WSTA

8th Gulf Water Conference

3-6 March 2008, Bahrain

"Water in the GCC.....Towards an Optimal Planning and Economic Perspective"

President's Message

Dr. Muhammad F. Al-Rashed
(President, Water Science and Technology Association)

All WSTA previous water conferences were related in a way or another to the GCC countries water issues and problems. The themes of the last seven conferences covered many important and updated subjects within the GCC countries. These conference attracted many water stakeholders including specialists, researchers and decision makers, in addition to the students in different fields of water. During all the Gulf Water conferences there was a good representation of the decision makers, especially, during the late conferences. We are proud in WSTA that many water related decision makers in the GCC countries are members in WSTA board whether previously or currently, also some of them are active members in WSTA.

The 8th Gulf Water Conference comes during an important stage of the GCC water sources. Starting from the higher costs of water production due to many factors; high oil prices; the main energy source for desalination plants, many of these plants reached the end of its live time. Additionally, most of the existing desalination plants need to be developed using more advanced techniques with higher efficiency and lower cost. There is more demand on the available water resources as all the GCC countries compete on economic and social development, which led to higher numbers of expatriates and therefore higher population rates.

Planned and running mega economic and real estate projects all over the GCC countries will cause huge pressure on the water resources. Therefore, it is essential to link between our planning for the water resources and the planned major economic and social developments which will affect all the financial and water resources of the region. This was our motive to select the theme of this conference, in order to concentrate in this issue during the discussion of views and ideas between all sector representatives; decision makers, researchers and specialists and also consumers. International and regional experts will be invited to gain from their experiences, views and ideas.

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Programme Details

Opening Ceremony & Plenary Session Programme
Location: Gulf Convention Centre-Gulf Hotel

FIRST DAY MONADAY 03/03/2008		
09:30-11:00	***Opening Ceremony***	
09:30	*Reading from the Holy Quran*	
09:35	*Speech by* ***H.E. Fahmi Bin Ali Al Jowder*** *Minister of Works & Minister in Charge of Water and Electricity Authority, Kingdom of Bahrain*	
09:50	*Speech by* ***Dr. Mohammed Bin Fahad Al-Rashed*** *President,Water Science and Technology Association*	
10:05	*Speech by* ***Prof. Abdulaziz Bin Sulaiman Al-Turbak*** *Chairman, Scientific Conference Committee*	
10:15-11:00	Exhibition Opening and Refreshments	
11:00-12:30	***Conference Plenary Session***	
11:00-11:20	*Keynote Speech by Dr. Ahmad Ghosn* *U N Environmental Program/ROWA*	
11:20-11:40	*Keynote Speech by Lisa Henthorne* *President IDA*	
11:40-12:00	*Keynote Speech by Prof. Ebrahim Khamis* *International Atomic Energy Agency*	
12:00-12:20	*Keynote Speech by Prof. Paul Hana* *UN Economic & Social Commission for Western Asia BGR/ESCWA*	
12:20-12:30	*Discussion*	
12:30-14:00	Dhohr Prayer and Lunch Break	
14:00-15:00	***Roundtable Discussion on*** **"Localizing and Acquisition of Desalination Technology in the GCC Countries"** *Facilitator: Mr. Ahmed Al Mudaiheem*	***AWARENET Meeting, Facilitator:*** **BGR/ESCWA**

SECOND DAY **TUESDAY 04/03/2008**		
08:20-08:30	**Welcome & Introduction** **Conference Program Outline, Conference Conclusion & Recommendations Committee Meetings, Session Chairmen Roles and Responsibilities** Prof. Abdulaziz S. Al-Turbak, Chairman, Scientific Committee	
08:30-10:20	**Session 2A-1 Water Strategies and National Plans** Location: Hall A	**Session 2B-1 Natural Water Resources** Location: Hall B
	Co-Chairman: Dr. Moh'd Al-Rashed Co-Chairman: Mr. Abdulrahman Al-Mahmoud	Co-Chairman: Prof. Ali Sorman Co-Chairman**:** Prof. Walid Abdulrahman.
08:30-08:50	*Keynote speaker Dr. Ali Al Tokhais on water resources management issues*	*Integrated Groundwater Resources Management in the GCC Countries- A Review, Waleed K Al-Zubari, Kingdom of Bahrain, A/13*
08:50-09:10	*IWRM Strategies and Policies in Oman's National Water Resources Master Plan, Sulaiman bin Said Al Obaidani, Sultanate of Oman, A/11*	*Three-Dimensional Geological and Groundwater Flow Modeling of Drought Impact and Recharge Potentiality in Khatt Springs Area, Ras Al Khaimah Emirates, UAE, P. Wycisk, et al., Germany, C/12*
09:10-09:30	وإدارة الموارد المائية بتونس، حليمة مموكم لبان، تونس، *A/2*	*The Expected Effects of Climatic Changes on Water Resources of the Arabian Peninsula, Vincent Kotwicki and Zaher K. Al-Sulaimani, State of Kuwait, C/21*
09:50-10:10	*Development of the Water Resources Management Strategy and policy in Yemen, National Water Sector Strategy and Investment Plan (NWSSIP), Abdulla Noman, Yemen, A/1*	*Application of Aquifer Storage and Recovery System (ASR) for Shallow aquifers in UAE, Asam A. Almulla and Arnaud Levannier, UAE, C/18*
10:10-10:20	*Discussion*	*Discussion*
10:20-10:40	Refreshments Break	
10:40-12:10	**Session 2A-2 cont., Water Strategies and National Plans** Location: Hall A	**Session 2B-2 cont., Natural Water Resources** Location: Hall B
	Co-Chairman: Dr. Ahmad Ghosn Co-Chairman**:** Dr. Saleh Al-Mogrin	Co-Chairman: Mr. Abdullateef Al-Mogrin Co-Chairman: Dr. Waleed Al-Zubari
10:40-11:00	*Present and Future Water Supply and Demand in Saudi Arabia, Abdulaziz S. Al-Turbak, Saudi Arabia, A/6*	هٍ المياه الجوفية في دولة قطر، طارق موسى الزدجالي، دولة قطر، *C/1*
11:00-11:20	*Water and Territorial Planning Strategy in Algeria, N. Aroua and E. Berezowska-Azzag, Algeria, A/4*	*Natural Radioactivity Levels for Groundwater in Al Hassa, KSA, A.M Assafarjalani, Yousef Al-Dakheel and A.S. El Mahmoudi, Saudi Arabia, C/8*
11:20-11:40	*An Expert System Proto-type in Integrated Water Resource Management Plan (IWRMP), Abdulbaqi Al-Khabouri, Sultanate of Oman, A/12*	*Integrated Concept for Groundwater Evaluation and Protection -Barka Catchment (Oman) as Case Study", Ahmed Al-Futaisi, Natarajan Rajmohan, and Said Al-Touqi, Sultanate of Oman, C/20*

11:40-12:00	الموارد المائية البديلة في المملكة إبراهيم محمد علي الفقي وحصويك العربية السعودية، A/5 العربية السعودية، سيف السيف، المملكة	*An Advanced Technology for Groundwater Treatment in the Northern Aquifer of the State of Qatar, Ahmed Abdel-Wahab, Kamel Amer and Mohamed Shamrukh, State of Qatar, C/2*
12:00-12:10	*Discussion*	*Discussion*
12:10-13:30	Dhohr Prayer and Lunch Break	
13:30-15:30	**Session 2A-3 Water Resources**	**Session 2B-3 Public Awareness,**
	Management Location: Hall A	**Conservation and Capacity Building** Location: Hall B
	Co-Chairman: Dr. Moh'd Abdulrazzak Co-Chairman: Dr. Mubarak Al-Noaimi	Co-Chairman: Dr. Asma Aba Hussain Co-Chairman: Mr. Ali Redha
13:30-13:50	*Management of Groundwater in Greater Dammam- Metropolitan Area, Walid A. Abderrahman, Abdalla S. Elamin, Ibrahim M. Al-Harazin, and Badie S. Eqnaibi, Saudi Arabia, C/16*	*Outlines for Water Saving Practices in Kuwait, M. Al-Senafy, A. Al-Khalid, A. Mukhopadhyay and K. Al-Fahad, State of Kuwait, E/1*
13:50-14:10	*Groundwater Management in Sana'a Basin – Republic of Yemen, Mansour Haidera and Abdulla Noaman, Yemen, C/13*	*Community Involvement as a Tool for Integrated Water Resources Management in Greywater Use for the Middle East and North Africa Region, by Shihab Najib Al-Beiruti, Jordan, E/3*
14:10-14:30	*Towards Sustainable Management of Jerash Watershed- The SMAP Project, Walid Saleh and Anan Jayyousi, UAE, C/23*	*Assessment of Rainwater and Run-off Quality from Government Buildings, Kuwait, by A. Al-Haddad, T. Rashid, E. Ebrahim, M. Farhan, F. Marzouk and H. Bhandary, State of Kuwait, C/10*
14:30-14:50	*Application of 2D Earth Resistivity Imaging Tomography and GIS for the Sustainable Management of Water Resources in Northern Emirates, UAE, S. F. Akram, M. M. Al Mulla N. B. Al Suwaidi, A.S. Al Matari, A.M. Ebraheem, and A. Shetty, UAE, C/5*	*Modern Piping Solution – Conserving The Environment For The Future, by Wolfgang Ronfeldt, Georg fischer Piping System, Germany.*
14:50-15:10	*The Water Crisis in the Gulf Area: Seawater Desalination a Path to a Partial Solution, Ehab Sadek Taha, Saudi Arabia, D/22*	
1510-15:30	*Discussion*	*Discussion*
15:30-17:00	**WSTA General Assembly & Elections**	
20:00-22:00	**Conference Gala Dinner (Gulf Hotel)**	

THIRD DAY WEDNESDAY 05/03/2008		
08:30-10:00	**Session 3A-1 Water Economics and Finance** Location: Hall A	**Session 3B-1 Natural Water Resources (2)** Location: Hall B
	Co-Chairman: Prof. A. Aziz Al-Turbak Co-Chairman: Mr. Moh'd Al-Asam	Co-Chairman: Dr. Meshaan Al-Otaibi Chairman: Dr. Ahmed Al-Futaisi
08:30-08:50	*Keynote speaker, Dr. Loui Al Musalem on Water Financing*	*Wadi System Components in the Arab Region & Estimation of Actual Evaporation, Transmission Losses and Groundwater Recharge, Ali. U. Sorman, Turkey*
08:50-09:10	*Groundwater Demand Management: An Electricity Quota Approach, Slim ZEKRI, Sultanate of Oman, B/4*	*Maintenance Works of Water Structures, Aflaj Challenges in the Sultanate of Oman, Zaher bin khaled al-Sulaimani, Hamad bin Khamis Al Hatmi, Seif bin*
		Sulaiman Al Amri and Tariq Helmi, Sultanate of Oman, C/9
09:10-09:30	*Water Pricing Reform for the Kingdom of Saudi Arabia, Saleh Al-Mogrin, Saudi Arabia, B/3*	*Assessment of Groundwater Recharge in some Wadis by Using Different Isotope Methods in UAE, by Ahmed Saif Almatri, UAE, C/4*
09:30-09:50	*Affordability of Household Water and Sewerage Services in Waitakere City - A Case Study, Mahmood, B. and Jing H., New Zealand, B/5*	*3-D Characterization of the Complexity of Groundwater Alluvial Aquifer Systems using Geophysical Logging and Geostatistical Analysis in Arid Region, Mohamed A. Dawoud and Ahmed H. Al Muaini, UAE, C/19*
09:50-10:00	*Discussion*	*Discussion*
10:00-10:30	Refreshments Break	
10:30-12:10	**Session 3A-2 cont ., Water Economics and Finance** Location: Hall A	**Session 3B-2 cont., Natural Water Resources (2)** Location: Hall B
	Co-Chairman: Mr. Zaher Al-Sulaimani Co-Chairman: Dr. Adel Bushnak	Co-Chairman: Dr. Sabah Al Jenaid Co-Chairman: Dr. Yousif Al-Remaikhani
10:30-10:50	*Trends of Investment Costs in Irrigation: A Focus on the MENA Region, by Maher Salman. Jean-Marc Faure, Philip J Riddell, Morten Frederikson and Claudia Casarotto, Italy, B/6*	*Electrical Resistivity Imaging of Quaternary Aquifer at Wadi Muraykhat and Wadi Sa'a, Al Ain Area, UAE, Ahmed S. El Mahmoudi, (UAE), C/14*

11:10-11:30	*Optimizing the Water Allocation System at Jordan Valley through adopting WEAP Model with emphasis on Financial and Economic implications", Dr. Iyad Hussein, Jordan, B/7*	*Submarine Groundwater Discharge: The Phenomenon, its Implications and Initial Assessments at Kuwait Bay, A. Fadlemawla, M. Al Senafy, A. Al-Khalid, H. Bhandary, and A. Mukhopadhyay, State of Kuwait, C/24*
11:30-11:50	*Economic and Engineering Optimization for Groundwater Assessment, Use and Management in Agriculture Sector in GCC Countries", by Mohamed A. Dawoud, UAE, B/2*	*Crossing the Threshold of a Higher Order Urban Groundwater Level Forecast, by Jaber Almedeij, State of Kuwait, C/22*
11:50-12:10	خطط تقطير المياه في تلبية احتياجات البدلية والتقييم البيئي له، دراسة محمد الكندري، دولة الموارد المائية حالة– دولة الكويت، سميرة كويت، *D/21*	*Density-Dependent Flow and Transport Model of A Carbonate Aquifer, Mohammad Makkawi, Saudi Arabia, C/3*
12:10-12:30	*Discussion*	*Discussion*
12:30-13:30	Dhohr Prayer and Lunch Break	
13:30-14:40	**Session 3A-3 Desalination Water** Location: Hall A	**Session 3B-3 Water Treatment and Reuse** Location: Hall B
	Co-Chairman: Dr. Abdulla Al-Shaikh Co-Chairman: Dr. Nader Al-Bastaki	Co-Chairman: Mr. Khalifa Almansoor Co-Chairman: Dr. Abdulrahman Buali
13:30-13:50	*Enhancing the Part Load Operational Performance of MSF Desalination Plants, Hassan E. S. Fath and Mohamed A. Ismail, Egypt, D/3*	*Policy Guidelines, Regulations and Standards of Wastewater Treatment and Reuse in Jordan", Ahmed A. Uleimat, Jordan, D/5*
13:50-14:10	*Contribution of Large Scale Desalination Facilities in Integrated Coastal Zone Management, by Khaled A. Mohamed, (UAE), D/16*	*Virus Removal from Tertiary Treated Wastewater using Dune Soil Columns in Kuwait, A. Al-Haddad, H. Al-Qallaf, H. Bhandary, B. Al-Salman and H. Naseeb, State of Kuwait, D/6*
14:30-14:50	*Material Selection and Stress-Induced Corrosion in Desalination and Power Plants", Anees U. Malik and Ismael Andijani, Saudi Arabia, D/17*	*Evaluating Different Types of Irrigation Water and Its Effect on the Level of Heavy Metals in Soil and Plants in Al-Hassa Oasis, KSA, A.H.A. Hussein, Y.Y. Al-Dakheel, M.A. Massoud and M. Shahin, Saudi Arabia, D/11*
14:50-15:10	*Performance of a Domestic Membrane Bioreactor Unit, by Abdulrahman Buali Kingdom of Bahrain, D/18*	تخطيط ومعالجة مطلقات المياه الصناعية في لمحطات الكهروحرارية بـمدينة بغداد الكبرى، محمد يوسف حاجم الهيتي، العراق، *D/12*
15:10-15:30	*Analysis of the Operation and Maintenance of RO and ST Plants Installed in One of the Government Referral Hospitals in Sultanate of Oman, Ali Al Alawi, M. Ramaswamy and Farooq Aljahwari, Sultanate of Oman, D/15*	*Alansab MBR STP: Step Towards Greener Muscat, M. S. Alhakawati, K. Al Badi, H. Al Jabri and Omar Al Waihabi, Sultanate of Oman, D/14*

15:30-15:40	*Discussion*	*Discussion*
15:40-16:30	**Session 4-4 Conference Conclusion and Recommendation** Location: Main Conference Hall	
	Co-Chairman: Dr. Abdulmajeed A. Alawadhi, Conference Co-Chairman Co-Chairman: Dr. Mohammed F. Al-Rashid, Conference Co-Chairman Raporteur: Prof. Abdulaziz S. Al-Tubak, Scientific Committee Chairman	

Development of the Water Resources Management Strategy and policy in Yemen, National Water Sector Strategy and Investment Plan (NWSSIP)

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Abstract

Yemen is facing one of the most complex development problems and its most serious challenge, namely: the problem of water resources scarcity and over-exploited aquifers. As a result, the water shortage is worsening one year after another, aggravated by the continued imbalance between annual recharge and the growing water demand. This has led to the alarming depletion of groundwater in a number of basins, wiping out agricultural production and investments in some of these areas.

Integrated water resources management (IWRM) is generally seen as a solution to water management problems. In Europe, the European Water Framework Directive is a means to implement IWRM in order to improve the water quality of surface waters. In the water-scarce Republic of Yemen, IWRM is seen as a method to improve water use and thus to better balance water supply and demand. IWRM should, however, not be seen as a magic solution that creates more water.

This paper highlighted on the status of water resources and management in Yemen and implementation of IWRM approaches through a National Water Sector Strategy and Investment Plan (NWSSIP), which aims at streamlining the strategies and investments in all water related issues in the Republic of Yemen.

Key words IWRM; Yemen; NWSSIP**,** Strategy -Sana'a University, Faculty of engineering -Yemen Republic. P.O.Box 14469
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1- INTRODUCTION

Yemen, with a total area estimated at 527 970 km^2, is located on the south-western edge of the Arabian Peninsula. The total population is 19.5 million, of which 66 % is rural. The average demographic growth rate is estimated at 3.7%, which is very high [1].

Yemen's total annually renewable water resources are estimated at 2. 5 billion cubic meters (cm), this amount to little more than 128 m^3 per person each year, compared with the Middle East and North Africa average of 1250 m^3 per person each year [21]. The problem in Yemen is made more acute by the fact that water resources are unevenly distributed and that 90% of the population has under 90 m3 per year (m^3 a^{-1}) annually for domestic uses (10% below the worldwide norm). It is estimated that only 32% of the population have access to mains water supply and only 21% to safe sanitation. In general, all surface water resources are harnessed and exploited, and in most areas groundwater (which accounts for 60% of the country's renewable resources) is already being exploited beyond the level of recharge [3]. This very rapid development has brought with it major problems. Groundwater is being mined at such a rate that parts of the rural economy could disappear within a generation. There are thought to be about 70,000 private wells in the country and about 200 drilling rigs. Areas of the country under greatest pressure are the central highlands, western escarpment and coastal plains, where most of the population is concentrated. In the Sana'a basin, where 10% of the population lives, it was estimated in the mid—1990s that water extraction (224 million cm) exceeded the level of recharge (42 million cm) by over 400% [4]. Groundwater is expected to be pumped dry in the Sana'a basin within the next decade. In Amran water levels have dropped 60 meters during the last twenty years — 30 meters in the last five years. Meanwhile by 2005, consumer demand in the country is expected to rise to 3.42 billion cm, posing a shortfall of 920 million m^3 [5].

2-THE PROBLEMS OF THE WATER SECTOR

Yemen is facing one of the most complex development problems and its most serious challenge, namely: the problem of water resources scarcity and over-exploited aquifers. As a result, the water shortage is worsening one year after another, aggravated by the continued imbalance between annual recharge and the growing water demand. This has led to the alarming depletion of groundwater in a number of basins, wiping out agricultural production and investments in some of these areas. This water reality imposes on the country the challenge of reducing the existing unsustainable use of water resources through improved management and better planning for its rational utilization, and the challenge of providing safe drinking water and sanitation service to the great majority of urban and rural populations who still lack such services (it is estimated that 32% of the population have access to public drinking water systems and 21% have access to public sanitation networks) [6]. The importance of water, not only for drinking and food production, but also as a basis for sustainable development is well known, particularly in view of the strong linkages between water availability on the one hand and public health, unemployment, poverty, girls' education, and socio-economic development in general on the other.

3-REFORMS TO DATE

Since the mid-1990s, Yemen has embarked on courageous reforms in the water sector, including the creation of NWRA and MWE; a successful reform program in the urban water and sanitation sub-sector and establishing the AFPPF to increase rural productivity, to fund various water structures to provide farmers with more water, and to improve water use productivity (or return from water). However, the deteriorating condition of groundwater aquifers, as a result of overdraft, is still continuing, and population growth is faster than the rate of building new water supply schemes. This highlights the importance of concentrating efforts on water demand management to rationalize water use.

4-NATIONAL WATER SECTOR STRATEGY AND INVESTMENT PLAN (NWSSIP)

Following reorganization of the water sector in 2003, the MWE initiated a multi-stakeholder process of preparing a consolidated strategy, action plan and investment program for the water sector as a whole – the National Water Sector Strategy and Investment Program (NWSSIP).This strategy proposes a set of institutional, financial and other measures, which aim at addressing discrepancies in the five sub-sectors in order to protect the interests of all stakeholders in the resources.

4.1-Proposed Objectives and Policies of NWSSIP

4.1.1 Sector Management and Coordination

NWSSIP sets four objectives for sector management, namely: 1) to ensure coordination among all partners working in urban and rural water supply and sanitation sub-sectors, within and outside the MWE, to ascertain that policies in each of these two sub-sectors are unified and that investments are equitably allocated among governorates according to unified rules and that no projects are duplicated, especially in rural areas, so as to ensure that investments complement each other; 2) to ascertain integration of water policies and national policies of sustainable growth and poverty reduction; 3) to ensure that sector financing effectively supports sector goals; and 4) to monitor and evaluate performance. To achieve these objectives, NWSSIP proposes three policies, namely: 1) giving immediate priority to defining and implementing the strategy, investment program and action plan; 2) to organize the institutional and administrative setup of sector institutions and to ensure that they are properly functioning and managed; and 3) to ensure that cross-cutting issues are being dealt with in an integrated manner (funding, community contribution, tariffs, training, etc).

4.1.2Water Resources Management

The following five water resources management objectives were set by NWSSIP; namely: 1) to ensure greater degree of sustainability; 2) giving priority to domestic needs of rural and urban populations; 3) improved water allocation, while mindful of equity, social norms, meeting the domestic needs and maximizing economic benefits; 4) creating a realistic and holistic water vision among the general population; and 5) contributing to poverty alleviation by promoting efficient water use and equity in water allocation.

To implement these objectives, NWSSIP adopted a set of policies, bringing into attention that the exhaustion and pollution of aquifers beyond possibility of recovery, will amplify (among an increasing numbers of the population) the feeling of inequity in access to water. This may potentially lead to intensified social tensions. Hence, the government has to provide suitable institutional interventions, particularly through forging of partnerships with local communities for co-management of water basins.

4.1.3 Urban Water Supply and Sanitation

NWSSIP adopted the same objectives as those of the WSS Sector Reform Program set out in Cabinet resolution (237/ 1999), namely: 1) to increase coverage by WSS services (the goal here is to meet the MDGs, which translates to providing services to more than 4 million inhabitants by 2015); 2) financial sustainability of WSS utilities; 3) separation of sector regulatory and executive functions; 4) decentralization of WSS service provision; 5) knowledge and skills development; and 6) involvement of the private sector.

To achieve these objectives, NWSSIP adopted the policy of progressively decentralizing responsibility for service provision, by continuing the current WSS Sector Reform Program, 1) transforming more of NWSA branches to autonomous local corporations (at the governorate level); 2) consolidating the autonomy of existing local corporations; 3) reformulating the role of NWSA to progressively undertake a regulatory, monitoring, supporting and policy making role; 4) and promoting a wider private sector and community role in sector funding and management.

4.1.4 Rural Water Supply and Sanitation

NWSSIP adopted an overall objective for rural WSS sector, namely: the rapid expansion in WSS services in rural areas (a realistic and more modest objective of achieving "half the MDGs" was set). This means providing services to more than 5 million inhabitants by 2015, and facing the main challenge in this sector, namely: how best to ensure sustainability of implemented schemes?. A sector review is underway and is expected to produce within 2004/2005 a sector strategy, a restructuring plan, and an investment program. However, the major policy issues of this sector include 1) adoption of decentralized implementation mechanisms; 2) enhancement of beneficiary community role; 3) adopting a demand responsive approach (DRA) to identify targeted communities and making this approach the standard practice; and 4) targeting and cost effectiveness, by identifying means to implement projects that meet the needs at lower cost.

4.1.5 Irrigation and Watershed Management

Within the overall objective of improving the well-being of the rural population, by increasing farmers' income, contributing to poverty alleviation and making the added value in the sector sustainable; the specific objectives for irrigation and watershed management are: 1) sustainability through water resources protection and reduction of groundwater extraction; 2) improving farmers' incomes through increased water use efficiency; 3) enhancing water supplies; and 4) improving institutional performance with the aim of supporting the farmers. The adopted policies include promoting 1) water use efficiency, producing more crop per drop; 2) improving water supplies; and 3) giving a wider role for local communities and water user associations (WUAs).

4.1.6 Human and Environmental Aspects

Objectives at the human level are to ensure equitable access to water and efficient use. At the environmental level, the objective is to ensure sustainability both in quantity and quality of natural resources in general and water resources in particular.

Policy issues include 1) expanding coverage with WSS services, while giving priority to the poor communities, which is an implicit policy since Yemen has adopted the WSS goals of the MDGs and incorporated them as a major objective of PRS); and 2) preventing environmental degradation to avoid its profound negative impact on poverty.

4.1.7 Existing Investments in the Sector

NWSSIP has clearly revealed the inadequacies in investment financing in the five water and environment sub-sectors as well as the imbalances among them. Per capita share of available funds for the next five years (2005-2009) is $129.00 for urban WSS projects, $13.00 for rural WSS projects, $8.00 for irrigation projects, approximately $1.33 for water resources management, and $0.10 for environmental aspects. What is needed is to raise the per capita share during the five years (2005-09) in these five sub-sectors to $ 160.00, $32.00, $13.00, $2.35, and $1.00; respectively.

4.2 Implementation of NWSSIP

The NWSSIP investment program (2005-9) totals about $ 1.54 billion, of which almost $ 1 billion is already committed/pipelined by government and donors. The estimated financing gap at present is about $ 560 million (see table below).

NWSSIP will be a rolling program, updated periodically and with provision for monitoring, benchmarking and donor coordination. It is intended to be a comprehensive agreement between all stakeholders in the water and environment sector.

5. CONCLUSIONS

Considering current status and trends of water resources in Yemen and the influences of driving forces, and evolution of the balance between available water resources and water demand in the direction of a state of high water stress as indicated by availability and sustainability indicators, the following conclusions could be obtained:

1. Considering the importance of water as a corner stone in social and economic stability and security and the importance of achieving water resources sustainability,
2. Being aware of the growing water scarcity faced by most Yemeni cities and rural areas as a result of continued irrational water use,
3. The importance of enforcing the Water Law, especially with respect to licensing of water well drilling, water planning and environmental monitoring,
4. Rationalization of water use in cities through adoption of an awareness campaign by the water utilities and through promotion of water saving devices,
5. Improve the work conditions of technical and administrative staff in the sector and give capacity building more attention,
6. A demand-orientated approach should be considered as an important element in water resource management,
7. Economic and financial incentives should be considered seriously in water management and pollution control. Pricing could play an important role in demand reduction and pollution prevention,
8. Sustainable use of scarce water resources should be included in the regional and national economic and social development plans and strategies,
9. The need to establish a financing mechanism for the water sector, not only to attract more donor funding, grants and loans but also to coordinate and prioritize projects and to remove distortions in sub-sectoral funding.

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التحكم و إدارة الموارد المائية بتونس

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الملخص:
تقدر الموارد السطحية بحوالي 2500 مليون م^3 /السنة. أما الموارد المائية الجوفية فهي تقدّر بحوالي 2140 مليون م^3 /السنة. تتم تعبئة المياه السطحية عن طريق سدود التخزين والتحويل وكذلك الضخ مباشرة من مجاري الأودية وقد سمحت خطة تعبئة الموارد المائية من سنة 1990-2001 من تعبئة الموارد المائية بنسبة 90% أما الخطة العشرية الثانية والتي تتواصل من 2002-2011 فهي تهدف إلى تعبئة حوالي ما يقارب عن 95% من الموارد مما يساعد من تثمين مياه السنوات الممطرة لبلوغ المزيد من الأمن المائي و خاصة في السنوات الصعبة قصد تأمين التزويد بمياه الشرب و ضمان مياه الري للمناطق السقوية. أما المياه الجوفية فقد وقع تعبئة حوالي 117% من المياه القليلة العمق بواسطة الآبار السطحية و حوالي 81%من المياه الجوفية العميقة بواسطة الآبار العميقة.

كما شهدت المنظومة المائية بتونس تطورا هاما وذلك بالتكثيف في انجاز المنشآت والتجهيزات المائية التي تطورت من 23سدا و 663 سد جبلي سنة 2000 إلى 27 سد و 800 سد جبلي سنة 2005 وأصبحت المنظومة مطالبة أكثر فأكثر بتلبية الحاجيات المتزايدة من المياه التي تطورت من 190 مليون م^3 سنة 2000 إلى 220 مليون م^3 في سنة 2005 بالنسبة لمياه الشرب و التي تزايدت نظر لتزويد المناطق الريفية بالماء الصالح للشرب.
ولمجابهة الاستغلال المكثف للخزانات المائية الجوفية ا

اتخذت العديد من الإجراءات للحدّ من الاستغلال ولتطوير الموارد المائية للخزانات المائية الجوفية المستهدفة. ومن بين هذه الإجراءات:

- إحداث مناطق الصيانة والتحجير للخزانات المائية الجوفية ،
- جلب مياه الشمال من مناطق الشمال الغربي إلى مناطق الشمال الشرقي والوسط،
- التشجيع على الاقتصاد في الماء خاصة في الميدان الفلاحي الذي يعتبر أكبر مستهلك للمياه،
- تطوير الموارد المائية الجوفية بشحن أكبر كمية ممكنة من المياه السطحية والمستعملة المتوفرة والمناسبة.

نظرا لارتفاع الحاجيات المستقبلية نتيجة التزايد السكاني و التوسع العمراني والتطور الاقتصادي للبلاد باعتبار نسق الاستهلاك الحالي للقطاعات المستعملة للمياه فان تلبية هذه الاحتياجات يصبح تحديا من الصعب تخطيه خصوصا أنها تتطلب استثمارات متزايدة لذا تم اللجوء إلى التحكم في الطلب وتنمية الموارد غير التقليدية كإعادة استعمال مياه الصرف وتحلية المياه المالحة والاعتماد على الاقتصاد في المياه وخاصة في قطاع الري باستهلاكه الهام الذي يقدر ب80% من جملة حاجيات القطاعات الأخرى.
كلمات دالة أو فصلية: تونس، الموارد المائية، تعبئة المياه، مياه الشرب، تنمية الموارد، التغذية الاصطناعية،

1-المقدمة

تقع البلاد التونسية شمال القارة الإفريقية ويحدّها من الشمال والشرق البحر الأبيض المتوسط ومن الغرب الجزائر ومن الجنوب الشرقي ليبيا. وتبلغ مساحتها حوالي 000 164 كلم^2 بطول 800 كلم وعرض 200 كلم ويصل طول السواحل على واجهة البحر الأبيض المتوسط إلى 1500 كلم. تتدرج التضاريس بالبلاد التونسية من السهول الساحلية إلى المرتفعات الجبلية الواقعة داخل البلاد، وهي تمتد في شكل سلاسل جبلية تفصلها السهول والمنخفضات السبخية، وتسمى "الشطوط". ويمكن
الشمالي ويتميز بالتضاريس والإلتواءات الجبلية، وأهمها سلسلة الظهيرة التي هي امتداد لجبال الأطلس، و يصل أعلى نقطة بها إلى 1554م (جبل الشعانبي).

- الشمالي ويتميز بالتضاريس والإلتواءات الجبلية، وأهمها سلسلة الظهيرة التي هي امتداد لجبال الأطلس، و يصل أعلى بها إلى 1554م (جبل الشعانبي).
- الجنوبي وهو منطقة سهول (السباسب العليا) وسهول كسهل الجفارة الساحلي، تتخللها بعض المرتفعات كجبال الظاهر وسلسلة جبال ققصة.[1]

2-المناخ

تتوسط البلاد التونسية في أقصى شمال القارة الإفريقية منطقتين ذات مناخين مختلفين تماما: المناخ الصحراوي الجاف من ناحية والمناخ المتوسطي المعتدل من ناحية أخرى أما توزع الأمطار فهو مرتفع في أقصى الشمال حيث يتعدى المعدل السنوي 400 مم ويصل إلى 1500 مم ويتناقص في اتجاه وسط البلاد (300 مم إلى 150 مم) لكي تصبح الأمطار قليلة في الجنوب ولا تتعدى 150 مم/ السنة. وتتوزع هذه الأمطار على أغلب فصول السنة وخاصة الخريف والشتاء والربيع، في حين يتميز الصيف بقلة الأمطار وارتفاع درجة الحرارة. أغلب الأمطار بالبلاد التونسية رعدية ناشئة عن تسرب الهواء البارد الشمالي أو الأطلسي والتقائه بالهواء الصحراوي الجاف. وبصفة عامة فإن المناخ الغالب متوسطي جاف[2].

3-الموارد المائية

تنقسم الموارد المائية بالبلاد التونسية إلى موارد سطحية وجوفية. أما الموارد السطحية فهي تلك التي تعبأ بواسطة السدود الكبرى والسدود التلية والبحيرات الجبلية وغيرها. أما الموارد المائية الجوفية فهي تنقسم بحسب طبيعة الخزانات الجوفية إلى موارد قليلة العمق وأخرى عميقة.

3-1 المياه السطحية

يبلغ معدل الأمطار السنوية بالبلاد التونسية إلى230 مم في السنه، أي ما يعادل 36 مليار م^3 / السنة. كما تقدّر المياه السطحية السنوية الإجمالية بحوالي 2700 مليون م^3 /السنة منها 960 مليون م^3 /السنة في أقصى الشمال وبحيرة إشكل، وما يقارب 1230 مليون م^3 / السنة، بالشمال التونسي (أحواض "مجردة" , "الوطن القبلي" و "مليان"). أمّا في الوسط فتقدر الموارد المائية بحوالى 320 مليون م^3 / السنة (أحواض "نبهانة","مرق الليل" و "زرود"). أما منطقة الجنوب فتمتاز بمحدودية مواردها المائية السطحية التي لا تفوق 190 مليون م^3 /السنة[2].

تتم تعبئة المياه السطحية بالبلاد التونسية عن طريق سدود التخزين والتحويل وكذلك الضخ مباشرة من مجاري الأودية. وتتمثّل منشآت التخزين في 27 سدا من السدود الكبرى و252 سدا جبليا وحوالي 800 بحيرة جبلية (جدول 1). وأغلب السدود الكبرى مركزة بمناطق الشمال التونسي، وهي مرتبطة فيما بينها بقنوات تحويل تمكن من إحكام إدارتها خلال فترات الجفاف، وتستعمل أيضا في تحويل المياه إلى المناطق الأخرى على مسافة 200 كم لتلبية الحاجيات المتزايدة من مياه الشرب في المدن والقرى الريفية ومن مياه الري وكذلك لتلبية حاجيات الصناعة والسياحة[3].

وقد سمحت خطة تعبئة الموارد المائية من سنة 1990-2001 من تعبئة الموارد المائية بنسبة 90% أما الخطة العشرية الثانية والتي تتواصل من 2002-2011 فمن المتوقع أن تصل تعبئة الموارد إلى

95% مما يساعد من تثمين مياه السنوات الممطرة لبلوغ المزيد من الأمن المائي و خاصة في السنوات الجافة قصد تأمين التزويد بمياه الشرب وضمان مياه الري للمناطق السقوية.

جدول 1: منشأة تخزين المياه السطحية وطاقة استيعابها بالبلاد التونسية

المنشأة	العدد	طاقة التعبئة	طاقة التخزين الأجمالية
سد كبير	27	2600	1927
سد جبلي	220	280	160
بحيرة جبلية	800	113	-

وتهدف عملية ربط السدود إلى:

- تعديل مخزون السدّود
- التصرف في مخزون المياه لتسديد الحاجيات حيث يشمل هذا الربط مياه أقصى الشمال ذات النوعية الحسنة ومياه حوض مجردة ذات النوعية الأقل جودة.
- ضمان المزيد من أمكانية تسديد الطلب على المياه في الفترات الصعبة للمناطق العمرانية الهامة.

2-3 المياه الجوفية

تقدّر الموارد المائية الجوفية بحوالي 2140 مليون م^3 /السنة، وتصنّف إلى مياه جوفية قليلة العمق وتقدر بحوالي 740 مليون م^3 /السنة [4] وهي جلّها مياه متجدّدة، ومياه جوفية عميقة وهي ذات موارد مائية هامة وغير متجدّدة وتتمركز في جانب كبير منها بالجنوب ومن أهمها القاري الوسطي والمركب النهائي وخزان الجفارة. وتقدر الموارد المائية الجملية لهذه الخزانات العميقة بحوالي1400 مليون م^3/ السنة، [5]والتى تم حاليا تعبئة حوالى مايقارب عن81% (جدول 2).

جدول 2: تعبئة الموارد المائية (مليار متر مكعب)

الخزانات الجوفية	طاقة الاستيعاب	الممكن تعبئتها	التي تم تعبئتها	النسبة المئوية %	منشات التعبئة	عدد المنشات
السطحية	0.75	0.75	0.870	117	أبار سطحية	137700
العميقة	1.41	1.41	1.143	81	أبار عميقة وينابيع	4786 بئر 94 نبع
الجملة	2.16	2.16	2.013	93		

أدّى تطوّر الطلب على المياه (الشكل 1) إلى استغلال مكثّف لبعض الخزانات المائية الجوفية ممّا نتج عنه هبوط متواصل للمنسوب المائي بالخزانات الجوفية وتملّح المياه الجوفية بالمناطق الساحلية والمحاذية للسباخ. ولمجابهة الاستغلال المكثف للخزانات المائية الجوفية اتخذت عدة إجراءات للحدّ من الاستغلال ولتطوير الموارد المائية للخزانات المائية الجوفية المستهدفة. ومن بين هذه الإجراءات :

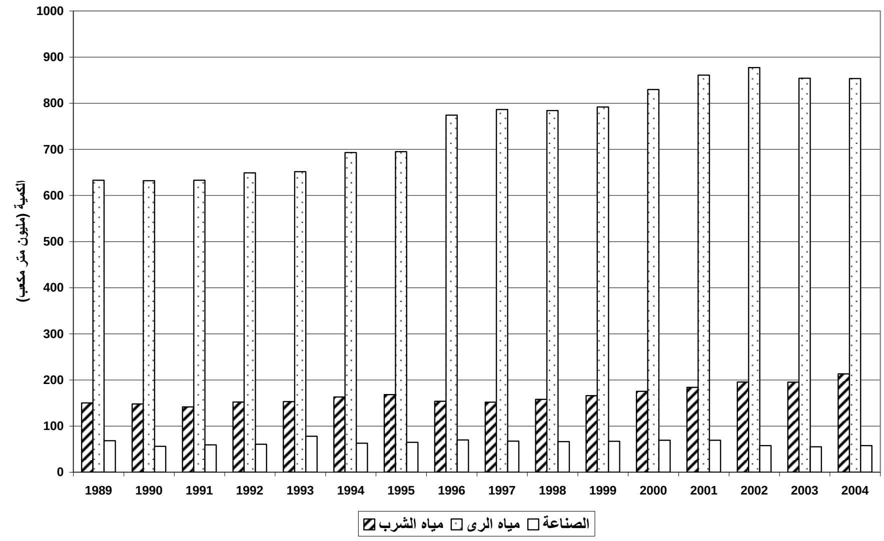
- إحداث مناطق الصيانة والتحجير
- جلب مياه الشمال من مناطق الشمال الغربي إلى مناطق الشمال الشرقي
- التشجيع على الاقتصاد في الماء خاصة في الميدان الفلاحي الذي يعتبر أكبر مستهلك للمياه
- تطوير الموارد المائية الجوفية بشحن أكبر كمية ممكنة من المياه السطحية والمستعملة المتوفرة والمناسبة.

