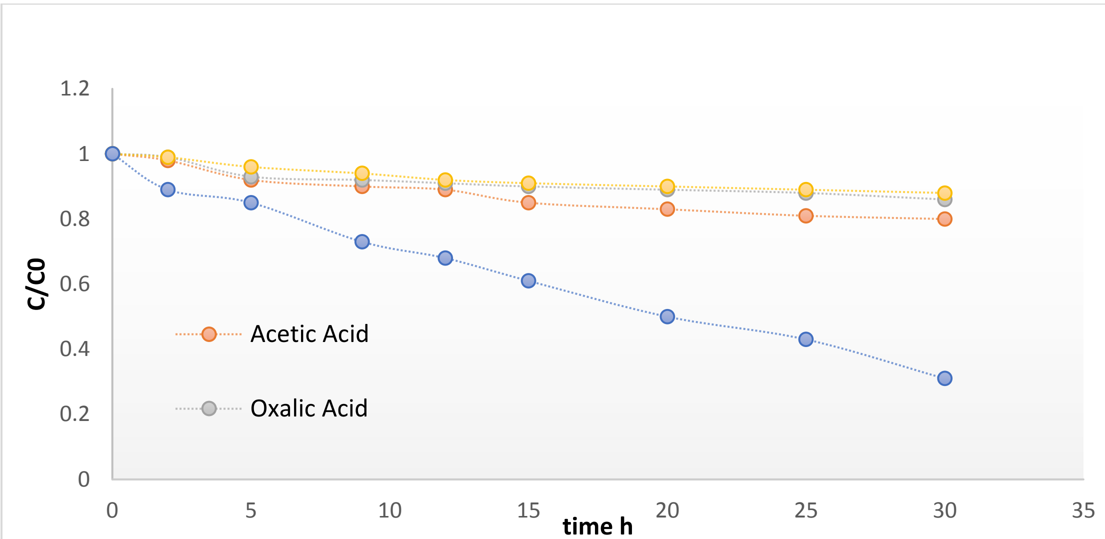


Figure 8: Effect of Different Scavengers on photo catalytic nitrate reduction. The c/c_0 refers to the concentration at different time interval divided by the original concentration in the solution

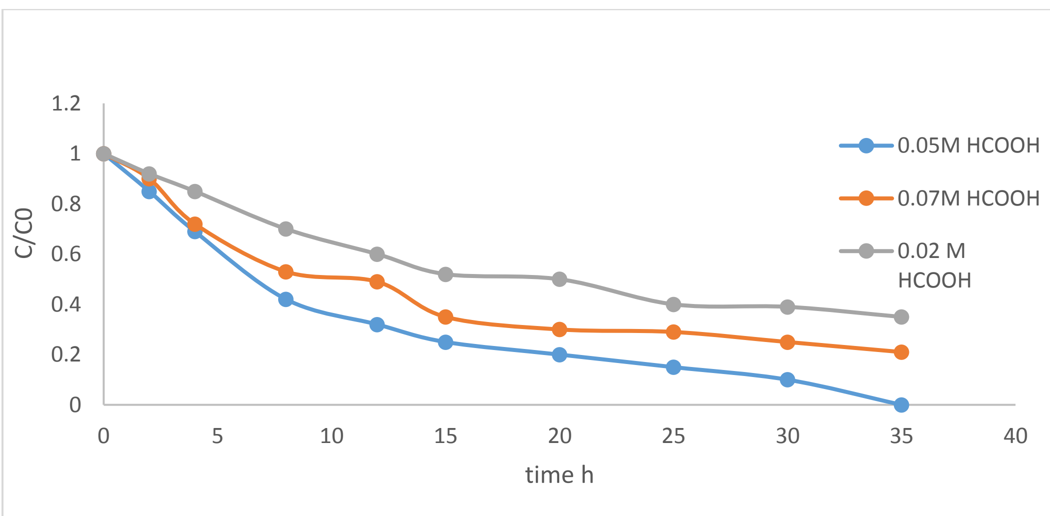


Figure 9: Effect of formic acid concentration on the photocatalytic reduction of nitrate

3.3. Mechanism of photo catalytic reduction

Recent reports show that activated carbon possess semiconductor properties with energy band gap between 3.1 and 3.6 ev and absorb light radiations in the UV, Visible and Near Infrared from 200 to 1200 nm [17-18]. Also the absorption of visible light and UV radiation by activated carbon was reported and used for photo catalytic degradation of phenol from water [19]. The effect of solar radiation on the carbon materials may be described as absorption caused by electronic transitions between the bonding and antibonding π orbitals forming h^+ in the valence band and e^- in the conduction band. When an incident photon has energy greater than the band gap it is absorbed and created an electron- like hole pair. The photogenerated electrons would spread throughout the graphene layers forming conduction band and reach molecules of the nitrate pollutants.

Nobel metal decorating activated carbon is apparently an efficient media to enhance catalytic effect. The impregnation of activated carbon with bi-metallic Ag-Pd nanoparticles, as performed here, is aimed to enhance further the photocatalytic properties of the activated carbon. This is done through electrons photo-exited from HOMO to LUMO under visible light irradiation to produce Plasmon –exited electron and electron–hole pairs [20-21]. When the AgNPs on the surface of activated carbon are subjected to visible light irradiation, the dispersion of AgNPs on activated carbon surface promotes the light absorption and generates more Plasmon exited electrons and electron hole pairs. These will thereby enhance the photocatalytic reduction of NO_3^- through a transfer of Thiess plasmon exited electron to the activated carbon surface along the interface between AgNPs and graphene sheets on the surface of activated carbon. Consequently, heterojunction is formed between the activated carbon surface and silver nanoparticles; thus inhibiting the electron-hole recombination and promoting the photocatalytic activity for nitrate reduction.

Formic acid is capable of forming reducing radicals such as $.CO_2^-$ by nucleophilic attack of the basic format anions and h^+ of valence bands of activated carbon or silver nanoparticles on activated carbon surfaces. The format radicals provide strong reducing agent having E^0 $(CO_2/{\cdot}CO_2^-)=-1.8V$ [22-24], which attack and reduce nitrate ion. Also the reduction of nitrate may be take place by direct contact between nitrate ions and conduction band of silver nano particles or activated carbon.

In the presence of formic acid, the nitrate reduction can be expressed as one mole of nitrate requires 8 mol of electrons to be reduced to nitrogen which needs equivalent 8 mol of HCOOH according to the reaction of equation 3.

$$2HCOO^- + h^+ \longrightarrow CO_2 + CO_2^{\cdot -} + H_2 \qquad (3)$$

The reduction of nitrate could be expressed as follows:

$$NO_3 + 2e^- + H_2O \longrightarrow NO_2^- + 2OH^- \qquad (4)$$

$$NO^-_2 + 6e^- + 7H^+ \longrightarrow NH_3 + H_2O \qquad (5)$$

$$2\,NH_3 \longrightarrow N2 + 3H_2 \qquad (6)$$

The produced carbon dioxide from formic acid decomposition neutralize OH^- produced in reaction 4 and prevents pH gradient and creates in situ buffering. Apparently this process is generated at the right time and the right place (the catalyst surface) to convey the reaction further.

4. Conclusion

Removal of nitrate from drinking water is necessary in order to protect the environment and human health. Activated carbon prepared from low coast resources (date palm stone) and impregnated with bi-metals silver and palladium nanoparticles may provide a new approach to denitrification of water. The photocatalytic reduction of nitrate was undertaken through exposure to solar radiation (sun light) suing several scavengers as reducing agent. The results suggest that use of formic acid strongly enhanced the nitrate reduction process when the activated carbon was impregnated with Ag-Pd NPs. Although mechanisms for the nitrate reduction reaction are proposed, further investigation to identify the exact reaction entities can better constrain the mechanisms involved.