نظرا لارتفاع الاحتياجات المستقبلية نتيجة التزايد السكاني والتوسع العمراني والتطور الاقتصادي للبلاد باعتبار نسق الاستهلاك الحالي للقطاعات المستعملة للمياه فان تلبية هذه الاحتياجات يصبح تحديا من الصعب تخطيه خصوصا أنها تتطلب استثمارات متزايدة لذا وقع اللجوء إلى التحكم في الطلب وتنمية الموارد غير التقليدية كإعادة استعمال مياه الصرف وتحلية المياه المالحة والاعتماد على الاقتصاد في

المياه وخاصة قطاع الري باستهلاكه الهام الذي يقدر ب76%(جدول3) من جملة حاجيات القطاعات الأخرى [3].

جدول 3: توزيع استهلاك المياه حسب القطاعات

الإستعمال	الكمية (مليون متر مكعب في السنة)	النسبة المئوية %
مياه الشرب	213	18.6
مياه الرى	869	76
الصناعة	58	5.1
السياحة	3	0.3
المجموع	1143	100



الشكل 1: تزايد طلب المياه حسب قطاعات الإستهلاك

و من الملاحظ ان نسب الاستغلال تغيرت مقارنة بما كانت عليه سنة 2002 وهذا راجع الى تحسين وسائل الرى بتطبيق برامج الاقتصاد فى مياه الرى أما مياه الشرب فقد ارتفعت نسبتها وهذا راجع إلى تغطية الطلبات المتزايدة بأغلب مناطق البلاد.

4- إدارة المـوارد المائيـة

4-1:التقليل في مياه الري

يحمل الاقتصاد في مياه الري مفهوما واسعا متعدد الجوانب منها:

- تنمية المياه التقليدية كوسيلة لمجابهة الطلب المتزايد وذلك باستغلال المياه ذات النوعية المتدنية شبه المالحة وإعادة استعمال المياه المستعملة المعالجة في المناطق السقوية،
- ترشيد استخدام مياه الري وذلك بالحد من الكميات المفقودة التي تنتج عن عمليات النقل والتوزيع.

شهد نسق تجهيز الأراضي الفلاحية بمعدات الاقتصاد في مياه الري منذ سنة 1995 تطورا هاما بلغ ما بين 20 و 25 ألف هكتار سنويا، وبلغت المساحات المجهزة بمعدات الاقتصاد في مياه الري حوالي 322 ألف هكتار بنهاية سنة 2006 أي 79 بالمائة من المساحة الإجمالية للمناطق السقوية المهيأة[3].

وتتوزع نوعية معدات الاقتصاد في المياه في الأراضي المجهزة كالأتي:

- الري الموضعي 32%
- الري بالرش 34%

- الري السطحي 34%

والجدير بالذكر أن مساحة الرى الموضعى التى كانت لا تتعدى نسبة 3% من المساحة الجملية المروية فى سنة 1995 قد بلغت حاليا 33% وهى تعد من اهم أنجازات البرنامج الاقتصاد فى مياه الري.

إلى جانب الأثر الهام الذى تمثل فى أقبال الفلاحين على تجهيز ضيعاتهم بوسائل عصرية، سجل البرنامج الوطني للاقتصاد في مياه الري عدة نتائج إيجابية على مستوى المحافظة على الموارد المائية حيث تم توفير بين 15 و25 بالمائة من الموارد المائية حسب المناطق منذ سنة 1995 وتقدر الكميات المقتصدة بحوالى 210 مليون متر مكعب منذ سنة 1995 أي مايعادل الكمية المخزونة بإحدى السدود الكبرى وهى كمية تمكن من ري حوالى 43 ألف هكتار.

4-2: الشحن الاصطناعي

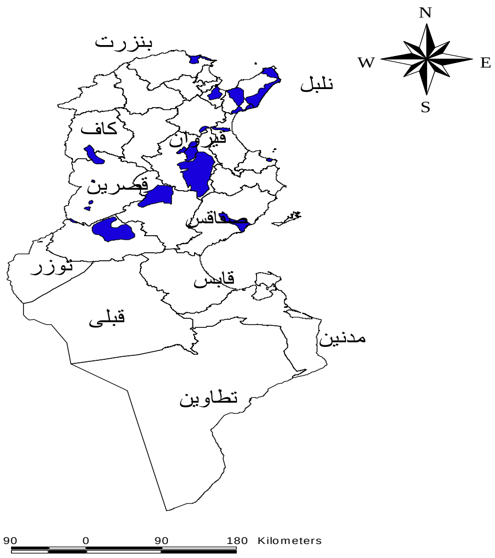
تتمثل عملية الشحن الاصطناعي **أو** التغذية الاصطناعية للخزانات المائية الجوفية في تسريب كميات من المياه السطحية و المياه المستعملة المعالجة إلى باطن الأرض وخزنها بالطبقات المائية الجوفية لاستعمالها عند الضرورة. و يتم تسريب المياه عن طريق الآبار أو الأحواض أو المقاطع أو مجاري الأودية.

وتعتبر عمليات التغذية الاصطناعية للمياه الجوفية عنصرا هاما من عناصر التعبئة والتحكم في الموارد المائية التي اعتمدتها البلاد منذ سنة 1990 في نطاق مشاريع الخطتين العشرية الأولى والثانية. وتهدف هذه العملية إلى:

- إعادة التوازن المائي للخزانات ذات الاستغلال المكثف،
- تنمية الموارد المائية لهذه الخزانات وتوفير موارد إضافية للمستغلين،
- تخزين المياه السطحية الزائدة عن الحاجة في الفترات المطيرة لاستغلالها في فترات الجفاف،
- الحد من تداخل المياه المالحة ومياه البحر في الخزانات المائية الجوفية الساحلية والمحاذية للسباخ،
- تطهير وتخزين المياه المستعملة المعالجة لاستغلالها بدون قيود أو شروط،
- خزن المياه و حمايتها من التبخّر.

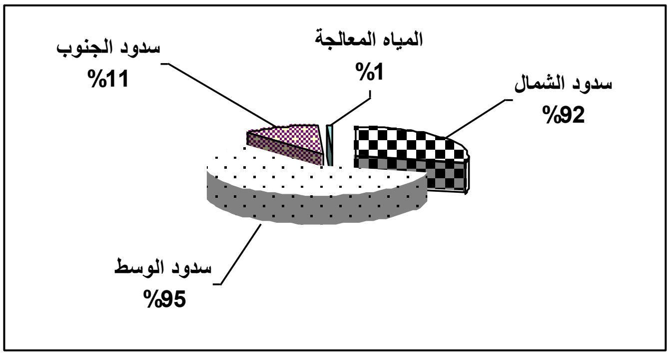
و قد اختلفت كميات التغذية من سنة إلى أخرى وذلك حسب المخزون المائي المتوفر بالسدود و السدود الجبلية. وتراوحت الكميات من 7.3 مليون متر مكعب سنة 2001 التي تعتبر سنة جافة إلى 67 مليون متر مكعب خلال سنة 1996 التي تعتبر من السنوات المطيرة في كافة أنحاء البلاد [6] . و تمت عمليات التغذية الاصطناعية ب 20 خزان مائي جوفي (الشكل 2) و بواسطة 63 موقع تغذية و بلغت كميات التغذية 480 مليون متر مكعب في الفترة من 1992 إلى 2005 أي بمعدل سنوي يقارب 37 مليون متر مكعب.

الشكل 2: مواقع الشحن



4-2-1:مصادر مياه التغذية الاصطناعية:

تعتبر الموارد المائية السطحية المتوفرة بالسدود و المياه المستعملة المعالجة المصدرين الأساسيين لتغذية الخزانات المائية الجوفية(الشكل 3) ومن أهم هذه المصادر مياه السدود المتوجدة بالوسط حيث تبلغ نسبة الموارد 59% من النسبة الإجمالية وخاصة من سد سيدى سعد والهوارب أما مصادر المياه المعالجة فهى ضئيلة وتقدر بحوالى 1% وذلك يعود الى الحذر والتوخى من استعمال هذه الموارد لماتتوخاه من ردائة من حيث النوعية:

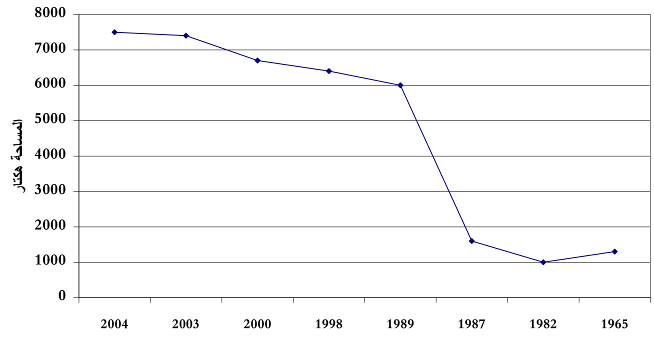


الشكل 3: مصادر مياه الشحن

4-3: تنمية الموارد غير التقليدية

يعتبر استخدام المياه المعالجة جزءا هاما من إستراتجية ترشيد مياه الري إذ ساهم في الاقتصاد في مياه ذات النوعية الجيدة والتي يمكن توظيفها لأغراض أخرى و يمكن من تثمين هذه المياه ذات النوعية الخاصة لري بعض الزراعات المحددة قانونيا منها الحبوب والأعلاف والأشجار المثمرة وكذلك في تغذية الخزانات الجوفية كما يمكن استخدمها في قطاعات أخرى غير فلاحية كرى ملاعب الصولجان والمساحات العمومية الخضراء و الصناعة.

وتقدر الكميات الممكن استغلالها حاليا بالمناطق السقوية بحوالى 35 مليون متر مكعب سنويا إي ما يقارب 30% من طاقة محطات المعالجة التي يقدر عددها ب 72 محطة وتنتج حوالي 120مليون م^3 سنويا [3]. يتم حاليا ري حوالي 870 هكتار في الميدان السياحي والبلدي وتبلغ بهذا المساحة الجملية المستعملة لمياه المعالجة حوالي8350 هكتار(الشكل 4).



الشكل 4: المساحات السقوية المروية بالمياه المعالجة(هك)

وباعتبار أن المياه المستعملة تتم معالجتها على مستوى الدرجة الثانية فقد اعتمدت عدة توجهات تمكن من الاستغلال الأمثل لهذه المياه في الميدان الفلاحي منها.

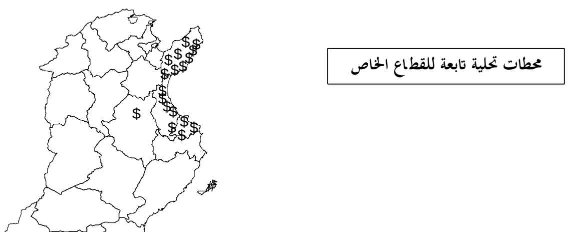
- توفير نوعية من المياه المعالجة حسب مواصفات تضمن تفادى المخاطر على المستوى الصحي والبيئي،
- اختيار مناطق فلاحية ذات تضاريس وتربة ملائمة قريبة من محطات المعالجة مع عدم وجود موارد مائية بديلة.

أما بالنسبة لعملية التغذية بالمياه المستعملة المعالجة فإنها لاتزال في بديتها إذ أنها أقيمت أول تجربة ناجحة لتخزين مياه الصرف المعالجة بواسطة أحواض رشح في المنطقة الساحلية لخليج الحمامات. وقد أدّت هذه التجربة إلى تخزين حوالي 200 الف متر مكعب سنويا[6] ونظرا لنجاح هذه التجربة يقع حاليا برمجة مواقع أخرى للتغذية بالمياه الصرف الصحي على الشريط الساحلي بالوطن القبلي.

4-4:التجربة التونسية فى مجال تحلية المياه

أصبحت تعبئة المياه و توفير الماء الصالح للشرب من أهمّ الأوليات بالبلاد التونسية. فإلى جانب خطّة لتعبئة الموارد المائية وما مكنته من إنجاز المنشآت المائية و ترشيد استهلاك الماء تضاف جهود الدولة الرامية إلى تحسين نوعية المياه الموزّعة. و في هذا الاتجاه تم إنشاء محطّات التحلية للمياه الجوفية المالحة في مناطق الجنوب التي تشكو مياهها المّعدة للشرب من ارتفاع درجة الملوحة.

و توجد أربع محطات لتحلية المياه المالحة الجوفية في كل من قرقنة ، قابس ، جربة و جرجيس بسعة إنتاج 57000 م^3/اليوم وتعد البلاد حوالي 18 محطة صغرى(الشكل 5) بسعة 8450 م^3/اليوم[7] .



الشكل 5: مواقع محطات التحلية بالبلاد

وتشمل المشاريع المبرمجة لتحلية المياه الجوفية المالحة إنجاز 13 مشروعا منها إنجاز 10 محطات

جديدة للتحلية و 3مشاريع لنقل المياه الجوفية ذات النوعية الجيدة على مسافات قريبة. وفى نطاق تحلية مياه البحر وقع برمجة مشروع نموذجي لتحلية مياه البحر بجربة بسعة 50 الف م^{3}/اليوم لتامين درجة الملوحة لا تتجاوز1.5 غ/ل.

5-الخاتمـة:

نظرا للتقدم الحاصل فى نسبة تعبئة وإستغلال الموارد المائية بتونس التي تعتبر موردا أساسيا للحياة باعتبار ندرتها وذلك بحكم تزايد الطلب في ميادين الفلاحة والصناعة والسياحة، تصبح المحافظة على هذه الموارد مؤكدة وذات أولوية وذلك لتجنب تدهور حالة هذه الموارد كمّا ونوعا. ولضمان استدامة استعمال المياه في تونس تتظافر جهود جميع الأطراف المتدخلة في قطاع المياه وخاصة في استغلال الموارد المائية وذلك بواسطة:

- تطوير شبكات قياس ومتابعة الموارد المائية (شبكات قياس الأمطار وجريان مياه الأودية والمناسيب البيزوميترية وإستغلال المياه الجوفية والسطحية ومتابعة نوعية المياه)،
- تنمية التغذية الإصطناعية للطبقات المائية الجوفية،
- تعزيز إمكانيات مراقبة ومتابعة تلوث المياه وذلك باتخاذ العديد من الإجراءات التشريعية لحماية المياه من التلوث بالبلاد التونسية،
- مواصلة توعية الفلاحين بمخاطر تلوث المياه من جراء تكثيفهم إستعمال المخصبات والمبيدات الكيمياوية في المناطق السقوية.

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السيـرة الذاتيـة:

السيدة: حليمة ممّو لبّان تحصلت على:
شهادة مهندس أشغال الدولة حماية المياه والتربة والغابات سنة 1990
شهادة مهندس أول هيدروليكا مياه سنة 1992
اشتغل رئيسة قسم البحوث والدراسات والنمذجة الرياضية للخزانات الجوفية بوزارة الفلاحة والموارد المائية بتونس إدارة الموارد المائية.
تحصلت على عضوية في:

- الشبكة العربية لحماية المياه الجوفية سنة 2004،
- شبكة المرآة العربية للتدريب والبحوث سنة 2006،
- المعهد المتوسطي للمياه سنة 2007.

ممّو أنتجت عدة أبحاث في المواضيع التالية:

- الشحن الاصطناعي ،
- حماية المياه والتربة،
- الاستغلال في الطبقات الجوفية،
- نوعية الموارد المائية بتونس،
- المياه المستعملة المعالجة وإمكانية شحن الخزانات الجوفية،
- تثمين مياه الصرف الفلاحى.

Water and territorial planning strategy in Algeria.

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ABSTRACT.

If the traditional socio-economic development policies consisted in satisfying the continual increase in the water requirements whatever the cost may be, the sustainable strategy now requires the introduction of two concepts that could seem at the very least revolutionists:

- First establishes the necessity of limiting the urbanisation requiring a balanced distribution of the land use both on the territorial and local scales.
- - Second recalls the limit of the water resources' load capacity that will hardly need a wide synergic action towards the preservation of the natural water cycle and the management of the water related risks.

In connection with these objectives, it can be suggested that the improvement of the territorial planning practice can effectively contribute to meet the imperative needs for a sustainable water resources' management especially in countries suffering from scarcity like Algeria. Now, relating to the territorial planning's some institutional and operational insufficiencies have been raised as detailed in the text.

Such approach leads to organise the text around three principal parts based on the analysis of the following materials:

- Part I: Water resources potentialities related datum in Algeria.
- Part II: Territorial planning practice related documents and reports.
- Part III: Territorial planning's tools used in Algeria.

The anticipated results being:

- Demonstrate the necessity of taking water resources into consideration by professionals in charge of territorial planning.
- Analyze now territorial planning trends in Algeria.
- Evaluate now territorial planning tools' ability to contribute in solving similar problems and propose some integrated measures.

Key words: Algeria – territorial planning practice - water management – sustainable development.

INTRODUCTION.

Because of its geographical position and whatever its hydrous potentialities should be, Algeria is interdependent of the Mediterranean countries northward and the African ones southward concerning water related risks as pollution, floods and dryness(1). Admittedly, the new water policy(2) has obtained some legal texts, budgets and operational organisms in order to mobilize, distribute and protect the water resources quite as well as possible. The mobilizing programme shows that the water works have been intensified at the beginning of the Eighties(3) when dams, reservoirs, drillings and purification stations began to be multiplied (4). Then water supply and sewage networks have been prolonged and reached a remarkable connection rates(5).

Now the water requirements' unsatisfaction still persists today for the whole economic sectors and the urban areas of Algeria (6). The annual allocation per capita continues to decrease: from 1500 m^3/inhab in 1962, to 500 m^3/inhab in 2000 (7). When Algeria mobilizes only 16% of its potentialities(8), it seems that this ratio highly depends of the technical and financial means allocated to the hydraulic sector on one hand, of the number of geologically favourable sites to build reservoirs on the other one(9).

However, one can see that a great part of the shortage the country knows from several decades is as much if not more related to a deficient compatibility between the territorial planning and the hydrous strategies (10). Since 1998, when *the sustainable development* option has been introduced into the urban and territorial planning processes related law, the reinforcement of the environmental measurements imperiously calls upon some new territorial planning's tools(11) able to effectively intervene on the water request and consumption modes, to prevent risks and to preserve durably the resource.

METHOD AND MATERIALS.

Since the Rio Summit in 1992, an abundant literature devoted to the concept of sustainable development has clearly defined both the sustainability concept (12) and the sustainable strategy parameters (13). Today it is definitively allowed that no total or sustainable development could be attempted without any sustainable settlements (14). Likewise, nor effective water management without any control of the cumulative and interactive effects of the space planning on the resource. If the traditional socio-economic development policies consist in satisfying the continual increase in the water requirements whatever the cost may be, the sustainable strategy now requires the introduction of two concepts that could seem at the very least deeply modifying:

- First establishes the necessity of limiting the urbanisation requiring a balanced distribution of the land use both on the territorial and the local scales.
- Second recalls the limit of the water resources' load capacity that will hardly need a wide synergic action towards the preservation of the natural water cycle and the management of the water related risks (15).

From this point of view, the priority goal to reach is "*to avoid any rupture of the balance of water supply/demand which would be prejudicial to the development, while stabilizing the pressures on the natural environment on an acceptable level»*(16*)*. In connection with these objectives, it can be suggested that the improvement of the territorial planning practice can effectively contribute to meet the imperative needs for a sustainable water resources' management especially in countries suffering from scarcity like Algeria.

The present paper argues this logic, discusses and evaluates the main territorial planning trends and tools' ability to solve similar problems in Algeria. Such approach leads to organise the text around three principal parts based on the analysis of the following materials:

Part	Materials	Anticipated results
I	Water resources potentialities related datum in Algeria.	Demonstrate the necessity of taking water resources into consideration by professionals in charge of territorial planning.
II	Territorial planning practice related documents and reports.	Analyze now territorial planning trends in Algeria.
III	Territorial planning's tools used in Algeria.	Evaluate now territorial planning tools' ability to contribute in solving similar problems and propose some integrated measures.

RESULTS AND DISCUSSION.

Part I: *Hydrous potentialities and constraints in Algeria.*

The geography of Algeria divides the territory into areas definitely differentiated by the relief, the climate, the agricultural capacities and the hydrous and mining reserves. The mounts of the Tell and the Sahara Atlas, deployed at variable distances from the Mediterranean coast, distinguish the rainy North from the dry South (**Fig.1**). Between eastern and western Tell the rainfall ratio and the climate mark a similar difference (17). These natural parameters command the distribution of the human settlements. Thus the northeast is a privileged area, favourable to the sedentary way of life, the demographic growth and the urbanization (18).

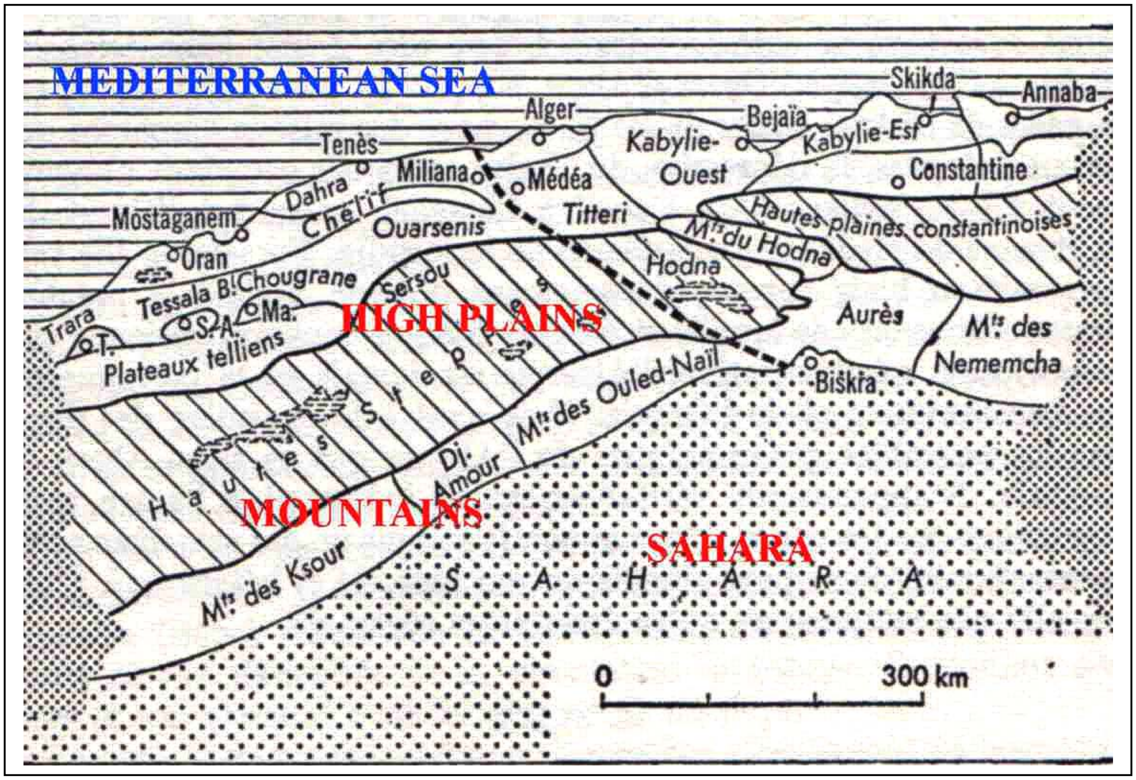

Fig. N ° **1**: **Main geographical areas of Algeria.**

Source: DESPOIS, J. & RAYNAL, R., Géographie de l'Afrique du Nord-Ouest, Ed Payot, Paris, 1975, 570 p, page 73.

The principal water resources of the country are localised northward and decrease as advances the desert which covers 80 to 90% of the territory. Consequently, by the long term, it is allowed to advance that the pressure on the water resources "*will not stop increasing under the combined effects of the demographic growth and the policies applied to the activities consuming water, in particular agriculture, industry and tourism* "(19). Admittedly, natural conditions (20) (rainfall's spatial and temporal irregularity) are exacerbated by the general socio-economic context. Moreover the water supplying process seems also to be subjected to some constraints concerned with the institutional, the administrative and the technical management of the resource on one hand (21), the impact of the uncontrolled urbanization on the other one. Indeed such is the healthy conditions(22) that it is oftenly no more a preventive matter but a heavy curative therapy whose cost increases proportionally with the delay in starting (23). Sanitation is critical in the large cities such as Algiers, Oran, Constantine and Annaba (24). Inside the urban area the conflict of interests between the various components can reach such a degree of complexity that the best way to reconcile them should be to apprehend them before their appearance, it means at the very first planning's stage. The national and international experiments show that it is necessary to implement a total water resources' management as financial means only do not suffice.

That's what let us remind some developing countries' case that do not undergo as much the water shortage effects as the lack of a global managing strategy considering the whole territory(25). Inside these apparent contradictory problems, although Algeria has some real hydrous potentialities, it counts amongst the poorest countries sustaining a water crisis (26). Thus the search for a clean technology mobilizing non conventional resources asserts itself (27). However, the appeal they bring should not make forget the socio-economic reality of our country. Very rare are the potential uses and users whom could be supplied from this relative expensive water.

This is why a sustainable territorial planning practice has to bring an effective intervention regarding to the request, the modes and volumes of consumption, the risks' prevention and the safeguarding of the resource.

***Part II*: *Main territorial planning guidelines by 2025*.**

The subscription of Algeria to the International convention on biodiversity (28) has precisely lead to initiate a progressive revision of the space planning tools. For the present it primarily concerns the legislative texts and statutes related to the territorial and the environmental planning within the framework of the sustainable development as the national and regional master schemes are currently brought up to date.

The current National Territorial Planning Scheme (SNAT) envisages from now to 2025, a demographic growth over 30% (29) and a water demand increase reaching more than 50%(30). It displays the country wilfulness in registering within a sustainable development framework ensuring a " *triple balances: social equity, economic effectiveness and ecological sustainability"* (31) while the objective is to reconcile the economic and the territorial planning interests in order to restore "*a sustainable balance»* between the large territorial components: the Tell (littoral and northern lines), the interior High Plains and the South (32). In agreement with the National Environment and Sustainable Development Plan (33), it proposes to mitigate the inequalities in term of economic development, urbanization and life conditions beyond the "*geographical and climatic natural constraints"* (34). For that, it envisages to limit the development of the fragile and vulnerable zones, to intensify that of the interior High Plains and the South and then to carry out the reorganization of the Tell (35). To answer this objective, the first identified guideline (36) recommends ensuring «a development compatible with the environmental load capacity of the territories», i.e. watering resources' and soils' protection, major risks' prevention, biodiversity protection and fighting against the desert advance (37).

The analysis of the SNAT assessments in term of urbanisation and water requirements by 2025, raise simultaneously the problematic of the large cities' sprawling (Algiers, Annaba, Constantine, Oran) and the natural areas they belong to. The environmental and hydrous solidarity of the natural entities, the narrow relationship of the local and the regional scales inside the same water catchment area expose them at various degrees to the same water risks. Indeed this territorial planning policy seems to weigh in favour of two alternatives. One relating to the land arrangement concerns the creation of new settlements and the densification of the most significant urban agglomerations through the country (38). The other concerning the water resources privileges the interbassin water transferring(39). It would have found in the formula of new settlements an optimal solution to balance the dynamic of the urban development and the environmental risks. Meanwhile the mainly future new settlements would become localised on ecologically sensitive zones yet threatened by a significant risk of pollution. It seems at the very least that the water supply and sewage constraints are quite undervalued (40). By term these answers supposed rising the pressure on the agricultural and water resources conceal a problematic dimension. Bus the creation of new settlements and the practice of inter basins transfers could have harmful consequences both on the natural and the urban ecosystems if their impacts have not been previously well studied and controlled on all geographical scales.

In conformity with these problematic, three cases should require a detailed analysis:

- First, the High Plains' urban development where the water resources are quite probably insufficient to satisfy the industrial, the agricultural and the daily life activities that will be deployed there (41). The necessary inter basin transfers' from the Northern areas towards its overdrawn ones will involve other socio-economic problems whom exact value has to be apprehended in the anticipatory phase of the studies to ensure the double land and hydrous balance and the social equity.
- Second, the new settlements will have to be studied under the same climatic and especially hydrographical criteria referring to the local potentialities and the cost of the water mobilization, treatment and transfer.
- Third, the urban sprawling phenomena whose concerns about all the Algerian cities, particularly the large metropolises, must be preceded by an

assessment of the local and the regional hydrous potentialities, water and the sewage networks' capacities, risks' prevention, as well as authorization to build or to set up an industrial activity out of the protected perimeters.

Part III:

In Algeria, during nearly twenty five years(42), space planning practice has been resulted from statistics and distinct sectors' requirements (functionalist vision) looking for a theoretical balance between the needs induced by the demographic growth and the national economic alternatives(43) without disposing of any effective tools able to control or manage the land use process(44). It would seem however that the results of this policy are partly due to the maladjustment of its own institutional, lawful and operational supports with the local characteristics, and partly to the local communities' negligence of its main guidelines (45). About this subject, the CNES report (46) concludes with their quasi inapplying character because of the same reasons as those concerning the regulation, namely the standardization of the plans and their ignorance of the local realities. As an example, let us cite the urban problems in the Algerian littoral area where the supply and demand imbalance is worsened by the increasing urban sprawling and the overexploitation of both surface and underground resources. The Northern Regional Schemes (SRAT) (47) and the Littoral one (SDAL) (48) have in their turn seized upon the environmental question especially that tied to water and could note that formerly small problems (or minimized?!) have became extensive and accentuated fault of any effective application of the previous plans' recommending. However, to satisfy the water demand, the state of the resource by term has dictated an acting program expressely required to be coherent "*with the guidelines of both the territorial and the environmental planning schemes*"(49). Now no lawful text precise the terms of this *coherence* which seems to be essential regarding our problematic. Would it consist with a simple recommendation or in an explicit obligation? Would it be related to a total responsibility at the stage of the space planning process or a tacit carrying up on the level of the spatial arrangements?

Besides, the attentive reading of the text related to the territorial planning process within the framework of the sustainable development admittedly makes it possible to raise some equivalent rules to these just cited (50). But they are undirectly related to the compatibility with the water national policy which could consist of stating some constraining rules concerning the land use by the short, the average and long terms although measurements that aim to increase the mobilizable hydrous potential, to protect water quality, to save or rationalize its use have, as we saw above, a direct effect on the space planning practice. They indeed require some installations or imply some specific constraints that the city plans have to take into account at all scales.
It is thus only in the new law text related to water (51) that some specific constraints are currently prescribed (52). However, the single one expressely fixed consists with the prohibition of any construction around the natural and the public artificial hydraulic domains (53). It is the equivalent of an immediate protected perimeter reaching three or five meters broad according to cases. If necessary, the supervising administration reserve itself a right to use of the expropriation procedure (54). It is hoped that they will be lawfully integrated into the future territorial planning scheme, but in practise, in spite of its fundamental role in the natural ecosystem; water continues to be victim of a restrictive vision comparing it to a natural resource in the exclusive mankind's service.

Although not developed in detailed form, the principle of pollution, shortage, flood and erosion risks' management is clearly contained in the text and act to delimit the protected perimeters (PP) and control the activities or the general land occupation mode inside the PP (55). From now on the PDARE (56), being claimed of an integrated water management, will have to define the strategic choices in term of needs' satisfaction, resources' protection and risks' management related to the exceptional natural phenomena (dryness, floods). It also proposes to establish a quantitative protected perimeter, i.e. an underground waters exploitation's threshold (57) of which it is very interesting to know the regulations and implications in term of space planning.

As underlined before, the complementarity between the prerogatives, the texts and the recommending related to the land and the water resources planning processes, precedes and logically continues through their respective master schemes. Table n°7 notes the general correspondence between them at all scales.

Table n°7: Coherence between the land and the hydraulic master schemes at different geographical scales.

Geographical scales concerned.	*Spatial planning.*	Hydraulic planning.
national territory.	Territorial Master Planning Scheme. Economic development, main communication networks.	Water management master scheme. Optimum water resources management, great hydraulic works.
Regional territory. Hydrographic area. Water catchment.	Regional Master Planning Scheme. Regional development, communication and environmental protection networks.	Water catchment's Planning Scheme. Hydraulic works, transfers, resource's protection program.
Urban agglomeration. Hydrographic Under-basin. Inner basin.	Urban development master plan. Local urban development, traffic, public services, combat pollution's risk, etc.	Local Water Resources management program. Supply and sewage management, water distribution and storage.

Source: Drawn up by the author referring to: MAKSIMOVIC, C.; TEJADA-GUIBERT, J A.; ROCHE, P-A., *Les nouvelles frontières de la gestion urbaine de l'eau. Impasse ou espoir?* Op.cit, 443 p, page 170.

Concerning the delimitation of the protected perimeters for example, the division of labour between the local officials (municipalities) and the State institutions have to be decided at the higher geographical scales to become optimum. In other words, the general interest at the territorial level must anticipate the local one which has to introduce some constraints being used as strategic guidelines. This is why the legislative texts and master territorial schemes would have to clearly define the development programs on the national and the regional scales, the objectives of the economic strategy, the great traffic systems and the protected or being urbanised zones. These referencing factors strongly determine the local city planning strategy and hydrous policy. Thus, because of the diversity and the complexity of the parameters considered within the framework of the sustainable development process, the territorial planning scheme is invested of a triple function:

the urban space arrangement, the coordination between the public sectors and the information per synthesis about the objectives of the global development at all scales (58). As it is, the main objectives of the sustainable development would have to be required around water, the quite very federator element (**Table 8**).

Table n°8: The contribution of the territorial, the environmental and the hydrous planning tools to the water's sustainable management:

Territorial planning		Environmental planning	Hydraulic planning
Intervention level.	Urban ecosystem	Urban water cycle	Hydrological cycle
Acting programme	- Rainfall water management. - Land use management.	- Sewage and waste management. - Hydraulic works adequacy. - Qualitative protection.	- Limit of mobilization. - Water economy. - Development of alternative techniques.
Objectives	Management of Flood and hydrous erosion risks.	Qualitative protection of the water resources.	Quantitative protection of the water resources.
	Conformity of the space arrangements with the inherent local natural characteristics.	**Definition of some specific constraints related to the hydraulic public domain.**	**Adaptation of the spatial arrangements to the really mobilizable hydrous potentialities.**

Source: Bench by the author.

CONCLUSION.

It is clear that the water sustainable strategy is basically necessary and conditional to any urban development especially in a country such as Algeria where the natural parameters determine a medium fairly sprinkled to frankly arid environment. Consequently, the territorial and environmental planning objectives within the framework of the sustainable development must logically be united with those of water resources such driving essence of the general development (59) They have to forecast the long term water requirements according to one or more assumption (programming phase) for demographic growth and water risks prevention within the urban area (urban arrangement).

Admittedly these elementary principles constitute a true challenge. They are all the more heavy to rise that the agglomerations on which they have to intervene have known an inadequate development and that the local constraints reach such an inextricable complexity level(60).

However, the principal quality of a sustainable territorial planning is not to be able to adapt itself to the pre-existent local contexts as changes are apprehended or new constraints noted revising periodically the acting programmes?

NOTES :

(1) They would be evaluated to 12.4 billion cubic meters of surface water and 2.8 billion cubic meters of subsoil water. Water resources of Algeria, Web site of the Ministry for the water resources, http://www.mre.gov.dz

Since 1974 or 1975, a long sequence of dryness came to worsen the situation of shortage.

"... *during the three last decades, the North of Algeria undergo a severe dryness during the seasons 1965-1966, 1970-1971, 1977-1978, 1981-1984, 1987-1990 and 1993-1994* ", KADI, M., *La saison pluviométrique 1990-2000 compromise?*, Alger, 02.03.2000, ONM/ Dar el-Beida.

(2) The water sector has been amongst the first public ones in Algeria to ratify the concept of sustainability supplementing and modifying the law text n°83-17 of the 16/07/1983 bearing Water code by the Ordinance n°96-13 of the 15/06/1996. In 2005, a new law came to repeal the latter: Law n° 05-12 of 04/08/2005 related to water having for object the use, the management and the water resources sustainable development.

Since 1996, the water resources are managed by water catchment's unity. Executive decree n° 96-100 of the 06/03/1996 defining the water catchment's and fixing the standard statute of the publicly managing establishments.

(3) *L'eau en Algérie: Le grand défi de demain*, Avant-projet de rapport, Avant-projet de rapport, CNES, Mai 2000, 72 p, page 22.

(4) "*Since 1962, many dams_have been realized, 110 others are currently exploited (...); 22 works are under construction and 52 in project (...). In 1979, there were 44 reservoirs_essentially located in well sprinkled North wilayas, (...). between 1985 and 1987, 667 reservoirs have been carried out (..)...in 1985, the number of exploited drilling was approximately 5500. More than 2000 drillings were realized by the Administration between 1990 and 1999 in the North of the country (...). In addition, 742 drillings would have been also*

realized in the South (...). *In the Seventies, (...) 49 purification stations of wastewater... have been built.* ". *L'eau en Algérie: Le grand défi de demain*, Avant-projet de rapport, op.cit, pp 20-23.

(5) At the national level, the access rate to drinking water by connection with the network would be among 97.7 % and that to sewage network 85 %. Idem, pp 24-25.

(6) "*Amongst all the public services, that of water is undoubtedly the least continuous. Indeed, everyone knows that the large majority of the agglomerations do not have continuous supply water*". *L'eau en Algérie: Le grand défi de demain*, Avant-projet de rapport, op.cit, page 48.

(7) Table n° 1: Evolution of the yearly water allocation per capita in Algeria.

Date	m³/hab/an.
1962	1500 m³
1990	720 m³
1995	680 m³
1998	630 m³
2000	500 m³
2020	430 m³

Source: *L'eau en Algérie: Le grand défi de demain*, Avant-projet de rapport, op.cit., page 3.

(8) ARRUS, René, *Les retards de la politique hydraulique*, in Repères, Hors série n°5, 1997, pp 69-78, page 69.

(9) *L'Algérie de 2020,* Ministère de l'aménagement du territoire et de l'environnement, Alger, 2003, 182p, page 18.