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Safe Use of Reclaimed Water in Jordan

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Abstract

Jordan is an arid to semi-arid country with a land area of approximately 89,342 km2, more than 90% of Jordan receives less than 200 mm of rainfall per year approximately 85% of the total average rainfall in Jordan are lost to evaporation. The remaining rainfall recharges ground water and contributes to rivers, wadi flows, and reservoirs. Groundwater contributes to about 61% to the total water supply and the Surface water supplies contribute approximately to 27% of Jordan's needs. In many Jordanian cities, residents receive water only sporadically, and domestic water consumption is among the lowest in the world, less than 100 liters/capita/ days and the water per capita is 88 per cent below the international water poverty line of 1,000 cubic meters annually.

The most feasible options for reducing the gap between water demand and supply are improved management of existing water resources, treating wastewater for reuse, and the rehabilitation of existing water sources. Moreover, optimal development and utilization of water resources in Jordan and the institution of associated Water Policy requires the establishment and Implementation of several integrated resources, information and management systems. The Ministry of Water and Irrigation (Ministry, Water Authority of Jordan and Jordan Valley Authority) is responsible at the national level for Administering water policy, pollution control and managing water resources in coordination with other concerned ministries.

In fact, with the advent of industrialization and increasing populations, fluxes of refugees, the range of requirements for water have increased together with greater demands for higher quantity and quality of water. Water issues are linked to scarcity of water, which leads to a shift in water planning in Jordan towards, the use of non-conventional water resources mainly desalination of brackish water and reclaimed domestic wastewater for the intended uses according to the set standard.

Domestic wastewater means water that has been used in the home including toilets, clothes washers, showers and laundry that makes up 99.85% of sewage entering the treatment plant and it shall be collected and treated to standards to be used in restricted agriculture and other non-domestic purposes. This important resource, reclaimed water, has been considered from the highest level of Jordan government that it has a full value to the overall water resources of the country. This will help in meeting water supply needs, providing sanitation services that protect public health, preserving the source value of reclaimed water and ensuring environmental protection.

In this paper I will present Jordan experience as a developing country in reclaimed water reuse activities, updating reclaimed water standard to reflect the international knowledge, safe implementation of water reuse, enforceable water reclamation standard, providing sanitation services to protect the public health, and it will include a reuse pilot project as a model in the region for using reclaimed water in a safe manner taken in consideration the WHO guidelines issued in 2006 as road map in setting wastewater reuse policy issued in the year 2016.

Keywords: Reclaimed Water, Reuse, Health, Sustainable, Bio Solids, Standard, Quality, Monitoring, and Efficiency**.**

Introduction

MWI/WAJ is responsible for providing both services of water supply systems and wastewater services according to WAJ law number (18) for the year (1988) and its amendments. The wastewater Master plan was prepared and issued in (2013) to determine investment priorities in wastewater service in Jordan. There are (32) operating wastewater facilities owned by WAJ in the various governorates across the Kingdom [1]. Moreover, MWI/WAJ implements quality monitoring programs for wastewater treatment plants all over the country according to (JS893/2006). The monitoring of reclaimed wastewater quality involves many distinct activities to give reliable and usable data. Collecting representative samples through quality assurance program and analyzed at accredited laboratories according to ISO No.17025/2008. Reclaimed wastewater discharged from domestic wastewater treatment plants is an important component of Jordan water budget. About (152) MCM in the year 2015 was treated and discharged into various watercourses or reused directly for irrigation and other intended uses or indirectly with blending it with flood water and surface water collected in some dams like King TalalDam. Effective protection of the environment requires accurate and detailed knowledge of existing environment conditions and the ability to detect and measure the water quality trends. In fact, wastewater treatment is a multi-stage process to renovate wastewater before it reenters a body of water, or it is reused. The goal is to reduce or remove organic matter, solids, nutrients, and disease-causing organisms and other pollutants from wastewater. Treatment plants should reduce pollutants in wastewater to a level nature can handle and protect the water resources and the environment as well as public health. The total treated quantity which is discharged from the wastewater treatment plants is about 147 MCM with 91.5 % used for restricted irrigation and the main goal is to reach full usage of reclaimed water reuse country wide.

What is wastewater and why treat it?

Wastewater is not just sewage. All the water used in the home that goes down the drains or into the sewage collection systems is wastewater. This includes water from baths, showers, sinks, dishwashers, washing machines, and toilets that is called black water. In combined municipal sewage systems, water from storm drains is also added to the municipal wastewater sewer system. The average Jordanian contributes < 100 liters of wastewater each day [4]. Wastewater is about (99.85) % water by weight and is generally referred to influent as it enters the treatment plant. Domestic wastewater is wastewater that comes primarily from individuals and the domestic wastewater treatment plants in Jordan receive limited quantities of industrial wastewater from industrial establishments connected to the public sewer system according to WAJ regulations issued in 1998.

Wastewater Treatment

Most of the cities of Jordan are equipped with wastewater treatment plants and it was decided to treat wastewater up to the secondary level and meet the current standards and WHO guidelines. The existing public–sector wastewater treatment plants in Jordan are 32 using different type of treatment systems. The systems are divided into trickling filters, activated sludge and waste stabilization ponds shown in table-(1) [1].The aim of Water Authority of Jordan (WAJ) is to increase the volume of treated wastewater through improvements in the existing treatment infrastructure and the construction of new treatment systems ensuring compliance with current standards. It is also planned to upgrade the existing treatment plants to ensure that it is always comply with the Jordanian standard as well as WHO guidelines and the reclaimed water can be reused for the intended uses.

Wastewater treatment plants in Jordan

The treatment plants are classified according to the type of system into below table:

Table 1: Wastewater Treatment Plants in Jordan [1]

Treatment System	Treatment Plant
Activated Sludge (AS)	WadiHasan, Salt, Madaba, Abu- Nusier, Tel Mantah, Fuhais, Wadi Musa, Ramtha, Maan , ,South Amman,Mouatah,Jarash,Maarad
Advanced systems	New Aqaba, Samra, Central Irbid, Wadi Arab, Shalalah
Trickling Filter (TF)	Kufranja, Tafilah, Baqah, Karak
Waste Stabilization Ponds (WSP)	Mafraq,Old Aqaba, Wadiesseir, shoubk,NorthShuna, Ekeder,Mansourah,Lajoon

A common Set of processes that might be found at a municipal mechanical treatment plant would be:

- Preliminary treatment to remove large or hard solids that might clog or damage other equipment.
- Primary settling basins, to allow organic suspended matter to settle out or float to the surface, and these settling tank can be rectangular or circular.
- Secondary treatment, a type of wastewater treatment used to convert dissolved and suspended pollutants into a form that can be removed, producing a relatively highly treated effluent. It utilizes biological treatment processes followed by settling tanks and will remove approximately 85% of the BOD and TSS in wastewater. Secondary treatment for municipal wastewater is the minimum level of treatment required such as Salt, Madaba and others.
- Tertiary treatment: any level of treatment beyond secondary treatment, which could include filtration, nutrient removal (removal of nitrogen and phosphorus) and removal of toxic chemicals or metals. This type of treatment is used in the new Aqaba treatment plant, Irbid, Shallalh and others.

Jordanian Waste water Quality Standards [3]

The most important standards which wastewater quality is governed by can be summarized into:

1. Reclaimed Domestic Wastewater Standard No. (JS 893/2006):

In 1995, Jordan’s Department for Standards published a comprehensive reuse standard for treated domestic wastewater principally developed by the Water Authority of Jordan and approved by the technical committee for water and wastewater at (JISM). This standard was amended in 2002 to widen the reuse activities. These standards are currently applied to all municipal wastewater treatment systems. The final version of this standard was issued in year (2006). The standards establish a variable standard for wastewater quality for (7) categories of discharge or direct reuse. WAJ follows national legislation that has been issued by the Jordanian Institute of Standards and Metrology (JISM) (JS893/2006) and regulations issued by the Minister of Water and Irrigation .This Jordanian standard addresses the standard requirements and quality control for reclaimed water. It deals with requirements and properties that domestic wastewater must meet before being discharged to any receiving body or reused for agriculture or other various intended uses. The standard (JS 893/2006 gives guidance on which treatment technologies should be applied and which quality it has to meet to be used in agriculture and other intended uses.

2. (JS202/2007): This standard deals with the industrial wastewater, which is produced after being used for industrial purposes. The aim of implementing Industrial wastewater monitoring program is to protect the environment, water resources, safeguard health and human safety. In case of discharging the industrial wastewater or reuse, it should meet and comply with the above standard that has been renewed.

3. Regulations issued by the Ministry of Water and Irrigation according to WAJ Law No. 18/1988 and its amendments. These regulations deal with industries to be connected to public sewer systems only issued in the year 1998.

4. Bio solids standard. No (1145/2006): In 1996, Jordan's Department of Standards issued the first version of a standard for the use and treatment of sludge and septage in Jordan and it was amended in 2006. This standard provides rigorous control on the process of sludge conversion to organic soil conditioner for agricultural use and it limits the places that such converted sludge can be used for soil enrichment. Use of untreated sludge is prohibited. The standards also limit the times during which the digested sludge can be applied to agricultural soils. At present the regulations severely restrict the uses of sludge so that much of the by-product of wastewater treatment is now disposed of by landfill.

Monitoring Activities

The monitoring programs are designed a according to JS 893/2006 and monitoring agencies and the operational party should implement several Waste water Monitoring Programs .These programs are implemented by MWI/WAJ through labs & Water Quality Control department. These programs are summarized as follows:

A. Domestic wastewater quality monitoring program:

1. This program focuses on monitoring the influents & effluents from the public treatment plants, which are operated by WAJ. These treatment plants are all mainstream technologies that are in common use throughout the world.
2. This program focuses on monitoring the effluents of 20 treatment plants that are operated by private sector.

The basic objective of the implementation of this program is to control the pollution loads and minimize their effects on ground water and surface water and ensuring the compliance with the set standard.

B. Streams, Wadis, Dams and reservoirs Monitoring Program:

The number of sites to be monitored is about (60). This program is designed to monitor selected sites such as King Talal dam(KTD), Wadi Arab Dam, and sails receive direct treated flow from domestic wastewater treatment plants mainly Zarqa river to the inlet of KTD.

C. Industrial Wastewater Monitoring Program:

This program focuses on monitoring the effluents of more than 50 industrial establishments. These factories are classified as follows:

1. Connected industries to the sewer system: the evaluation is based on WAJ regulations in order to protect the sewer pipelines and the treatment plant system.

2. Non-connected industries to the sewer system: the evaluation of the water quality is based on the Jordanian standard 202 witch is specified for factories dumping their waste into the environment.

The overall value of implementing this monitoring program is to protect water resources from the toxic materials and pollution loads resulting from industrial emissions and protects treatment systems to keep reclaimed water meeting the standard and can be reused.

New approach for monitoring mechanism

The role of government in monitoring is being reevaluated in Jordan. The old model – government that does everything and pays for everything, is being replaced by private sector participation. In fact, this means that Jordan government will focus in setting and enforcing rules and standards for this sector. Therefore, adequate treatment has to be provided to improve water quality and prevent health hazards and environmental problems.

Wastewater Analysis

Various types of pollutants are present in domestic wastewater that can be measured by many different parameters such as, (heavy metals, NO3, E.coli, Cl, PO4, TSS, and TDS…etc). The most important class of wastewater contaminants are compounds that react with oxygen which are characterized by COD, BOD, TSS and the second class is public health parameters (E-coli and nematode eggs). The collected samples from the several monitoring programs are analyzed at WAJ central laboratories which have international accreditation according to ISO (17025/2008).

Examples of wastewater treatment plants effluents quality

South Amman treatment plant is working with activated sludge system. It was constructed in 2013 and the operation process has started on October 2015.The treatment plant is working efficiently and the effluent complies with JS 893/2006.The data shown in below table (2) and figures (1,2,3,4,5,6,7) confirm the sustainability of treated water for reuse aspects.

Table 2: treated water parameters for south Amman WWTP [9].

Water parameters	**PO4 AS PO4**	**T-N**	**NO3 as NO3**	**NH4 as NH4**	**TDS**	**TSS**	**COD**	**BOD5**	**PH**
	mg/l								**unit**
Jan-16	0.37	28.54	5.38	17.8	968	55	100	50	7.73
Feb-16	9.85	61.32	0.41	41.5	1144	73	61	18	7.92
Mar-16	0.6	99.58	3	60.2	1014	77	91	17	7.66
Apr-16	0.47	42.21	20.13	25.8	1165	25	32	10	7.83
May-16	3.4	19.07	64.7	< 0.2	998	49	65	17	7.51
Jun-16	< 0.3	-	45.32	< 0.2	1382	16	70	4	5.84
Average	-	41.79	23.16	-	1111.83	49.17	69.83	19.33	7.415

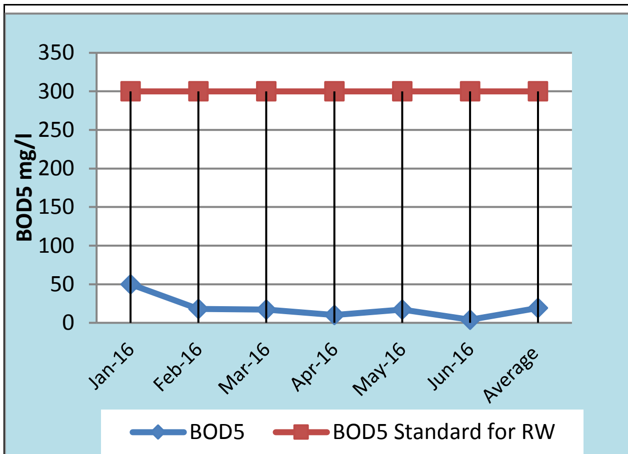

Fig. 1: BOD5 analysis for RW [9]

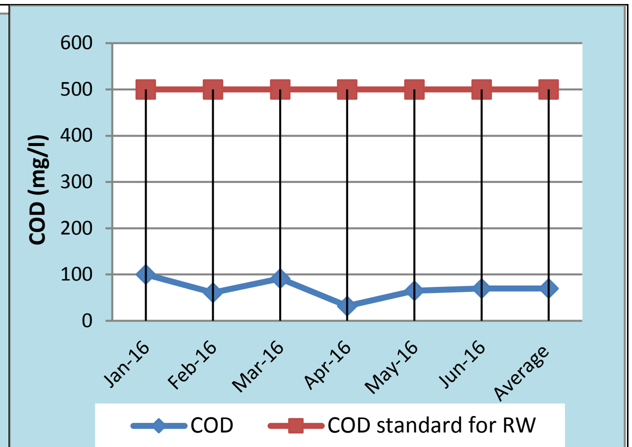

Fig. 2: COD analysis for RW [9]

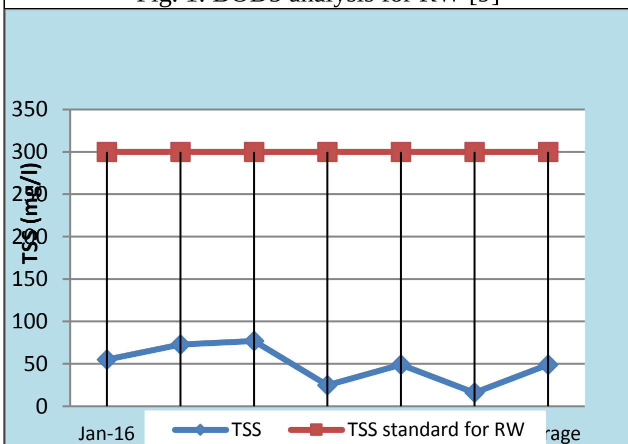

Fig. 3: TSS analysis for RW [9]