(10) The cyclic dryness character would have been officially and definitively ratified only in 1994. The early knowledge of this phenomenon as that of the really mobilizable hydrous potentialities would have made it possible to develop a protection plan based on the implication of the whole water users in the economy, the protection and the rational mobilization of the resource. *L'eau en Algérie: Le grand défi de demain*, Avant-projet de rapport, op.cit, page 33.

"*The evaluations of the surface waters were possible thanks to the measurement network managed by the ANRH (in French: Agence Nationale des Ressources Hydriques = Water resources National Agency). This agency which is in charge of the inventory of the water resources currently manages* *more than 160 hydrometric stations. The density of the gauging stations is unsufficient to carry out a good evaluation of the water resources. The number of the observation years is also a determining parameter* ". Idem, page 34.

(11)In this spirit, the document entitled " *L'Algérie de 2020*" [1] endeavoured to reformulate the ambitions of " *the territory reconquest* " expressed in 1995 in " *Demain l'Algérie* " [1] inside a sustainable development vision.

L'Algérie de 2020, Ministère de l'aménagement du territoire et de l'environnement, Alger, 2003, 182p.

Demain l'Algérie. L'état du territoire. La reconquête du territoire, Ministère de l'équipement et de l'aménagement du territoire, Alger, 1995, OPU, 432p.

(12) The concept of sustainability implies "*the concept of justice towards the members of the same generation, justice between generations and justice towards nature* ", under the direction of: MAKSIMOVIC, C.; TEJADA-GUIBERT, J A.; ROCHE, P-A., *Les nouvelles frontières de la gestion urbaine de l'eau. Impasse ou espoir?,* op.cit, page 36.

(13) The sustainable strategy integrates the principles of *effectiveness*, *equity* and *integrity of the ecosystem*, Idem.

(14) Idem, page 59.

(15) "*The scale matter, borders and geographical planning entities are in the center of the efforts defining the problems identifying actions and mechanisms»* related to the sustainable urban development.Under the direction of:: MAKSIMOVIC, C.; TEJADA-GUIBERT, J A.; ROCHE, P-A., *Les nouvelles frontières de la gestion urbaine de l'eau. Impasse ou espoir?, op.cit, page 51.*

(16) MARGAT, J.; VALLEE, *L'eau pour le XXIè siècle: de la Vision à l'Action, Vision méditerranéenne sur l'eau, la population et l'environnement*, Plan Bleu, Conseil Mondial de l'Eau et Global Water Partnership, janvier 2000, 62 p, page 43.

(17) Tableau n° 2: Water resources distribution between the North and the South of Algeria.

Geographical area	Surface resources (billion m³/year)	Underground resources (billion m³/ year)
Mediterranean basin and High Plains.	11, 8 = primarily supplied with precipitations. Irregular distribution in time and space = 7% of the total territorial surface = 90% of the total yearly flow.	1, 750
The Sahara	0, 6 = very weak resources.	5,000 = no renewable resources.

Source: Established by the author refering to: Actes de la conférence ministérielle*, Stratégies de la gestion des eaux dans le bassin méditerranéen Horizon 2010*, Ministère de l'Equipement- Commission des Communautés Européennes, Vol 2, 1990, 246 p, pp 130-132. (18) In addition to the Sahara area, the national territory is divided into 4 Northern hydrographical areas.

Table n° 3: Yearly water allocation per capita compared to the potentialities of the North water catchment s areas of Algeria.

Designation	Oranie Chott Chergui (O-CC)	Cheliff Zahrez (C-Z)	Algérois Hodna Soumam (A-H-S)	Constantinois Seybouse Mellegue (C-S-M)
Potentialities (Hm³/year)	1200	2200	4900	5900
Available allocation in 2000. (m³/inhab/year)	300	500	540	980
Available allocation by 2020/2030. (m³/inhab/year)	200	300	350	650

Source: Drawn up by the author referring to data of the Ministry for the water resources (MRE).

It can be deduced from this table:

- The disparity of the water potentialities between the Northern hydrographical areas of Algeria: In the Northern-East (water catchment C-S-M = 5900 Hm³/year) it nearly reaches four times that of the Northern-West (water catchment O-CC = 1200 Hm³/year).

- In all the water catchments only a small percentage of water is truly available, lower than the water stress level according to the World Bank.

- A considerable reduction (more of the third) in the equipment per capita and per year by 2020/2030 so that the increase in demand will be necessarily accompanied by a supplyreduction.

With 630 m³/inhab/year, Algeria is located below the *water stress* level as fixed by the World Bank at 1000 m³/inhab/year. The threshold *water scarcity* level being fixed at 500 m³/inhab/year. Ministry for the water resources, http://www.mre.gov.dz

(19) *L'eau en Algérie: Le grand défi de demain*, Avant-projet de rapport, Avant-projet de rapport, CNES, Mai 2000, 72 p, page 3.

(20) In Algeria rainfall ratio varies from more than 2000 mm/year on the high relief by the Mediterranean coast, to less than 100 mm/ year in the North of the Sahara. The national rainfall ratio average attempts 68 mm/ year.

Table n° 4: Rainfall ratio in the different regions of Algeria.

Area	*WEST*	*CENTER*	EAST
Littoral	400 mm	700 mm	900 mm
Tell Atlas(flat)	500mm	450 mm	700 mm
Tell Atlas (releifs)	600mm	700-11000 mm	800-1600 mm
High telliens plains	-	-	400 mm
High steppics plains	250 mm	250 mm	-
Sahara Atlas.	200 mm	200 mm	400-700 mm (Massive of Aurès)
The septentrional Sahara.	50 mm	-	150 mm

Source: Actes de la conférence ministérielle, Stratégies de la gestion des eaux dans le bassin méditerranéen Horizon 2010, Ministère de l'Equipement-Commission des Communautés Européennes, op.cit, page 130.

(21) "Compared to the stages of the agricultural, industrial and urban development, hydraulics shows a delay of more than one decade. Very symptomatic delay of the distortions existing within the Algerian development, and which result in damages, as much on the living lived standard (water cuts in the majority of the cities) as on the planning level (bottleneck of the development) ", ARRUS, René, Les retards de la politique hydraulique, in Repères, Hors série n°5, 1997, pp69-78, page 69.

(22) "Since the independence, the evolutionary tendency of the notifiable diseases generally shows the prevalence of the diseases related to the public hygiene and in particular the ones with hydrous transmission. Indeed, the diseases with hydrous transmission (especially the cholera, the typhoid fever, dysenteries, the poliomyelitis) are, in term of morbidity, the first notifiable diseases notified by the health ministry ", Dr OUAHDI, M, Problématique des maladies à transmission hydrique. Situation actuelle et perspectives, in Algérie Santé n° 05 mai-juin 2001, pp 1-16, page 11.

(23) The social and economic cost of the diseases of hydrous origin includes the therapeutic expenses, the loss in term of working days (death, hospitalization, and convalescence), the fighting medical programmes against these diseases, etc. Dr OUAHDI, M, Problématique des maladies à transmission hydrique. Situation actuelle et perspectives, op.cit, page 16.

(24) Epidemiologic Wilayas considered high-risk: Chlef, Batna, Béjaïa, Blida, Bouira, Tlemcen, Tiaret, Tizi Ouzou, Oran, Algiers, Djelfa, Skikda, Annaba, Constantine, Médéa, Mostaganem, Me sila, Mascara, Bordj Bou Arreridj, Tissemsilt, Tipaza, Aïn Defla, Relizane. Dr OUAHDI, M, Problématique des maladies à transmission hydrique. Situation actuelle et perspectives, op.cit, page 11.

(25) Certain countries potentially low in water, but whose financial means is significant, succeeded in improving this total yearly volume (In term of percentage of access to drinking water and not of connection to the public networks) thanks to the recourse to very expensive technical solutions (desalination of sea water - case of the United Arab Emirates and Saudi Arabia) in addition to the adoption of a rational management of their conventional resources, while others do not manage to ensure the quantitative and qualitative minimum because of a bad management (however considerable) and the lack of any control of the *supply demand* balance.

(26) With 630 m³/inhab, Algeria is located below the *water stress* level as fixed by the World Bank at 1000 m³/inhab. The threshold *water scarcity* level being fixed at 500 m³/inhab. Ministry for the water resources, http://www.mre.gov.dz

(27) The de-salted sea waters, demineralised brackish water as well as purified wastewaters belong to the public natural hydraulic domain. Law n° 05-12 of 04/08/2005 related to water, Title II, Chap.1, Section 1, Art.4.

(28) Order n° 95-163 of the 06/06/1995 bearing ratification of Rio de Janeiro convention on the biological diversity signed in 05/06/1992.

(29)*Schéma National d'Aménagement du Territoire 2025. Lignes directrices du SNAT*, op.cit, p28.

(30) Idem, p 16.

(31)*Schéma National d'Aménagement du Territoire 2025. Lignes directrices du SNAT*, Ministère de l'aménagement du territoire et de l'environnement, Avril 2006, 86 p, page 4.

(32)*Schéma National d'Aménagement du Territoire 2025. Orientations générales d'organisation du territoire 2025.* Ministère de l'aménagement du territoire et de l'environnement, Décembre 2005, 26 p, page 3.

(33)In french : PNAE DD = Plan National d'Actions pour l'Environnement et le Développement Durable.

(34)*Schéma National d'Aménagement du Territoire 2025. Lignes directrices du SNAT*, op.cit, page 4.

(35)The strategy of great interregional balances by 2025 is implemented by seven (07) large territorial building projects (GCAT). The GCAT 1 envisages the reorganization of the Tell. The strategy is organized around three axes: - Setting in network and articulation of the cities. – Managing the cities in particular three metropolitan areas (Algiers, Oran, Constantine). - Reinforced the articulation between the littoral, the piedmonts and the mountain. - Recovering the balances broken between urban, rural zones and natural spaces. *Schéma National d'Aménagement du Territoire 2025. Lignes directrices du SNAT,* op.cit, page 22.

(36)Five general lines by 2025:1 - Towards a sustainable territory. 2 Creating a dynamic territorial balance. 3 Ensuring a territorial attractivity and competitiveness. 4 Implementing a territorial equity. 5 Governance. *Schéma National d'Aménagement du Territoire 2025. Lignes directrices du SNAT,* op.cit, page 8.

(37)Let us remark that all these actions could contribute to the prevention of the hydro climatic risks in Algeria Idem.

(38) Within this framework, a rigorous selection of the becoming urbanised sites is theoretically recommended according to their agricultural value, geotechnics characteristics, accessibility and hydrous potentialities. *Maîtrise et organisation de l'urbanisation dans l'aire métropolitaine d'Alger*, 70 p, ANAT, 1997, page 16.

(39)*Rencontre avec les walis sur la mise en œuvre du programme d'urgence d'alimentation en eau potable*, Communication de Monsieur le Wali d'Alger, Annexes III, Fiches de synthèse par wilaya, ENA, Samedi 09/02/2002 130 p, page 1.

(40) *Rapport sur l'état et l'avenir de l'environnement 2003*, MATE, 463 p, page 172.

(41)Table n°5: Water potentialities and urban development project in the High Plains area.

Site	Hydrous potentialities.
Western High plains	"*This area already located on the High plains is known for their low rain density, represents the weakest natural resources rate in the country:* *- 2,1 %, including 0,9% of the surface resources, this zone being made up only of oueds with intermittent flow, generally dry,* *- 6,5 % of underground resources* ".
Centers High plains	"*As for the whole of the North of the country, one notices a progression of the rainfall ratio from West towards the East, thus the H.P - Center more sprinkled, have a weakest rate of underground resources: 2,4 % ".*
Eastern High plains	"*A light improvement is noted in this area, which has denser precipitations: - surface resources = 2,4 % - underground resources = 3,2 % ".*

Source: Drawn up by the author refering to: SNAT 2000, Phase 2, Rapport intermédiaire, op.cit, page 262.

(42)"*It is only from 1987 that the urban and territoriall planning system take more complete form and contents, in spite of the persistence of certain gaps which remain very significant* ". SIGUERDJIDJANE, A., *Planification régionale. Système de planification urbaine et régionale en Algérie*, in Aménagement urbain n°16, Ecole Polytechnique d'Architecture et d'urbanisme d'Alger (EPAU), Janv. 1997, 92p, page 26.

(43)"*In Algeria, the priority has always been given to the economic planning to the detriment of the spatial planning and it is the sectoral planning which is operational (ministries and various territorial structures)".* Idem, page 4.

(44) Order n° 75-67 of 26 September 1975 regulating the construction, replaced by the law n° 02-82 of bearing 20 February 1982 allowed to build and parcel authorization.

(45) *Bases pour une politique de l'urbanisme.* Ministère de l'habitat et de l'urbanisme. Direction Générale de l'urbanisme. Alger le 03-10-1984.

(46)*Rapport sur la ville algérienne ou le devenir urbain du pays*, CNES, Nov. 1998, 73p.

(47) *SRAT*, Phase 2, Ministère de l'aménagement du territoire et de l'urbanisme et de la construction, - ANAT, Mai 1989, 211p.

(48) The littoral master development scheme (SDAL), Rapport final- Mission

1: Evaluation des ressources naturelles et potentialités économiques et analyse critique du phénomène de littoralisation, Ministère de l'Equipement et de l'Aménagement du territoire - ANAT, Février 1996, 208p.

(49) Law n° 05-12 of 04/08/2005 related to water, Title I, Art.3.

(50)Let us note for example: "*(the national policy of sustainable development) It retains like finalities: (…):*

- the protection and the valorisation of the territories and areas ecologically and economically significant,

- the protection of the territories and the populations against the natural risks,

- the protection, development and rational use of the patrimonial, natural and cultural resources and their safeguarding for the future generations ". Law n° 01-20 of 12/12/2001 relating to the installation and the durable development of the territory, Art.4.

(51)Law n° 05-12 of 04/08/2005 related to water.

(52)Table n°6: Specific constraints related to the public hydraulic domain contained in the Water code and concerning the space arrangement.

Text of law	Bond	Applicability.
Art.3: Compatibility of the water management with the territorial planning policy.	Indirect	Necessity of taking into account the SNAT(Territorial Planning Scheme), SRAT(Regional Planning Scheme, SDAM(Metropolitan Planning Scheme, SDAL(Littoral Planning Scheme:
Art.2: Combat water pollution.	Indirect	Delimitation of the areas becoming urbanised. Localization of the polluting activities.
Art.10: Immediate Protected perimeter.	Direct	Constraint of public utility = unrestricted passage from 3 to 5 m accessing to the oueds, lakes, etc.
Art.12 and 15: Prohibition of any building on the submarines surfaces. Prohibition to block the rain water run-off.	Direct	Constraint of public utility: Protection measure against the flood risk.
Art.55: Obligation to establish a flood fight plan.	Indirect.	This plan induces some space constraints. Instituted but unregulated up to date.
Art.118: Obligation to envisage a purification system of wastewaters for the agglomerations having more than 100 000 inhab. or located upstream the water supply works.	Direct	To envisage the site where the purification stations would be installed.
Art.47: Prohibition or regulation of certain activities located inside the protected perimeter.	Direct	Distribution of the activities inside the urban area.
Art.38: Qualitative protection.	Indirect	Localization of the activities near the rivers and the works used to mobilise, collect or stock water.
Art.39: Prohibition of certain activities around works used to mobilise or stock water.	Direct	Traffic system, fuel stations.
Art.44: Prohibition of any activity inside the medium or distant protected perimeters without previous administrative agreement.	Direct	Constraints related to sites of future urbanization.

Source: Drawn up by the author referring to law n° 05-12 of 04/08/2005 related to water.

(53)Idem, Title II, Chap. 1, Section 1, Art.4.

(54)Idem, Title II, Chap. 1, Section 3, Art.13.

(55)Idem, Idem, Chap. 1, 2, 3, 4 and 5.

(56)Water management master scheme. In french : Plan Directeur d'Aménagement des Ressources en Eau

(57)Law n° 05-12 of 04/08/2005 related to water, Contains III, Chap. 1, Art.31 & 32.

(58)To see on this subject: *Manuel sur l'environnement. Documentation pour l'étude et l'évaluation des effets sur l'environnement*. Vol.1. *Instructions, planification multisectorielle, infrastructure*. Ministère fédéral de la coopération économique et du développement, GTZ, 1996, 587p, page 16.

(59)Let us note that certain legislative texts are used as common reference between the space and the hydraulic planning tools:

- Law n° 03-10 of the 19/07/2003 relating to the environmental protection within the framework of the sustainable development.
- Law n° 01-19 of 12/12/2001 relating to waste management and control.
- Law n° 85-05 of 16/02/1985 relating to the protection and the promotion of health.
- Law n° 90-08 of 07/04/1990 relating to the commune.
- Law n° 90-09 of 07/04/1990 relating to the wilaya
- Law n° 91-30 of the 01/12/1990 bearing domanial law.
- Law n° 91-11 of the 27/04/1991 fixing rules relating to expropriation due to public utility.

(60)At least three cases can facing the team in charge of the city planning:

- Dense central zones, of relatively old urbanization, where the hydraulic installations from now on are exceeded or deteriorated.
- Zones of more recent but uncontrolled urbanization/ spontaneous districts where the hydraulic installations are almost non-existent.
- New settlements or agglomerations whose have completed studies however did not integrate a sustainable water management predicting some technical and financial problems by term.

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استراتيجية الموارد المائية البديلة في المملكة العربية السعودية

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ملخص البحث

أدت العوامل السياسية والاقتصادية والاجتماعية التي تشهدها المملكة العربية السعودية منذ اكتشاف النفط، والنمو السريع والمتزايد في كافة القطاعات التنموية،إلى زيادة الاهتمام بأمن الموارد المائية خاصة بعد استنزاف جزء كبير من مواردها المائية من خلال إستراتيجية استندت على العرض دون ترشيد للطلب لفترة طويلة مع عدم وضوح لبوادر الإدارة المتكاملة للموارد المائية.

وقد تبنت المملكة، بهدف تحقيق أمن مواردها المائية، عددا من الاستراتيجيات المطروحة من قبل عدد من الجهات الحكومية من داخل المملكة، أو من قبل المنظمات ومراكز البحوث في الخارج،كإستراتيجية استخراج المياه الجوفية العميقة،وتحلية مياه البحر، وإعادة استخدام مياه الصرف الصحي والصناعي المعالجة، وخصخصة القطاعات المائية، ونقل المياه عبر الأنابيب أو الناقلات من مناطق غنية بالمياه، و إعادة تسعير المياه،والحصاد المائي.وقد تم اختيار بعضا من هذه الاستراتيجيات بناء على عدد من الأسس السياسية والاقتصادية والاجتماعية، والذي كان له دوره في تحقيق جزء من أمن الموارد المائية،وسعى المملكة ضمن استراتيجيات تنموية نحو تطويره وزيادة فاعليته، بينما تم استبعاد أو تأجيل البعض الآخر من تلك الاستراتيجيات لما تحمله في طياتها من مخاوف أمنية.

أهداف البحث

يهدف هذا البحث إلى دراسة الموارد المائية البديلة في المملكة العربية السعودية والعوامل المؤثرة في إقرارها أو اعتمادها دون سواها من الاستراتيجيات المقترحة وأثر ذلك على الأمن المائي في المملكة العربية السعودية، دراسة تحليلية مقارنة من وجهة نظر الجغرافيا السياسية.

كلمات البحث

الموارد المائية البديلة -الإستراتيجيات-الحصاد المائي-محطات التحلية-إعادة استخدام المياه

مقدمة

ساهمت العوامل السياسية والاقتصادية والاجتماعية والنمو السريع والمتزايد في كافة القطاعات التنموية إلى أن أصبح أمن الموارد المائية هدفاً تسعى المملكة إلى تحقيقه لاسيما بعد استنزاف جزء كبير من هذه الموارد من خلال إستراتيجية استندت على العرض دون ترشيد للطلب لفترة طويلة مع عدم وضوح لبوادر الإدارة المتكاملة لهذا المورد الثمين الذي يفوق في الأهمية نظيره من الموارد الإستراتيجية كالنفط مثلاً.

وقد تأثرت الموارد المائية في المملكة العربية السعودية وطرق استغلالها بعدد من العوامل الطبيعية والبشرية والسياسية والاقتصادية، المؤثرة على أمن واستقرار المشاريع التنموية التي اتبعتها المملكة في استغلال الموارد المائية وتنميتها، وسعيها حثيثاً في البحث عن موارد مائية أخرى، وضرورة إيجاد موارد مائية بديلة وآمنة كخيار استراتيجي،فكان انطلاق خطة التنمية الأولى،والتي واكبها انطلاق برامج تحلية المياه، إيذانا ببدء إستراتيجية الموارد المائية البديلة،ضمن سياسات المملكة في تحقيق أمن مواردها المائية.

تبع ذلك ظهور عدد من الاستراتيجيات التي طرحتها الجهات الحكومية ذات العلاقة داخل المملكة، أو المنظمات ومراكز البحوث في الخارج،كإستراتيجية استخراج المياه الجوفية العميقة، واعذاب المياه، وإعادة استخدام مياه الصرف الصحي والصناعي المعالجة، وخصخصة القطاعات المائية ونقل المياه عبر الأنابيب أو الناقلات من مناطق غنية بالمياه، و إعادة تسعير المياه.حيث تم اختيار بعضا من تلك الاستراتيجيات، والذي ساهم في تحقيق الأمن المائي للفترة الحالية،و سعى المملكة في تطوير بعض هذه الاستراتيجيات وزيادة فاعليتها، بينما تم استبعاد أو تأجيل بعضا من الاستراتيجيات لما حملته في طياتها من مخاوف أمنية.

أولاً- العوامل المؤدية إلى ظهور إستراتيجية الموارد المائية البديلة:

- **العوامل الطبيعية:**

تقع المملكة العربية السعودية في منطقة صحراوية جافة يقل فيها سقوط الأمطار بصفة منتظمة باستثناء المناطق الجنوبية الغربية. وبذلك تتميز بمناخ قاري حار صيفا، بارد جاف شتاء، مع قليل من الأمطار المتذبذبة من حيث الموقع والكمية والفصلية, بالإضافة إلى كبر مساحة المملكة و التي تبلغ نحو مليوني كيلو متر مربع (دارة الملك عبد العزيز، 1424: 41). تكاد تكون خالية من النباتات ومن المصادر المائية السطحية دائمة الجريان, وضعف الوسائل المساعدة لتحقيق قدر من الأمن المائي والغذائي، مع الأخذ بالاعتبار التغيرات المناخية العالمية المصاحبة للاحتباس الحراري والتي تضاعف من شدة تأثير موجات الحرارة و الجفاف المحلي والعالمي (مركز الأمير سلطان لأبحاث البيئية والصحراء، 2006 :72).

- **العوامل البشرية:**

1. **سياسات الأمن الغذائي والأمن المائي:**

أثرت العوامل الطبيعية في الحياة الاجتماعية لمعظم سكان المملكة،حيث بنيت على أساس الزراعة المعيشية المعتمدة على الأمطار والآبار،وبعد توحيدها، بدأت المملكة في التفكير في تأمين مواردها

المائية لعدة أهداف منها استقرار الشعب وتحقيق أمن الموارد المائية لتظهر إستراتيجية جديدة ركزت في البداية على تحقيق الأمن الغذائي والتركيز على إنتاجه محليا، ومرتكزة في الوقت نفسه على سياسة العرض، التي تأسست على توفير المزيد من المياه، عن طريق حفر الآبار، وجلب المياه منها إلى المدن الرئيسة التي عانت من ندرته، مثل مكة وجدة والرياض (تويتشل,1955: 174)، معلنة في الوقت نفسه عن انطلاقة جديدة في مسيرة المتغيرات البشرية والطبيعية ذات التأثير إيجابا و سلبا على موارد المياه و انعكست آثار ذلك كله، سلبا على الموارد المائية، وبدأت بوادر الندرة تزداد، وملامح التصحر والجفاف تزحف نحو الهجر والقرى والمدن، وتضاعف من وسائل تهديد الأمن المائي والغذائي وما تبع ذلك من وسائل البحث عن موارد مائية جديدة، ففي عام 1936م تمكنت المملكة من إضافة مورد مائي جديد هو المياه الجوفية العميقة، وفي عام 1948م تم إنشاء مديرية الزراعة ثم تم تطويرها عام 1953م إلى وزارة للزراعة (معهد الادارة العامة،1999: 182)، لضمان تحقيق سياسة الأمن الغذائي، والتوسع في برامجها ومشاريعها وما يؤكده ذلك من أهمية الماء اقتصاديا وسياسيا.

ومع استمرار التقدم الحضاري والنمو الاجتماعي والعددي لسكان المملكة من ناحية، وضعف التقديرات والمتطلبات المستقبلية لذلك النمو من ناحية أخرى، بالإضافة إلى التقلبات المناخية التي أفضت إلى مزيد من ندرة الموارد المائية، زادت الحاجة إلى المياه، و بدأت المملكة تواجه المشكلة ذاتها مع بداية الخمسينات الميلادية من القرن الماضي، فأخذت أعماق الآبار تزداد مع استمرارية تطبيق سياسة الأمن الغذائي إلى عمق تجاوز في الوقت الحالي 1.307 أمتار, ليطلق مرحلة جديدة من استنزاف الموارد المائية غير المتجددة بطريقة عشوائية, تسير وفق إستراتيجية كان أساسها توفير المزيد من المياه للمحافظة على الأمن الغذائي، لاسيما وأن ذلك الاستنزاف توافق مع بعض الأحداث السياسية العالمية التي أسهمت في هبوط حاد لإيرادات الدولة (معهد الإدارة العامة،289:1999)، كتأميم قناة السويس، وثورة مصدق في إيران وغيرها، والتي أثرت على طرق التجارة عبر الخليج العربي والبحر الأحمر، وجابهت معه الدولة عجزا ماليا خطيرا عمق من أهمية تحقيق الأمن المائي ليكون رافدا لسياسة الأمن الغذائي ومحققا لدورها في الاستقرار والأمن من ناحية، و لكونها أحد مصادر الدخل من ناحية أخرى(آل سعود،2005: 469). وعلى الرغم من أن الدولة قد تنبهت منذ نشأتها إلى أهمية إيجاد وسائل معينة ترفد بها مصادر المياه الجوفية، مثل مشاريع الري والصرف، و بناء السدود, وبمساندة قوية من عودة الطفرة النفطية، إلا أن نتائج الدراسات والبحوث التي أجرتها وزارة الزراعة والمياه بالتعاون مع بعض المنظمات الدولية، في عام 1384هـ/ 1964م (الجمعية الجغرافية لدول مجلس التعاون،2007: 163)، قد فتت من عضد تلك البرامج الترشيدية، وشجعت على مزيد من الاستنزاف المائي استمر حتى يومنا هذا بما أوحت به من وفرة المياه الجوفية في المملكة، وبإمكانية تغطيتها لحاجة التنمية فيها لسنوات عديدة، إذ على ضوء تلك النتائج، أصبح الطريق أكثر تمهيدا أمام سياسة الأمن الغذائي، وانطلقت المشاريع الزراعية تسندها تقنيات حديثة للري والحصاد، و نهضة صناعية تعتمد على منتجات زراعية وحيوانية ومعدنية، تعتمد جميعها في استمرارها ونجاحها على الماء، ولا سيما الأحفوري منه، وتقود ضمن سياسة العرض المائي، المملكة إلى مزيد من الجفاف والتصحر (الجمعية الجغرافية لدول مجلس التعاون،2007: 52).

2. <u>النمو السكاني والحضري:</u>

شجعت خطط التنمية في بداية ظهورها على الهجرة من الريف إلى المدن الرئيسية (معهد الإدارة العامة 1999 :344), ونتج عن ذلك تطور حضاري استقدام أيد عاملة، وانخفاض في معدل الوفيات، ونمو في حجم السكان والوافدين فاق الكثير من التوقعات، حيث تزايد عدد السكان من (7)مليون نسمة عام 1974م إلى (17) مليون نسمة عام 1993م، ليصل عام 2001م إلى حوالي (21)مليون نسمة (وزارة الاقتصاد والتخطيط، 2004م : 20)، ويتوقع أن يصل إلى (28) مليون نسمة عام 2009م وإلى

نحو (30) مليون عام 2025م (وزارة الاقتصاد والتخطيط -خطة التنمية الثامنة، 63). مع ارتفاع مستمر لمؤشر التحضر، والذي بلغ عام 1421هـ(86.2%) وتشير التوقعات نمو التحضر في عام 1446هـ ليصل إلى (92.3%) وهو من أعلى نسب النمو في العالم (العمري، 2007 : 109). نجم عن ذلك النمو السكاني تمدد أفقي عشوائي للمدن والقرى وتناثرالمزارع في هيئة قطع صغيرة في مساحات شاسعة (وزارة التخطيط، خطة التنمية الثانية:178) , و نمو مضطرد في استهلاك الموارد المائية، دونما خطة مائية متناسقة مع العرض والطلب. ويتضح ذلك من خلال تضاعف استهلاك المياه في مدينة الرياض إلى أكثر من 25 مرة منذ عام 1388 هـ (مصلحة المياه والصرف الصحي,1419: 15)، واحتلال المملكة للمرتبة الثالثة عالميا في استهلاكه، لتستمر عملية استنزاف كافة الموارد المائية مع تعرضها المستمر للتلوث، وتعدد الأسباب التي أسهمت في تدهور الموارد المائية كما وكيفا ومنها دفن وردم الأودية ومجاري السيول في المدن والقرى على حد سواء وإقامة المباني والمنشآت عليها، مما حد من دورها في تغذية الموارد المائية الجوفية لاسيما السطحية منها التغذية السليمة (الهيئة العليا لتطوير مدينة الرياض، 1424: 111), (وزارة الشؤون البلدية والقروية، 1422: 3).

ثانياً-استراتيجية الموارد المائية البديلة في المملكة العربية السعودية:

شهدت المملكة نهضة اقتصادية في ظل ندرة مواردها المائية،وتأثيرات التغيرات المناخية العالمية على تلك الموارد والحاجة الماسة إلى تنميتها وتطويرها (وزارة التخطيط، خطة التنمية الثالثة:162)، وظهور شائعات تنذر بدنو حرب مائية شرق أوسطية، وطرح عددا من الاستراتيجيات التي تقدم حلولا لمواجهة الأزمة المائية (عثمان، 1404 : 283) وكان من بين تلك المقترحات، إنتاج الهيدروجين في البحر الأحمر ونقله عبر خط من الأنابيب إلى المناطق الجبلية ليتم حرقه واستغلال ما ينتج عنه من طاقة وماء عذب، وشق قناة بين الخليج العربي والبحر الأحمر يمكن استخدامها في تسهيل عملية إقامة محطات لتحلية مياه البحر للمدن الداخلية من المملكة، واستخدام الطاقة الشمسية لإنتاج المياه العذبة من البحار، والاستمطار، وإقامة الصهاريج حول التجمعات السكانية ومواقع القرى بتوجيه بعض السواقي المنحدرة من تلك الجبال لتكون من بين الموارد التي يلجأ إليها وقت شح المطر، وإقامة حواجز صغيرة وذات كلفة مادية محدودة وتعميمها على منحدرات الأودية الصغيرة والشعاب لحجز المياه التي تنطلق من تلك المرتفعات، حيث تسهم هذه الطريقة في المحافظة على السيول بتوجيهها لأغراض السقيا، وتدعيم الآبار وتغذية الخزانات الجوفية، ونقل المياه من خارج المملكة إما عن طريق الأنابيب الممتدة من أنهار الدول المجاورة، أو باستخدام ناقلات النفط العائدة فارغة بعد تصدير النفط إلى خارج المملكة، والتي تملأ عادة بمياه البحر للمحافظة على توازنها، حيث يستعاض عنها بالمياه العذبة. أو باستخدام بالونات بلاستيكية ضخمة يمكنها نقل ثمانية مليون جالون يتم جرها بالقاطرات إلى المناطق الساحلية والتي تمت تجربتها عام 1997م لنقل المياه من اليونان إلى الجزر والمنتجعات الساحلية التي تعاني من نقص المياه، كما قامت شركة نرويجية باستخدام هذه التقنية لنقل المياه من تركيا إلى شمال قبرص (Gleick, 2001:5).

بالإضافة إلى أقتراح سحب الجبال الجليدية العائمة من القطب الجنوبي إلى المملكة، اعتمادا على أن (77.1 %) من المياه العذبة توجد في المناطق القطبية، وأن كمية المياه التي يمكن الحصول عليها من جبل جليدي أبعاده (90كم-35كم) تكفي لتزويد العاصمة الأمريكية واشنطن بالمياه لآلاف السنين(Frazier, 1977). وأن سحب الجليد ارخص من بناء محطة للتحلية وأكثر أمنا من الناحية البيئية (Jeff ,2004).

لم تكن معظم تلك المقترحات ذات ذات دلالة اقتصادية آمنة في تلك الفترة، لا سيما وأن التوترات السياسية والحروب التي تعرضت و تتعرض لها المنطقة، ما زالت توقد في الأذهان مدى حساسية تلك المناطق والتي يمكن أن يطلق عليها مناطق ارتطام Crush Zoones. ومع ذلك, فقد تداولت الأوساط العالمية أهم تلك الحلول والذي تمثل في مشروع نقل المياه عبر الأنابيب، والذي أطلق عليه في الآونة

الأخيرة (مشروع السلام) كمشروع ريادي حتى وقتنا الحاضر (محمد، 2005 :210)، إلا أن المملكة وان كانت كغيرها من الدول التي اقترح أن يشملها هذا المشروع، لم تقبل به لاعتبارات سياسية واقتصادية وأمنية، حيث تميزت عن معظم تلك الدول بتجارب تاريخية مماثلة مرت بها في بداية اكتشاف النفط في أرضها عندما أنشأت خط أنابيب التبلاين لنقل النفط من ساحل الخليج العربي نحو البحر المتوسط عبر عدد من الدول العربية (باخشب، 1415) و الذي أكد نتائجها ما حدث له بعد حرب اكتوبر 1973م، وما تعرضت له أنابيب نقل النفط العراقي عبر الدول المجاورة لها من مشكلات بعد حرب الخليج الأخيرة. هذا إلى جانب الأزمات السياسية التي قد تحدث بين الدول التي يمر بها ذلك الخط، خاصة وأن العلاقات بين هذه الدول غير مستقرة (أمين،2005 :94). كما يلعب التطرف المناخي الذي يسود معظم اراضي دول العبور دوره في جعلها بأمس الحاجة إلى تلك المياه فكيف بتصديرها. يضاف إلى ذلك التكلفة العالية لانشاء مثل هذه المشاريع, والوضع الجغرافي الطبيعي للمناطق التي تعبرها تلك الأنابيب، والمضخات، و الأيدي العاملة الفنية لادارة المشروع، في الوقت الذي تفتقر فيه معظم دول المنطقة إلى الخبرات الفنية المؤهلة للقيام بذلك (الن وملاط، 1995: 374).

أدركت المملكة أن إستراتيجية جلب المياه من الخارج غير مناسبة لتحقيق أمن الموارد المائية، إلا أنها أدركت أهمية تصحيح الخلل في الميزان المائي بين الموارد المائية المتاحة، والطلب عليها، لتتحول إستراتيجية المملكة من البحث عن موارد مائية جديدة للمياه التقليدية، إلى البحث عن موارد جديدة للمياه غير التقليدية، ، فكانت إستراتيجية المياه البديلة هي الحل الأمثل والتي يمكن تطبيقها بالاعتماد على برامج تنفيذية يتم من خلالهما استغلال الموقع البحري للمملكة لتحلية مياه البحر، وتعذيب المياه الجوفية قليلة الملوحة من ناحية، إلى جانب معالجة و تنقية مياه السيول والصرف الصحي والزراعي والصناعي، والاستفادة القصوى من الموارد التقليدية بترشيد استخدامها وتطوير إدارة التعامل معها من ناحية أخرى. يضاف إلى ذلك برامج خصخصة تلك المشاريع لمضاعفة أدائها ومشاركة رؤوس الأموال المحلية فيها، ومشاركة الدولة في تحمل بعض من المسؤوليات المالية وغيرها على النحو الآتي:

1. محطات التحلية كمورد مائي بديل وأهم المعوقات

يرجع استخدام محطات التحلية كموردمائي استراتيجي بديل الى عام 1328هـ باستخدام ما يعرف آنذاك بالكنداسة أو مكثف الماء القديم الذي كان مقاما في جدة (المديهيم، 1412 :15). وفي عام 1389هـ تم تشغيل أول محطتين للتحلية في كل من ضبا والوجه بطاقة قصوى بلغت (230) متر مكعب في اليوم لكل محطة (المؤسسة العامة لتحلية المياه المالحة،1419 :116 -117). وتعد تلك الفترة البداية الحقيقية لاستخدام محطات التحلية كبديل استراتيجي للموارد المائية،

كما شهدت تلك الفترة أيضا تكليف وزارة الزراعة والمياه بوضع خطة وطنية للمياه، إلا أن الوزارة لم تتمكن من وضعها لأسباب فنية ومادية، منها نقص وتباين المعلومات الهيدرولوجية لكافة المناطق، وتضارب نتائجها من جانب آخر (عثمان، 1383: 219). وبعد استكمالها، أكدت نتائج تلك الدراسات اهمية تحلية المياه ودورها الذي اصبح حقيقة مؤكدة بعد انشاء المؤسسة العامة لتحلية المياه المالحة بهدف إدارة مشروعات التحلية، وأهمية الدور الذي تسهم فيه تلك المشروعات من خلال انشاء التجهيزات الأساسية لاقامة محطات حديثة للتحلية كما أسست لوسائل نقل وتوزيع مياهها, كما بدأ في الفترة نفسها الاتجاه نحو استخدام نظام نقل مياه التحلية إلى قلب الجزيرة العربية لأول مرة، لتغذية المناطق الداخلية التي تعرضت مياهها للاستنزاف والهدر، أو للتدهور أو لحل مشكلة رداءة مياهها الجوفية وعدم امكانية استخدامها مباشرة، ليتم خلطها بمياه التحلية (المؤسسة العامة لتحلية المياه المالحة، 1419 :151). لتتمكن بذلك من حل مشكلة الندرة وسوء النوعية، وان لم تحل مشكلتي الاستنزاف،

والتدهور الناتج عن نقص مشاريع شبكات الصرف، وعدم الوعي بمخاطر استخدام الاسمدة والمبيدات الحشرية في الزراعة على أمن الموارد المائية. وقد رافق إنشاء هذه الأنابيب عدد من المشاريع المكملة لها والتي تشمل 27 محطة لضخ المياه و146 خزانا بسعة إجمالية تبلغ حوالي ثمانية مليون م3 و17 محطـــــــــة لخلـــــــــط ميـــــــــاه التحليـــــــــة بميـــــــــاه الآبار الجوفيـــــــــة (http://pr.sv.net/aw/2006/June2006/arabic/pages040.htm) وفي عام 1415هـ/1994م ارتفعت طاقة المياه الانتاجية لتصل إلى (508.32) مليون جالون أمريكي يوميا في المتوسط. أما في العام الثالث لخطة التنمية السابعة فقد زاد الانتاج حتى بلغ (740.52) مليون جالون (وزارة الاقتصاد و التخطيط، خطة التنمية الثامنة: 528).