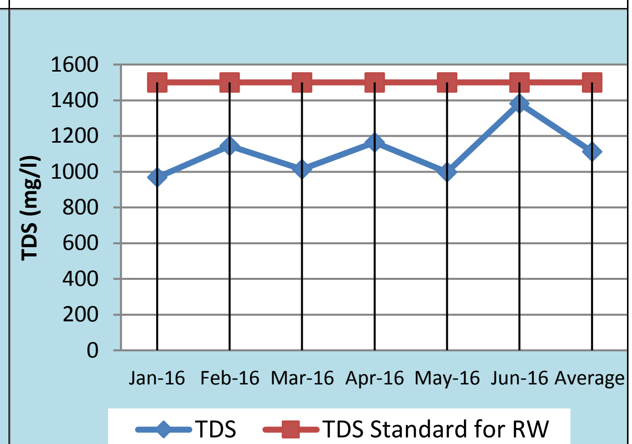

Fig. 4: TDS analysis for RW [9]

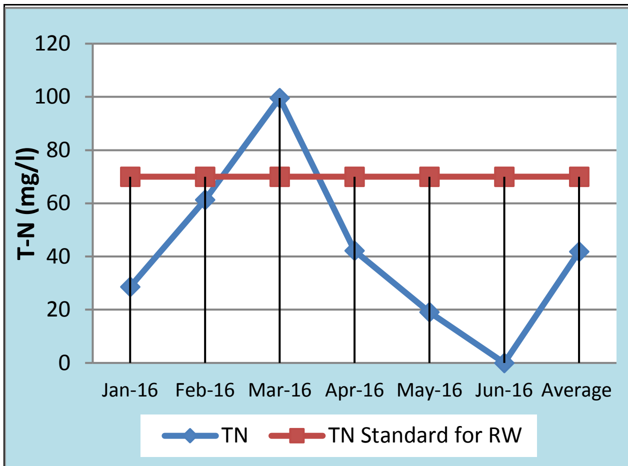

Fig. 5:T-N analysis for RW [9]

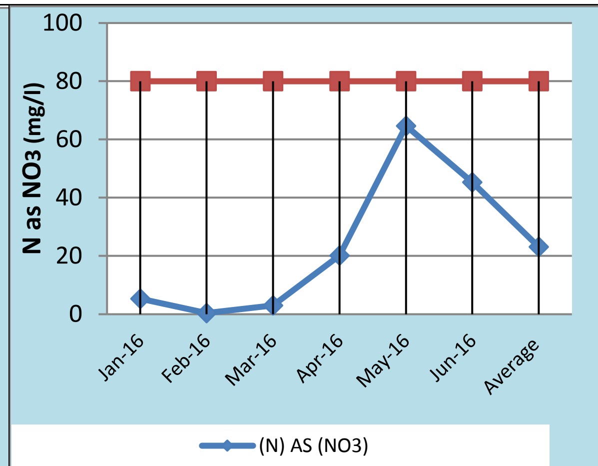

Fig. 6: NO3 analysis for RW [9]

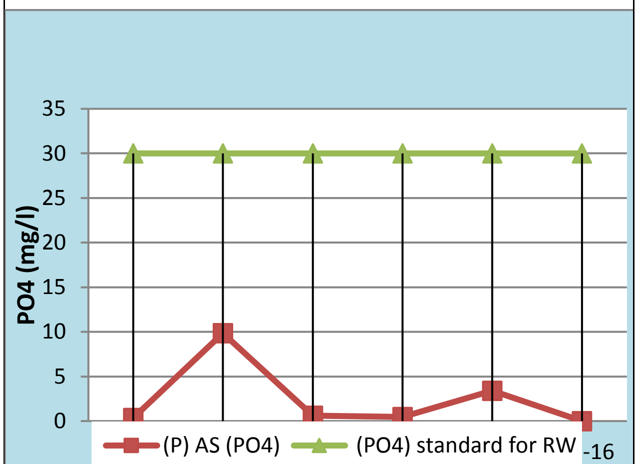

Fig. 7: PO4 analysis for RW [9]

Data source for the graphs: MWI/WAJ (2016) South Amman Wastewater Treatment Plant (Monthly reports (1, 2, 3) MWI/WAJ 2016.

Quality Monitoring

The Wastewater Treatment Plant Owner Party must ensure that the reclaimed water quality complies to the standards and according to its end use. And must carry out the required laboratory tests and document results in official logbooks and present them whenever requested by the governmental monitoring parties. The operating party must take composite samples every 2 hours for a period of 24 hour in accordance with the frequency indicated in the standard. Monitoring parties can collect samples in any way found suitable. The frequency of collecting samples for both the operating and monitoring parties are determined in the standard. No (893/2006) [3].

Collecting, preserving, transporting and analyzing samples will be as stated in the Standard Methods for the Examination of Water and Wastewater issued by APHA and the federal American Association for Water Research and Pollution Control and any of its amendments or any other approved method if it is not mentioned in the above mentioned reference.

When there is a need to define a standard value for a criterion not mentioned in this Standard then the Institution for Standards and Metrology must be contacted to take the proper action. In case of epidemics the monitoring and operational parties must investigate the presence of intestinal pathogenic microorganisms that may be found in the water.

Furthermore, the standard defines the mode of monitoring and values for WWTP effluents to be discharged in water bodies and aquifers or to be reused in the allowed aspects.
The standard explicitly prohibits the direct use of reclaimed water for irrigation of crops (vegetables) which are eaten uncooked [3].

Wastewater Evaluation

The generated water quality data shown in Tables (3&4) are for Madaba and As-Samra T-P evaluated according to the reclaimed wastewater standard No. 893/2006[3]. After the evaluation process the directorate issues monthly, quarterly, biannual, annual reports and official letters that show treatment plants violating the standard. The objective of issuing these reports is to address the problems and asking the operational party for immediate correction actions. Implementing this policy is to protect and minimize their effects on water resources and the environment and ensure safe use of reclaimed water.

Table 3: MADABA WWTP [5]

MONTH	PO4 As PO4	NO_3 as NO_3	T-N	NH_4	TDS	TSS	COD	BOD_5	pH
	mg/L								Unit
JAN/2015	0.3	0.85	49.25	38.8	1138	17	73	39	7.39
FEB/2015	0.3	21.19	31.92	23.4	1170	6	54		7.78
MAR/2015	0.3	1.52	36.4	30.3	1036	59	123		7.60
Apr/2015	0.65	16.5	22.28		1176	12	58		7.62
May/2015	8.73	0.89	53.29	60.63	1126	15	62		7.7
June/2015	3.81	13.13	36.62	35.46	1196	8	38		7.37
Jul/2015	0.3	0.36	55.07	49.4	1106	22	122	13	7.55
Aug/2015	0.3	0.25	34.11	32.3	1052	17	31	14	7.50
Oct/2015	0.3	0.85	49.25	38.8	1138	17	73	39	7.39
Nov/2015	0.3	0.25	8.94	28.7	1160	18	48	26	7.07
Dec/2015	0.3	0.46	9.82	5.7	1068	19	54	20	8.06
AVG	1.42	5.11	35.18	34.35	1124.18	19.09	66.91	25.17	7.55