ومن هنا نلمس مدى فاعلية إستراتيجية محطات التحلية كمياه بديلة، حيث أسهمت بطريق مباشر وغير مباشر في استمرارية التنمية في المملكة، بيد انها مع ذلك لم تتمكن من تغطية كافة احتياجات سكان المملكة من الموارد المائية، إذ لا تزال المياه الجوفية العميقة تغطي قرابة 50% من تلك الاحتياجات، في حين غطت مياه التحلية 51% من اجمالي الطلب على المياه للأغراض البلدية (وزارة الاقتصاد والتخطيط، خطة التنمية الثامنة:525). فإذا أخذنا في الاعتبار كون هذه المياه مياها أحفورية، تمتد خزاناتها إلى الدول المجاورة وغير المجاورة،(العمري،2007 :67) وأنها تعرضت وتتعرض للاستنزاف والهدر والتلوث في جميع تلك الدول المتشاركة بها، ومدى تأثير ذلك كله على قيمتها في دعم الأمن المائي للمملكة من منظور استراتيجي مستقبلي، ومن ثم على الخطط الإستراتيجية للتنمية فيها بصورة أو بأخرى، لا سيما وأن خطة التنمية الثامنة أشارت إلى أنه بغض النظر عن حجم المياه المتوفرة، فإن تحقيق هدف التنمية المستدامة وتحسين مستوى المعيشة يتطلب سرعة تخفيض الاعتماد على موارد المياه غير المتجددة، والاحتفاظ بها كاحتياطي استراتيجي لأغراض الشرب والاستخدامات المنزلية في المقام الأول (وزارة الاقتصاد والتخطيط، خطة التنمية الثامنة: 542), إلى جانب التحديات العديدة التي تجابه برنامج التحلية، مثل النمو السكاني السريع و قلة الوعي بأهمية الماء وحسن استخدامه، والتوسع الأفقي للكثافة السكانية، والتوسع في القطاع العمراني، وطبيعة المملكة الجغرافية واتساع مساحتها. يضاف إلى ذلك ارتفاع الفاقد من الشبكات المائية،وارتفاع التكلفة المالية لإقامة محطات التحلية وتشغيلها وصيانتها. وانخفاض قيمة تعرفة المياه بصفة عامة والاعتماد في إنتاج المحطات ومستلزماتها على شركات أجنبية، وإحجام رجال الأعمال والمستثمرين عن الدخول في مجال الخصخصة في مشاريعها لقناعتهم بضعف المردود المادي في مثل هذه الاستثمارات تحت تلك الظروف، لا سيما مع افتقار التشريعات الحالية المنظمة لقطاع المياه إلى "اللوائح التنفيذية التي تحدد أولويات الستخدام المياه، وتلك التي تحدد مسؤولياتالمستفيد من الخدمة، والملوث للبيئة ومصادر المياه، وصلاحيات الهيئات الإقليمية والمحلية، إضافة إلى مقاييس الجودة للمياه المعالجة، ولوائح صارمة للعقوبات والغرامات التي تطبق على مخالفي الأنظمة والقواعد." (وزارة الاقتصاد والتخطيط، خطة التنمية الثامنة:536). إلى جانب الموقع الجغرافي لمحطات التحلية التي تقع على سواحل الخليج العربي وما يتميز به من توترات سياسية قد تعرضها للتخريب من ناحية، وما تتعرض له مياهها من تلوث متعدد الأنواع والمصادر كالنفط ومشتقاته ومخلفات السفن والصرف بأنواعه،

وأخيرا الطاقة النووية. (وزارة الداخلية، 2007م: 175-176) لأدركنا مدى الحاجة الفعلية لترشيد استخدام كافة الموارد المائية واعتبار كل مورد منها خيار استراتيجي بحد ذاته، وأهمية دعم كل مورد للمورد المائي الآخر، وهو ما حاولت المملكة تنفيذه في بقية البرامج التنفيذية لسياسة المياه البديلة.

2. مياه الصرف الصحي المعالجة كمورد استراتيجي بديل وأهم معوقاته:

أصبحت المياه المستخدمة من أهم المشكلات التي تواجه دول العالم كافة نتيجة تضخم المدن من جهة، وزيادة كمياتها التي تحتوي على ملوثات متنوعة وصعبة التحلل من جهة أخرى، والاستفادة

منها كمورد مائي إضافي ومتجدد في الدول التي تعاني من شح المياه، مثل المملكة العربية السعودية، لا سيما وأن تلوث المياه يعد من أخطر المعوقات التنموية في استراتيجيات الأمن المائي، إذ من السهولة بمكان أن تتلوث مصادر المياه، ولكن من الصعوبة تنقيتها ومعالجتها من تلك الملوثات.

لذا، تعد عملية إعادة استخدام المياه العادمة أمرا مهما في المملكة، إذ يمكن لها عن طريقها تحقيق هدفين،الأول التخلص من أحد أهم مهددات الأمن المائي وهو تلوث الموارد المائية بأنواعها الثلاثة، الجوفية والسطحية والمحلاة، جراء سوء طرق التخلص منها، بإلقائها دون معالجة خارج المدن فتتسرب نحو الأحواض المائية الجوفية، أو يلقى بها في بطون الأودية لاسيما تلك التي تقع بالقرب من المدن الرئيسة (الجمعية الجغرافية بدول مجلس التعاون لدول الخليج العربية،2007: 163)، مما أسهم في تدهور نوعيتها وحال دون الاستفادة منها رغم أهميتها القصوى كموارد مائية أساسية، أو يتم تصريفها في شواطئ البحر الأحمر والخليج العربي المصدرين الأساسيين لمياه التحلية وما ينتج عن ذلك من تهديد لتلك المحطات، ومضاعفة تكلفة إنتاجها (وزارة الداخلية، 2007 :175-176).

أما الهدف الثاني فهو إيجاد مورد آخر من الموارد المائية البديلة يمكن من خلالها إنشاء الحدائق والأحزمة الخضراء وبرامج الترفيه المعتمدة على هذه الموارد، كما يمكن استخدامها في حقن آبار النفط والتبريد في المصانع، بتكلفة أقل نسبيا مقارنة بتكلفة تحلية المياه، أو البحث عن موارد جوفية جديدة (الجمعية الجغرافية بدول مجلس التعاون لدول الخليج العربية، 2007 : 74).

وإلى جانب هذين الهدفين، يبرز هدف استراتيجي ثالث لا يقل عنهما أهمية يتمثل في المحافظة على البيئة بصفة عامة (الشايقي، 1425: 7)، حيث تم بنهاية خطة التنمية الأولى انجاز عدد من مشروعات تصريف مياه السيول والصرف الصحي، إلا أنه كان أقل مما تم توقعه، اذ واجهت المملكة عددا من التحديات، مثل توقف عملية المعالجة للمياه المستخدمة لهذه المياه، ونوعيتها، وما يتطلبه ذلك من خبرات لتحديد مواقع تلك المحطات، ومشاريع إنشائها ذات التكلفة المادية، ومد الشبكات، و دراسة مدى تأثير ذلك على البيئة (عثمان،1404: 264)، إلى جانب طول المدة الزمنية التي تستغرقها مراحل عمليات التنقية، وما يترتب على كل مرحلة منها من مميزات تضاعف القدرة على الاستفادة منها. بالإضافة إلى العشوائية في توزيع المساكن، وعدم أخذ شبكات الصرف في الاعتبار عند بنائها، وقلة الوعي الاجتماعي بأهميتها، وحاجة المخططين والعاملين على مشاريعها للدراسات الميدانية والتطبيقية. يضاف إلى ذلك بعض الصعوبات الفنية التي لم تتمكن أجهزة ومعدات إنشاء الشبكات في تلك الفترة من التعامل معها (الخطيب،1986 :78). بالإضافة رفض المجتمع المبني على ناحية دينية هي الشك في طهارة هذه المياه، وأخرى نفسية ترفض شرب المياه المنتجة بتلك الطريقة، أو حتى أكل ما ينتج عن استعمالها في الزراعة.

أما التحدي الآخر فقد قاده القلق حول الصحة، حيث أن الأمر يستوجب التأكد من أن تحقيق تلك الأهداف، والفائدة المرجوة منها لا تؤدي إلى حدوث مخاطر في الصحة العامة لا تحمد عقباها سواء للمزارعين أنفسهم، أو للمستهلكين لمنتجاتهم، أو لرواد الحدائق، والعاملين في المصانع، كي لا يكون حل مشكلة المياه سببا في مشاكل صحية(عثمان، 1404: 267).

وسعيا لتطبيق تلك الإستراتيجية والعمل على زيادة فاعليتها في المحافظة على الأمن المائي والبيئي، تم التأكيد عليها في المادة الثانية والثلاثين من نظام الحكم في المملكة الصادر عام 1412هـ، والتي تنص على أن " تعمل الدولة على المحافظة على البيئة وحمايتها وتطويرها ومنع التلوث عنها" (الشايقي، 1425 :7). كما صدر في عام 1420هـ نظام إعادة استخدام مياه الصرف الصحي المعالجة التي تنتج

عن مياه الصرف الصحي أو الصناعي أو الزراعي, كما صدر قرار مجلس الوزراء رقم (219)، وتاريخ 1423/9/6هـ ، الذي أتاح للقطاع الخاص الاستثمار في مشاريع المياه مثل إنشاء محطات التحلية أو معالجة مياه الصرف الصحي أو إقامة السدود والقنوات المائية وشبكات المياه وغيرها بهدف تحسين الكفاءة وزيادة الإنتاجية وتخفيض التكلفة على الدولة، ولفتح مجالات جديدة للقطاع الخاص. إلا أن إستراتيجية إعادة استخدام المياه لم تؤت ثمارها حيث لم يتجاوز معدل استخدام هذه المياه (12%) من حجم إمدادات المياه، وهو معدل منخفض قياسا بالعديد من الدول التي تعد مياه الصرف الصحي المعالجة من مصادر التنمية المستدامة (وزارة الاقتصاد والتخطيط, خطة التنمية الثامنة: 534)، وهذا الانخفاض يرجع الى عدة عوامل منها تهالك شبكات الصرف نتيجة قدمها والتهاون في صيانتها، أو لعدم وصول هذه الخدمة لما يقرب من ثلثي المياه البلدية حتى تاريخه، وبالتالي لا تتم معالجتها، رغم ما يترتب على ذلك من تسربها إلى باطن الأرض وما ينتج عن ذلك من ارتفاع منسوب المياه السطحية في بعض المناطق من ناحية، وما يطال البيئة والصحة من أضرار (الهيئة العليا لتطوير مدينة الرياض،1422: 25)، علاوة على عدم الاستفادة منها في مضاعفة كميات المياه البديلة والمحافظة على المخزون الاستراتيجي للمياه الجوفية، مما يحتم سد الفجوة بين طاقات إمدادات المياه وشبكات الصرف الصحي (وزارة الاقتصاد و التخطيط، خطة التنمية الثامنة:535). حيث بلغ المتوسط العام لمعالجة مياه الصرف الصحي في المملكة (33.5%) عام 1425هـ/ 2004م، ويتباين هذا المعدل بشكل كبير بين مدن المملكة، إذ يقترب من التغطية الشاملة (100%) في كل من مدينتي الدمام والجبيل، فيما يتراوح بين (30%) إلى (40%) في مدن الرياض وجدة والمدينة المنورة. و تشير التقديرات إلى توقع زيادة هذه النسبة إلى (40%) بنهاية الخطة الثامنة 2009م مع ارتفاع الحاجة إلى (2.22) مليون توصيلة صرف صحي، وأكثر من (40) ألف كيلو متر من شبكات الصرف الصحي، وهنا أيضا تشير التقديرات إلى زيادة نسبة المياه المستخدمة من إجمالي المياه المعالجة من (37 %) إلى (40%) خلال نهاية الخطة الثامنة, مما سيتيح زيادة حجم المياه المعاد استخدامها من (260), إلى (380) مليون متر مكعب خلال المدة ذاتها. (وزارة الاقتصاد والتخطيط، خطة التنمية الثامنة: 538)، مما يوضح مدى قصور خدمات الصرف الصحي في تحقيق إستراتيجية المياه البديلة، وبالتالي ضعفها في تحقيق أمن الموارد المائية الأمن، وإسهام ذلك في هدر وضياع ما يقرب من (77%) من كمية المياه المستعملة دون استفادة منها من ناحية، وأثر ذلك في تلوث مصادر المياه التقليدية الجوفية والسطحية، وتهديد مياه التحلية من ناحية أخرى، كما تهدد برامج الترشيد وتقلل من فاعليتها نتيجة، وهي أمور بالغة الخطورة والحساسية على نوعية المياه إن لم يتم تداركها (الأسكوا,2005 :25).

3. **الحصاد المائي كمورد بديل وأهم معوقاته:**

يعد الحصاد المائي أحد أهم الوسائل التي استخدمت لمواجهة ندرة الموارد المائية في العالم، وكان للمملكة العربية السعودية نصيب في استخدامها عندما اعتمد سكانها على تجميع مياه الأمطار التي تجرى في الأودية والشعاب بطرق عديدة إلا أنها ،وعلى الرغم من بدائيتها وتقنياتها البسيطة، ذات تأثير فعال في تزويدهم باحتياجاتهم المائية والمحافظة على المياه كمورد حيوي إلى جانب محافظتهم على البيئة،إما عن طريق الصهاريج التي تتراوح سعتها من بضعة مئات من الأمتار إلى عدة آلاف، استخدمت في بعض مدن المملكة التي تعاني من ندرة المياه مثل جدة والوجه واملج وضباء، أو عن طريق تجميع مياه الأمطار وتوجيهها نحو خزانات في أسفل المساكن (العمري,2007 :168).كما تمكن سكان المناطق الجبلية من عمل المدرجات الزراعية على امتداد سفوح الجبال وجوانبها،أو بإنشاء الحفر مختلفة الأحجام في طريق السيول لتجميع مياهها قبل وصولها إلى المصبات، أو ببناء السدود الترابية التي تعرف بالعقوم لحجز مياه الأمطار والسيول. ويعد إنشاء السدود الخرسانية بمختلف الأحجام والأغراض والأنواع،على معظم الأودية المنتشرة في المملكة ليصل عددها إلى حوالي (230) سدا تربو سعتها التخزينية على (850) مليون متر مكعب، هي إحدى صور الحصاد المائي (وزارة المياه والكهرباء،2006: 5). ومن المتوقع التوسع في ذلك خلال خطة التنمية الثامنة حيث يجري حاليا تشييد

(17) سدا بطاقة تخزينية قدرها (979.5) مليون متر مكعب، بالإضافة إلى (15) سدا في طريقها للتنفيذ (وزارة الاقتصاد والتخطيط،خطة التنمية الثامنة:522). ومن المتوقع أن يحقق الحصاد المائي من خلال التوسع في إنشاء السدود، أهدافا إستراتيجية ذات قيم اقتصادية وأمنية، تتجسد في تغذية الطبقات الحاملة للمياه و رفع مستوى الماء في الآبار المحفورة في الأودية، وتوفير المياه الصالحة للشرب في المدن والقرى بعد تنقيتها وتعقيمها, إلى جانب تأمين مياه الري المباشر للمزارع والحقول(وزارة المياه والكهرباء،2006: 7). ويؤكد في الوقت نفسه فاعلية حصاد المياه كأحد استراتيجيات المياه البديلة، وأن العودة إلى الاهتمام بها ووقف تعرض معظم روافد الأودية وشعابها للردم والدفن وإقامة المباني والمنشآت عليها، في ظل الظروف الطبيعية الراهنة والتغيرات المناخية المحلية والعالمية وما قد ينتج عنها من مضاعفة ندرة المياه، يعد قيمة مائية مضافة للموارد المائية. بيد أن تلك السدود ما زالت بحاجة ماسة إلى الدراسات التقييمية لآثارها على مستجمعات المياه الجوفية السطحية في المناطق التي كانت تغذيها تلك الأودية ولم تعد تصل إليها مياهها بعد إنشاء تلك السدود. خاصة وأن المياه الجوفية ما زالت هي المورد الأول للمياه وبنسبة تقدر بنحو 50% من جملة المياه المستهلكة بالمملكة، وأن هذه النسبة في تناقص مستمر لاستنزافها و تدهورها نوعيتها (وزارة المياه والكهرباء،2006 :44).

اتضح مما سبق ذكره، أنه على الرغم من تعدد الاستراتيجيات المائية التي طبقتها المملكة خلال العقود الماضية من القرن العشرين وبداية القرن الحالي، إلا ان التحديات الطبيعية والبشرية حالت وتحول دون تحقيق للأمن المائي المأمول تحقيقه من تلك الاستراتيجيات. وظهرت الحاجة إلى دعمها بعدد من السياسات، يمكن حصرها في:

1- ترشيد استهلاك المياه في القطاع الزراعي:

نتج عن سياسة الأمن الغذائي والتركيز على الزراعة، وتوزيع الأراضي البور مجاناً، و تقديم قروض زراعية ميسره بدون فوائد، و شراء بعض المنتجات بأسعار تشجيعية طفرة زراعية، وصل إنتاج الحبوب خلالها عام 1993م إلى أكثر من خمسة ملايين طن من القمح والشعير وأصبحت المملكة سادس دولة في تصدير القمح، كما نمت مشاريع الألبان وتعبئة المياه، بل وتصديرها,

رغم عدم وجود جدوى اقتصادية من منافسة الإنتاج العالمي لارتفاع تكاليف الإنتاج في المملكة، إضافة إلى الخسارة غير المنظورة المتمثلة في تدني مخزونات المياه الجوفية غير المتجددة، والتكاليف المالية التي يتم صرفها على برامج إستراتيجية المياه البديلة رغم ظهور الدعوة إلى ترشيد ذلك منذ خطة التنمية الثانية (وزارة التخطيط، خطة التنمية الثانية: 522)، والتأكيد عليه في خطة التنمية السابعة (وزارة التخطيط, خطة التنمية السابعة:235) واتخاذ عدد من الإجراءات التنفيذية، كوقف توزيع الأراضي الزراعية لمدة خمس سنوات، وتخفيض الدعم لبعض المحاصيل، ومراجعة نظام المحافظة على المياه الصادر بالمرسوم الملكي رقم م/34 في 1400/8/24هـ وتعديل لوائحه التنفيذية. إلا أنه من المتوقع أن يشهد قطاع الزراعة خلال السنوات القادمة نموا حقيقيا بمعدل سنوي قدره (3.2%)، مما قد يشكل ضغطا على استراتيجيات المياه البديلة لسد العجز الذي قد ينشأ عن ذلك، خاصة مع استمرار توفير المياه لهذا القطاع دون قيود تذكر حيث تشير التقديرات إلى ان الزراعة تستهلك (86.5%) من مجموع الاستهلاك المائي في المملكة, مع معدل فاقد يقدر بحدود (30%) وهو معدل مرتفع نسبيا وفقا لتقدير وزارة الاقتصاد والتخطيط (وزارة الاقتصاد والتخطيط، خطة التنمية الثامنة:96)، مما يتوجب معه العمل الجاد لاتخاذ كافة التدابير للحد منه، مثل التقنية الحيوية، والمزارع المائية، تغيير التركيب المحصولي أو على الأقل إحلال محاصيل زراعية تستهلك كميات اقل من المياه، واختيار المواسم الزراعية المناسبة، والمناطق الملائمة لكل محصول بهدف خفض استهلاكه للمياه ، مع رفع كفاءة الري

كونه أحد الوسائل الناجعة في خفض استهلاك القطاع الزراعي للمياه،وتحقيق مساعي المملكة الحثيثة لتطبيق خطط مكثفة لترشيد كافة أنواع استخدام المياه، وإعداد برامج توجيهية لمختلف شرائح المجتمع.

2-صيانة شبكات المياه:

رافق ظهور إستراتيجية المياه البديلة في المملكة، إنشاء شبكات لتوزيع المياه في المدن والقرى، إلا أن ارتفاع معدلات الفاقد من هذه الشبكات، قبل وصولها إلى المستهلك والذي قدر بنحو (28.5%)، نتيجة لقدمها وتهالكها، أو لتعرضها للانكسار وتسرب المياه، وما قد يحصل من تلوثها بالمياه العادمة أو بالملوثات الأخرى (وزارة الاقتصاد والتخطيط، خطة التنمية الثامنة: 529)، مما أخل بتنفيذ تلك الإستراتيجية ومن ثم بسياسة الأمن المائي، إلى جانب ما تسببه هذه المياه من آثار بيئية واقتصادية خطيرة، مما دفع بخطة التنمية الثامنة إلى التأكيد على أهمية تحسين أداء شبكات نقل المياه، لمنع الهدر، و اعتبار ما يتم توفيره نتيجة ذلك مورداً مائياً إضافيا يعتمد عليه للوفاء بالاحتياجات المائية في المستقبل. مما يعني عدم فاعلية هذه الإستراتيجية في الوقت الحالي في توفير المياه البديلة، في جميع مدن المملكة لقصور الشبكات الحالية أو لرداءتها، رغم أهميتها في المحافظة على المياه المعالجة والتقليدية على حد سواء (العمري،2007: 156).

3-التخطيط الشامل والإدارة المتكاملة للموارد المائية:

كان لتعدد الهياكل المؤسساتية المسئولة عن المياه ومرافقها وأماكن تواجدها، كوزارة الزراعة ،ووزارة المياه، والمؤسسة العامة لتحلية المياه المالحة، ومصالح المياه والصرف الصحي، ووزارة الشئون البلدية والقروية، دوره في الحيلولة دون إيجاد حلول جذرية للتحديات التي تواجه قضايا الماء بصفة عامة، وإستراتيجية المياه البديلة بصفة خاصة في المملكة العربية السعودية، مما ترتب عليه ظهور عدد من الأنظمة والتشريعات لتلافي ذلك القصور أو الحد منه.

بيد ان تلك التعددية حالت أيضا دون التقيد بها كما يجب، بالرغم من محاولات التنسيق بين تلك الهياكل المؤسساتية، إلى جانب ضعف تلك الجهود وتداخل المسؤوليات و عدم وجود خطة وطنية للمياه تدعم ذلك كله، إلى أن تم تلافيه في خطة التنمية السابعة بإنشاء وزارة المياه بناء على قرار مجلس الوزراء رقم (125) وتاريخ 1422/4/25هـ لتشرف على قطاع المياه ومرافقه، و لتقوم بتطوير السياسات المائية، وإزالة الازدواجية والتداخل في تنفيذها، وإعادة هيكلة إدارة العرض والطلب للموارد المائية. اسهم ذلك في دفع هذه الوزارة إلى البدء في تحديث الدراسات المائية السابقة وإجراء دراسات تفصيلية جديدة، تمهيدا لتحديث الخطة الوطنية للمياه (وزارة الاقتصاد والتخطيط، خطة التنمية الثامنة،532)، بما يحقق تفعيل إستراتيجية المياه البديلة وابتكار وتطبيق برامج جديدة ومتطورة تسند البرامج سالفة الذكر وتحقق التوازن بين الأمن المائي والأمن الغذائي، لاسيما مع وجود المراكز العلمية المحلية والعالمية التي تدعمها المملكة، وتقديم الجوائز العلمية السخية في سبيل ذلك. بالإضافة إلى الدعم المستمر للمؤتمرات والندوات العلمية التي تعين على طرح الحلول العلمية القابلة للتطبيق.

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Summary

Since the discovery of oil, political, economic, and social factors, rapid growth, and increased development in all sectors, has witnessed by Saudi Arabia, which seek to achieve water security, especially after over-consumption of a large amount of its water resources

through a strategy based on the demand without any rationalization of supply or a sign to integrated water resources management of this precious resource. Saudi Arabia adopted a preliminary step aimed to achieve water security and examining a number of strategies ,which have been put forward by many government bodies within the kingdom, or by organization and research centers abroad. These strategies, which include, extraction of non-renewable deep ground water, sea water desalinization, treated water reuse, water sector privatization, water transportation by pipelines and tankers from water-rich countries and regions, and water re-pricing. Based on many economic, political, and social factors, Saudi Arabia has adopted many strategies to achieve its water security to develop strategies for sustained development and greater effectiveness, while excluded other strategies for potential security concerns. The aim of this research is to study alternative water resources strategies in Saudi Arabia and the factors which influencing the adoption of proposed strategies and their impact on water security.
Keywords: water resources alternative strategies, water security, water resources integrated management, water harvesting.

Present and Future Water Supply and Demand
in Saudi Arabia

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INTRODUCTION

The Kingdom of Saudi Arabia has seen tremendous changes in its social and economic spheres in the last 30 years. Wealth from oil revenues made it possible for the government to develop all sectors of the economy. One major sector which has seen tremendous growth is the agricultural sector. It has grown so fast during this period causing huge withdrawals from the country's limited deep groundwater reserves. The growth of cities, increase in the population and the rise in the standards of living caused domestic and industrial water consumption to increase many folds.

The constant pressures on the country's water resources made it necessary to develop both the conventional water resources (surface and groundwater) and the unconventional ones (desalination of sea water and treated wastewater). More than 230 dams for different purposes were constructed to utilize surface water which is available in some regions of the country. The Kingdom's huge aquifers were also extensively studied and utilized for different uses. With respect to desalination of sea water, many stations were built on the Red Sea and the Gulf. Saudi Arabia is currently the world's largest producer of desalinized sea water. Desalination plants produce water for coastal urban centers and for many cities in the interior of the country including the capital city of Riyadh. Wastewater treatment plants were also constructed in many urban areas. Utilization of treated wastewater, however, is still limited.

In spite of the tremendous efforts made by the government to develop the water supplies in the country, the consumption of water in Saudi Arabia has reached alarming levels. The objective of this paper is to seek sustainable management for water resources in the Kingdom of Saudi Arabia through the following:

1. Review charges in supply and demand for water during the last few decades.

2. Predict future supplies and reserves as well as demands (for all sectors) up to the year 2025. This was done using different scenarios and assumptions.

3. Discuss major future problems facing water resources management in the country and suggest possible solutions to meet these problems.

PAST WATER SUPPLIES AND DEMANDS

Available Water Resources

Water resources In Saudi Arabia can be classified into four types: surface water, groundwater, desalinized water and treated wastewater.

Except for the mountainous area, in the southwestern part of Saudi Arabia, precipitation is very low and infrequent with extreme variation from one year to the next. The average rainfall for the whole country is about 90 mm per year. In Saudi Arabia surface runoff occasionally occurs during the rainy seasons when there are rain storms. Estimates of the amount of runoff water range between 2,000 and 2,400 MCM (Ministry of Planning, 1985) per year. Most of the runoff occurs in the coastal areas and highlands of the southwest, where rainfall is relatively abundant and regular. The Ministry of Water and Electricity (MOWE) has constructed about 230 dams throughout the country to utilize surface runoff water.

While these dams store runoff water and increase infiltration for recharging groundwater resources, they also prevent flash floods. It is expected that the efficient use of dams provided a potential surface-water supply of up to 900 MCM/year for the Kingdom in 1985 (Ministry of Planning, 1985). Since 1985, more surface water has been utilized especially after the completion o King Fahad Dam in Bishah (capacity 325 MCM), but surface water resources in Saudi Arabia are very limited and are important only in the southern region of the country.

Al-Ibrahim (1990) presented the most concise summary of groundwater resources. He stated that groundwater is the most important source of water in Saudi Arabia. It comes from two types of aquifer: renewable and nonrenewable. The first type, shallow aquifers, contains a renewable water supply charged by infiltration from rainfall and surface-runoff. The renewable groundwater is estimated at around 950 MCM/year. The other type, deep aquifers, contains a reservoir of water formed thousands of years ago when water was trapped in sedimentary rocks such as limestone and sandstone. These deep aquifers receive negligible or no recharge and therefore store nonrenewable and depletable groundwater resources. The depth of these aquifers ranges between 100 and 500 m and may exceed 1,000 m in some areas. Nonrenewable groundwater reserves were estimated at 500,000 MCM of which 67% is stored in seven major aquifers, while a series of secondary aquifers holds the rest (Ministry of Planning, 1985). The renewable groundwater resources are utilized mainly for agricultural purposes in small farms located adjacent to wadis (dry water courses) in many areas of the country. The nonrenewable groundwater has been used extensively especially since 1980 at alarming rates to provide water for irrigation in the extensive areas put under cultivation outside the traditional agricultural oases. It was estimated by Al-Turbak and Al-Dhowalia (1996) that about 30% of the nonrenewable groundwater resource (500,000 MCM) has been used by 1995. However, there are detailed studies going on now to review existing reserves of groundwater.

Due to scarcity of fresh water resources in Saudi Arabia desalinized sea water is extensively used as an additional source for domestic water supplies. Saudi Arabia is the largest producer of desalinated seawater in the world. The Saline Water Conversion Corporation (SWCC), which is the authority incharge of desalination, presently operates 25 desalination plants, with a total daily production capacity of about 3 MCM. Seawater desalination is an expensive operation that requires a large amount of money to construct, operate, and maintain. In addition, the TDS level in the Red Sea and the Gulf (which varies between 40,000 and 60,000 ppm) is much higher than that of other seas and oceans (Wojcik, 1981). For this reason, water desalination in Saudi Arabia is more expensive than in other countries using the same methods of desalination. Moreover, considering the fact that the operational life of a desalination plant is in the range of 15-25 years, Saudi Arabia will require large amounts of expenditure to replace worn-out plants. This will impose a heavy burden on the country's financial resources.

In an arid country where natural water resources are limited reclaimed wastewater can be an important potential source of water supply. In addition, the treated wastewater has several advantages over other sources of water. It is cheaper than seawater desalination; it minimizes pollution; and it is good nutrient source for landscape and farm irrigation. The total amount of collected wastewater in all urban centers of the Kingdom was estimated to be 1017 MCM in 1995 (Al-Turbak and Al-Dhowalia, 1996). Out of this amount, 418 MCM were treated using secondary treatment or better. This has increased in 2005 to 1300 MCM and it is expected to grow rapidly as more sewer network and more treatment plants are constructed in the future.

Water Demand

Water demands in different sectors are met from either traditional sources (surface and groundwater) or from non-traditional ones (desalination and treated wastewater) depending on the type of use. The agricultural sector uses mostly non renewable groundwater with some of its demands met, by surface water, renewable groundwater and treated wastewater. Water for domestic use comes mainly from desalination or groundwater. Industrial sector demand comes mainly from deep nonrenewable groundwater. Table (1) shows water demand in different sectors from 1985 to 2005. Demand for water in the agricultural sector has grown at a very alarming rate since 1985. In 1985, it reached a level of 7430 MCM. By the year 1990, this demand reached 14580 MCM/year and in 1995 it was estimated at about 16400 MCM. Since then, however, the increase was at lower rates.

Table (1): Water Demand in Different Sectors (MCM).

	1985	1990	1995	2000	2005
Urban	900	1300	1400	1750	2100
Industrial	300	350	400	450	640
Agricultural	7430	14580	16400	18540	17530
Total Demand	8600	16230	18200	20740	20270

Municipal water demands has also increased during the same period due to increase in population; rising standard of living and the immense growth of urban centers. In 1995, municipal water requirements were put at 1400 MCM. Industrial and other demands were estimated for 1995 to be 400 MCM. For the year 2000 and 2005 the table shows the demands.

FUTURE WATER SUPPLY AND DEMAND

Prediction of Future Water Resources

It is expected that utilized surface water resources will increase to about 2000 MCM by the 2025. This will be mainly due to the construction of more dams throughout the country.

Renewable groundwater resources that are utilized are also expected to increase due to developments taking place in the areas where they are available. It is expected that by the end of the study period, about 1500 MCM of renewable groundwater will be available. Available nonrenewable groundwater resources will continue to decline as more water is pumped from major aquifers. The amounts withdrawn upto the year 2025 will highly depend on different scenarios future development especially in the agricultural sector.

Desalinized seawater is expected to increase at about 3% annually. This estimate was based on the last few years increases and on the number of desalinization projects planned during the future development plans. This resource will be about 1750 MCM by the year 2025 and will exclusively be used for domestic purposes.

Treated wastewater will continue to be available at increasing amounts as more treatment plants are constructed and as more parts of different cities are connected to sewage networks. It is anticipated that the amounts of this important resource will increase from about 30% of domestic water supply to almost 70% by the end of the study period.

Estimating Future Water Requirements

Al-Saadi (2006) conducted a study on estimating water requirements for Saudi Arabia for the next 20 years taking 2005 as the base year. The following is a summary of that study.

The agricultural water requirements were estimated based on crop irrigation requirements of the major crops in the Kingdom and the recent agricultural strategy put forward by the Ministry of Agriculture. Table (2) shows the estimated consumption of the agricultural sector based on the new strategy.

Table (2): Agricultural Water Requirements (MCM).

Year	2005	2010	2015	2020	2025
Water Requirement	17373	16099	14823	13546	13546

Future urban (domestic) water needs were estimated based on present population and their growth rates and the per capita consumption. Table (3) shows the Kingdom's population (Saudis and Non-Saudis) estimates based on growth rates given by the Department of Public Statistics.

Table (3): Future Population Estimates.

Year	Population (Millions)
2005	22.67
2010	25.65
2015	29.02
2020	32.84
2025	37.15

The urban water requirements for the next 20 years were then calculated based on two per capita values. The first alternative (A1) : 273 ℓ/cap./day is the average water available in 2005 while the other alternative (A2) is based on reduction of present figure (273) to 200 ℓ/cap./day by the end of the period. Table (4) shows the estimates of urban water requirements up to 2025 for these two alternatives.

Table (4): Urban Water Requirements (MCM).

Year	(A1)	(A2)
2005	2190	2190
2010	2479	2307
2015	2805	2425
2020	3174	2534
2025	3591	2630

The future industrial water requirement was estimated with an annual increase of 5% based on estimate of previous studies.

Total future water requirement with urban water consumption given by the alternative (A2) is given in Table (5).

Table (5): Total Future Water Requirements (MCM).

	2005	2010	2015	2020	2025
Agriculture	17373	16099	14823	13546	13546
Urban	2191	2307	2425	2534	2630
Industrial	640	800	960	1120	1280
Total	20204	19206	18208	17200	17456

DISCUSSION

Based on the previous analysis, future demands in different sectors will be met as follows:

1. Demand for agriculture is met by all renewable surface and groundwater and 80% of treated wastewater. The rest is met by pumping from nonrenewable groundwater.

2. Municipal water supplies will come from desalinization and from well fields drilled in deep aquifer.

3. Industrial and other uses will be met by 20% of treated wastewater with the balance coming from deep groundwater.

If the second alternative in meeting municipal water requirement and the new agricultural strategy is adopted, the dependence on non-renewable groundwater will be greatly reduced. This will result in making at least 45% of the agricultural water demand comes from renewable resources by the end of the study period. This will not only result in the conservation of deep groundwater resources but also will allow the country to have a sustainable agricultural production.

MAJOR PROBLEMS FACING WATER SECTOR IN SAUDI ARABIA

Water supplies and demands in any developing country face many difficulties and problems. Saudi Arabia provided the water supplies with its utmost attention. However, certain problems continued to bother planners and there will be probably worse in the future if no solutions are introduced. The most serious problems are:

1. Demand for water in the agricultural sector has grown to a level much higher than the renewable resources of the country. This meant that major aquifers were mined at a very fast rate. If this trend continues in the future, nonrenewable groundwater resources will be depleted soon. The government, however, has introduced some measures to reduce to some extent the excessive pumping from groundwater reserves.

The proposed agricultural strategy is the most important development in this direction.

2. Desalinized sea water is currently used to meet part of the ever growing domestic demands. The government has spent billions of dollars in the construction, operation and maintenance of desalination plants. But with the increase of population in urban centers, decreasing groundwater supplies and lack of conservation, domestic water supplies will be in danger in the future.

3. Treated wastewater represents a very important source to be utilized for many purposes in Saudi Arabia. However, the amounts actually used are now small. This is mainly due to slowness in wastewater treatment plants construction and in providing necessary facilities to transport treated wastewater to areas where it can be efficiently used.

4. Surface water and renewable groundwater represents the most important natural water resources for the future. In spite of this, they have not been developed properly in some parts of the country. They also suffer from neglect and inefficiencies in the areas close to wadis and in old oases.

SUGGESTED SOLUTIONS TO MEET FUTURE WATER PROBLEMS

Shortages of water in arid areas are normal and expected. However, severe shortage of water will have serious social and economic effects. They will also cause severe health problems and may result in economic collapse. To avoid the problems that will be faced by the water sector in Saudi Arabia, or at least reduce their effects, it is necessary to concentrate actions in the following areas:

1. Reduce, in a gradual manner, the consumption in the agricultural sector, to a safe level. That level should be no more than the sum of renewable surface and groundwater resources and treated wastewater. The proposed agricultural strategy should be followed.

2. Conservation of water use in arid regions is of a paramount importance. Although some conservation efforts (public awareness programs, television and other public media messages etc.) were made in the past, there is urgent need to do more. Actions needed include the use of drip irrigation, increase prices for water and require drainage water recycling.

3. Give priority in government spending to wastewater treatment plants construction and to distribution and pumping facilities for transporting treated wastewater. This will result in more treated wastewater being available for different uses. Hence, some of the demands for agriculture and industry can be met from this resource.

4. Due to possible future shortages of domestic water supplies, it is necessary to reserve parts of the areas covered by major aquifers for future domestic use. MOWE has made an effort in designating few protected areas for that purpose. However, there is need to do more in this regard. The reserved areas should be large enough especially close to major urban centers with at least 1 km^2 of protected surface area per 1000 people.

5. Increase production of desalination sea water and carry on more research in the area of desalination especially on methods and materials that will help to reduce costs.

6. Develop water resources in areas adjacent to wadis and use the renewable surface and groundwater in old oases in an efficient manner.

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IWRM STRATEGIES AND POLICIES IN OMAN'S NATIONAL WATER RESOURCES MASTER PLAN

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Abstract

Optimization and strategic management of the Water Sector was seen as a key dimension of the Omani Economic Diversification Strategy at the "Vision 2020" Conference in 1995. Oman has completed a National Water Resources Master Plan for the period 2000 to 2020 to assist meeting this strategy and maintaining the country's water security. The Plan adopts the widely-accepted Dublin (1992) principles and meets the requirements of the Hague Declaration (2000). In line with current best practice, the plan has adopted a holistic approach taking into account technical, institutional and legal reforms, stakeholder participation, public and private sector management and environmental issues. The Plan recognizes that water is a critical element for life and that:

- water resources are a national wealth and a sustainable approach must be taken to their long-term use to preserve these for future generations when income from energy resources may be reduced.
- Safe and assured water sources and supplies coupled with sanitation and sewerage facilities are a prerequisite for social harmony, economic development and the health of the country.
- Development of water resources should be linked to the country's social and economic policies and should take account of the needs to conserve the country's natural habitats and ecosystems for the health and wealth of future generations.

Implementation of the Plan, by the MRMWR and other agencies and through encouragement of the private sector will provide a sustainable use of the country's renewable water resource by the year 2020 and will increase the currently renewable resource and improve its security through the construction of appropriate facilities; improved management; support and advice to farmers, particularly those using wells for irrigation.

Through the provision of sustainable water resources, other Ministries will be able to provide higher levels of services through piped water supplies and complementary wastewater systems to large towns and assured water supplies for delivery to other small towns and rural populations and support in the development of wastewater re-use schemes.

This paper discusses the basis for integrated water sector planning, IWRM Strategies and Policies in Oman's National Water resources Master Plan, including the encouragement of increased community participation in planning and decision-making processes, as well as establishment and protection of secure sources of potable water supplies for all towns and priority purposes with consideration to agricultural water demand management (through introduction of a quota system). The paper also discusses the implementation of the Plan and the required institutional changes, modifications to legislation and regulations, human resources development, training and public awareness campaigns.

1. Introduction

The Sultanate of Oman has undergone rapid development since 1970 with major investment in infrastructure, education and health. Standards of living and the quality of life have risen very significantly. A modern state with a dynamic economy and forward looking policies is now in place to meet the future development needs of a population which is predicted to increase by fifty percent in the next twenty years. Important features of current policy are the diversification of the economy to reduce its dependence on oil, increased participation of the private sector, Omanisation of employment and a commitment to sustainable development. The growth envisaged will present a major challenge for the Ministry of Regional Municipalities and Water Resources to find ways of meeting the demands for water from the country's domestic, industrial and agricultural consumers.

The importance of water in the development process has long been recognized in Oman. The country's record in developing and implementing sound water management policies and practices has been impressive in meeting the country's requirements. Committed and responsible management has contributed to this. Oman is one of the leaders in the Region in the fields of water resources assessment and management and has an excellent record in related institutional capacity-building. Continued efforts are required in these fields if Oman is to meet the country's future needs and maintain its position in the Region.

The agricultural sector in Oman, much of which sustains important national traditions and culture, is currently the dominant water-using sector, but provides relatively low returns on its use. As urban and industrial demands for water increase, water consumption by these sectors will become more significant, thereby increasing the value of indigenous water to the economy. At the same time, there is a growing awareness of Oman's important natural habitats and environmental features which are dependent on water for their existence. Conservation of these must continue to be a key element in water resources management.

The quality of life in Oman is not supported by the water sector solely through the exploitation of indigenous water. Every year, imports of food and other consumer products account for a major water contribution through "virtual water" import. This is currently about three times Oman's limited and almost fully developed renewable water resource. There is, therefore, a strong case for including the assessment of "virtual water" imports in future planning of the water sector.

Optimization and strategic management of the Water Sector was seen as a key dimension of the Omani Economic Diversification Strategy at the "Vision 2020" Conference in 1995. The National Water Resources Master Plan for the period 2000 to 2020 recognizes that water is a critical element for life and that:

- Water resources are a national wealth and a sustainable approach must be taken to their long-term use to preserve these for future generations when income from energy resources may be reduced.
- Safe and assured water sources and supplies coupled with sanitation and sewerage facilities are a prerequisite for social harmony, economic development and the health of the country;
- the development of water resources should be linked to the country's social and economic policies;
- water resources development should take account of the need to conserve the country's natural habitats and ecosystems for the health and wealth of future generations.

By implementation of the Plan, the Government will, through the responsible ministry, other agencies and through encouragement of the private sector, provide:

- Sustainable use of the country's renewable water resource by the year 2020;
- An increase in the currently renewable resource and improvement in its security through the construction of appropriate facilities;
- Improved management of the country's water resources;
- Preservation of water resources supplied to *aflaj* communities;

- Support and advice to farmers, particularly those using wells for irrigation, but also to those using *falaj*, on improved water use and on means of increasing agricultural production;
- Through the provision of sustainable water resources, other Ministries will be able to provide higher levels of service through piped water supplies and complementary wastewater systems to large towns and assured water supplies for delivery to other small towns and rural populations;
- Support in the development of wastewater re-use schemes;
- A basis for integrated water sector planning and encouragement of increased community participation in planning and decision making processes.

Realization of the plan will require studies, design, procurement, implementation and supporting activities to be undertaken by the MRMWR and a number of other Ministries either working individually or together with common objectives.

Key elements of the Plan include:

- Establishment and protection of secure sources of potable water supplies for all towns and priority purposes.
- Increases in water resource availability.
- Establishment of sector water allocations.
- Management of agricultural water demand (through introduction of a quota system in areas irrigated from wells) and improvement in *aflaj* areas.

In order to implement the Plan it plan suggests institutional changes within the responsible Ministry, modifications to legislation and regulations, human resources development, training and public awareness campaigns. Increasing public awareness and education on the need to conserve water will be an important supporting element to the Plan.

Coordinated action, principally between Ministry of Regional Municipalities and Water Resources (MRMWR) and the, Ministry of Agriculture, Ministry of Housing, The Authority of Electricity and Water, and the Ministry of Health (MOH) were achieved.

2. WATERRESOURCES IN OMAN

2.1 Water availability

Three prime sources of water have been considered in developing the National Water Resources Master Plan: (i) natural resources which arise from rainfall, (ii) desalinated seawater or brackish water and (iii) "virtual water". Figure 1 represent sources of water used in Oman.

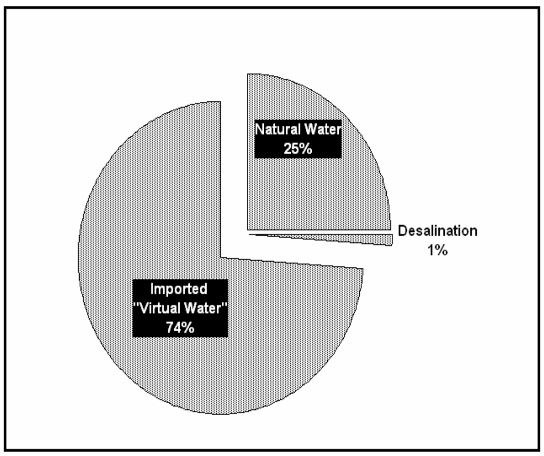
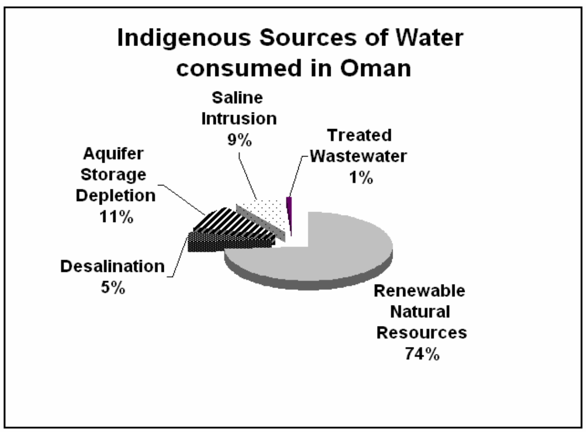


Figure 1 Sources of water used in Oman (2006)

Natural resources

Mean annual rainfall in the coastal plains and desert areas is relatively low, less than 40mm, and sporadic. In mountain areas, however, where rainfall is greater (up to 350mm) and relatively frequent, it provides a source of natural recharge to a number of aquifers including those in the interior and coastal plains. Droughts of two or three years duration are not uncommon, however, in the interior and coastal plains and despite recharge from other regions, aquifers can become stressed in some areas.

The natural water resources comprise "renewable" resources, arising from rainfall and predominantly stored in underground aquifers, and "non-renewable" resources which comprise underground fossil water which if abstracted would mostly not be replenished. The renewable resources are not all available for abstraction. A proportion is currently lost through seepage across submarine or national boundaries. The current annual per capita water availability for drinking, washing/cooking, services, industry and local food production from natural renewable resources and desalination is estimated to be 391 m^3 (2000). International indices regard this level as a condition of extreme water stress.



In Oman, the total quantity of renewable resource available for sustainable use is currently just less than 1,000 Mm^3/yr. Consumption, predominantly for agriculture, already exceeds this amount in the Batinah where some aquifers are consequently suffering the impact of saline intrusion. Nitrate pollution of aquifers from untreated wastewater is also an incipient problem near some towns. The indigenous sources of water consumed, including desalinated water, is shown Figure 2 below.

Figure 2: The indigenous sources of water consumed (2006)

<u>Desalination</u>

Desalination of seawater has become an important contributor to water supplies where natural water resources are unavailable or inadequate.

It supplies 68 $M.m^3/yr$ to Muscat, equivalent to 90% of the city's water and contributes to the domestic supplies of a number of small coastal towns and industry. This source of water is relatively expensive, however, at least three or four times the cost of using a reliable groundwater resource. New desalination plants have been constructed in Barka, Sohar and Sur to improve drinking water supplies.

Virtual water

Oman relies significantly on "virtual water" imports which are currently sustained by the country's strong economy and provides one of Oman's solutions to its water constraints. The estimated annual per capita "virtual water" import of 1,688 m^3 (1998) is more than four times the currently available indigenous resource. Virtual water will continue to play a substantial role in the future as the population increases. As long as other sectors of the economy (the energy sector, but increasingly also the gas based petrochemical and metallurgical sectors and the services and manufacturing sectors) are strong enough, the provision of more indigenous water for agriculture is less imperative. Nevertheless, the Government recognizes that it is important for the country to maintain an agricultural base for its long term future.

Other sources

Treated wastewater is being used very effectively for municipal greening in some urban areas and is a valuable resource. With the future development of water and wastewater systems there will be considerable potential for increasing its use for municipal greening, irrigation or aquifer recharge and there is further potential for its use in Muscat. The increasing water table levels in Muscat, however, arising from water supply scheme losses and disposal of wastewater, is a potential hazard and will require careful management.

2.2 Present water demand

The demand for water in Oman comes principally from four sectors: (i) domestic; (ii) industry and municipalities requiring water for irrigation of parks, trees and roadside reservations; (iii) agriculture (*aflaj* and farms irrigated from wells); and (iv) the environmental demands (such as support to the *Prosopis cineraria* forest in Ash Sharqiyah and for natural vegetation in Dhofar).

In many areas, demand for water exceeds availability. Where this situation exists, the demand is met by withdrawals from aquifer storage. This situation currently occurs in the Batinah, the northern interior parts of Oman and the Salalah regions. In coastal areas, over-abstraction has led to saline intrusion induced by declining groundwater levels. Nationally, the consumption of water is 25% more than the currently sustainable resources made available from renewable resources and desalination. The stress, currently imposed by over-abstraction, is exacerbated during periods of drought. In areas where aquifers have limited groundwater storage, supplies for priority domestic and community supplies are placed at risk. The use of treated wastewater to meet municipal demands is increasing but is not a significant national component at present. Consumption of water resources as in 2000 is given in Figure 3.

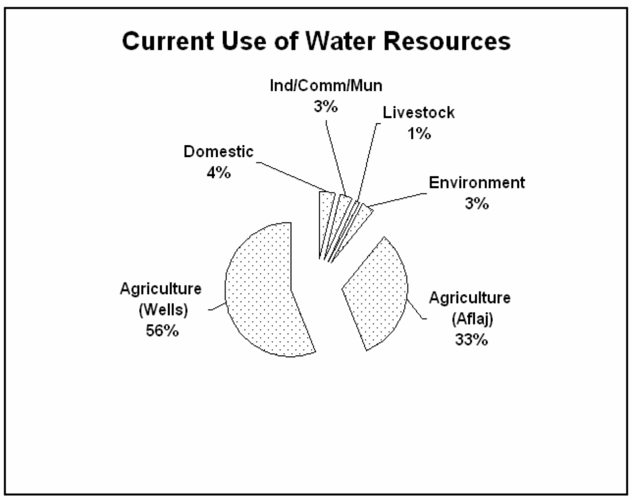


Figure 3: Consumption of water resources as in 2006

2.3 Future development

Water will remain one of the nation's most valuable resources. It will be of vital importance in the future to:

- Preserve and build on the achievements its use has brought to Oman through its contribution to the standards of living, quality of life and health;
- Protect and maintain investments made to date in water infrastructure;

- Maximize the potential for its future development in support of economic diversification;
- Afford maximum protection to the water based environment
- Provide for water security in times of drought;
- Secure the sustainability of water resources to meet the increasing demands and standards of a modern economy for future generations

Over the next twenty years the population of Oman is forecasted to grow from 2.5 million (2006) to over 3.6 million (2020). There will be increased demand for food and domestic water. Literacy and education standards will increase and political organisations and processes will mature. Stakeholder participation will be sought and is likely to increase. The private sector is likely to establish a substantially increased role in development.

The Government's programme of economic diversification will increase industrial water demand. Whilst large, high value industries are likely to locate on the coast and be able to meet the costs of desalination, the current water availability will be a constraint in inland areas for smaller industrial operators.

The growth in domestic and municipal water demands, for which sources will have to be found by MRMWR, will depend principally on population growth, rates of urbanization and the levels of service provided. The Master Plan anticipates that piped water supplies and associated wastewater systems would be provided to towns which have populations exceeding 10,000 by 2020. It is predicted that there will be about 50 towns of this size in Oman by 2020. Standards of service provided in Oman should match comparable International standards. A per capita gross demand of 240 l/c/d was applied.

Elsewhere, in all rural and urban areas without a piped water supply network, the per capita consumption is assumed to be 80 l/c/d (a value widely used by the Authority of Electricity and Water (AEW) for communities without direct connections who receive tankered supplies or use wells).

The demand for water for domestic, industrial, commercial and municipal purposes will increase by more than 50% during the next twenty years as services are improved and extended. If sustainable use of the renewable water resources is to be restored and maintained, aquifers in some parts of the country will have to be allowed to recover by reducing abstraction in some critical area, notably near the coast, to re-establish natural hydro-environmental conditions.

Within the agricultural sector, which currently utilizes about 90% of all indigenous water consumed. This level of consumption will remain high unless reductions are made in cropped areas, changes are made in cropping patterns or water application is improved by modernizing irrigation systems. Demand for water from *aflaj* communities is likely to remain near current levels and, if the current supplies of water continue to be made available, these important elements of Oman's cultural heritage can be maintained. The demand for water from farmers irrigating from wells is also expected to remain high. However, the current levels of abstraction can not be maintained without causing further saline intrusion and environmental degradation in the Batinah coastal areas and lowering of the water table in the northern interior part of the country. Although regulations exist to control the construction of new wells, if no further action is taken the areas irrigated from wells will decrease significantly as irrigated agriculture become untenable in these parts of the country.

3. <u>THE NATIONAL WATER RESOURCES MASTER PLAN</u>

3.1 Plan objectives

The purpose of the Master Plan is to provide a sound basis for development and management of the country's water resources. The Plan has a planning horizon of 2020 but also takes account of the need to provide for sustainable development and security of supplies beyond this date.

The Plan has been prepared for the Ministry of Regional Municipalities and Water Resources but the responsibility for development, management and use of water is not limited to MRMWR. The Plan takes into account the roles of other Ministries and the private sector in meeting national objectives. It is anticipated that through implementation of the Plan, the Government will, through its various Ministries and agencies and through encouragement of the private sector, deliver the following:

- Sustainability of the country's renewable water resources by the year 2020 and protection from pollution of the hydrological and hydrogeological catchment areas, well fields and *aflaj* water supplies;
- An increase in the currently renewable resource through the construction of facilities, such as storage dams, recharge dams, water harvesting facilities and the interception of outflow losses from aquifers where these are found to be technically and economically feasible;
- Improvement in the management of water resources to achieve sustainability, including the introduction of (i) sector water allocations and (ii) water quotas in areas irrigated from wells;
- Advice to farmers, particularly those using wells for irrigation, but also to *aflaj* areas, on water savings. Complementary agricultural extension services to focus on increases in agricultural production that could be made through improved irrigation water distribution and water application technology, improved crop varieties, modified cropping patterns and other agronomic means;
- Preservation of water resources supplied to *aflaj* communities;
- Through the provision of sustainable water resources, other Ministries will be enabled to provide piped water systems (240 l/c/d gross) and complementary wastewater systems to towns whose populations exceed 10,000 persons in the period 2000-2020 or similar standards defined by the AEW. This provision would be available to reach 50 towns and serve 60% of the country's population by 2020. It is anticipated that water savings would also be made in town water supply, through the reduction of "unaccounted-for" water, through

public awareness campaigns and the introduction of a progressive water tariff;

- Water resources available to other small town and rural population by tanker or alternative means at 80 l/c/d;
- Development of the re-use of wastewater from towns provided with wastewater collection systems but particularly Muscat and Salalah, for municipal use, irrigation and aquifer recharge;
- Increased public awareness and education of the need and means of water conservation.

The impact of the Plan is shown on Figure 4. Studies, designs, procurement, implementation and supporting activities will be required to be undertaken by the MRMWR and a number of other Ministries to meet these objectives.

3.2 Key elements of the Master Plan

The Plan has been developed to meet the objectives described above. There are more than twenty components in the Plan but these include four key elements. These are:

- Establishment, development and protection of secure sources of potable water supplies for all towns and priority purposes
- Increase of water resource availability
- Establishment of sector water allocations
- Management of agricultural water demand (through the introduction of quota system in areas irrigated from wells) and improvement in *aflaj* areas

These key elements of the Plan, summarised below, are to be supported through the implementation of appropriate institutional changes, amended legislation and regulations, continued human resources development, training and public awareness campaigns. The Plan assumes that water infrastructure development, agricultural advice and support to farmers and associated water sector activities will be achieved through a programme involving inter-Ministry coordination.

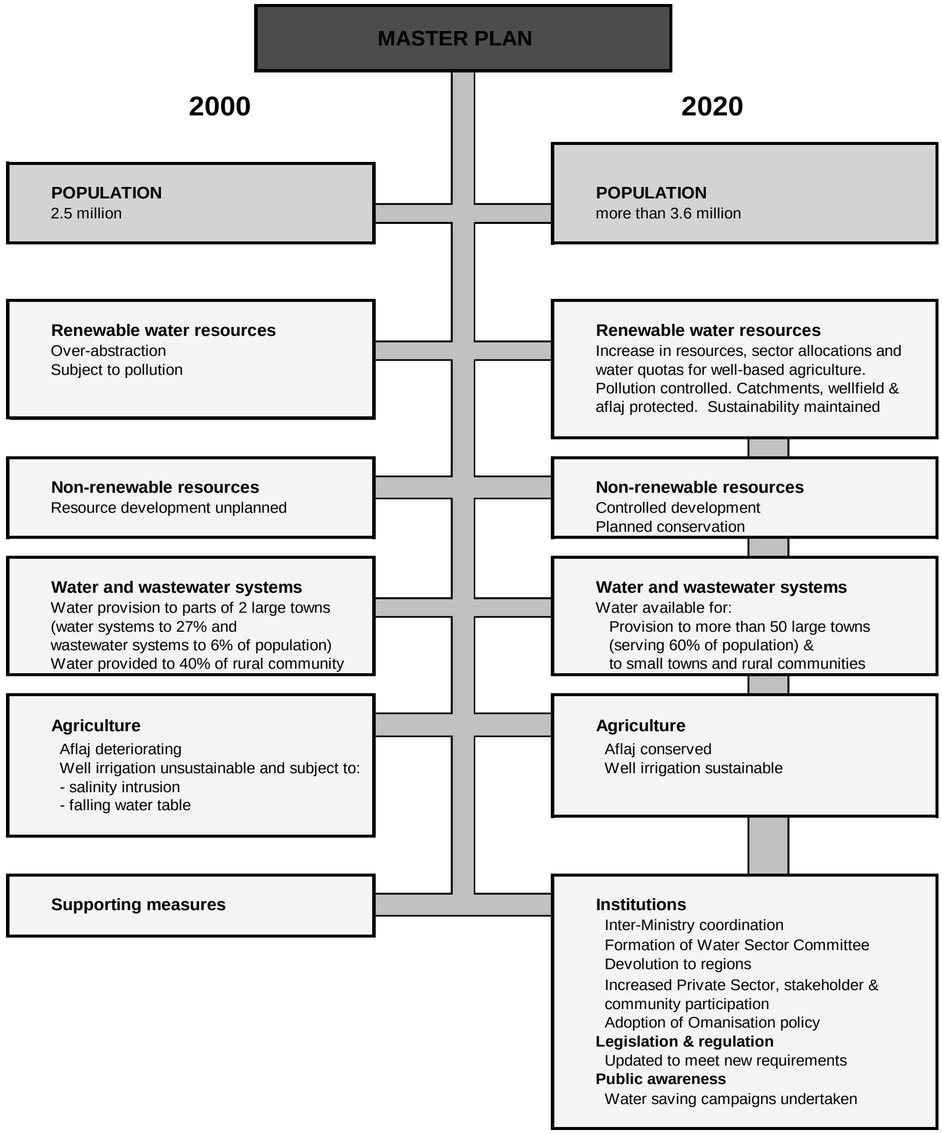


Figure 4: Impact of the Plan

Potable water supplies for all towns and priority purposes

Secure potable water sources will be required for about fifty towns with populations greater than 10,000 by 2020 and for other smaller towns, rural areas and priority purposes. The Plan includes for the necessary water resources investigations and assessment, including identification and investigation of wellfields, monitoring and protection of water sources.

Increase of water resource availability

The current level of water availability from natural renewable water sources and desalination is 391 m^3/capita/yr. If unattended, this level will reduce to less than 300 m^3/capita/yr by 2020, as the population increases, putting further stress on the water sector and economic development. The Plan will examine and develop means of increasing the availability of indigenous water in order to reduce the dependency of the country on desalinated water supplies and the imports of "virtual water". This will be done, where technically and economically feasible, through:

- Reducing surface and sub-surface losses to the sea or to the desert;
- Increasing water availability by treating and re-using wastewater;
- Making limited and strategic use of non-renewable potable and brackish water reserves.

Some surface and sub-surface losses can be intercepted to increase the country's sustainable resources from renewable sources. A number of sites that appear to have good potential for recharge or storage dams have been identified. Further studies and investigations are required to determine their technical and economic feasibility. The Plan makes provision for this work through allocation of an annual resource development fund utlilised on a priority basis. A potential increase in resources of about 60 $M.m^3$/yr has been identified. Other, as yet unidentified schemes, if proved feasible may increase this.

Increased treatment and use of wastewater can provide significant quantities of wastewater for municipal and selected agricultural purposes or for recharge to existing aquifers. This will become of increasing importance in urban areas as new piped water and wastewater systems are introduced and recommendations for development of these sources are made in the Plan.

The Sultanate has a number of strategic reserves of non-renewable potable and brackish water which are currently uncommitted. Most of these occur in inland areas where the environment and lack of infrastructure pose serious constraints on development.

A number of sites (e.g. Najd, Central Region and Al Masarrat, Interior) have been identified as worth further investigation for agricultural development. The Plan includes for further study of these to establish regional development opportunities. If found feasible the sites could be developed by the private sector. Close monitoring of water abstraction would be required to ensure that the non-renewable reserves are not over-exploited.

<u>Establishment of sector water allocations</u>

With the increasing demands on indigenous water resources, the Plan recommends that sector water allocations are set which formally establish the prioritization of water use. Allocations would be made for each of the following sectors on a catchment basis:

- Domestic
- Industrial/Commercial/Municipal
- Environmental
- *Aflaj*
- Agriculture (irrigated from wells)

Allocations could be introduced at the end of 2001 and be subject to review every five years. The establishment of allocations of the renewable resources would be seen within the context of the overall water resources availability which would include non-renewable, desalinated water supplies and virtual water imports.

<u>Management of agricultural water demand and improvement in aflaj areas</u>

About two thirds of the agricultural area is irrigated from wells and one third falls within the *aflaj* areas. Together these areas use about ninety percent of the water consumed for all purposes in Oman. *Aflaj* areas are regarded as an important part of the Sultanate's cultural heritage and the Plan is committed to maintaining the current allocation of water to them and improving *aflaj* communities use of water.

The current use of water in many areas where wells are used for agricultural purposes, however, is unsustainable and agricultural production is being adversely affected. Conditions will worsen if no action is taken to improve irrigation practices and water management. Some improvement can be made in these areas by adapting cropping patterns and through the introduction of modern irrigation systems. Alone, these measures would have insufficient impact on reducing water consumption and controls on abstraction will be required.

Quotas, calculated on the basis of the sector allocation for each catchment, would be introduced for those farmers using water from wells for irrigation. This would ensure that resource depletion and saline intrusion are halted by 2020 and that sustainability is achieved. It is envisaged that the quota system would be based on a system of equity with provision for variations which are subject to ownership and land-use factors. The establishment of quotas will be linked to well permits and will require monitoring. The introduction of quotas is scheduled for 2006.

For all except the worst affected areas, water use reductions in the range 5 – 25% will be required over the period to 2020. The situation is most acute in the southern Batinah where land-use changes appear inevitable even if quotas are to ameliorate the long term Stalinization of the land. The introduction of quotas and the changes in land use are seen as a regional opportunity, particularly in the Seeb-Barka coastal strip which is the preferred location for urban development and Muscat City overspill.

Generally, the introduction of quotas need have no significant impact on current farm income if farm practices and cropping patterns are adjusted appropriately. The Plan envisages that the water use reductions through quotas will act as a catalyst for reform, stimulating improved on-farm practices and water management. This will in turn provide opportunities for gains in productivity and better returns and will encourage the modernization of the agricultural sector.

3.3 Implementation support *Institutions*

Implementation of the Master Plan will have an impact on the existing institutional arrangements and it will be necessary to separate the roles and responsibilities for water resources development from those for monitoring and compliance control. In view of the need to restrict water use in the agricultural sector, inter-Ministry agreements and complementary institutional arrangements will be required which clearly define responsibilities. These should:

- Through institutional changes, remove areas of overlap in some activities.
- Integrate water supply and wastewater services to improve the environment for investment in water services provision.
- Establish a centralized body to coordinate and advise on water sector policy and planning.

A long-term independent custodian of the nation's water resources is required to ensure they are managed wisely to support sustainable development and conservation of the environment. The recommended institutional framework is given overleaf.

Provision is made in the Plan for studies on devolution to determine the optimal organisational, institutional, legal and regulatory arrangements. The Plan recommends that social acceptability studies and participatory surveys should be incorporated in the implementation programme.

Legislation and regulation

Implementation of the Plan is generally supported by existing legislation and regulations. The principal area where new regulations will be required is in implementing water quotas. There will be a need to develop existing regulations so that abstraction from wells is defined, licensed, monitored and controlled effectively.

The Master Plan l have an impact on water users, stakeholders and communities who are active in the development of water resources. Private sector participation is encouraged under the Plan.

Involvement and participation of stakeholder and community groups in the development and implementation of the Plan is necessary to ensure its successful implementation.

Increased community participation will be sought for economic and social development purposes. The current trend for increasing stakeholder contributions will be extended to *aflaj* maintenance programs. Public expenditure for such programs will be gradually scaled down to zero in 2020. Provision will be made, however, for an Emergency Relief Fund to cater for extreme cases of risk and/or hardship. Education and public awareness campaigns will be required emphasizing the need to conserve water in all sectors. A coordinated inter-Ministry initiative for this is recommended.

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An Expert System Proto-type in Integrated Water Resource Management Plan (IWRMP)

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Abstract

Water Resources Management is a continuous challenge in the Sultanate of Oman. Due to its rapid development during the last thirty years, the growing economy has brought an increase in urbanization with a high demand for quality water supplies. Increasing demand to be met include agriculture, population increase, and the rapid industrial and commercial development. These factors have created a lot of stress in the water resources availability in the country. To better manage the water resources in Oman, an Integrated Water Resources Management Plan (IWRMP) need to be adopted. Demand management is one of the critical elements of IWRMP. To assist the decision makers in prioritizing the best management option for a particular case, an Expert System (ES) need to be formulated. A proto-type Expert System for the evaluation of water management options and regional strategic plans is presented. The system incorporates the Benefit over cost ratio and the social implication of each supply/demand option to give an expert advice on the best available management scenario. The evaluation procedure of the Expert System compares the effect of water management instruments and social implications on the basis of well-defined, comprehensive indicators expressing principles of Integrated Water Resources Management Planning.

Key words: *integrated water resources management plan(IWRMP), demand management, expert system Oman*

1. Introduction

Integrated Water Resources Management Plans (IWRMP) has become an essential technique to save guard the scarce water resources in arid region. As different management scenarios are become available, the decision-making processes associated with the utilization of water resources are very complex, and require thorough consideration and analysis. Water resources development and management have been and still are dominant (Lilburne et al.,1998; Salman et al., 2001) but there is need for a shift towards a holistic approach to avoid fragmented and uncoordinated water management options (Rosegrant et al.,2000; Staudenrausch and Flugel, 2001). Additional challenges arise in the field of water management scenarios from the multi-dimensional interactions between the various aspects of Integrated Water Resources Planning (IWRMP) i.e. human activities, their impact on natural systems and the corresponding influence of natural responses upon the human domain (Simon et al. 2004; Salewicz and Nakayama, 2004). In the context of the Integrated Water Resources Management Planning (IWRMP) the systematic evaluation of water management interventions should be performed for a long time horizon, simulating long-run accumulative effects and anticipating potential future changes and uncertainties. Indicators selected should assist decision-makers in identifying the appropriate IWRMP and management instruments in relation to catchment water resources health, social acceptability, benefit cost ratio and environmental sustainability. Complex integrated modeling can meet those objectives when based on comprehensive information systems. Multidisciplinary information is needed for the analysis of strategies and evaluation of their effects, taking into account economic, hydrologic and environmental interrelationships (McKinney et al., 1999; Bouwer,2000; Albert et al., 2001). A variety of models and systems have been developed for water allocation and quality estimations, such as MIKE BASIN by DHI, or WEAP by the Stockholm Environment and Tellus Institutes. Systematic formulation and evaluation of alternative water resources management options is however missing (Research, 2001). A prototype ES which can be developed under Visual Basic environment for strategic planning in the context of the economic and environmental sustainability objectives, with special emphasis on the water stress problems encountered in arid and semi-arid regions is presented.

2. Overview of the ES

The ES uses the concept of IWRMP, defined as a set of different water management scenarios required to enhance the groundwater availability through either supply and/or demand management. The water balance components need to be calculated using classical hydrogeological methodology which then fed to the ES. Available water management scenarios with their economical benefits as well as water savings and social acceptability need to be evaluated. Combination of different water management scenarios will be evaluated by the ES for the best option. The impact of the application of one or more water management options can then be simulated by the ES to determine the overall water availability. An ES is defined in terms of a database containing information on the water balance components at a particular reference year, at which the implementation of scenarios and strategies begins. A base case is always present, serving as input for the creation of new water management scenario. User interaction with the ES falls under three functional groups, accessed via a hierarchical navigation tree: (a) base case editing, allowing for the editing and introduction of new data for the reference year; (b) creation of Water Management Schemes, providing the capabilities for defining scenarios on water supply and demand, definition of strategies and visualization of results and for conducting economic cost benefit analysis, and; (c) evaluation, which permits the comparison of different water management options(Figure-1).

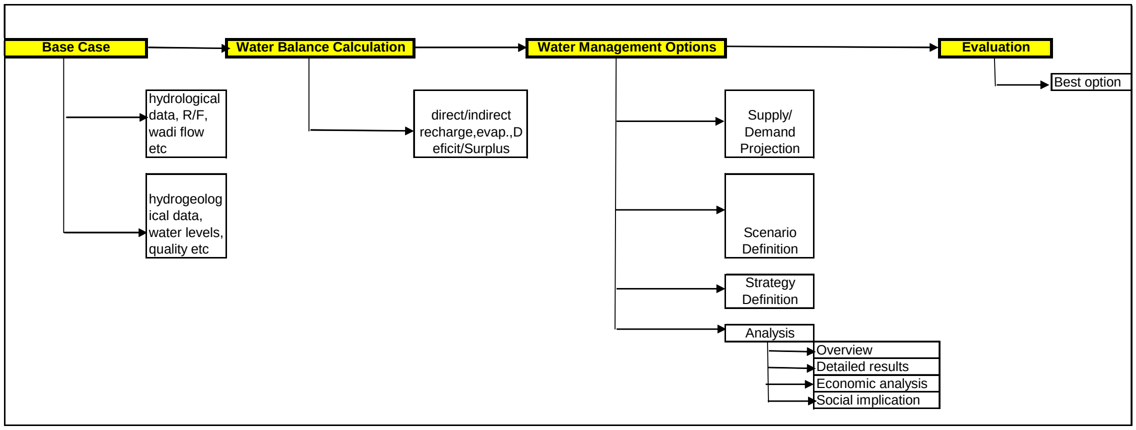

Figure 1. The ES operational framework

The Demand Scenarios Module produces forecasted time-series of water demand for all water uses, generated by specifying appropriate growth rates to the key variables (Drivers) that govern demand pressures, such as population for domestic use, cultivable area and livestock for agricultural practices and the industries demand. Using a pre defined criteria, the ES is then used to evaluate all the available management scenarios and recommendations offered for the feasible options. It should be noted that social acceptability is considered very critical for the implementation of the IWRMP, therefore unacceptable social scenarios (i.e. metering) are declined by the ES.

3. ES Structure

The Expert System will be implemented using Visual Basic environment. The tool is designed according to the four step schema presented in Fig. 2 that involves a) the database b) the object model linked to mathematical models for water balance calculation, c) water management options model and d) the user interface which allows for the definition of parameters related to the management option and its benefit cost ratio and social impact.

Water management strategies or single interventions can be simulated under different scenarios, compared, and the decision maker or the analyst can formulate responses to mitigate water stress impacts with respect to their objectives.

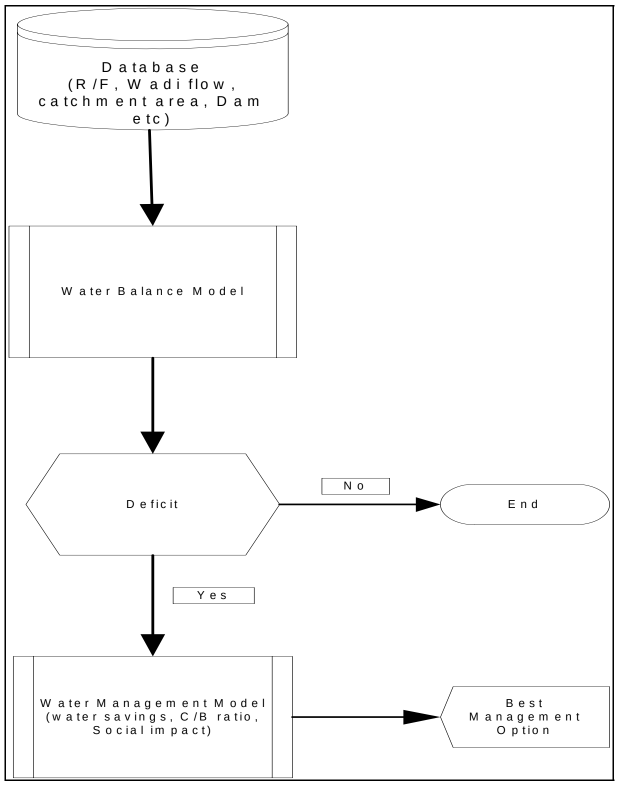

Figure 2. The ES Structure

Water Balance Module

Water balance calculation is carried out using the hydrological/hydrogeological information. Average volume rainfall, wadi flow and percent of recharge in the catchment need to be evaluated and entered in the ES. The catchment will be subdivided based on hydrological characteristics (i.e. upper vs. lower catchment). The ES will calculate the amount of recharge, evaporation, groundwater through flow and hence the amount of surplus or deficit in each sub-catchment for the base year.

Water Management Module

Water demand projection can be simulated by the ES using different criteria and growth rates. Domestic demand projection can be calculated by using the population growth rate up to the year of interest. Similar approach can be followed for other demand area (i.e. livestock, industrial and agricultural) . Different demand measure will be simulated by the ES and calculated water savings, cost and social impacts need to be verified by the user. Social impact is been taken as a critical measure on the applicability of the measure.

4. ES Strategy Formulation

A characteristic of the ES is that it predefines a number of "abstract" water management instruments (actions) and incorporates them as methods into the system. An "abstract" action becomes "application specific" by the user-definition of its magnitude, time horizon and geographic domain. An initial set of actions that can be taken into consideration is presented in Table 1. Actions incorporated are mainly focused on instruments to deal with the frequent water shortages occurring in arid regions. The main aim is to have an Integrated Water Resources Management Plan (IWRMP) which looks into the possibility of enhancing supply and regulating demand through the promotion of conservation measures, technological adjustments for promoting efficiency of water use, and pricing incentives.

Table 1. Summary Table of IWRM Options and related Actions

Policy Options	Actions
Supply Management	- untapped resources - Flood harvesting (i.e.dams0 - Desalination - Water Reuse - Aflaj Development
Demand Management	- Modern Irrigation System (MIS) - Water recycling - Conservation measure in the home - Abstraction Control
Social Development Policy	- Change in agricultural practices - Change in Land use
Institutional Policies	- Economic policies (i.e. quota)

5. Conclusions

The application of Integrated Water Resources Management Plan (IWRMP) involves a comprehensive approach of the water situation in a particular catchment and the available water management options. To better assess the best water management actions, an ES is developed using Visual Basic software to evaluate the best available option. This ES uses a set of indicators which facilitate the actions of the authorities involved. Those indicators should serve as a basis for the selection and scheduling of appropriate measures under different hydrology and socio-economic conditions. .

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Integrated Groundwater Resources Management in the GCC Countries- A Review

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Abstract

With an average groundwater dependency ratio of 75%, groundwater resources in the GCC countries require careful planning and management so that they can continue to contribute in the sustainability of human socio-economic development and to support their dependent ecosystems. However, groundwater resources in these countries are under threat of degradation both by inappropriate use/mismanagement and by numerous sources of contamination. Despite their importance, groundwater resources are often misused, usually poorly understood and rarely well managed. Proper management is required to avoid serious degradation and there needs to be increased awareness of groundwater at the planning stage, to ensure equity for all stakeholders and most important of all to match water quality to end use. This paper presents the status of groundwater resources and their utilization in the GCC countries, diagnose the current level of groundwater management interventions, presents groundwater management strategies from an integrated framework, and available approaches and planning tools. Then it discusses the conundrum of exploitation and sustainability and the impacts of over-exploitation on society (socio-economic and ecosystem) illustrated with a case study from the region. Furthermore, the issue of utilization of non-renewable groundwater resources from a socio-economically-sustainable approach is presented and discussed. Finally,

the use of system dynamics is presented as one of the efficient novel available tools that can be used in the integrated planning and management process of groundwater resources to capture and incorporate their multi-disciplinary nature.

Keywords: *Groundwater, renewable, non-renewable, utilization, Integrated Planning and Management, GCC countries.*

1. Introduction

In the predominantly arid countries of the GCC, groundwater is a vital and essential source for all sectors, the irrigation sector, as well as for urban and rural communities; groundwater dependency ratio in the GCC countries averages about 75%, and reaches more than 80% in some countries like Saudi Arabia (ESCWA, 2005). In the last four decades, rapid increase of population, ambitious agricultural policies in several countries, and increase of economic activities, as well as unplanned utilization and mismanagement, have lead to extensive groundwater withdrawals leading to its "over-exploitation[1]" in all of these countries. Currently all countries are experiencing a deficit, which is manifested by a continuous water level declines and degradation of water quality due to salinization (Al-Mahmood, 1987; Al-Zubari, 1999; Sayid and Al-Ruwaih, 1995; Al-Murad, 1994; Rizk *et al.*, 1997; Al-Asam and Wagner, 1997; Macumber *et al.*, 1997; Abdulrahman, 2000). In addition to their over-exploitation and quality deterioration, groundwater resources in the region are being threatened and polluted by numerous point and non-point sources of pollution generated from anthropogenic activities (agricultural, industrial, and domestic) (Al-Zubari, 2002).