Table 4: AS-Samra WWTP [5]

water parameters	pH	COD mg/l	BOD5 mg/l	TKN mg/l	N-NH3 mg/l	TSS mg/l	N-NO3 mg/l	TN mg/l
18/12/2015_17/1/2016	6.93	46.30	6.81	4.00	0.90	12.43	19.47	23.54
18/1/2016_17/2/2016	6.94	52.20	8.71	4.30	1.03	13.86	16.20	20.57
18/2/2016_17/3/2016	7.02	54.47	8.07	4.45	1.34	12.17	15.03	19.62
18/3/2016 _17/4/2016	7.01	49.22	7.00	4.00	0.90	9.43	16.59	20.68
18/4/2016_17/5/2016	7.07	44.69	5.77	4.14	1.06	7.43	15.98	20.20
18/5/2016_17/6/2016	7.04	40.03	5.16	4.00	0.90	6.92	14.86	18.96
18/6/2016_17/7/2016	7.15	39.08	5.60	4.13	0.90	6.89	13.32	17.52

Treatment plants efficiency

The efficiency of the above treatment plants and other 32 treatment plants measured by BOD_5 as an indicator of removing dissolved organic matter from treated sewage is exceeding 90%, generally it ranges from 90 % for activated sludge and trickling filter T.P to 99%. These figures clarify that the activated sludge is very effective in removing dissolved organic matter and WAJ can rely on it as a first choice and after that the trickling filter. The historical data show that the wastewater stabilization ponds have a low efficiency in removing dissolved organic matter, [10].

Safety Control and Risk Monitoring

Jordan is a pioneer among Arab countries in the establishment of a Risk Monitoring System for water reuse. A long term collaboration between government, research institutions and donors have elaborated many methodologies and tools that benefit the safe reuse of reclaimed water. Many important elements of a risk monitoring exist today; however, they are not used to the most efficient and effective extent. One obstacle is the communication among the above mentioned actors and stakeholders. Some tasks are partly duplicated while other relevant issues remain untouched.

Examples for existing elements/ tools:

- Frequent monitoring system of effluents from WWTP (WAJ)
- Monitoring of Soil and Groundwater in the Jordan Valley (JVA)
- Advice to farmers on wastewater reuse (JVA and various donor projects)
- Monitoring of Fresh Fruits and Vegetables from the Jordan Valley and Whole Sale Market Amman (JFDA).
- Water Quality Monitoring among Jordan by ministry of Environment.

The German Technical Cooperation supported the MWI, WAJ and JVA in the establishment of a Safety Control and Risk Management System in the Jordan Valley. This model will be the basis for a general Risk Monitoring concept to be adjusted to other areas in Jordan.
The basis for the currently planned Risk Management Concept for Jordan is the WHO Guidelines on Wastewater and Grey water Reuse (2006). These guidelines are allowing an adjustment to the needs of a country [11].

Many elements of a Risk Management System are already available in Jordan. However, the major challenge is a smooth and trustful cooperation between the involved stakeholders. Therefore, it is planned to establish standard operational procedures for the Risk Management System together with all stakeholders [7].

The future of laws and standards

Although much progress has been made in Jordan on laws and standards for wastewater reuse, the critical water situation suggests the need for further evolution of wastewater reuse standards and related law. Due to the expected rapid growth of treated wastewater supplies, it will be necessary for Jordan to expand the agricultural reuse of wastewater and to enhance industrial and domestic recycling of water in the future. Currently, Jordanian Standards forbid the use of reclaimed water for irrigation of vegetable crops that may be eaten raw like lettuce, tomatoes and onions. In the future, wastewater treatment processes and treated wastewater quality will improve in Jordan and quantities of reclaimed wastewater are likely to grow substantially. Jordan is also making progress in on-farm management of irrigation. Thus, it may be beneficial for Jordan to expand the use of high-quality reclaimed water standard on high-value crops where a good standard of public health can be assured. In the longer term, Jordan’s standards for wastewater treatment may be amended to achieve even greater flexibility to meet specific conditions of effluent reuse and to control the cost of treatment. Such amendments may include suggested ranges of constituent concentrations in standards rather than single maximum value. The increasing value of reclaimed wastewater and the obligation for improved use of this resource is underlined in Jordan's Wastewater Management Policy of 1998 and confirmed in the new policy issued in 2016. In the future, it will be increasingly necessary for wastewater plant designers and planners to carefully consider wastewater reuse as an important part of the planning for wastewater treatment. Thus, concepts for wastewater treatment may be increasingly driven by the need for optimal wastewater reuse. Wastewater treatment plant location, the priority of treatment plant construction, the type of treatment, downstream conveyance and the treatment standard may all be linked to the planned reuse of the water produced. It seems likely, therefore, that the next step will be improved standards and flexible decision-making processes that allow designers to shape the entire wastewater collection, conveyance and treatment design around the anticipated reuse of wastewater.

Treated wastewater quantity
The wastewater quantity flows to treatment plants is about 152 MCM for the year 2015 and it was increased by (6.27%) from the year 2014(142) MCM. Moreover, 70% of wastewater quantity was treated at Sammra T.P. The used quantity of reclaimed water is about (147) MCM for the year 2015[1].In fact, reclaimed water has long been recognized as a valuable resource for use in irrigation and other intended uses and considered as an important water resource according to Jordan Water Strategy issued in the year 1997 and it was confirmed in the strategy issued in 2016. MWI/WAJ has a goal of attaining total water reuse by having highly treated effluent to be used in the planned aspects.

Wastewater reuse
The water reuse policy was launched at the beginning of 1997 and the water reuse has been made an integral part of overall environmental pollution control and water management strategy. Water reuse is now a part of Jordan's overall water resources balance and also a way of protecting water resources, coastal areas and receiving bodies from pollution effects. Planned reclaimed water reuse has been practiced in Jordan and some pilot projects have been launched or are under study for irrigation& other intended use such as south Amman reuse project to irrigate more than (10000000 m^2)[9]. Water reuse programs have been set up and experimental research conducted on several projects and the output coming from these studies improve and confirm the safe use of reclaimed water in the restricted irrigation. The main problem with the use of reclaimed water is the threat to public health, the soil and water resources if reuse is not done carefully. Given the emphasis that Islam, like places on cleanliness, there is also a persistent notion within the region that wastewater reuse is against Islam. However, as noted in Water Management in Islam, published jointly by IDRC-UNU Press (2001)[8], wastewater reuse is permissible for all purposes excluding Wudi, provided that it is treated to the required level of purity for its intended use and does not result in any adverse public health effects. South Amman reuse project is a project constructed by MWI/WAJ in collaboration with private sector. This reuse project is to implement direct reclaimed water reuse to irrigate an area that covers 10000 dunums of land available for irrigation. Reuse projects which have been implemented all over the country reliable, commercially viable, socially acceptable, environmentally sustainable and safe. In doing so, it will demonstrate to decision makers and the public at large that water reuse is an effective, viable and safe component for managing water resources. The reuse program will

work towards a practical approach to reuse of reclaimed water, while incorporating poverty alleviation, economic improvement and long –term project sustainability.

Cost of Treatment

The treatment cost differs from treatment plant to another depending on the type of treatment system. The average cost was (250) fils/m^3 in the year 2015 which is equivalent to (0.35 US $) [10].

How well are we doing?

In Jordan, the government's policy is to achieve and improve wastewater collection, conveyance, treatment, and disposal and reuse systems. WAJ so far has provided the service on sewer and treatment systems, 32 treatment plants exist all over the country working 24 hours a day Therefore, urban sanitation coverage is more than 66% of urban areas and about 62% of the total population and it is planned to raise the percentage to 80% by 2025, [6] and this will improve the sanitation all over the country.