The deterioration of groundwater quality has become a critical issue throughout most of the countries in the GCC countries. As the quality of groundwater deteriorates, either by over-exploitation or direct pollution, its uses diminishes, thereby reducing groundwater supplies, increasing water shortages, and intensifying the problem of water scarcity in these countries. Moreover, the loss of groundwater resources will have dire consequences on the countries' socio-economic development, increases health risks, and damages their environment and fragile ecosystem regimes.

[1] "over-exploitation" here is concerned about the consequences of intensive groundwater abstraction than in its absolute level, and the definition is an economic, that the 'overall cost of the negative impacts of groundwater exploitation (including social, economic, and environmental) exceed the net benefits of groundwater use.

As a scarce resource in the GCC countries, groundwater needs careful planning and management if its use to be sustained for future generations, so that groundwater can continue to sustain human socio-economic development and the various water-dependant ecosystems. Proper management is required to avoid serious degradation and there needs to be increased awareness of groundwater at the planning stage, to ensure equity for all stakeholders, and most important of all to match water quality to end use.

Moreover, many countries in the region possess fossil, i.e., non-renewable groundwater, and the issue of "sustainability" of non-renewable resources is problematic, and requires clear definition. Sustainability of these resources should be interpreted in a socio-economic rather than a physical context, implying that full considerations must be given not only to the immediate benefits and gains, but also to the "negative impacts" of development and to the question of "what comes after?". An "exit strategies" need to be identified, developed, and implemented by the time that the aquifer is seriously depleted. An exit strategy scenario must include balanced socio-economic choices on the use of aquifer storage reserves and on the transition to a subsequent less water-dependent economy, and the replacement water resource.

This paper presents the status of groundwater resources and their utilization in the GCC countries, diagnose the current level of groundwater management interventions, presents groundwater management strategies from an integrated framework, and available decision-support systems and planning tools. Furthermore, it discusses the conundrum of exploitation and sustainability and the impacts of over-exploitation on society (socio-economic and ecosystem) illustrated with a case study from the region. Finally, the issue of utilization of non-renewable groundwater resources from a socio-economically-sustainable approach is presented and discussed.

2. Groundwater Resources and Utilization

Most of the area of the GCC countries is situated in an extremely arid zone. 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 south-western Saudi Arabia and along the Gulf of Oman on the eastern shore, where orographic rainfall reaches more than 500 mm (Table 1). The total annual evaporation rate ranges from 2,500 mm in the coastal areas to more than 4,500 mm inland.

The amount of renewable aquifer volume is very limited and shallow alluvial aquifers provide some renewable groundwater mainly in those limited coastal strips. Currently, all groundwater from the shallow alluvial aquifers are used extensively for domestic and irrigation purposes, with most of them, especially those located at the coastal areas, experiencing seawater intrusion.

Limited large deep aquifers are present in the region, which contain non-renewable supplies of fossil water, but have a finite life and quality limitations. Only Saudi Arabia possesses substantial amounts of non-renewable groundwater in deep aquifers amounting to about 430 Bcm (WB, 2003). However, these are rapidly depleting; e.g., Al-Turbak (2003) estimated that about 35% of non-renewable groundwater resources in Saudi Arabia were already depleted by 1995.

Table 1: Available conventional water resources in the GCC countries.

Country	Annual Rainfall (mm)	Annual Evaporation (mm)	Surface Runoff (Mcm)	Groundwater (Mcm/y)		
				Groundwater Recharge[2]	Abstracted (2000)	Deficit (2000)
Bahrain	80	1,650-2,050	-	110[3]	195	85
Kuwait	110	1,900-3,500	-	160[3]	393	223-335

Oman	20-300	1,900-3,000	1,450	900	1,240	340
Qatar	75	2,000-2,700	-	50	270	220
Saudi Arabia	70-500	3,500-4,500	3,210	3,850	19,680	15,830
UAE	89	3,900-4,050	150	190	2,673	2,483
Total			**4,810[1]**	**3,470**	**20,768**	

(1) Most are seasonal flow of wadi systems; (2) Recharge figures represent recharge to shallow alluvial aquifers, estimated non-renewable reserves for Saudi Arabia = 428.4 Bcm, Oman = 102 Bcm, negligible for Bahrain and Qatar, and not available for other countries; (3) Recharge to aquifers occurs by underflow from equivalent aquifers in Saudi Arabia.

Sources: compiled data from Al-Alawi and Abdulrazzak, 1994 and AGFUND/WB, 2005.

The water scarcity in the region is being aggravated by the high population growth rates, averaging more than 3% per annum, which is considered highest in the world, with its associated water requirements to satisfy the population domestic water needs as well as its food production needs. Per capita freshwater availability fell from about 680 m^3 in 1970 to about 180 m^3 in 2000 (Table 2). Based on the projected population increase to about 56 million in 2030, per capita freshwater availability of the GCC countries could fall by nearly one-half to about 95 m^3.

Table 2. Changes of annual per capita renewable water in the GCC countries, 1970-2000

Country	Renewable GW (Mcm/y)	Population (millions)				Renewable water per capita* (cm/y/capita)			
		1970	1980	1990	2000	1970	1980	1990	2000
Bahrain	100	0.2	0.3	0.5	0.7	524	329	219	164

Kuwait	160	0.7	1.4	2.1	2.2	215	116	75	73
Oman	900	0.7	1.1	1.6	2.4	1,245	817	553	373
Qatar	50	0.1	0.2	0.5	0.6	450	218	103	85
Saudi Arabia	3,850	5.7	9.4	15.8	20.7	670	411	244	186
UAE	190	0.2	1.0	1.8	3.2	864	182	107	59
Total	5,260	7.8	13.5	22.3	29.8	678	391	236	176

* This calculation is based only on renewable natural water resources. However, it is customary in the GCC to add to the renewable groundwater resources the available non-conventional water resources, i.e., desalination capacity and available wastewater. Adding these resources would increase the per capita water share and would give a better picture of the availability of water resources in the region.

Source: AGFUND/WB, 2005

During the past few decades, economic policies in most of the GCC countries have given priority and support to the development and expansion of irrigated agriculture. Food security is the major economic goal and it is used to justify the expansion of certain grains and crops characterized as water-intensive. Economic policies in some countries encourage over-pumping of groundwater for irrigation use[2]. During this period, total water demands (mainly agricultural and domestic) in the GCC countries have increased dramatically from about 6 Bcm in 1980 to about 27 Bcm in 2000 (Table 3). The deficit has been met by mining of renewable and non-renewable groundwater resources (Box 1), seawater desalination, and by reusing small amounts of treated wastewater.

Table 3. Water Demands Development in GCC countries, Mcm

Country	1980[1]	1990[1]	Growth Rate (1980-1990)	2000[2]	Growth Rate (1990-2000)

[2] Subsidized prices of gasoline and electricity, subsidized credit for buying water pumps and irrigation equipment, exemptions of tariffs on imported fertilizers and equipment, subsidized prices of certain agricultural products, protection against foreign competition in the domestic markets, are all examples of the tools used to implement these agricultural-based economic polices. It is obvious that none of these policies have been subject to serious assessment in terms of their impact on the sustainability of groundwater resources.

Bahrain	138	223	162%	269	121%
Kuwait	186	383	206%	993	259%
Oman	665	1,236	186%	1,303	105%
Qatar	110	194	176%	433	223%
Saudi Arabia	2,362	16,300	690%	20,800	128%
UAE	789	1,490	189%	3,506	235%
Total	6,230	19,826	318%	27,304	138%

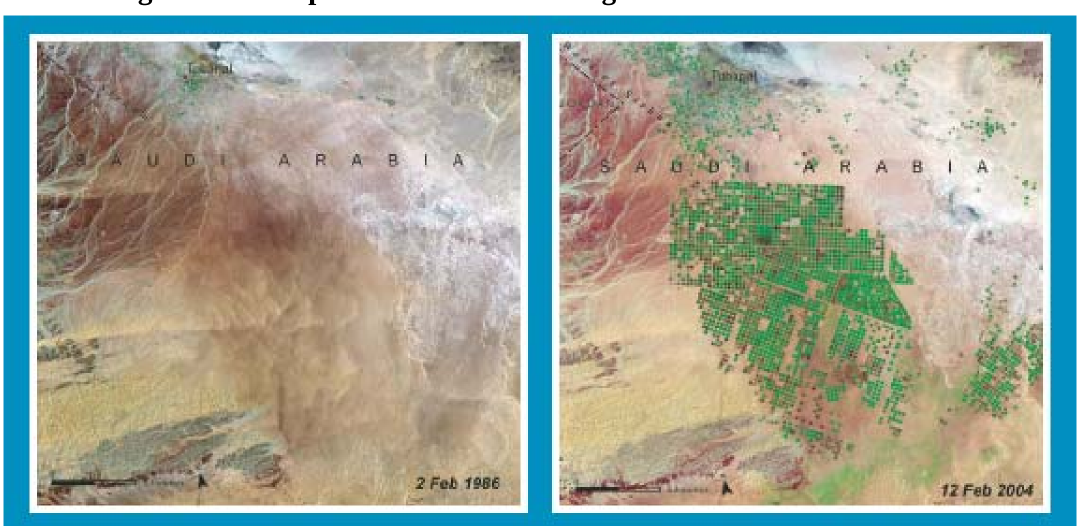
Sources: 1) Al-Alawi and Abdulrazzak, 1994, 2) AGFUND/WB, 2005

Although agriculture is the largest user of water in the region (Table 4), rapid urbanization and improved quality of life in terms of health, sanitation and social services have resulted in a sharp increase in water demand for municipal purposes. Conflicts between the agricultural and domestic sectors are rising in most of the region, and as a result, groundwater over-exploitation and mining is expected to continue in order to meet growing demand in these two sectors.

Box 1. Depletion of fossil groundwater in the GCC

Over the past three decades, economic policies and generous subsidies in most of the GCC countries supported the expansion of irrigated agriculture in an effort to achieve food security. Irrigation water is often used inefficiently without considering the economic opportunity cost for potable and urban/industrial purposes. Agriculture contributes less than two per cent of GDP in GCC countries but it over-exploits groundwater resources, most of which are non-renewable fossil groundwater, resulting in their depletion and quality deterioration due to seawater intrusion and the up-flow of saltwater. No clear “exit strategy” exists to address the question of “what comes after?”.

Agricultural expansion based on fossil groundwater in Saudi Arabia



Credit: UNEP/Grid-Sioux Falls

Table 4. Sectoral Water Use in the GCC countries, 1990-2000

Country	1990[1]			2000[2]			Growth Rate		
	MUN	AGR	Total	MUN	AGR	Total	MUN	AGR	Total
Bahrain	103	120	223	132	137	269	128%	114%	121%
Kuwait	303	80	383	772	221	993	255%	276%	259%
Oman	86	1,150	1,236	179	1,124	1,303	208%	98%	105%
Qatar	85	109	194	163	270	433	192%	248%	223%
Saudi Arabia	1,700	14,600	16,300	2,500	18,300	20,800	147%	125%	128%
UAE	540	950	1,490	1,344	2,162	3,506	249%	228%	235%
Total	2,817	17,009	19,826	5,090	22,214	27,304	181%	131%	138%
sector share	14.2%	85.8%		18.6%	81.4%				

Sources: 1) Al-Alawi and Abdulrazzak, 1994, 2) AGFUND/WB, 2005

Currently groundwater reserves in both renewable shallow and non-renewable deep aquifers are the main source of water in the GCC countries, and are being used to meet domestic and agricultural water requirements. Many countries have been exploiting their non-renewable groundwater to meet rising demand in the agricultural sector. In 2000, groundwater withdrawal in the GCC countries was about 24.5 Bcm, indicating an over-drafting or mining of about 19 Bcm (Table 4).

Table 4. Increasing Groundwater Abstraction/Mining in the GCC countries (AGFUND/WB, 2005).

Country	Renewable Volumes (Mcm/yr)	Abstraction Volumes (Mcm/yr)		Pumping as a Percent of Renewable Volumes	
		1990	2000	1990	2000
Bahrain	110	167	195	152%	177%
Kuwait	160	143	393	89%	246%

Oman	900	1,204	1,240	134%	138%
Qatar	50	111	270	222%	540%
Saudi Arabia	3,850	15,505	19,680	403%	511%
UAE	190	1,148	2,673	604%	1407%
Total	5,260	18,278	24,451	347%	465%

3. Impact of Groundwater Depletion on Society

When evaluating the impact of groundwater depletion on society, two key issues are typically considered: the ***level of reliance on groundwater*** and ***the marginal cost***, which is the cost of providing replacement supplies from another source. Moreover, groundwater in the GCC countries has a scarcity value and the opportunity cost for alternative or competing uses need to be incorporated, as well as its functional value in maintaining the ecosystem (Box 2).

Box 2. The cost of groundwater overexploitation and depletion on society, the case of Bahrain

Groundwater in the Dammam aquifer is the only natural source of relatively freshwater in Bahrain. The aquifer safe yield is about 110 Mcm/y, estimated as the steady state under-flow from Eastern Saudi Arabia. The fast growth rate in population and the associated development processes, represented by rapid urbanization, expansion of irrigated agriculture and industrialization, in the last four decades have brought about substantial water demands increases, met mainly by groundwater abstraction. However, this heavy reliance on groundwater beyond the aquifer safe yield (currently about 250 Mcm/y) and its prolonged overexploitation has led to severe deterioration of its water quality, as well as loss of all the naturally flowing springs. Currently, most of the original groundwater reservoir in Bahrain has been lost to salinization. The marginal cost of providing replacement supplies from another source is enormously high, and would be equal to the cost of producing about 110 Mcm/y of sweater desalination and/or treated wastewater.

In addition, the deterioration of groundwater quality had a significant and strong impact on agricultural activities in Bahrain; as groundwater used for irrigation has become increasingly more saline, major traditional agricultural areas has been abandoned due to the loss of their productivity and desertification, leading to their transfer to urban areas. Furthermore, groundwater depletion had a significant impact on the environment, wetland, and biodiversity in Bahrain (although it is difficult to assign a value to it). The loss of all natural springs and the dryness of their surrounding environment have caused the destruction of wildlife flora and fauna habitats as well as the habitat of migratory birds, loss of animal species, and have definitely compromised the hidden ecosystem services and functions, as well as their investment potential.

Examples of natural springs drying and loss of natural habitat, 1950s and 1990s

4. Integrated Groundwater Resources Management

Groundwater resources management has to deal with balancing the exploitation of a complex resource in terms of quantity, quality, as well as surface water interactions, with the increasing demands of water and land users. Unfortunately, calls for groundwater management do not usually arise until a decline in well yields and/or degradation of quality occurs.

If further uncontrolled pumping is allowed, a 'vicious circle' (Figure 1) may develop and damage/loss to the resource as a whole may result, with serious groundwater level decline, aquifer saline intrusion, or even land subsidence. To transform this 'vicious circle' into a 'virtuous circle' it is essential to integrate the socio-economic dimension (or demand-side management), and the hydrogeological dimension (or supply-side management) (GWMATE, 2003).

On the groundwater demand management side it will be essential to bear in mind that social development goals greatly influence water use, especially where agricultural irrigation and food production are concerned, such is the case in the GCC countries. Thus, management can only be fully effective if cross-sector coordination occurs. Moreover, regulatory interventions (such as water rights or permits) and economic tools (such as abstraction tariffs) become more effective if they are not only encoded in water law but implemented with a high level of user participation (GWMATE, 2003).

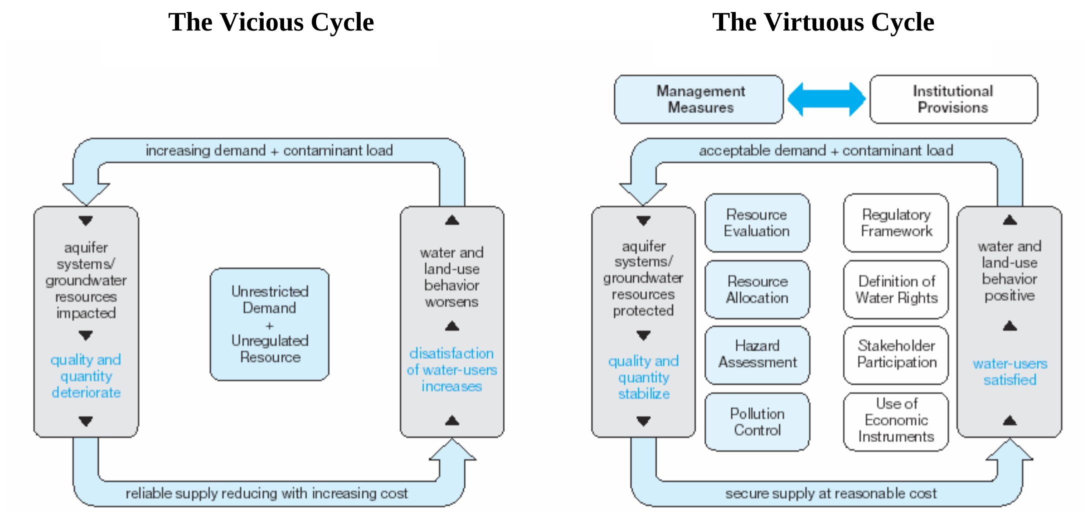


Figure 1. Supply-Driven vs. Integrated Groundwater Resources Management Approaches (modified after GWMATE, 2003)

5. Analysis of the Status of Groundwater Management in the GCC countries

An analytical framework of groundwater management tools, instruments, and interventions, suggested by GWMATE (2003), is utilized to diagnose and assess the adequacy of existing groundwater management arrangements for the current stage of groundwater development in the GCC countries. The current groundwater development level in most of the GCC countries is illustrated in Figure 2 (using Bahrain main aquifer as a typical example), while the required interventions/level of management are listed in Table 5. The condition of excessive and unsustainable abstraction, which is occurring widely in most of the GCC countries, is indicated in Figure 2 (3A—Unstable Development). Figure 2 indicates that the stage of groundwater resources development in Bahrain is at this stage. The shaded parts in Table 5 indicate the current practiced levels of groundwater management interventions in Bahrain, which is typical in most of the GCC countries. Two general conclusions can be drawn: 1) the necessary management level and interventions are inadequate and lag behind the level of the critical groundwater development stage; and 2) compared to technical tools, there is a major deficiency in the institutional instruments (i.e., water rights, regulatory provisions, water legislation, stakeholder participation, awareness and education, and economic instruments) and management actions (i.e., prevention of side effects, resources allocation, and pollution control). In other words, the major challenge in the GCC countries is a management challenge and not a technical challenge.

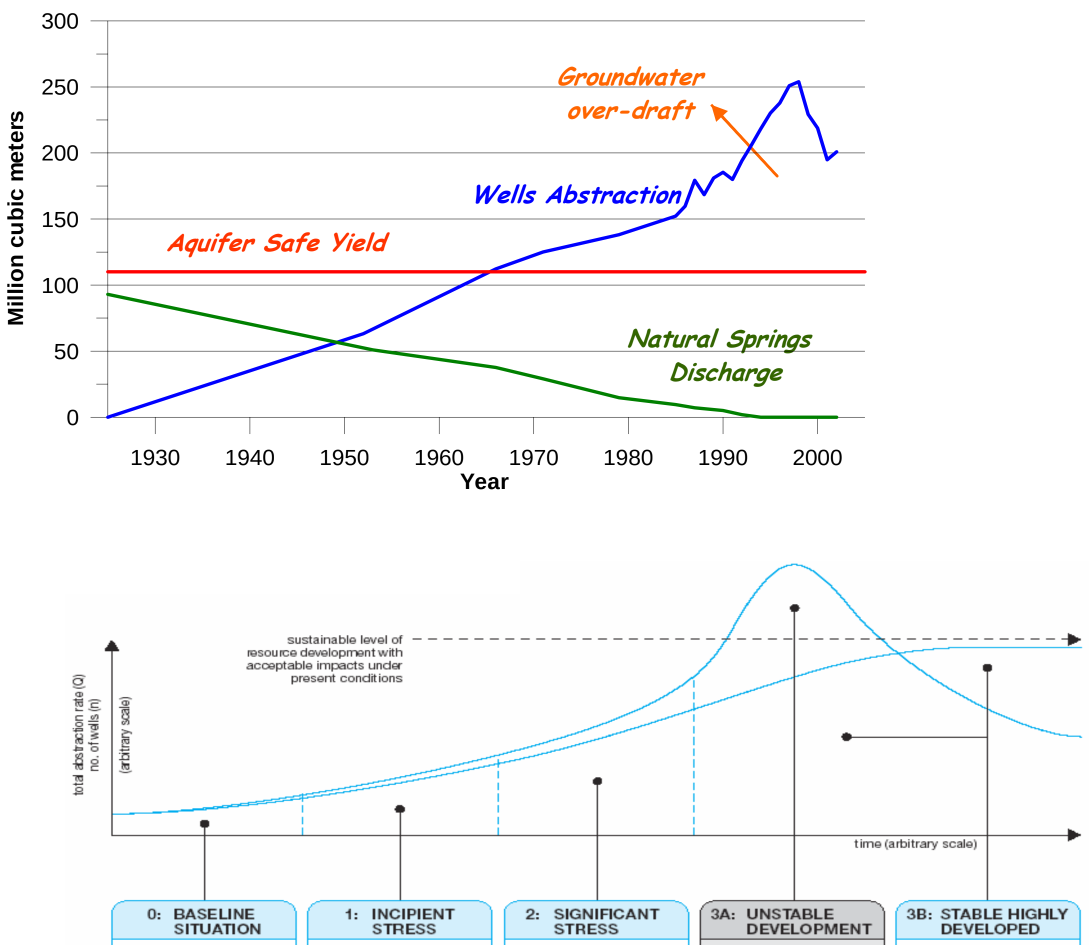


Figure 2. Stages of groundwater resource development in a major aquifer and their corresponding management needs (GWMATE, 2003), compared to groundwater abstraction history in Bahrain (Al-Zubari, 2005).

Table 5. Levels of groundwater management tools, instruments and interventions necessary for given stage of resource development (shaded parts indicate practiced management in Bahrain).

GROUNDWATER MANAGEMENT TOOLS & INSTRUMENTS	**LEVEL OF DEVELOPMENT OF CORRESPONDING TOOL OR INSTRUMENT (according to hydraulic stress stage/see Figure above)**			
	0	**1**	**2**	**3**
TECHNICAL TOOLS				
Resource Assessment	basic knowledge of aquifer	conceptual model based on field data	numerical model(s) operational with simulation of different abstraction scenarios	models linked to decision-support and used for planning and management
Quality Evaluation	no quality constraints experienced	quality variability is issue in allocation	water quality processes understood	quality integrated in allocation plans
Aquifer Monitoring	no regular monitoring program	project monitoring, ad-hoc exchange of data	monitoring routines established	monitoring programs used for management decisions
INSTITUTIONAL INSTRUMENTS				
Water Rights	customary water rights	occasional local clarification of water	recognition that societal changes override	dynamic rights based on management

		rights (via court cases)	customary water rights	plans
Regulatory Provisions	only social regulation	restricted regulation (e.g. licensing of new wells, restrictions on drilling)	active regulation and enforcement by dedicated agency	facilitation and control of stakeholder self-regulation
Water Legislation	no water legislation	preparation of groundwater resource law discussed	legal provision for organization of groundwater users	full legal framework for aquifer management
Stakeholder Participation	little interaction between regulator and water users	reactive participation and development of user organizations	Stakeholder organizations co-opted into management structure (e.g. aquifer councils)	stakeholders and regulator share responsibility for aquifer management
Awareness and Education	groundwater is considered an infinite and free resource	finite resource (campaigns for water conservation and protection)	economic good and part of an integrated system	effective interaction and communication between stakeholders
Economic Instruments	economic externalities hardly recognized	only symbolic charges for water	recognition of economic value (reduction and	economic value recognized (adequate

	(exploitation is widely subsidized)	abstraction	targeting of fuel subsidies)	charging and increased possibility of reallocation)
MANAGEMENT ACTIONS				
Prevention of Side Effects	little concerns for side effects	recognition of (short- and long-term) side effects	preventive measures in recognition of *in-situ* value	mechanism to balance extractive uses and *in-situ* values
Resources Allocation	limited allocation constraints	competition between users	priorities defined for extractive use	equitable allocation of extractive uses and *in-situ* values
Pollution Control	few controls over land use and waste disposal	land surface zoning but no proactive controls	control over new point source pollution and/or siting of new wells in safe zones	control of all point and diffuse sources of pollution; mitigation of existing contamination

Source: World Bank GW-MATE, 2003, www.worldbank.org/gwmate, visited September 2003

6. Groundwater Management Strategies

Strategies needed to stabilize heavily-stressed aquifers can be generally sub-divided into demand-side management interventions (for the GCC these will be in the irrigation and domestic sectors) and the supply-side engineering measures (water harvesting, aquifer recharge enhancement, recycling and reuse).

6.1. Demand Management in Irrigation

In the GCC countries, agricultural policies have been exerting an overriding influence on the behavior of groundwater abstractors, and thus on resource development pressures and management strains. Reducing groundwater used for irrigated agriculture is of paramount importance, for it is the main consumer of groundwater resources (about 90%; Table 6), and where major and effective savings can be achieved; current irrigation efficiencies are very low at 30-45% levels, due to the widespread use of traditional irrigation practices, lack of monitoring and tariffs for irrigation water, and the plantation of high water consuming crops, such as alfalfa (Al-Zubari, 2003). Groundwater savings can be achieved by changing crop types to higher-value crops and shift to greenhouse cultivation and modern agricultural techniques, such as soil-less culture. An even more radical option would be to place a ban on the cultivation of certain types of irrigated crop in critical groundwater areas (e.g., Bahrain attempting to ban alfalfa growing, while Saudi Arabia has recently removed wheat subsidies). The success of agricultural water-saving measures in reducing the decline in aquifer water levels depends directly on these savings being translated into permanent reductions in well abstraction rights and actual pumping, and not to be used to expand the irrigated area or to increase water usage in other sectors.

Table 6. Groundwater irrigation and agriculture, Mcm (adopted from AGFUND/WB, 2005)

Country	1990[1]		2000			1990-2000
	Irrigation Water	Total GW Abstraction	Irrigation Water	Total GW Abstraction	Irrigation Water Share	GW Irrigation Volume Increase
Bahrain	120	167	137	195	70%	14%
Kuwait	80	143	221	393	56%	176%
Oman	1,150	1,204	1,124	1,240	91%	-2%
Qatar	109	111	270	270	100%	148%
Saudi Arabia	14,600	15,505	18,300	19,680	93%	25%
UAE	950	1,148	2,162	2,673	81%	128%
Total	17,009	18,278	22,214	24,451	91%	31%

1) Al-Alawi and Abdulrazzak, 1994

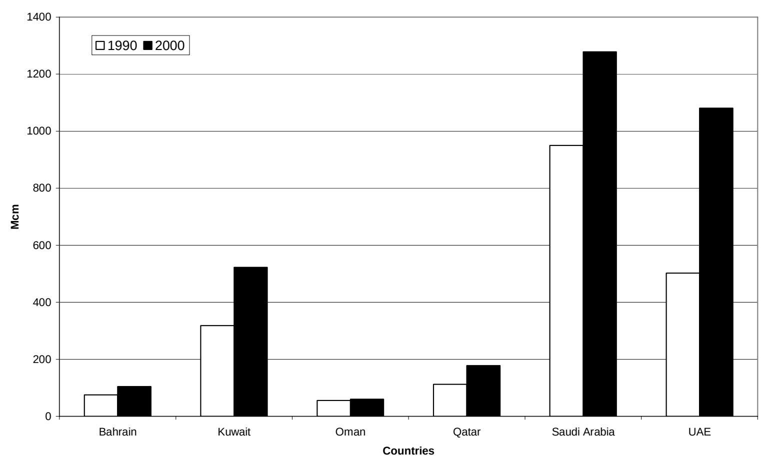
6.2. Supply Management and Augmentation

Supply management can be implemented simultaneously with demand management to increase water supply availability and augment water supplies by such means as desalination, reuse of treated wastewater, recycling, and artificial recharge. Currently, supply management measures with the greatest potential to increase water resource availability in the GCC countries are desalination, reuse of treated water, and artificial recharge.

Desalinated Water

Desalination technology was introduced in the GCC countries in the mid fifties and has developed very rapidly to counteract the shortage and quality deterioration in groundwater resources and to meet the qualitative requirements for drinking/domestic water standards. At present, municipal water supplies in major cities of the GCC rely mainly on desalinated water, which are used either directly or blended with groundwater.

Figure 3 shows the development of desalination capacity in the GCC countries. Despite their relatively enormous cost, short operational life (15-25 years), their dependence on depleting fossil fuel, and their negative environmental impacts on the surrounding air and marine environment, the GCC countries are going ahead with desalination plant construction and expansion in order to meet the spiraling domestic water demands - a function of population and urbanization growth. It is worth mentioning that in 1995 projected desalination capacity in the GCC was estimated at 3,000 Mcm/y by the year 2020 (Ismail 1995). However, due to the large population growth and the escalating needs for domestic water, the total desalination capacity has surpassed the above projected capacity to about 3,200 Mcm/y in 2000. Despite these relatively large volumes of desalinated capacity, it is still expected that domestic sector competition with the irrigation sector on groundwater to increase, due to the anticipated population growth and expansion of urban centers.



Data sources: 1990=Al-Alawi and Abdulrazzak, 1994; 2000=AGFUND/WB, 2005

Figure 3. Development of Desalination Capacity in the GCC Countries, 1990-2000

Treated Wastewater

Wastewater treatment in the GCC countries constitutes an increasing water source driven by escalating water consumption in urban areas. These waters have become available in the early eighties in most of the GCC countries due to the completion of sewage water treatment facilities and urban sewage networks in most of the large cities. Almost all of the countries are operating modern treatment facilities with tertiary and advanced treatment capabilities. In 2000, the treated wastewater in the GCC represented about 20% of the total municipal water volumes (Table 7), posing the problem of wastewater discharge and its associated health hazards caused by the pollution of shallow aquifer, coastlines, and the marine environment, in addition to its contribution to the problem of water table rise in urban areas, e.g. Riyadh, Doha, and Kuwait Cities (UNEP, 2003).

Table 7. Treated Wastewater and Reuse in the GCC countries, 2000, Mcm

Country	Domestic Water Supply[1]	Treated Wastewater[1]	Reused Wastewater[1]	Wastewater Treatment Rate from Total Domestic Supply	Treated Wastewater Reuse Rate from Total Domestic Supply
Bahrain	115	24	17	21%	15%
Kuwait	465	260	182	56%	39%
Oman	169	12	8	7%	5%
Qatar	132	44	31	33%	23%
Saudi Arabia	2,500	240	98	10%	4%
UAE	831	265	159	32%	19%
Total	4,212	845	495	20%	12%

1) AGFUND/WB, 2005

Furthermore, reused treated wastewater did not exceed 12% of the available domestic water supply volumes, and about 60% of treated wastewater. Treated wastewater are used mainly for urban uses (irrigating gardens, parks, and road ornamentals), fodder crops irrigation, and highway landscaping (Al-Zubari 1997), which does not give these waters their economical value under the present water shortage conditions in the region. The remainder is dumped at wadis to infiltrate the shallow aquifers or to the sea. However, all of the GCC countries have ambitious plans for the expansion in the utilization of reclaimed wastewater as a strategically alternative source to meet their future demands of irrigation water and to reduce groundwater abstraction for agricultural purposes (Al-Zubari 1997).

Aquifer Recharge Enhancement

Where conditions are favorable, complementary local supply-side measures, such as rainwater harvesting, Aquifer Storage and Recovery (ASR), and Soil Aquifer Treatment (SAT) need to be encouraged and widely implemented in the GCC countries. Long-term storage can be utilized in situations where desalination production is in excess of water demand. Emergency storage is of significance in building up strategic reserves of groundwater to meet demand when primary water sources are unavailable. The other important aspect of artificial recharge is the storage of reclaimed wastewater. High-quality treated water may be stored seasonally, to be recovered later for irrigation and industrial uses; large volumes of treated wastewater are allowed to flow into the sea in a number of GCC countries. Treated wastewater being disposed of along coastal zones or in wadi channels in most of the countries could be used to recharge the alluvial aquifers. However, the quality of treated effluent must be taken into consideration in order to avoid groundwater pollution and the consequent diminution of water supply availability. Treated effluent must meet certain water quality standards. Treated effluent used for recharge may entail further treatment following conventional secondary treatment (Soil Aquifer Treatment, SAT) in order to comply with health regulations concerning stable organisms, heavy metals and the presence of pathogenic organisms.

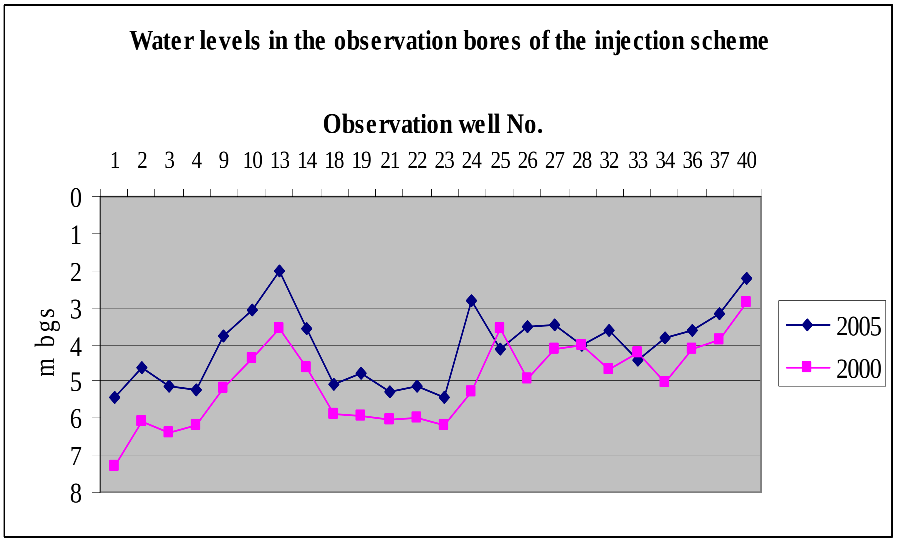
Artificial recharge is considered one of the more effective means of combating saltwater intrusion along coastal zones (Box 3). In many of the GCC countries pumping exceeds natural recharge, and withdrawal from alluvial and limestone aquifers is accelerating the advancement of the saltwater front. Before it drains into the coastal zone on both the eastern and western sides of the Arabian Peninsula, flood water, and reclaimed wastewater can be used to build up a groundwater barrier. The same methods can be used to control the movement of contaminant plumes.

Managing natural groundwater recharge and enhancing the magnitude by artificial means represents an excellent option for increasing water supply availability for most of the countries of the GCC. Increasing the volume of groundwater recharge from surface runoff stored behind dams can provide additional water in time of need, especially for Oman, Saudi Arabia, and United Arab Emirates. Large volumes of surface runoff lost to the sea from coastal drainage basins and evaporation from inland drainage basins can be utilized for artificial recharge purposes. The ratio of estimated flood volume to runoff being utilized ranges from a low of 0.25 to 1.35 Mcm in Qatar to a high of 900 to 2,230 Mcm in Saudi Arabia. Distribution ratios are estimated at 900 to 2,230 Mcm in Saudi Arabia, 275 to 918 Mcm in Oman, 75 to 125 Mcm in the United Arab Emirates, and 0.25 to 1,055 Mcm in Qatar (ESCWA, 1999).

Within the last 10 years, more than 256 dams have been constructed in the Arabian Peninsula, and at least 58 new dams are planned for the next decade. Approximately 85 dams of various sizes have been constructed in Saudi Arabia with a combined storage capacity of 475 Mcm, especially in the western and south-western regions, where relatively abundant runoff is available. Most of the dams in Saudi Arabia have been constructed in mountainous regions due to the availability of runoff from frequent rainfall and the high infiltration characteristics of the coarse wadi bed deposits. Fewer dams have been or are being constructed in Oman and the United Arab Emirates.

Box 3. Use of Tertiary Treated Wastewater to combat seawater intrusion

Over-exploitation of the Salalah coastal plain aquifer, mainly by the irrigation sector, has caused groundwater levels decline, seawater intrusion, and quality deterioration. Aquifer artificial recharge program using tertiary treated wastewater along a parallel line to the coast was implemented to create a hydrostatic barrier to prevent seawater intrusion and to stabilize aquifer groundwater levels, in addition to the long-term storage of water. The scheme have started in the first quarter of 2003, with forty injection wells located about 1.5-2 km^2 from the sea shoreline. More than 18,000 m^3/day of tertiary treated effluent is used to recharge the Salalah coastal aquifer. The injection scheme has helped to increase the water levels in the vicinity of the injection line area and to reduce the inflow of the salt water (source: Shamas, 2006).



7. Groundwater Quality Protection

In several GCC countries, groundwater is a vital natural resource for potable water supply in both the urban and rural environment (e.g., Saudi Arabia, Oman, and Bahrain). It thus plays a fundamental, but often little appreciated role in human well-being, as well as that of some aquatic and terrestrial ecosystems. Many aquifers in the GCC countries are experiencing an increasing threat of pollution from anthropogenic activities, such as agricultural (saline and contaminated irrigation return flows with pesticides, fertilizers, herbicides, etc,), industrial (discharge of hazardous and toxic industrial wastes, underground storage tanks, surface and deep disposal of oil and gas brines, etc.), and domestic activities (discharge of inadequately treated domestic wastewater, septic tanks, municipal land fills, etc.) (Al-Zubari, 2002). If groundwater becomes polluted, it is difficult and usually very costly to rehabilitate, especially that groundwater recharge rates in the region are very low leading to very limited aquifer self-purification. It is therefore advisable to prevent or reduce the risk of groundwater contamination rather than dealing with the consequences of pollution. Groundwater protection should therefore be a top priority. The followings are two concepts that are widely used to aid in the protection of groundwater resources on a regional and local level.

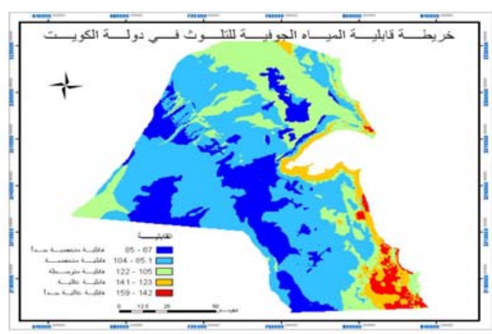
7.1. Groundwater Vulnerability Assessment

The goal of vulnerability assessment is to provide policy makers with groundwater regions most susceptible to contamination so that land management practices can be optimized to protect the groundwater resource, as major contaminates of concern have been significantly correlated to certain land uses and practices. In other words, in order to protect groundwater, vulnerable areas of aquifers must be mapped, then policies restricting harmful land use practices at the country level and the municipal level need to be implemented and enforced (Box 4). Groundwater vulnerability assessment is an issue of spatial distribution and therefore typically carried out using geographic information systems (GIS).