Conclusion

1. Water reclamation and reuse water expanded so rapidly in recent Years. It is a clear indication that the highest level of government in Jordan recognizes the full value of reclaimed wastewater to the overall water resources of the country.
2. Current reclaimed wastewater standards regulate water reuse and environmental discharges to ensure optimal performance of the wastewater treatment plants.
3. Reclaimed water used for restricted irrigation shall be used carefully to control and protect the health and safety of workers and the general public who may be exposed to the water.
4. Planned reuse programs should be created to stop discharging wastewater effluent to streams and catchments areas.
5. There is a need for active and collaborative involvement of another ministries and agencies and public participation to make use of reclaimed wastewater in different aspects.
6. Reclaimed wastewater monitoring program should be implemented according to standard 893/2006 from both the regulatory body and the operational agency.
7. There is a need to conduct research projects based on actual uses of reclaimed water.
8. Continuous public awareness programs should be implemented all over the country to ensure the safe reuse of reclaimed water and to let the people accept the reuse of reclaimed wastewater in irrigation and other uses.
9. Wastewater reuse provides a potential alternative resource for water scarcity in Jordan; in addition, Jordan made significant efforts towards achieving its goal of 100% reuse of reclaimed water.
10. The best performance is noticed in plants that used activated Sludge, Trickling Filter and its poor for WSP.

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Management of Infiltration in the Sewerage Network in the Kingdom of Bahrain

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Abstract
There are multiple critical links between water, sanitation and environmental issues relevant to livelihoods and coastal ecosystems. The acceleration in municipal water demands in the Kingdom of Bahrain, which ultimately results in an increase in the generated sewage flow rates, is considered one of the major challenges facing wastewater management in Kingdom of Bahrain. As such, there was a need to develop a management plan that will conform to the National Planning Development Strategies, and provide a more holistic view of the entire Sanitary Engineering Services in the Kingdom, to ensure that the Sanitary Engineering Services meet the current and future developments till year 2030. Under the conditions of limited infra-structure and treatment capacity, one of the major issues faced in Bahrain that exaggerates the sewage flow rates is the infiltration of shallow waters into the sewage network, which creates the problem of biological and hydraulic loading. Such loading impacts the quality of treated wastewater and eventually reuse as well as the surrounding marine environment due to the carryover volumes that need to be discharged to the sea. The average percentage of the infiltration in the daily flow conveyed to the main Sewage treatment plant in the kingdom (Tubli Water Pollution Control Center; Tubli WPCC), was found to be approximately 50% (NMPSES, 2008), which is a clear indicator of the bad conditions of major parts of the collection network and that the network in several areas is in imminent danger of pipe collapse. It also indicates that these extremely high infiltration rates are one of the main causes of treatment capacity shortages in the kingdom. Therefore, from a management point of view, it will be more cost-effective to reduce the infiltration rate into the collection network than to expand the treatment capacity. Hence rehabilitation of the wastewater collection is imperative. In general, this study presents a comprehensive and integrated assessment of the sewerage infiltration issue in Bahrain, and the proposed programs and measures that have been recommended by the National Strategy Plan for Sanitary Engineering Services (NMPSES) to reduce the infiltration rate and ultimately reduce the environmental and financial implications. Finally, the main results and achievements of the implementation of these programs and measures are summarized.

Keywords: Rehabilitation, CCTV Investigation, Infiltration Rate, Environmental Pollution, Sustainable Water Resources Management.

Introduction

The Kingdom of Bahrain is situated in an extremely arid zone with very limited endowment of freshwater resources. The Kingdom is facing major challenges in securing water supply due to the scarcity of its natural water resources, and non-natural factors such as rapidly rising urbanization and industrialization associated with its socio-economic developments.

During the past four decades rapid population and urbanization growth resulting from accelerating socio-economic developments has dramatically increased water demands, which has placed ever-increasing pressures on the water authority in the kingdom. The water resources in the kingdom are suffering from the large stresses because of the increasing pressure imposed upon them to meet the requirements of socio-economic development activities, which exceed the capacity of these limited resources, in addition to the inefficient use of water by different consuming sectors, and decreasing water supplies due to deterioration of groundwater quality. Increased water use will put stress on water and wastewater infrastructures, and additional investments in water and wastewater infrastructures will burden the national budget especially in a country with limited financial resources like Bahrain.

There are important links between water and sanitation and the environmental issues within a sustainable livelihood context. This offers opportunities to address policies and targets from both the water and sanitation, and environmental perspectives, particularly in coastal areas. In order to manage coastal and marine environments, sanitation must be improved and integrated with appropriate water supply and wastewater management.

The developments and therefore the bulk of sanitary services for the Kingdom of Bahrain have been concentrated in the northern half of Bahrain. The population of the Kingdom of Bahrain has grown significantly over the last 20 years. The Central Information Organization (CIO) has recently revised its population figures estimating the present population in the Kingdom of Bahrain to be approximately 1.36 million (Year 2015). With this, the country has reached its planning horizon for the year 2030, which was stipulated in the National Planning Development Strategies (2007).

The status of sanitation coverage conducted by the Sanitary Engineering Affairs concluded that approximately 90% of the population of Bahrain is connected to a sanitary sewer (SEA, 2015). A comprehensive sewerage networks have been constructed in the densely populated areas of the Island. The most densely populated areas of Manama and Muharraq are connected to the oldest networks of the Island. Looking at the sanitation coverage between 1985 and 2015, there has been a marked increase in the number of people across country that having access to sanitation. Thus the trend of the rising population must be taken into consideration while setting targets for sanitation coverage.

Existing Sanitary Infrastructure and status

An analysis of the available data shows that the construction of new sewers has been somewhat steady since the late 1970s. In a first wave of sewerage construction approximately 29% of the network was built by 1985. The remainder of the network was continuously expanded since then, with 21% built between 1992 and 1997. Expansion work never focused on a single area but was rather spread throughout the Island (Sanitary Engineering Affair, Ministry of work, 2008). The existing wastewater infrastructure is already being operated well beyond their capacities and this is compounded by the fact that the rate of urban development is dramatically increases and is expected to continue to increase at a rapid rate. The capital investment in the wastewater infrastructure will be limited for some years due to the lack of financial resources.

The sewerage system collects raw sewage from households and different establishments and transports it to the wastewater treatment plant. The sewerage systems were built as conventional gravity flow systems with intermittent lift stations to limit the system depth to approximately 7 m. The lack of slope, high groundwater tables, high salinity of the groundwater and raw sewage and the climatic conditions result in excessive deterioration of pipes and installations. This results in poor services and relatively high maintenance expenditures.

As an indicator of the present operational capacity of the foul system in the kingdom, an accounting of the current sanitation system is presented. The average daily flows received by the wastewater treatment plants are in the order of 310,000 m³/d for Tubli sewage treatment plant, 75,000 m³/d for Muharraq sewage treatment plant, and 13,102 m³/d for Sitra sewage treatment plant, representing a hydraulic overload at Tubli sewage treatment plant of 55% with respect to the original design value (200,000 m³/d). The conveyance systems, which are designed to deliver these original design flows to the plant, are similarly affected. Many pumping stations are performing below their design capacity (or are occasionally operated at less than full capacity in order to balance the flow to treatment to reduce the peak flows at the plant). This causes high water levels in the system and thus deposition of solids, which leads to odour problems and other operational problems. On the other end, the treatment plants are expected to treat the incoming sewage in an efficient way to protect the system from flooding and the environment from hazardous substances, as well as to utilize the effluent and sludge produced. The very large number of pumping stations in the system is a matter of concern. They are a strategic weak point in any system and under-performance of these pumping stations leads to surcharging of the sewers in many areas. Elimination of pumping stations, which will lead to less operation and maintenance, wherever possible, was therefore desirable.

In general, the sewers and pumping stations are serviceable but are under-capacity. The operation and maintenance equipment at many pumping stations is old and in need of replacement to bring them back to full design capacity. However, the loads on the systems are now greater than they were designed to convey, with the consequence that many main sewers are flowing surcharged for large parts of the day. The bulk of the available storage capacity in them (the 30% ventilation space) has been taken up and the only remaining reserve is the small amount of storage volume in the manholes, beside that the rehabilitation works will have further reduced the capacity of the systems.

CCTV surveys have been conducted sporadically throughout several parts of the Island to show the condition of the sewerage network. However, to gauge the condition of the remaining parts of the network, indicator parameters, like, amongst others, high groundwater infiltration rates, amount of silt collected in the system, etc. can be utilized. Based on NMPSES analysis, in the year 2008 the average infiltration rate of the average daily flow conveyed to the Tubli WPCC was found to be approximately 50%. This is a clear indicator that some major parts of the network are in bad condition and show that the pipe network in several areas is in imminent danger of pipe collapse. The areas with the highest infiltration rates, with significant siltation problems and damage visible in CCTV surveys, need to be rehabilitated first and must be classified with the highest importance.

Sewerage Networks Infiltration

Infiltration is the most important factor indicating that pipes or joints are damaged and malfunctioning. Virtually every sewer system has some degree of infiltration. Infiltration has strong impacts on the entire sewerage network, like hydraulic overloading of the network and STPs, prolonged runtimes of pumping stations, negative impacts on biological treatment due to salinity and dilution of the wastewater, public dangers due to the likelihood of road collapses (penetration of surrounding ground), and escalating costs due to the above mentioned aspects. Even where a system is not suffering from sanitary sewer overflows, systems experiencing surcharging may be good candidates for further infiltration investigation, as are systems where significant new growth is expected and existing collection system capacity may be inadequate or marginal for handling an additional flow.

As collection system capacity problems may indicate excessive inflow, the same can be said for treatment plant capacity problems. Sewers and treatment facilities are designed around expected average and maximum flows. Excess groundwater entering the sewer system through infiltration robs the system of its valuable capacity, puts a burden on operation and maintenance, and reduces the life expectancy of the treatment facility. Sewer surcharging, back-ups and overflows all require emergency response and contribute to disruption of operations.

The measurements of day and night flows as an indicator for infiltration are easy to handle, economic, reliable and fast to achieve. Hence, the night-time flow minima were reviewed in relation to the groundwater levels and the nature of the dischargers within the areas. According to the network (catchment area, length, population) upstream of the pumping stations, the infiltration rate was determined.

Groundwater Infiltration

Aquifers are sub-surface groundwater areas, which can influence the sewerage system by means of infiltration. They also permit the infiltration of groundwater into the conveyance system, or ex-filtration of sewage from the conveyance system, depending on the hydraulic gradient. Since the conveyance system is sloped, depth and therefore the hydraulic gradient increase in the downstream direction following the system. Therefore, infiltration rates increase at greater depths.

Shallow groundwater is the main source of infiltration. However, other sources with a continuous discharge are also accounted as infiltration. Other sources of infiltration might be for example dewatering at construction sites, industrial discharges of ongoing process water streams, process water from sand washing, leakage of toilet water, etc.

The measured infiltration rate in sewerage networks in 2008 was found to be roughly 142,000 m^3/d, which amounts to approximately 49% of the total average daily flow, measured as 289,500 m^3/d. Infiltration rates of more than 50% have been measured in parts of the sewerage network such as Manama and Muharraq. Figure (1) shows the incoming flow to Tubli Sewage Treatment Plant (the main sewage treatment plant in the Kingdom). It indicates that the infiltration rates are extremely high and are the main sources causing capacity shortages throughout the Island. The A network (Manama Area) and B network (Muharraq Area), which are in large parts the oldest sewerage networks of Bahrain, show the highest infiltration rates in access of 50%. The D Network (Isa Town Area) and the E-F Network (Hamad Town and Budaiya Highway Areas (North and North Western Area)) also have total infiltration rates in excess of 40%. Only the C Network (Bilad Al Qadeem & Jidhafs Areas) and R Network (Isa Town, JidAli and Tubli Areas) show infiltration rates below 40%. Figure (2) depicts the location Network areas and the existing STPs in the kingdom of Bahrain. In order to reduce these infiltration rates, significant rehabilitation measures are required, and in order to locate and define the source of the infiltration, CCTV survey is required.

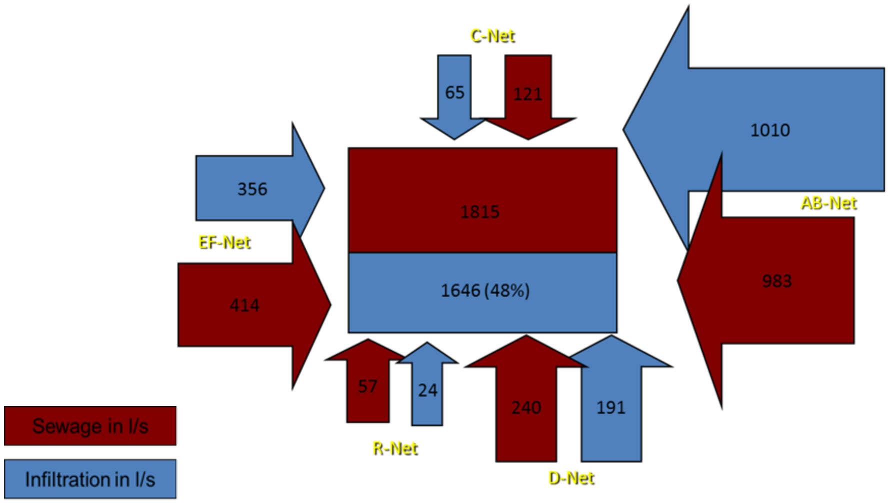

Figure 1: Incoming Flows to Tubli STP in year 2008

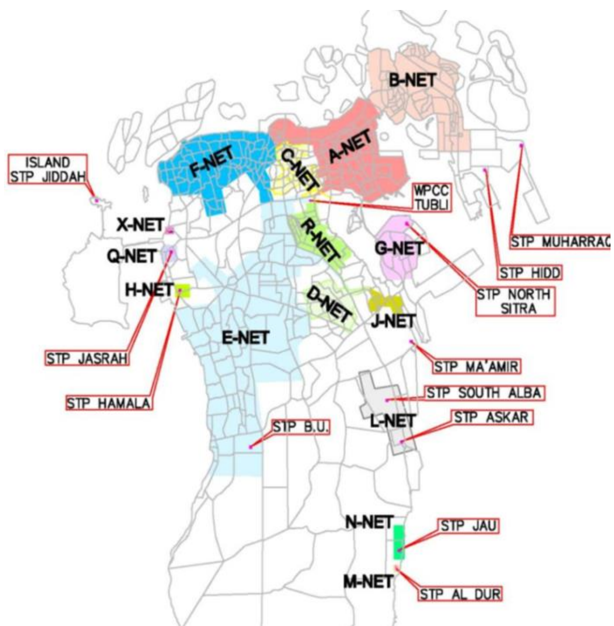

Figure 2: Sewerage Networks Areas

The infiltration rate was calculated as average flow per capita per day. An acceptable infiltration rate would be around 15-30% of the average daily wastewater generation rate (NMPSES, 2008). To reduce the infiltration rate with minimum efforts, a correlation to the length of the network is necessary. The measured infiltration rates have been correlated with the lengths of the corresponding network, upstream of the respective pumping station. These specific infiltration rates (l/s/km) are the best indicator for the extent of the damage in the respective network (High Infiltration rate > 3 l/s/km, Low Infiltration rate < 2 l/s/km). The result of the flow survey shows that about 700 km of the networks have infiltration problems.