Box 4. Vulnerability Mapping of Kuwait Groundwater Resources

Groundwater vulnerability assessment in Kuwait was made based on the DRASTIC methodology using GIS (Al-Tahou, 2006). DRASTIC is a scheme that assigns numerical values to hydrogeological factors so that scores can be developed which indicate the relative vulnerability of a given hydrogeological settings to pollution. These hydrogeological factors, from which the name of the model is derived, are: 1) **D**epth to water; 2) net **R**echarge; 3) **A**quifer media; 4) **S**oil media; 5) **T**opography (slope); 6) **I**mpact of the vadose zone; and 7) hydraulic **C**onductivity. A numerical ranking system is used to assess the groundwater-pollution potential for each Hydrogeological variable. The system contains three parts: 1) weights; 2) ranges;

The vulnerability assessment map is used to provide policy makers with groundwater areas most susceptible to contamination so that land management practices can be optimized to protect the groundwater resource by the implementation and enforcement of policies restricting harmful land use practices or take precautionary measures for the existing ones.



7.2. Wellhead Protection Area (WHPA)

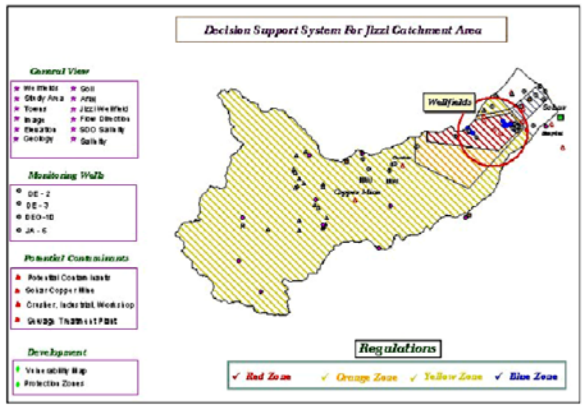
Whether this hazard will result in a threat to a public-supply source depends primarily on its location with respect to the groundwater sources (and their flow-zones and capture areas), and secondarily on the mobility of the contaminants concerned within the local groundwater flow regime. A number of areas and zones should normally be defined, using hydrogeological data on the local groundwater flow regime. Various analytical and numerical models are available to facilitate their delineation. Groundwater pollution hazard assessments should prompt municipal authorities or environmental regulators to take both preventive actions and corrective actions.

To protect aquifers against pollution it is essential to constrain land-use, effluent discharge and waste disposal practices. However, in practice it is necessary to define groundwater protection strategies that accept trade-offs between competing interests. Thus instead of applying universal controls over land use and effluent discharge, it is more cost-effective to utilize the natural contaminant attenuation capacity of the strata overlying the aquifer, when defining the level of control required to protect groundwater quality. Simple and robust zones (based on aquifer pollution vulnerability and source protection perimeters) need to be established, with matrices that indicate what activities are possible where at an acceptable risk to groundwater (Box 5).

Box 5. Wellhead Protection Plan for the Alluvium Aquifer in Wadi Al-Jizzi, Oman

Domestic water supply in the GCC countries relies on groundwater abstraction (54%) and desalinated water (46%). People living in rural areas are particularly dependant on groundwater as they do not have access to municipal water supplies. Groundwater is supplied to the public either directly (rural communities) or blended with desalinated water (cities). Many of these cities/rural communities are experiencing significant commercial, agricultural, and industrial development, causing serious threats to the quality of the groundwater used for public supply. These threats are manifested by the industrial/commercial effluent discharges and by the irrigation return flows, which might reach the capture zone of the domestic water supply wellfield. Furthermore, in many of the rural communities public sewage collection system does not exist and sanitary wastes are discharged into individual septic tanks, which poses an additional threat to the aquifers used for domestic public supply and eventually the loss of groundwater supply capacity (Al-Zubari, 2000).

In the GCC countries, the WHPA concept is implemented only in the Sultanate of Oman. The wellhead protection area of 30 government wellfields, administered by the Ministry of Regional Municipalities, Environment, and Water Resources, and used for public water supply are protected from possible surface pollution sources by restricting surface activities as well as aquifer utilization by other users to minimize well interference (Abdulkhaliq, 2001). The protection program consists of the delineation of 3 protection zones for the wellfields producing from inland aquifers and 4 protection zones for the wellfields producing from coastal aquifers.



These zones are designated as: red; orange, yellow, and blue zones. The red zone is the area where the wellfield gets its groundwater directly from it, where any surface pollution or groundwater extraction will have direct impact on the wellfield supply; the orange zone is the principal recharge area of the wellfield, where any surface pollution or groundwater utilization will probably have an impact on the quality and quantity of the groundwater produced by the existing and future wellfields on the medium-long time range; the yellow zone represents the up-gradient areas of the wellfield, where any unplanned groundwater development in this zone might impact the water supply of the existing and future wellfields on the long time range; the blue zone is the area between the wellfield and the coast, where any over-extraction might lead to the increase in seawater intrusion, and thus threatening the quality of the wellfield water supply.

8. Utilization of Non-Renewable Groundwater

The use of the term 'sustainability' for non-renewable groundwater resources requires clarification. It should be interpreted in a social and economic, rather than a physical context, implying that full consideration must be given, not only to the immediate benefits, but also to the 'negative impacts' of development and to the 'what comes after?' question, and thus to long time horizons.

In general, there are two very different situations under which the utilization of non-renewable groundwater occurs (GWMATE, 2003):

- Planned schemes in which the mining of aquifer reserves is contemplated from the outset, usually for a specific development project in an arid area with little contemporary groundwater recharge (e.g., the Libyan Sarir Basin, and Al-Sharqiyah Sand and Al-Massarat Basin in Oman).

- On an unplanned basis with incidental depletion of aquifer reserves, as a result of intensive groundwater abstraction in areas with some contemporary recharge but where this proves insufficient or where there is limited hydraulic continuity between deep aquifers and their recharge area (e.g., Saq aquifer, the Disi aquifer and the Paleogene aquifer in the Arabian Peninsula). Unfortunately, this is the case in most of the GCC countries.
- In the **'planned depletion scenario'** the management goal is the orderly utilization of aquifer reserves of a system with little pre-existing development, with expected benefits and predicted impacts over a specified time-frame. Appropriate 'exit strategies' need to be identified, developed and implemented by the time that the aquifer is seriously depleted. This scenario must include balanced socio-economic choices on the use of aquifer storage reserves and on the transition to a subsequent less water-dependent economy. A key consideration in defining the 'exit strategy' will be identification of the replacement water resource, such as desalination of seawater or brackish groundwater. In the case of the GCC countries, this will require an investment in the development of desalination and treatment technology in order to reduce its cost and its environmental impacts, and also in modern agricultural technologies if these countries envision themselves to continue in the agricultural development path.

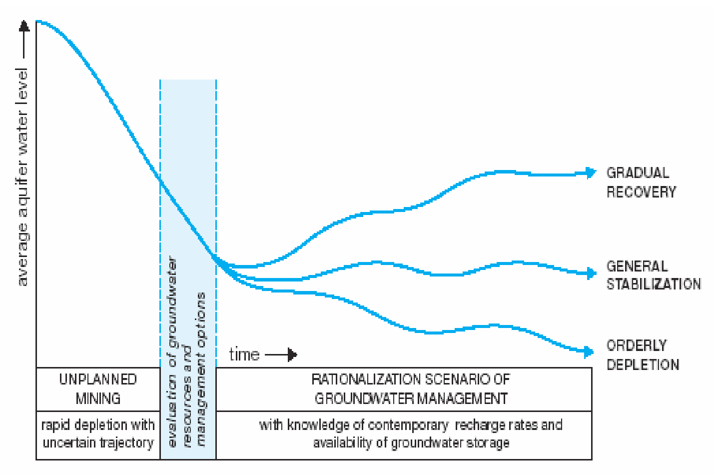


Figure 4. Targets for groundwater resources management in 'rationalization scenarios' following indiscriminate and excessive exploitation (GWMATE, 2003).

In the unplanned situation a **'rationalization scenario'** (Figure 4) is needed in which the management goal is:

- Hydraulic stabilization of the aquifer, or
- More orderly utilization of aquifer reserves, minimizing quality deterioration, maximizing groundwater productivity and promoting social transition to a less water-dependent economy. In both cases groundwater abstraction rates will have to be reduced, and thus the introduction of demand management measures (including realistic groundwater charges and incentives for real water-saving) will be needed.

In the 'planned depletion scenario' the impacts of the proposed exploitation of aquifer reserves on all traditional groundwater users need to be assessed. The fundamental concept should be to ensure that there are sufficient reserves of extractable groundwater of acceptable quality left in the aquifer system at the end of the proposed period of intensive exploitation to sustain the pre-existing activity (albeit at additional cost). Another way of achieving this end would be to restrict the 'design drawdown' of intensive exploitation to less than a given average figure over a stated period (for example, 20 m after 20 years). Adequate aquifer characterization and simulation modeling (both flow and salinity) are essential to facilitate such predictions.

It is vital that the groundwater is used with maximum hydraulic efficiency and economic productivity, and this implies full re-use of urban, industrial and mining water supplies and carefully-controlled agricultural irrigation. An acceptable system of measuring or estimating the volumetric abstraction will be required as the cornerstone for both realistic charging and enforcing regulations to discourage inefficient and unproductive uses. Furthermore, public awareness campaigns on the nature, uniqueness and value of non-renewable groundwater will be essential to create social conditions conducive to aquifer management, including wherever possible full user participation.

9. Groundwater Abstraction Rights, Monitoring

Groundwater resources, either renewable or non-renewable, must be treated as a public-property (or alternatively common-property) resource, with the state is the guardian or trustee of groundwater resources and can introduce measures to prevent aquifers depletion and pollution. In other words, turning wells owners to users that must apply to the state for water abstraction and use right. Therefore, there is a high priority to put in place a system of groundwater abstraction rights that is consistent with the hydrogeological realities. In the case of non-renewable, it is also important to agree the level in government to which the decision on mining of aquifer reserves must be referred, which should be given to the highest possible authority in the country.

The value of detailed monitoring of groundwater abstraction and use, and the aquifer state variables (groundwater levels and quality) response to such abstraction, cannot be overemphasized. Monitoring of water quality, water levels, and water extraction in an aquifer is the foundation on which groundwater resource management is based. This should be carried out by the water resource administration, stakeholder associations and individual users. The existence of time-limited permits subject to initial review will normally stimulate permit holders to provide regular data on wells. It will be incumbent upon the water resources administration to make appropriate institutional arrangements, through some form of aquifer database (databank or datacenter) for the archiving, processing, interpretation and dissemination of this information.

10. Groundwater Simulation Modeling – An Essential Management Tool

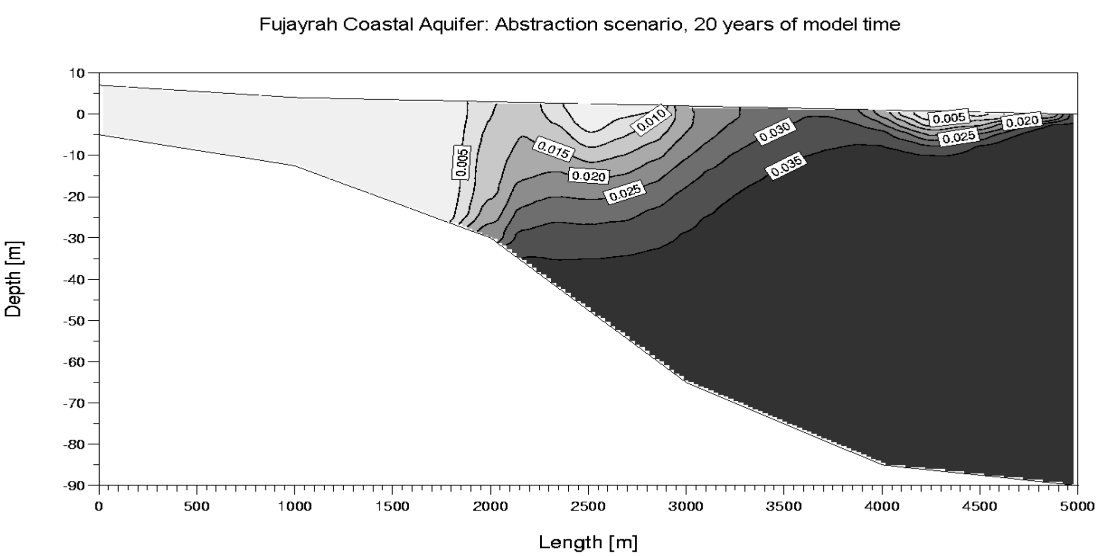
Numerical groundwater models are an efficient management and planning tool for the development of complex aquifer systems. Models, if properly constructed are useful to estimate the effects of future development/management schemes on the groundwater system.

In addition, they can aid in understanding of the overall behavior of a given aquifer system. The computed result of an aquifer simulation is the potentiometric surface distribution of the aquifer and the salinity distribution in the aquifer or the concentration of a particular contaminant species, which are the critical factor in water resources management and planning.

While the aquifer in reality can be developed only once at considerable expense, a numerical model can be run many times at low expense over a relatively short period of time. Observations of model performance under different development and management options aids in selecting an optimum set of operating conditions to use the aquifer without endangering its sustainability (Box 6).

Box 6. Use of Simulation Modeling in Studying Control of Saltwater Intrusion in the Coastal Aquifer, United Arab Emirates

In many GCC countries, fresh water is obtained from coastal aquifers which supply water to the often urbanized areas on the coast, as well as remote areas. Saltwater intrusion has become a crucial issue as increased groundwater abstraction has caused the fresh water/salt water interface to advance inland. A numerical model was applied to the coastal area near Al Fujayrah in the United Arab Emirates to study the salt water intrusion problem and assess options for counteracting the intrusion.



Sources: ESCWA, 2001

11. Use of DSS[3] in Groundwater Resources Management and Planning

The technical challenge in groundwater management and planning is in the integration of the disparate systems of hydrology, ecology, climate, demographics, economics, policy and law, each of which influence the supply and demand for water. Specifically, these systems, their associated processes, and most importantly the constitutive relations that link them must be identified, abstracted, and quantified. It is important to note that these systems are not static in time but rather behave dynamically, expressing the complex interplay of processes that underlie these systems. Additionally, these systems do not operate independently but in complex networks characterized by numerous feedbacks and time delays. That is, the dynamics of one process may depend on the behavior of one or more related processes. Thus, a second aspect of this task, and the most challenging, is to identify the constitutive relations linking disparate processes comprising the water budget. This involves understanding the strength of cause-and-effect relationships, and determining whether the response is immediate or delayed in time.

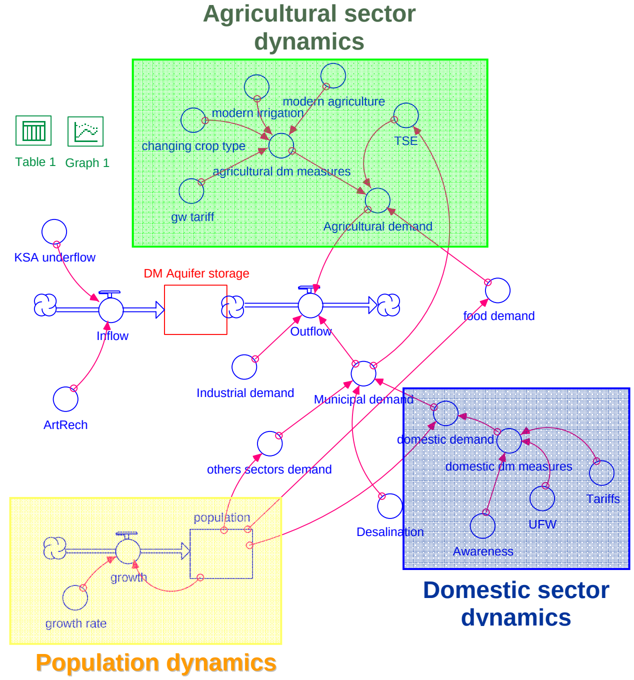
Therefore, there is a need for a tool(s) that fully integrate the diverse factors influencing groundwater management decisions, and to assist groundwater managers and policy makers in quantifying the consequences of decisions, exploring alternative water conservation and management strategies, forecasting resources sustainability, and assessing uncertainty. System Dynamics modeling provides an appropriate framework for managing multiple interacting subsystems, each of which vary in time, and able to quantify feed-backs, time delays, and coupling between subsystem components (Box 7).

[3] There is no universally accepted definition of Decision Support Systems (DSS) (for a an expanded discussion refer to Alter, 1980; Turban, 1995). However, DSS can be defined as a "class of computerized information system that supports decision-making activities". A decision is a choice between alternatives based on estimates of the values of those alternatives. Supporting a decision means helping people working alone or in a group gather intelligence, generate alternatives and make choices. Supporting the choice making process involves supporting the estimation, the evaluation and/or the comparison of alternatives.

Box 7. Conceptual System Dynamics Model for the Dammam Aquifer in Bahrain

System Dynamics model is being used in the management and planning of the Dammam aquifer in Bahrain. The aquifer storage (stock) fluctuates in response to "flow" into/out of the system. The model incorporates the aquifer physical system (underflow recharge) and its natural discharge (natural springs), abstraction rates (mainly agricultural and domestic), as well as factors influencing these rates, represented by agricultural practices, consumption patterns, and demographics.

Each of these factors, or subsystem, is influenced by its own dynamics, as indicated in the facing figure. e.g., the agricultural demand will depend on supply augmentation efforts (planned available treated wastewater volumes and reuse), demand management interventions (application of groundwater tariff, changing crop type, implementation of modern irrigation and modern agricultural techniques), and food demand which is influenced by population. By specifying the constitutive relations linking these disparate processes, the impact of each measure/intervention can be measured and assessed in terms of its impact on the total aquifer water budget. Future scenarios representing managemtn actions or their combination can be developed and their effectiveness in modifying groundwater budget and thus its water levels and quality can by compared.



12. Groundwater Sustainability Indicators

Sustainable groundwater resources development and protection is an integrated, holistic process. Its successful solution is closely linked to water planning, policy, and management and influenced social and economic constraints. The main objective of this process is to ensure quantity, quality, safety and sustainability of groundwater as a strategic source for life, economic development, and as an important component of the ecosystem. Groundwater indicators, based on monitoring and assessment programs, support sustainable management of groundwater resources, provide summary information about the present state and trends in groundwater systems, help to analyze the extent of natural processes and human impacts on groundwater system in space and time and facilitate communication and public participation in resources planning and policy (Vrba and Lipponen, 2007). Furthermore, a good monitoring and evaluation system with a set of well designed indicators can make the difference between an IWRM strategy/plan that has an impact on the ground and one that remains an expression of good intentions. Indicators can help to answer the questions where are we now, where do we want to go, are we taking the right path to get there, and are we there yet? (GWP, 2007).

The development of "groundwater resources sustainability" indicators is currently an area of active research, and has proven to be a difficult task due to the spatial nature of groundwater (scale) and its many social, economic and environmental links. Al-Zubari (2004) has proposed a set of IWRM indicators that were based on four main categories: Enabling Environment & Institutional Roles, Supply availability and management, Demand Management and Protection, and Health and Environmental Protection. The set of indicators included 71 indicators with 22 indicators related to groundwater resources. More recently Vrba and Lipponen (2007) have proposed a set of groundwater resources sustainability indicators as a first step for further development of more sophisticated, next generation indicators. These are: 1) renewable GW resources per capita; 2) total GW abstraction/GW recharge; 3) total GW abstraction/exploitable GW resources; 4) GW as a percentage of total use of drinking water on country level; 5) GW depletion; 6) total exploitable non-renewable GW resources/annual abstraction of non-renewable GW; 7) GW vulnerability; 8) GW quality; 9) GW treatment requirements; and 10) dependence of agricultural population on GW.

13. Conclusion and Recommendations

Groundwater resources are an essential resource in the GCC Counties that requires careful planning and management so that groundwater can continue to contribute in the sustainability of human socio-economic development and the various ecosystems that depend on it. Currently, groundwater resources are being over-exploited in all the countries of the GCC, and are experiencing serious water level declines and quality degradation. Diagnosis of the management level of groundwater resources in the GCC indicated that the necessary management level and interventions are inadequate and lag behind the level of the critical groundwater development stage, and that there is a major deficiency in the institutional instruments (i.e., water rights, regulatory provisions, water legislation, stakeholder participation, awareness and education, and economic instruments) and management actions (i.e., prevention of side effects, resources allocation, and pollution control). i.e., the major challenge facing the GCC countries is a management challenge and not a technical one.

In order to stop this trend, it is essential to recognize that managing groundwater is as much about managing people (water and land users) as it is about managing water (aquifer resources). i.e., the socio-economic dimension (demand-side management) is as important as the hydrogeological dimension (supply-side management) and integration of both is always required. It is essential that issues of groundwater quality protection, monitoring, abstraction rights, and tariffs are addressed in the process of groundwater management, and that modern tools such as mathematical models and system dynamics models are utilized in the management and planning for these resources and the process is monitored and evaluated by using groundwater sustainability indicators.

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Economic and Engineering Optimization for Groundwater Assessment, Use and Management in Agriculture Sector in GCC Countries

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Abstraction

In GCC countries, groundwater is abstracted at a faster rate than the renewable aquifer system can be naturally recharged. This water is mainly used in agriculture sector. The total annual of groundwater abstraction is about 19572 million cubic meters, however the recharge is about 4875 million cubic meters. The results are falling water tables, saline water intrusion into fresh aquifer systems, water quality deterioration and mining the nonrenewable aquifers. Moreover the deteriorated quality of this water is not promising for the agriculture production of many crops. The share of agriculture sector in the GCC countries GDP is very law compared with its water consumption which is about 76%. The groundwater quality and the harsh arid conditions affect the lifetime of the wells, pipes and pumps and increase the operation and maintenance cost. Optimal groundwater assessment, use and management technically and economically are interrelated problems. An economic and engineering optimization analysis of GCC groundwater resources in the agriculture sectors is presented. The approach's development, limitations, and results are reviewed and tested. Traditional economic analysis using a crop production function approach has assumed that all variable factors, including irrigation water, are fully employed in the crop production process. However, this paper first demonstrates that economic benefits of irrigation water are overestimated when the crop production function, and therefore the irrigation water demand function, is expressed in terms of irrigation water supplied, rather than consumptive irrigation water use. Second, the paper demonstrates that the magnitude of the estimation bias is proportional to the rate of irrigation water losses through leaching, runoff and evaporation.

Consequently, the model misspecification problem would lead to increased irrigation water use and reduce incentives for farmers to adopt improved irrigation technologies. The major methodological conclusions are that groundwater resources optimization analysis driven by economic objective functions is possible and applicable. Specific results for GCC countries indicated a great potential for other water alternatives and conjunctive use to improve economic performance and significant economic value of groundwater use in agriculture sectors. Also, it is indicated that the overall agriculture policy in GCC countries should be reviewed and reformed.

Keywords: Groundwater management, Economic benefits, Water alternatives, Optimization, Economic optimization, Integrated water resources management.

1. General Background

The Gulf Cooperation Council, GCC, countries experience a severe water shortage problem, that threatens the sustainable development and hinders the national plans for human, industrial and agricultural development. The territories of the six member states of GCC countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) occupy most of the Arabian Peninsula; an area of huge reserves of crude oil and gas. Figure (1) presents the geographical location of the GCC countries in the Arabian Peninsula. Oil production constitutes the cornerstone for the economic strength of this region. The living standard in the GCC countries is relatively high (Al Rashed and Sherif, 2000).

Figure 1: General location map for GCC countries.

GCC countries are a part of water competitive world and water deficit grows larger with each year, making it potentially more difficult to manage. One of the primary reasons for the unsustainable exploitation of groundwater resources has been the provision of direct and indirect subsidies to well excavation, pumps, fuel and other inputs as well as price support programs and trade protection in some GCC countries for achieving the food security. This has resulted in distorted costs and revenues as well as misallocation of resources by artificially attracting investment to the sector that have obscured the high opportunity cost of groundwater for municipal and industrial uses, and have created a disincentive for the rational use of this resource. While the governments intend to redistribute oil revenues for citizens, given that most of the employment in the agriculture sector is provided by expatriates, employment generation is not an objective of agricultural policy in GCC countries (Dawoud, 2006).

The irrigated agriculture areas has been increases from 1,500,000 ha in 1971 to be 4,250,000 ha in 2005 and the production of the vegetables has been increased from 750,000 tons in 1971 to 3,600,000 in 2005 as shown in Figure (2). The investment in the agriculture sector has been increased from 25 million Us Dollars in 1971 to be 345 million US dollars by 2005 (Al Zubari, 2002) as shown in Figure (3).

Figure 2: Increase in agriculture areas (1971-2005).

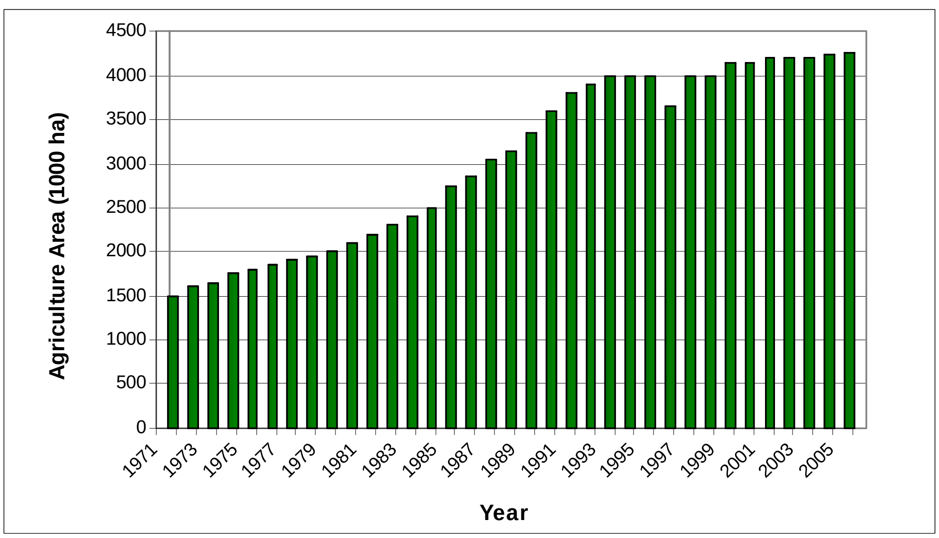
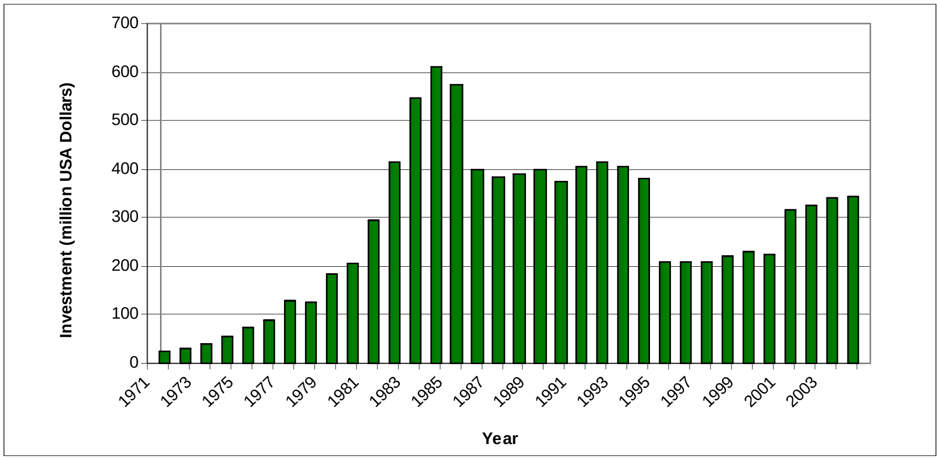


Figure 3: Increase in investment in the agriculture sector (1971-2005).



The statistics indicates that the water use in agriculture sector ranges between 75% and 85% of the total used water in GCC countries. About 91% of this water is groundwater, 7.2% is desalinated water and the rest (1.8%) is treated wastewater. The water use in agriculture sector has been increased from 17009 million cubic meters in 1995 to be about 19518 million cubic meters in 2005 and it is expected to be about 20466 million cubic meters by 2025 (Dawoud, 2005) as shown in Table (1).

The increase in water use for irrigation of low-value agricultural crops in GCC countries specially the desalinated costly water raised the question of the sustainability and the future of the agriculture sector in GCC countries and had resulted in the wastage of both non-renewable and renewable resources which would be better reserved for present or future high value uses. Only limited attempts have been made for controlling groundwater demand through the use of water charges, restrictions on groundwater pumping, limitations on groundwater development, and the introduction of advanced irrigation systems.

Table 1: Increase in water use in agriculture sector in GCC countries.

Country	Water Use (MCM)				Ration of increase % (1995-2025)
	1995	2000	2005	2025	
Bahrain	115	124	251	290	141
Kuwait	74	110	521	458	472
Oman	1129	1270	1325	1896	65
Qatar	98	185	245	298	173

Saudi Arabia	1489	15000	15854	17320	19
UAE	943	1400	2547	2935	208
Total	**17254**	**18089**	**20743**	**23197**	**36**

In comparison with a large share of water use for agriculture sector, the contribution of it to Gross Domestic Product (GDP) in GCC countries is small. Agriculture consumes around 60-90 percent of total groundwater use, but accounts for 2-6 percent of GDP in Saudi Arabia, the UAE, and Oman. The agriculture sector is much more insignificant in Bahrain and Kuwait, constituting less than 1 percent of GDP while still using around 55-70 percent of total available water resources. In Qatar, groundwater use is primarily for irrigation purposes despite its minuscule contribution to the economy. Table (2) below presents data on groundwater use in irrigation in the GCC countries (World Bank, 2006).

Table 2: Agriculture Sector share in GDP.

Country	1995		2005			1990-2005	2005
	Irrigation Water (MCM/Year)	Total Groundwater Abstraction (MCM/Year)	Irrigation Water (MCM/Year)	Total Groundwater Abstraction (MCM/Year)	Irrigation Water Share of Total Groundwater Abstraction (%)	Groundwater Irrigation Volume Increase (%)	Agriculture GDP share (%)
Bahrain	120	120	251	258	70	14	0.85
Kuwait	80	80	521	405	56	176	0.40
Oman	1150	1150	1325	1690	91	5	2.81
Qatar	109	109	245	185	100	148	0.85
KSA	14600	14600	15854	14430	93	25	6.23
UAE	950	950	2547	2650	81	128	3.34
Total	**17009**	**17009**	**20743**	**19618**	**91**	**31**	

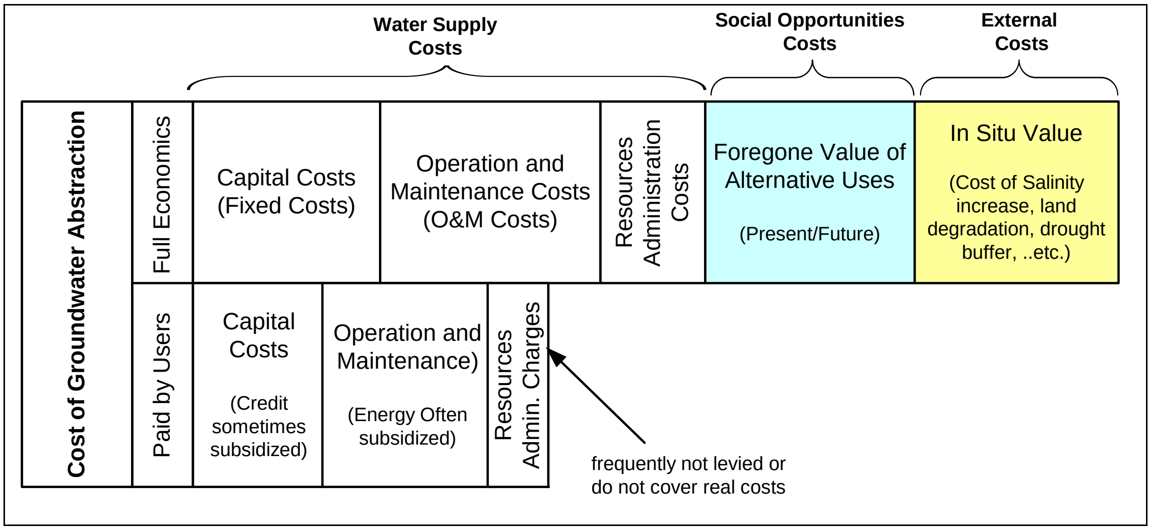
Planners must sometimes decide how to restrict or reduce groundwater use to prevent unacceptable future problems. Often there are several alternatives (policies). Comparing policies can involve formulating a sustained groundwater yield optimization problem and computing an optimal groundwater pumping strategy for each. A wide variety of groundwater management and development alternatives are being considered, ranging from greater conjunctive use of groundwater, more expensive and effective forms of water treatment and wastewater recycling, using desalinated water, water use efficiency and demand management, as well as experimental forms of environmental restoration. The integration of such a variety of options into an already complex groundwater management system is a difficult task. This task can be made somewhat easier by the judicious use of optimization modeling.

2. Optimization Objectives and Approach

Growing populations, changing in regional demands as well as improved estimates of groundwater resources are resulting in increased scarcity of these resources and, consequently, an ever-increasing need for improving policy analysis to provide efficient management planes. In the case of groundwater, this necessities the development of management plans that incorporate not only the salient characteristics of the groundwater system via hydrogeological models, but also the relevant characteristics of user behavior via economic models. The groundwater model provides a representation of the reserve of the resources, as well as inputs into the cost functions in the economic model. The transition equation incorporates not only production, but also inflows into the reserve and any feedback that may occur between the production path and the reserve. Evaluation of the efficiency of management plans requires the simultaneous interaction of the component pieces.

Groundwater tends to be undervalued, especially where its exploitation is uncontrolled. In this situation the exploiter of the resource (in effect) receives all the benefits of groundwater use but (at most) pays only part of the costs usually the recurrent cost of pumping (providing the energy input is not subsidized) and the capital cost of well construction, but rarely the external and opportunity costs. This undervaluation often leads to economically inefficient resource use as shown in Figure (4).

Figure 4: Measuring the costs of groundwater use.



True interdisciplinary models are, in general, a departure from traditional analysis. Historically, the majority of management plans, developed by engineers, have focused solely on the supply characteristics of the system. The role of economics in these plans has primary been one of accounting in order that the revenues from the water system were large enough to offset the costs of operating the system. Economic models, traditionally, have been equally limiting in that the impact from the physical sciences has been incorporated in an elemental fashion. When water seemingly abundant, the inefficient from such models were not particularly troublesome. However, as water becomes relatively, more scarce, the inadequacies of many of the existing models are becoming more apparent. More recently literature has begun to focus on specific aspects of hybrid models. This paper focuses on the development of a model that incorporates the hydrogeologic, engendering and economical characteristics into a dynamic optimization model.

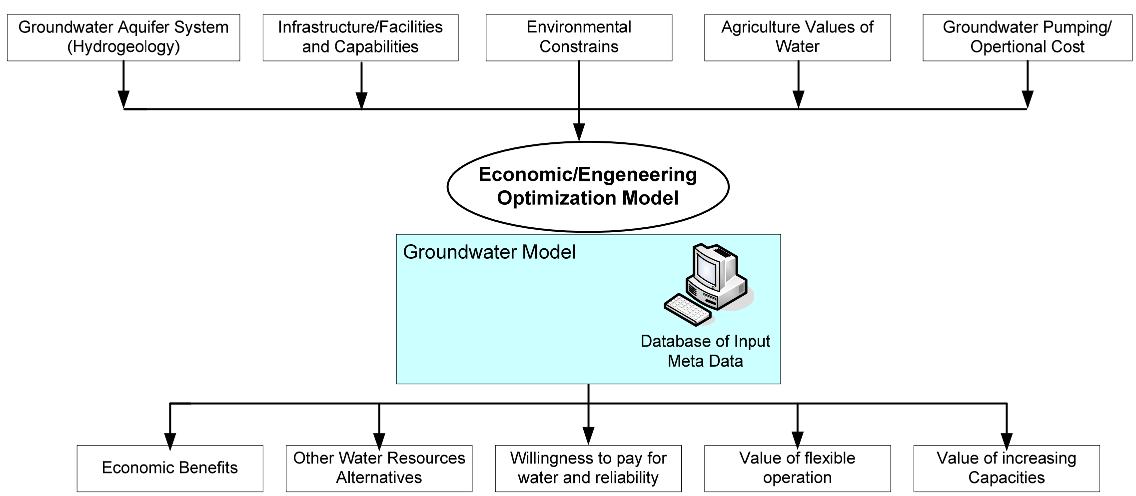
The developed optimization model is intended to help with the following activities in the context of GCC groundwater supplies:

- Identification of economically promising facility capacity changes,
- Assessment of user willingness-to-pay for water,
- Identification of other promising water alternatives,
- Integration of facility operations,
- Data assessment and reconciliation,
- Demonstration of advances in modeling technique and documentation, and

- Identification of promising solutions for refinement and testing by simulation studies.

The developed model demonstrates the feasibility of using economic-engineering optimization for the planning of GCC countries groundwater resources. The general approach of the developed model is to use optimization to suggest water facility operations, alternatives and allocations that maximize the economic value of agricultural in GCC countries. Agricultural is represented by economic value functions for year 2025 levels of development, population and land use. Data flows to and from the model are depicted in Figure (5).

Figure 5: Schematic Diagram for the Optimization Process.