Flow measurements at various locations in Bahrain revealed heavy surcharged sewer trunks with high infiltration rates. Infiltrations rates up to 57% (Muharraq) and in average of 50% for whole of Bahrain are common. The flow data analysis has shown that the sewage network is in critical condition, the measured peak flows exceed the capacity at several pumping stations, critical surcharge conditions exist throughout several large areas, and the capacities of the main lines are at limit. Two important factors aggravating these conditions are the very high infiltration rates and the resulting very large volumes of silt carried through the system, which results in excessive wear and tear on the installed pumps.

The main measures to improve the performance of the system are first and foremost to reduce the number of damaged pipes and secondly to ensure that damaged pumps are replaced immediately and installed with the original design capacity. Where capacity shortages exist, the pumps should be upgraded to increase the overall station capacity. Repairs will reduce infiltration rates, which will free up much needed capacity and release the pressure on the pumping stations. A reduction in infiltration will also reduce the amount of silt within the system thus improving the performance of the pumps installed.

A well-established sewer system infrastructure management programs that will maintain the sewerage networks in a state of good repair is a must. The main objective of the sewerage management programs is to ensure the sustainability of the collection system so that expensive repair and rehabilitation is not deferred to future generations.

Reasons for the high infiltration rates, proposal for the future

The available and analyzed CCTV film shows that most of the damages in the sewer networks are cracks and broken fragments which lead to high infiltration rates. The possible reasons for cracks during the life cycle of a given pipe are, but not limited to, manufacturers guidelines have not been followed correctly, unknown or insufficiently known ground and groundwater conditions, improper structural trench design and pipe selection, wrong bedding materials, wrong equipment (e.g. pate compactor), unaccounted for parameters such as traffic, chemical influences, end proof connection of pipe, insufficient bearing/bedding of the pipe, especially at connections, unknown characteristics of the discharge, hydraulic overloads, insufficient or incorrect maintenance (e.g. jet cleaning with the wrong pressure), and large amount of settling especially in reclaimed areas.

Rehabilitation Program

The Nation Master Plan from Sanitary Engineering Services (NMPSES) 2008 identified several sewerage network areas with significant groundwater infiltration rate with many having more than 50% infiltration rates. This indicated that large parts of the sewer network are severely damaged. Therefore it is decided to perform extensive CCTV inspection on the existing main sewerage system in connection with successive rehabilitation works. A comprehensive CCTV inspection of 153 km sewerage system in the A, B, C, D, F & R network areas was carried out. The evaluation of the CCTV inspection data confirm the assumption that large parts of the investigated sewerage network area are severely damaged with high infiltration rates. The survey indicated that a total length of 83 km (54.4% of 153 km) required urgent rehabilitation measure. The overall rehabilitation program will be implemented by several phases. Table (1) summarizes the proposed rehabilitation measures to reduce the amount of the infiltration rates.

Table No. 1: Summary of Rehabilitation Measures of Foul Sewerage

Network Area	**Reduction of infiltration**				**Percentage Reduction**
	From		**To**		
	[m³/d]		**[l/s]**		
A-Net	57,000	37,000	650	430	34
B-Net	30,000	18,000	350	210	40
DR-Net	13,000	7,500	147	87	41
E-Net	13,000	8,900	158	104	34
F-Net	11,600	8,600	135	99	27
Total	**124,416**	**80,352**	**1440**	**930**	**35**

Table (2) shows the results of the reduction of infiltration rate in the completed works (Phase 1-3 areas). The completed works is accounted for a total flow of 256.1 l/s or 22,127 m³/d reduction of infiltrate rates. It is predicted that after completing all rehabilitation works (Phase 1-6 areas), the total reduction of infiltrations rates will be 413 l/s or 35,692 m³/d (tables' no. 2 & 3). If the ongoing CCTV investigation defines additional areas which must be rehabilitated, the reduction of infiltration will increase. As a summary, the efficiency of the rehabilitation measures is considered very high and that the total costs of about 16.5 Million BHD were well invested. This shows the short amortization time of only 2.6 years.

Table 2: Results of measured reduction of infiltration rate during the Phase 1-3

Rehabilitation Phase/ Year	Associated Network Area	Infiltration Reduction		Total Reduction	Maintenance & Treatment Cost		Rehab. cost	Amortization
		[l/s]	[m³/d]	[m³/d]	[BHD/m³/d]	[BHD/m³/y]	[BHD]	[BHD]
2011 -2012	Total (A- networks)	31	2,644	4,476	0.5	816,782	1,480,000	1.8
	Total (B- networks)	7	588					
	Total (Q- networks)	14	1,244					
Phase 1 2012-2014	Total (A- networks)	19	1,633	7,975	0.5	1,455,386	3,842,000	2.6
	Total (B- networks)	55	4,787					
	Total (C- networks)	18	1,555					
Phase 2-3 2014-2016	Total (A- networks)	86	7,430	9,677	0.5	1,766,016	4,775,000	2.7
	Total (B- networks)	26	2,246					
Total 1		256	22,127		0.5	4,038,185	10,097,000	2.5

Table 3: Results of expected reduction of infiltration rate during the Phase 4-6

Rehabilitation Phase/ Year	Associated Network Area	Infiltration Reduction		Total Reduction	Maintenance & Treatment Cost		Rehab. cost	Amortization
		[l/s]	[m³/d]	[m³/d]	[BHD/m³/d]	[BHD/m³/y]	[BHD]	[BHD]
Phase 4-5 2015-2016	Total (A- networks)	36	3,110	8,122	0.5	1,482,192	4,050,000	2.7
	Total (B- networks)	16	1,382					
	Total (C- networks)	37	3,197					
	Total (E- networks)	5	432					
Phase 6 2016-2017	Total (B- networks)	50	4,320	5,443	0.5	993,384	2,400,000	2.4
	Total (D- networks)	8	691					
	Total (F- networks)	5	432					
Total 2		157	13,565		0.5	2,475,576	6,450,000	2.6

Anticipated Benefits of the Rehabilitation Program

The operation and maintenance savings associated with wastewater treatment will eventually lead to cost saving of the depreciating sanitary network. The other benefits of the rehabilitation program are reduction of carryover volumes being discharged to the sea, which will help preserve the coastal and marine environment and protect public health and reduce their associated costs. In addition, it is expected that this will lead to more economic activities and investment opportunities by the commercial sector, and improved appreciation of land and property value in the area.

Conclusion and Recommendation

To balance the increase of wastewater discharges due to rapid increase of wastewater flows resulting from major housing developments, a viable and cost-effective measure for the coming years is to reduce the infiltration rates. Therefore, CCTV investigations and rehabilitation of damaged lines are inevitable to reduce groundwater infiltration rates. Much of the sanitary infrastructure is already overloaded and consequently must be reinforced and/or replaced in order to provide adequate capacity for the present and up to the design horizon of 2030. In view of the current situation, and the relatively long-time in procuring the necessary works, it was necessary to consider urgent rehabilitation works that should be executed rapidly in order to improve the situation as soon as possible. Following the NMPSES recommendations, an additional 500 km of the remaining networks must be investigated in the future. A program should be worked out to define needed rehabilitation measures.

Infiltration rate has long been important aspect considered in the design of sewerage systems. In light of this, guidelines for designing the sewerage networks that will take into account the condition of the groundwater, the suitable pipes materials to be adopted to limit amount of infiltration rate in future networks should be develop. Site supervision should be extended to avoid damages caused by improper installation of pipes, bedding materials and joints fixing. Furthermore, the post CCTV inspection is essential and should be carried out after building the sewerage network to investigate the conditions of the pipelines and rectify any damage segment/s to minimize the infiltration rate into sewerage networks in future. It is indispensable to intensify the site supervision and to carry out post CCTV investigations to provide that all conditions of bedding, used materials and leak tightness are according to the specifications.

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