3. Optimization Model Development

3.1 Management Requirements

One of the most important challenges facing the water resources planners is to maximize the net social benefits from the consumption of groundwater. Based on the literature, the normalized-quadratic profit function has been frequently used to characterize the economic benefits of agricultural production (Huffman and Evanson 1989; Shumway 1983). In 1981 Levhari, Mischner, and Mirman demonstrated the net, competitive market equilibrium, with clearly defined property rights, is the equivalent to the social planners maximization of net benefits and provide the model in a competitive framework. The aquifer potentiality that can be physically withdrawn in the initial time period given by:

$$S(0) = S_0(\gamma) \qquad \text{Eq.(1)}$$

where γ is a vector representing the physical characteristics of the groundwater aquifer. More specifically this can be expressed as follows:

$$S(0) = AM(S_y) \qquad \text{Eq.(2)}$$

Where A is the aquifer surface area and M is the average saturated thickness of the aquifer, and (S_y) is the specific yield (which is the volume of water produced per unit of aquifer are per unit of decline in hydraulic head). The hydraulic head, h, is the mechanical energy per unit fluid weight and is the sum of the pressure and elevation heads. The pressure head is the work associated with the pressure per unit fluid weight and the elevation head is due to gravity. (S_y) is characteristic to a specific aquifer and also depends on the ability of the aquifer bearing formation to hold water, thus the porosity, the percentage void in a porous medium, is a factor. Porosity in most of the GCC countries explored aquifer systems ranges from 0.10 to 0.33. Since it is not physically possible to drain all available potential water from the aquifer due to capillary pressure, (S_y) is normally less than porosity (Freeze and Cherry,1979). The vector of physical characteristics, γ, that impact the aquifer potentiality include the physical dimensions of the aquifer, hydraulic gradients, the pressure heads and the aquifer physical characteristics including grain size, uniformity and porosity. The transient groundwater flow can be described as follows:

$$S(t) = R[S(t), q(t), \alpha] + SF - q(t) - ET \qquad \text{Eq. (3)}$$

where *R[s(t), q(t), α]* is the aquifer recharge. Recharge is the amount of water that moves into the aquifer, generally from rainfall, melting snow, or rivers, *R* is a function of the aquifer potentiality, the abstraction rate and a vector of other characteristics. *q(t)* is the pumping from the aquifer system at time (t) and ET is the evapotranspiration by the plants within the root zone in contact with the aquifer. The transient equation is analogous to the mass balance of the mass of water unless the mass out is equal to the rate of storage. The water allocation problem then is to select the abstraction scenarios to maximize the benefits from groundwater value. This can be expressed as follows:

$$\max_{q(t)} \int_0^\infty e^{-rt}\left[P(t;\beta)q(t) - C(q(t), S(t))\right]dt \qquad \text{Eq. (4)}$$

subjected to $S(t) = R\left[S(t), q(t), \alpha\right] + SF - q(t) - ET, S90) = (AM)S_Y$ Eq. (5)

Where *C(q(t), S(t))* is the production cost function, dependent on the rate of pumping and the aquifer potentiality, *P(t)* is the price per unit output from using the groundwater, which is a function of time and a vector of groundwater quality, β and r is the discount rate. The Hamiltonian is:

$$H(t) = e^{-rt}\left[P(t)q(t) - C(Q(t), S(t)\right] + \lambda(t)(R(S(t), q(t); \alpha) + SF - q(t) - ET \qquad \text{Eq. (6)}$$

where λ(t) is the user cost or scarcity value. Necessary first order includes:

$$H_q(t) = e^{-rt}\left[P(t) - C_q(q(t), S(t)) + \lambda(t)(R_q(S(t), q(t); \alpha) - 1\right] = 0 \qquad \text{Eq. (7)}$$

and $-H_s(t) = \lambda(t) = e^{-rt} c_s(q(t), S(t)) - \lambda(t) R_S(S(t), q(t); \alpha))$ Eq. (8)

Equation (7) implies the efficient pumping from the aquifer is such that:

$$P(t) = C_q(q(t), S(t)) - e^{rt}\lambda(t)(1 - R_S(S(t), q(t); \alpha)) \qquad \text{Eq. (9)}$$

The price of pumped water is equal to marginal cost of the pumped water from the aquifer in addition to the current value user cost less the current value user cost multiplied by the effect of the pumped water on the recharge rate of the aquifer. S is the dynamic optimality condition characterizing how the user cost varies over time according to the discounted value of the change in costs as the aquifer potentiality varies less the value of changes in the recharge rate as the potentiality varies.

The optimal water use path resulting from the planners optimization problems can be characterized by differentiating Equation (7) with respect to time and multiplying by e^{-rt} (and dropping the arguments of each factor for ease of presentation) yields:

$$e^{rt} H_{qt} = \left[-r(P - C_q) + (P - C_{qq} q) - C_{qS} S\right] + e^{rt} \lambda (R_q - 1) + e^{rt} (R_{qq} q + R_{qs} S) = 0 \quad \text{Eq. (10)}$$

Substituting Equation (8) into Equation (10) and solving for q yields the optimal pumping path as follows:

$$q = \frac{P - r(P - C_q) + (e^{rt} \lambda R_{qs}) S + (\lambda R_s - C_s)(1 - R_q)}{C_{qq} - e^{rt} \lambda R_{qq}} \qquad \text{Eq. (11)}$$

While normally assume that q is less than 0, at this level of generality there us little we can garner from Equation (11) that is particularly intuitive other than that the production path prior to a steady state solution, is dependent on elements from both the physical and social science components of the model.

The steady state solution represents a sustainable rate of groundwater pumping and use from the aquifer system. It can be shown for this type of model that the optimal path to a steady state (given the existence of a steady state) will always be monotonic in the state variable; S. Equation (10) implies that the denominator to Equation (11) is negative. Thus, whether q monotonically increases or decreases through time as the steady state is approached depends upon the relative magnitudes of the expressions in the numerator to (11). For example, if the price of water is growing at the rate of interest, then P=rP and the sign of $rC_q + (e^{rt}\lambda R_{qs} - C_{qs})S + (\lambda R_s - C_s)(1 - R_{q)}$ will determine whether groundwater use optimally increase or decrease towards the steady state. In general if:

$P - r(P - C_q) + (e^{rt}\lambda R_{qs} - C_{qs})S + (\lambda R_s - C_s)(1 - R_{q)} < 0$ the optimal groundwater use path will increase over time in approaching the steady state. Alternatively, if:

$P - r(P - C_q) + (e^{rt}\lambda R_{qs} - C_{qs})S + (\lambda R_s - C_s)(1 - R_{q)} > 0$ optimal groundwater use will reach the steady state from above (i.e., groundwater use is decreasing over time as it approaches the steady state).

The optimal abstraction rate $q^*(t)$ at any time (t) is found integrating Equation (11) from time 0 to time (t). That is:

$$q^*(t) = \int_0^t \left(\frac{P - r(P - C_q) + (e^{rt}\lambda R_{qs})S + (\lambda R_s - C_s)(1 - R_q)}{C_{qq} - e^{rt}\lambda R_{qq}} \right) dt \quad \text{Eq. (12)}$$

Given the existence of a steady-state solution, the steady state occurs when $S = \lambda = 0$. Combining (2) and (12) with this restriction yields the steady-state output q^*as follows:

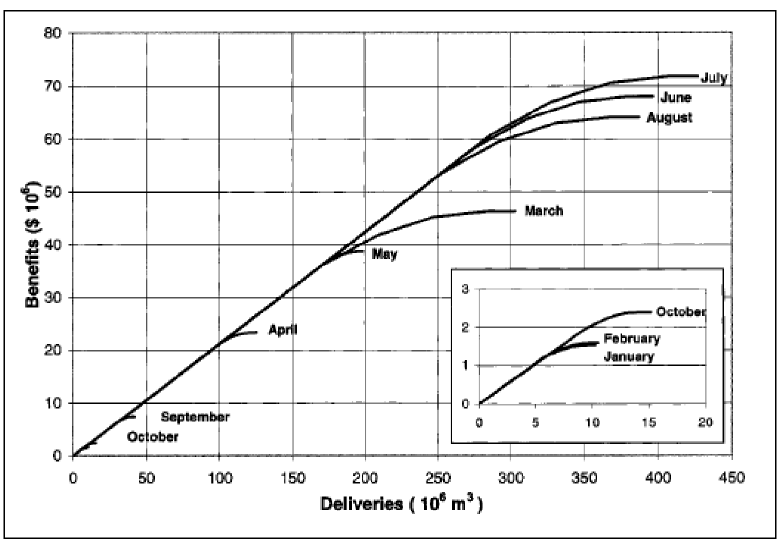
$$q^*(t) = \int_0^t \left(\frac{P - r(P - C_q)}{C_{qq} - e^{rt}\lambda R_{qq}} \right) dt \quad \text{Eq. (13)}$$

or, by (2), $q^*(t) = R(q;\alpha)$. That is, the optimal abstraction of groundwater will asymptotically approach the aquifer's recharge rate, so that groundwater out of the system equals water into the system. We see from Equation (12) and Equation (13) that the drawdown path prior to reaching the steady state and the path once the steady state is reached are both dependent on physical and social science inputs. These results, while general in nature, illustrate the importance of the hybrid in determining optimal management plans. The optimal plan will, of course, be dependent upon the specific functional forms that are used to describe supply and demand, as well as any institutional constraints that are required. Thus, the results from this model, indeed any model, are only as good as the information employed. We discuss the importance of information in the next section.

3.2 Agricultural Economic Values for Water Use

Agricultural economic values for water use are estimated for the 21 regions of the Central Valley and three regions of Southern California. For each region, an economic loss function is derived which decreases with water delivery to the agricultural region. This convex economic loss represents the reduction in net farm profits that results from limited water deliveries. The economic benefit and loss functions for farm groundwater use were derived using the Agricultural Production Model (APM), which is a separate optimization model that maximizes farm profit for each agricultural demand area, given a quadratic crop production function with water, land, technology, and capital inputs, and constraints on water and land availability. The production function is calibrated against actual cropping decisions in each GCC country. An example economic benefits function appears in Figure (6). Benefit functions are converted to equivalent loss functions for optimization by calculating the departures from maximum economic benefits for different delivery volumes. Marginal values of water range from zero, where water availability no longer limits farm profits, to over $250/thousand m^3 for high valued crops.

Figure 6: Example set of agricultural water value functions.

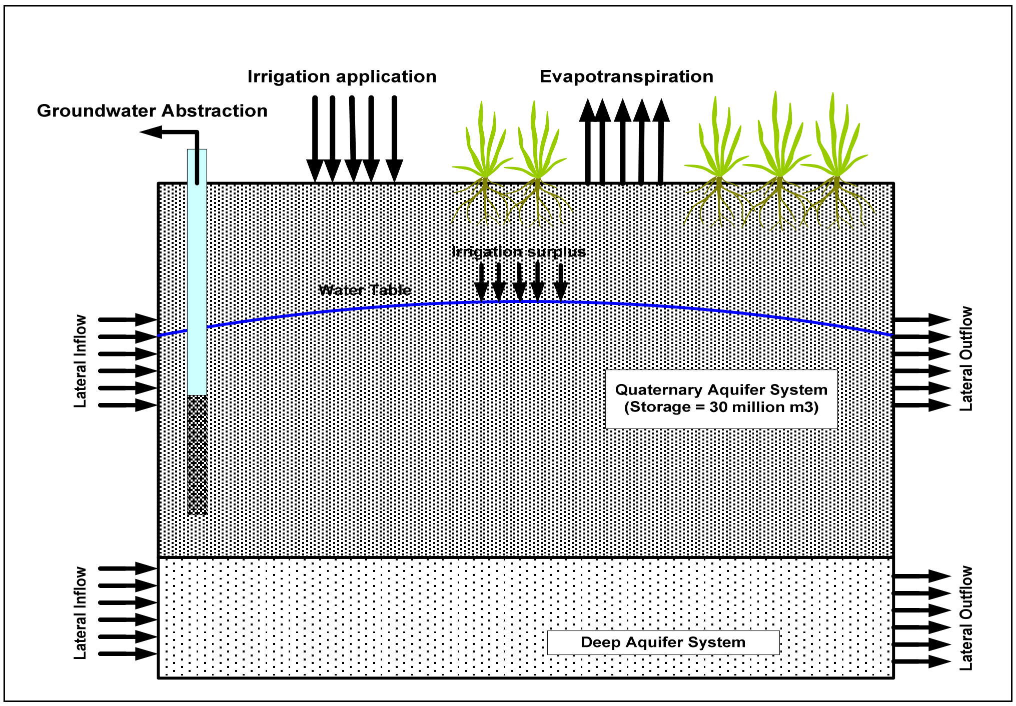


4. Numerical Model Verification

The model presented in the previous section incorporates the economic and hydrologic factors into an integrated model. To verify the developed model, a series of simulations for a hypothetical aquifer were carried out. The three simulation results include: the engineering solution without economic input, the economic solution with simplified hydrogeology, and the hybrid solution for both economic and engineering.

The simulated aquifer has an initial potential storage of 3 million cubic meters, with a specific yield of 0.3. The aquifer interacts with another deep aquifer system whilst there are no surface water bodies. There is also an evapotranspiration (ET) component. The marginal cost is constant and equal to $694 per cubic meter and is projected to increase by 5% per year over the time horizon of 50 years as shown in Figure (7).

Figure 7: Schematic Diagram for the simulated aquifer system.



A zero discount rate is assumed. Price is 10% over cost in order to cover all costs. The objective in all is to provide a sustainable resource. Demand, which is not estimated or used by the engineering group, is described by $Q = 150000P^{-.05}$. This represents a population of 500,000 with no growth.

Table (3) provides the summary results for the three simulations. In the case of the engineering and the economic simulation, the projected outcome is provided, as is the actual. The actual outcome is found by using the actions provided in the projected, but in the true state of the world. As can be seen, the engineering approach results in a steady state in the projected. However, in this case, there is no consideration of users responding to price and so the actual outcome is that consumption is much higher in all periods, resulting in a lower reserve at the end of the horizon and a steady state not being reached.

In the economic simulation, the projected uses a simplification of the aquifer dynamics. The optimal beginning price is found to be $1000 per m^3. A steady state is reached at 190 years, the ending production level is slightly more than 100,000 m^3. The actual in the economic simulation results in almost identical beginning and ending production level, but a steady state is not achieved in the actual. Also, because of the shape of the draw down path, the ending sock is lower than projected. The hybrid simulation, which incorporates both hydrologic and economic factors into the model results in a steady state being reached at year 60. Also, the cumulative present values are given as a proxy for social welfare. The hybrid model provides the highest social value over the time horizon.

Table 3: Hypothetical Simulation Results.

	Engineering		Economics		Hybrid
	Projected	Actual	Projected	Actual	Projected
Beginning Price	$754/m^3	$754/ m^3	$1000/ m^3	$1000/ m^3	$1100/ m^3
Ending Price	$5530/ m^3	$5530/ m^3	$2910/ m^3	$2216/ m^3	$3665/ m^3
Beginning Q	79,100 m^3	107,700 m^3	106,200 m^3	106,200 m^3	105,700 m^3
Ending Q	79,100 m3	97,320 m^3	100,700 m^3	100,600 m^3	99,500 m^3
Ending Reserve	1,114,390 m^3	863,000 m^3	2,239,671 m^3	1,118,326 m^3	1,132,800 m^3
Steady State	Yes T=60	No	Yes T=190	No	Yes T=60
Depletion	No	No	No	No	
Value	0	0	6	6.3	8.4

5. Limitations and Considerations

The previous section illustrates the value of a hybrid model in finding the optimal groundwater resources management plan. However, in the example, everything is assumed known with certainty. However, in the theory section we presented a number of variables and concepts, which may result in uncertainty or risk in the management plan. For example, price has been defined as a function of time and as a vector, β, of tastes and preferences, reserve depends on the physical dimensions and characteristics of the groundwater aquifer, and the change in the aquifer storage depends not only on the drawdown, but also on the hydraulic and physical characteristics of the aquifer itself and the surrounding strata, as well as the pressure profile within the aquifer. So in general, the hydraulic and physical characteristics of the aquifer system are important. For a more accurate model, not only are the physical and economic characteristics, but also their interactions, as can be seen in the optimal production levels during transient and steady state, equations (12) and (13), respectively. As is often the case, the "devil may be in the details" and the production path and steady state of a system will depend largely on the exact natures of the vectors of physical characteristics and tastes and preferences.

Differentiating (12) and (13) with respect to either an individual user or physical characteristic yields the comparative dynamics:

$\frac{\partial q(t)}{\partial \alpha_i} = \frac{\partial q(t)}{\partial S}\frac{\partial S}{\partial \alpha_i} \underset{\prec}{\overset{\succ}{=}} 0$ (transient flow) for the i=1,…,I physical characteristics and

$\frac{\partial q^*}{\partial \alpha_i} = \frac{\partial q^*}{\partial S}\frac{\partial S}{\partial \alpha_i} \underset{\prec}{\overset{\succ}{=}} 0$ (steady state flow) for the i=1,…,I physical characteristics,

for physical characteristics and:

$\frac{\partial q(t)}{\partial \beta_j} \underset{\prec}{\overset{\succ}{=}} 0$ for the j=1,…,J taste and preference characteristics and

$\frac{\partial q^*}{\partial \beta_j} \underset{\prec}{\overset{\succ}{=}} 0$ for the j=1,…,J taste and preference characteristics,

for user tastes and preferences.

At this level of generality, we cannot determine the sign on these conditions, but can surmise that the sign will be dependent on the water user or the aquifer physical characteristics. For example, if we consider the physical characteristics, an important factor may be vertical transmissivity. The complexity of many allocation problems has increased in recent years resulting in increased information. Within the economics world it is often cost prohibitive to undertake primary studies in order to estimate specific functions for a single study. Thus, information from other studies is transferred into the analysis in question. This is, in many ways, analogous to the practices in groundwater hydrogeology of employing, for example, a specific value for hydraulic conductivity for "sandstone," regardless of the individual characteristics of the sandstone in question. It is beyond the scope of this paper to consider all the factors of the economic and hydrologic components of the hybrid model to ascertain where primary studies would be beneficial and where information transfers are appropriate. We do however; provide a discussion of aspects of the physical and user characteristics that may be of importance.

5.1 Economic Considerations.

A main contribution of economics in this model is the component of user demand. In its most basic form, demand is a function of price, income, prices of substitute and compliment goods, expectations, number of users, and tastes and preferences. There are many empirical studies in the literature that estimate water demand. There is, even, surprising consistency in many of the results. To a large degree, the results indicate users are not particularly responsive to price and that demand is very inelastic. There are two general drawbacks to the using the existing studies. First, the price ranges in the studies are narrow and very low. As water becomes more scarce, we should expect higher prices. If the prices forecast from the empirical models are outside the range of prices, there will be uncertainty in the price and in the user response. The potential problem with this is twofold. First, there is the difficulty of finding the optimal starting price. Second, user cost is determined, in part by demand. If the demand function is inaccurate or incorrect for the particular problem, then the user costs determined from the inaccurate demand will also be incorrect.

Another difficulty with the currently available demand estimates is that they are estimated at an aggregate level and there is little distinction between user types. This results in a "one-size-fits-all" policy, because it assumes all users respond the same. Recent research indicates that urban water users are much more heterogeneous than past studies might indicate and do not respond in a similar manner (Chermak and Krause 2002). For a review of studies, see, for example, Brookshire et al (2002). Given the transient nature of society heterogeneity may become even more important in future analyses. The transient nature of society also highlights another important user characteristic. That is, population growth. If unreliable population growth forecasts are used, the resulting policy prescription will be inefficient. Finally we consider the impact of the discount rate, *r*. The usage paths represented by Equations (12) and Equation (13) are explicitly impacted by *r*. In general, the higher the discount rate, the less valuable the resource is in the future and the more we withdraw in the current periods. This results in a lower steady state consumption level. Understandably, the economics community argues vigorously about the appropriate discount rate. Uncertainty, of course, is not inherent only to the economics components of the model.

5.2 Hydrogeologic Considerations.

The aquifer storage of groundwater available and the recharge to the system are derived from general equations of groundwater flow. These equations, in turn require knowledge of the potential energy of the system, the aquifer properties, and the soil structure, and the boundary conditions of the aquifer. Parameter values used in the flow equations have been derived from studies done in specific areas and then extrapolated to other areas. As with economics, the impact of using transferred data depends on how accurately the transferred information describes the system in question.

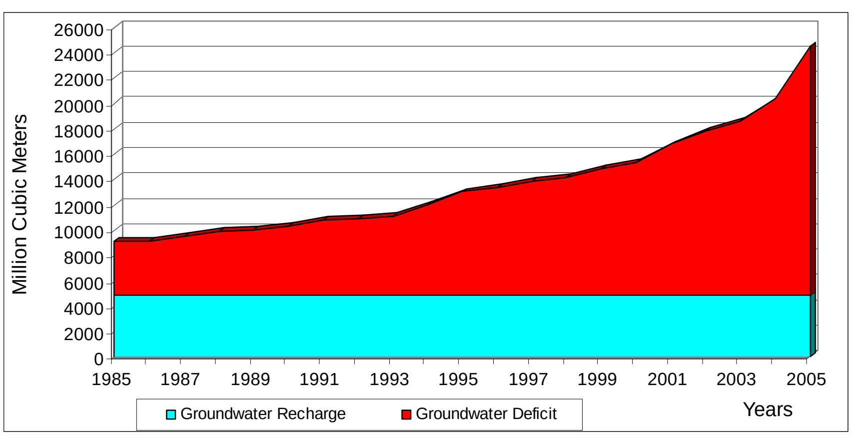
6. Model Application

During the application of this model to the groundwater conditions in GCC countries, the main constrains were the lack of information as well as the fact that all GCC countries are extracting groundwater resources in an unsustainable manner. In Oman, Bahrain, Kuwait, Qatar, and the UAE, this represents a level of extraction in excess of the natural recharge of the aquifers. In the case of Saudi Arabia, this represents the accelerated extraction of non-renewable resources without adequate knowledge of the finite life of water supplies within the aquifers. Due to this over abstraction, the deficit in groundwater in GCC countries reached about 15733 MCM by 2005, as shown in Table (4). The deficit in groundwater is increasing rapidly due to the rapid growth in various development sectors, as shown in Figure (8). Applying the model indicate that it is not possible with the present agriculture strategies in GCC countries is to reach the steady sate and sustainable management of the groundwater resources. This will lead to another identification of groundwater sustainability in the region.

Table 4: Groundwater Deficit (2005).

Country	Groundwater Deficit (MCM)
Bahrain	100
Kuwait	200
Oman	240
Qatar	140
Saudi Arabia	13558
UAE	1495
Total	**15733**

Figure 8: Increase in groundwater deficit (1985-2005).



7. Conclusions and Future Directions

This paper presents a general, economic-hydrogeologic model for efficient groundwater use in agriculture sector in GCC countries. The dynamic nature of the system requires that we consider the economic and hydrologic components simultaneously. The challenges associated with combining economic and hydrogeologic models are not small. Not only do the models have to be consistent in order to be merged, but also in order to obtain the consistency, economists and hydrogeologists must be able to interact and understand each other's disciplines and models. This is no small feat. A numerical hypothetical example was presented to illustrate the potential deviations in management plans when economics or engineering are considered separately and compare those outcomes to a plan based n a hybrid mode. We find the outcome from the hybrid model is superior, both in the value to society and in the sustainability of the plan. This, of course, is only an example, and lack some of the richness required in a model that would be applied in a real situation.

7.1 Water Use Efficiency Improvement Measures

Action is needed for improving water-use efficiency in both agriculture and domestic sectors. In several GCC countries, agricultural policies do not encourage rational water use, although this sector contributes an insignificant proportion of GDP, which causes an inordinate share of the agriculture sector in the over-exploitation of this valuable resource. The main challenge for policy makers in GCC countries is reducing the unsustainable rate of groundwater mining for use in agriculture, and making agriculture more competitive. Agricultural policies in GCC countries need to be revisited with the dual objectives of improving efficiency and competitiveness in the agricultural sector. This will help meet the challenges of integration within the global economy, and water conservation to sustainable, or less unsustainable, levels. This requires an integrated approach to water resource management through the implementation of policies that will help achieve the common goal of optimizing the use of scarce water resource for highest value activities. This could be achieved through phasing out the subsidies and price support programs, increasing the integration with global marketing and using efficiency indicators for agricultural policy analysis.

7.2 Increasing the Re-use of Treated Wastewater

In most GCC countries, sanitation coverage itself seems to be rather high; in the range of 80-90 percent although supporting data is not adequate.

What is clear is that some urban areas and most rural areas are covered mainly by on-site sanitation facilities, such as septic tanks and cesspits, which may not provide adequate treatment for preventing water pollution discharge to aquifers, wadis and coastlines. In some cases, wastewater effluent is not treated, leading to the pollution of local water bodies, even to the extent of causing hygiene programs among local population. Treated wastewater can be used for landscape irrigation, amenity purposes, irrigation of non-contact agricultural crops, and aquifer recharge. A water recycling and re-use master plan on a regional scale should be prepared based on the availability of treated wastewater in time and space and the identification of its potential uses. Treated wastewater can be used more efficiently as a precious water resource. Under the recycling and re-use plan, the degree of treatment and associated monitoring requirements should be defined based on the specific purpose of treated wastewater re-use as well as the required safety level and acceptable health risks. The use of modern treatment technologies should be considered in order to attain high health standard security for more extended use of the treated wastewater resources, considering both the environmental/health risks, economic benefits and costs. Furthermore, using treated wastewater for groundwater aquifers recharge programs should be piloted more extensively along with rigorous risk control measures for the environment and health. Aquifer storage recovery (ASR) using treated wastewater as well as desalinated water in winter has been piloted for establishing strategic groundwater reserves and maximizing its use in Kuwait and Abu Dhabi Emirate.

7.3 Achieving Sustainable Aquifer Management

All GCC countries over-abstract their non-renewable aquifer system. This causes severe depletion and pollution of these aquifers and there is an attitude that the eventual destruction of aquifers and the full reliance on desalinated water for meeting all water demands is inevitable. GCC countries should view aquifers as a strategic resource to sustain various water uses, conserve ecosystems and provide emergency reserves in the case of disruption of desalinated water supply due to large-scale oil spills. More importantly, reliance on desalinated water alone could be a risky policy considering the volatile nature of oil prices and revenues. The sustainable use of groundwater resources should be a consideration in the overall integrated water resource management policy of each country. In order to conserve the strategic aquifer water reserves and reduce unsustainable groundwater extraction to levels below the sustainable inflow to the aquifer, or at least to less unsustainable levels, GCC countries should adopt the following measures, taking into consideration the local conditions of each country:

- Establishing a comprehensive groundwater regulatory (well permits, drilling rigs control, etc.) and monitoring system
- Registering all wells and installation of flow meters in all large farms
- Imposing volumetric metering and charges (ideally on a progressive scale) to send price signals for all groundwater users
- Accelerating the instalment of efficient irrigation systems and growing more water-efficient and high value-added crops
- Conducting extensive education and public awareness programs at school and local levels, as well as an extensive media campaign that emphasizes the scarcity and economic value of water resources and the need for their conservation and economic use.

7.4 Water Laws, Regulation and Legal Reform

Water laws and the regulatory framework should be examined to determine what modifications need to be made to discourage water wastage and to improve the efficient use of this resource. For instance, water laws should mandate the registration and regulation of all wells within each country, the monitoring of groundwater extractions, and the issuance of water-use rights that allow authorities to limit extractions within safe yields. These laws should establish a strong regulatory body with power to regulate the extraction of water and to establish water-use rights. These laws should also establish a legal framework for the adoption of regulations on all matters regarding the use of water, including well excavation criteria, water appliance efficiency, water transport, water tariffs and collection, water quality, wastewater collection, treatment and discharge or reuse, water user participation, etc. Much of this type of framework is in existence but is not adequately administered or has not been adequately developed into workable regulatory forms.

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Water Pricing Reform for the Kingdom of Saudi Arabia

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Abstract

Kingdom of Saudi Arabia (KSA) is an arid country with very limited water resources due to its scarce precipitation. Total water demand (TWD) has tripled in the past two decades to reach nearly 45 Mm^3/d by the year 2000. As a result, the annual water balance shows an incremental increase of the deficit in the national water budget. The diminishing fossil-groundwater reserves account for at least 80% of total water supply while agriculture is the largest water sink (80% of TWD). It is anticipated that these reserves tolerate the present use level only a few more decades due to over-exploitation.

Therefore, the water situation in KSA calls for the change in water prices. The price reforms are discussed in term of types of water pricing, cross-country comparisons, and review of publications on the subject. Based on that,, the study suggests a new tariff system for domestic water use and gives conclusions which highlights main findings.

1. Introduction

Saudi Arabia has a limited water resources; it is the largest country in the world without running surface water. The country is charcterized by hot-dry climate with mean annual rainfall of 100 mm/year (Ukayli and Hussein 1988). Increased population, high standard of living and the increased use of water consuming machines caused water demand to increase rapidly while supply or resources are fixed or even declining. Therefore the gap between demand and supply increased rapidly causing a formidable water deficit.

The government action to water shortage has been seen on high level. For example, back in 1980 the Council of Ministry's issued ordinance that calls for conservation of water resources and wastewater is recognized as beneficial auxiliary water source rather than "waste" after it has been religiously approved by 1979 (Farooq and Al-Layla, 1985). The governoment is committed to a policy to use all available treated effluents as a supplementary source for irrigation by the year 2000. In late 1980, the Royal decree M/34 was issued: "Regulations for the conservation of groundwater resources". Public and private agencies are to comply with said decree. This was followed by the formation of Water Conservation Committee at Dahrain city in the same year.

As early as 1970s, the government acted by implementing countermeasure programs for non-conventional water resources development. Measures such as desalination, reuse of wastewater, conservation plans, water harvest, and vegetation have been considered. Among plans was also to transport the fresh water from neighbouring countries.

The fourth devlopement plan (1985-1990) included: Rational utilization of scarce water resources, introduction of conservation measures, srtict regional water management, establishment of priorities in water use, tarifs system, and coordination between agriculture and water developments. Domestic water conservation strategies such as leakage monitoring, domestic water metering and incremental pricing, public education, installation of water saving devices are among several measures for water conservation.

The aim of this paper is to examine the current tariff of water and use cross-country studies to compare with similar cases and shed some light on suggested proper pricing tariff for KSA.

2. Existing Condition:

Saudi Arabia has one of the largest population growth in the world (3.8% annually). Consequently, water consumption reached 3.715 Mm^3/d in 1994 and tipped over 5 Mm^3/d by the year 2000 (Al-Georgian 2000). The country has about 44,000 Km of network serving about 1000,000 house connections covering 85% of urban and rural area. Water use is reported to be 300 l/cap.d which exceed average use in many other countries (Table 1) (Al-Tokuars, 2000)

Table 1: Average water consumption (in l/u/d)

Country	Avg. Water Consumption
Saudi Arabia	300
Sweden	200
Frannce	150
Germany	135
Holland	104

Howevere, scattered figures are formed in literature ranging from 200-600 l/ca/d. Nevertheless, all reported figures exceeds the international average water use (200 l/ca/d). The reasons behind this phenomenon is not completely understood and deserve full attention and advanced study wide.

Two factors might have contributed to the phenomenon, low water tariff and high leakage from the net and in-house.

3. Water availability Vs. Water demand

The second and the third development plan (1975-1980 and 1980-1985) included commitment to provide sufficient quantity of good quality water for domestic use, water conservation, and development of water sources and to seek new water sources for agricultural and industrial uses. However, the situation called for a change in the water management planing from supply scheme to demand scheme. This is manifested in adoption of water conservation strategies rather than searching for new water supplies to meet the ever-increasing demand. Water resources are available solely from expensive desalination and groundwater in two types of aquifers: the shallow unconsolidated alluvial and the deep sedimentary confined aquifers (Abdulrazzak and Khan, 1990).

The country is highly dependent on groundwater stored in six major consolidated sedimentary old-age aquifers located in eastern and central parts. This fossil groundwater, formed some 20,000 years ago, is confined in sand and lime stone formations of a thickness about 300 m at a depth of 150-1500 m (Al'Mutaz, 1989).

The official estimate of these resources, according to the Water Atlas of the Ministry of Agriculture and Water (MAW), is 253.2 $x10^3$ Mm^3 as proven reserves while the probable and possible reserves of these aquifers were 405 and 705 $x10^3$ Mm^3, respectively (Abu Rizaiza and Allam, 1989). However, according to estimates of the Scientific Research Institute's Water Resources Division at Dahran city the reserves are as much as 36 $x10^6$ Mm^3 which exceeds the previous estimates by more than 70 folds. Yet, they estimated only 0.870 $x10^3$ Mm^3 to be economically abstractable. Another optimistic estimate 2.175 $x10^6$ Mm^3 has been presented by an engineering firm Saudi Engineering Consult. Depletion of these non-replenished aquifers is evidenced by the drop of the piezometric surface and increased pumping-lift costs.

For example, piezometric surface has decreased in eastern region by 4 m during 1967-1990 (Abderrahman and Rasheeduddin, 1994). Under the current drastic increasing pumping rates, the authors predicted the drop to be 6 m and 12 m by the years 2000 and 2010, respectively. The impact in northern area is even greater and also manifested in drop of water level by 100 meters in 10 years (Abu Rizaiza and Allam, 1989) due to much more agricultural activities than in eastern region.

The shallow aquifers are renewable and mainly located in the west and south-west of the country with a mean thickness of 200 m. These aquifers provide up to 3.14 Mm^3/d (Al'Mutaz, 1989) and are naturally recharged by an amount of 2.6 - 3.5 Mm^3/d (based on annual mean precipitation) (Ukayli and Husain, 1988; Abu Rizaiza and Allam, 1989) of which 80% occur in south-west. However, lower recharge figures have been reported by Mohorjy (1988), to be only 1.6 Mm^3/d. The storage capacity of these aquifers is estimated to be 84 $x10^3$ Mm^3 (Abdulrazzak and Khan, 1990). But due to low rainfall, the average supply of these unconsolidated aquifers is only 3.13 Mm^3/d (1.145 $x10^3$ Mm^3 /year which is only 1.4% of their estimated capacity). These aquifers are alarmingly exploited by 100%. Over-exploitation impacts of alluvial and surface water are already manifested in drop of water table and salt intrusion near coastal areas. For example, the water table have been reported to drop 10 meters in western and central regions in a 10 year period (Mohorjy, 1988). Increased cost of pumping in central area as well as dry-up of some natural springs in western regions have been experienced (Mohorjy, 1988; Ukayli and Husain, 1988).

Surface water is also obtainable from shallow wells near Wadis, especially following rainy season, as an "monsoon" as auxiliary supplemental water source for irrigation but with a mean recharge of only 2.5 Mm^3/d (Abdulrazzak and Khan, 1990). Other sources are classified as non-conventional sources which include desalinated seawater and treated wastewater effluents used specifically for drinking water and irrigation purposes respectively (Table 3).

This increasing trend has most probably been caused by the introduction of mechanised large-scale irrigation projects facilitated by technical development in groundwater exploitation and advances in well drilling in the past two decades. Yearly total water consumptions during period 1980 - 2010 are shown in Table 2 while contributions of different water sources to the total water demand are presented in Table 3.

Table 2. Total water consumption in million m^3/day for Saudi-Arabia

1980	1985	1990[a]	1992[a]	2000 [b]	2010 [b]	Ref.
	24.24					1
		31.5	36.6	45.2	55	2
12.36	24.20					3
	26.3	37.5	38.4	46.6	57.5	4

a: based on mean daily for the entire year
b: projected
(1) Ukayli and Husain, 1988. (2) Abdula'aly and Chammem, 1994
(3) Farooq and Al-Layla, 1985. (4) Abu Rizaiza and Allam, 1989.

Table 3. Proportions of water supplied to total water demand (in percents) conventional and non-conventional sources.

	1985	1990	2000	2010
Fossil groundwater	73.3	78.1	81.7	84
Alluvial groundwater	11	6	5.9	4.5
Surface groundwater	10	8	4.5	3
Desalination	4.5	5.7	4.8	4
Wastewater	1.2	2.2	3.1	4.5

From, Ukayli and Husain, 1988; Abu Rizaiza and Allam, 1989

Several conclusions can be made from Tables 2 and 3. There are unidirectional increasing trends in both total water consumption and fossil groundwater abstraction. There is a clear indication that the diminishing fossil groundwater is by far the largest supplier with an increasing share through the years (Table 3)

4. Institutions

Four main governmental institutions are involved in the field of water and wastewater: The Ministry of Water and Electrecity (MOWE), the Saline Water Conversion Cooperation (SWCC) and the Regional Water and Sewarage Auothoritis (WASAs). Each have a distinctive responsibility. Thier functions are shown in Table 4.

Table 4. Water Institution and Their Functions

FUNCTION	INSTITUTION
Water Production and treatment	MOWE SWCC WASAs
Water Transport and distribution	SWCC WASA
Metering and Billing	WASA
Wastewater collection and treatment	WASA

These institutions have overlapping functions and different regulations. But the formation of the Ministry of Water will solve many malfunctions and threfore, is a right step in water management. It is expected that the first task of the new Ministry is to draw a National Water Plans and stratagies.

5. Cost of water supply

The cost of water production varies from city to city ranges from 0.22 / m^3 in Burida to 9.18 / m^3 in Wadi Fatima (SR) with average 4.0 SR /m^3 (MOMRA,2000). Table (5) compares cost of water production KSA with other GCC countries.

Table (5) : Cost of Water Production in Some GCC Countries (SR)

	Production and Transport	Price / m^3 SR	Subsidy
KSA	4.0	0.75	81.3 %
OMAN	5.53	4.28	23%
KUWAIT	6.53	2.44	63%
BAHRIN	3.34	0.64	83%
QATAR	4.33	1.65	61%

6. Types of Water Pricing:

There are several models for water pricing applied world wide. The most commonly used are:

1- Flat Rate:

Consumers pay fixed rate regardless of quantity used usually nominal fee.

2- Marginal cost pricing (MCP):

In MCP model the charged price is fixed on volumetric to actual cost of water without profit. Problems of this system include difficulty in calculating marginal cost (actual) and other cost therefore application of this theory lacks considerable practicality changes in actual costs may lead to deficit.

3- Feldstein Pricing:

This method is proposed by Fledstien in 1972 to overcome shortcoming of MCP. The system, proposes two-part pricing: connection fee and volumetric pricing while volumetric charge is fixed at MCP and correction fee to coupe with deficit.

Feldstein pointed out that this system may affect low income and that connection charge acts like regressive tax. He developed an optional two-part pricing rule that allow for break-even constraint. Under this pricing rule, volumetric charge rises above marginal cost to lower valued the needed connection fee. Limitation of Feildstein module is that assumes consume will not respond to correction fee and difficulties in calculations marginal cost.

4- Decreasing Block Tarrif (DBT) :

Based on the concept that (the more volume used, the cheaper the charge). This is justified by the fact that the higher the volumes the lower the unit cost. This model is usually used to encourage industries and other special activities.

5 - Increasing Block Tariff (IBT):

Most commonly used designed to encourage conservation.

Other pricing systems include Coas two-part pricing and Ramsy Pricing which are less widely used and only fit special conditions.

7. Selection of Proper Pricing System

From the previous section, it is obvious that the most fit for situation in KSA is IBT or (Increasing Block Tarif). The system has the following advantages:-

1. Encourage efficient use of water
2. Delay the need for new water supply
3. Utilities become financially self-sufficient
4. Utilities may charge from quarterly billing to monthly

Implementing water reforms is very difficult task and needs adequate technical and managerial capacity. It may be complex and need different pricing methods for the same region. For example, in the USA 37% of pricing is uniform pricing, 22% is rising block, 38% is decreasing block and 3% are mixture.

Therefore, water pricing process has several set backs which need to be recognised:

1) Difficulty to calculate marginal cost from accounting data.
2) Marginal cost depends on distant and water supply source
3) Expected return may be offset by other costs (transport, high O&M..)
4) Need special skills.

5) There are no tool to test relation between marginal cost pricings.

8. Comparison between different Tariff:

a. GCC Countries

Water tariffs in the kingdom of saudi Arabia is the lowest among the GCC countries, which share common social and economical features Table (6).

Table 6 Tariff for GCC Countries for House hold use and other uses

	KSA	UAE	BAHRIN	KUWAIT	OMAN
0 – 50	0.10	3.4	0.25 (3)	3.4 (-)	4.28
51 – 100	0.15	3.4	0.80 (3)	3.4 (-)	4.28
101 – 200	2	3.4	2 (3)	3.4 (-)	4.28
201 – 300	4	3.4	2 (3)	3.4 (-)	4.28
> 300	6	3.4	2 (3)	3.4 (-)	4.28

1- The use include industrial, Commercial, or institutional.
2- All Countries adopt the same tariff for all user structure except Bahrin and Kuwait.

b. Water Tariffs in Saudia Arabia

The water tariffs are uniform througout the entire KSA. They were increased in 1994. The current water tariffs are shown in Table 7

Table 7. Existing Water Tariff in KSA; based on step function

Blocks	SR / m^3
0 – 50	0.10
51 – 100	0.15
101 – 200	2.0
201 – 300	4.0
> 300	6.0

As shown in Table 7, the tariff for the first 50 m^3 is only SR 0.10 and the next 50 m^3 is at SR 0.15. This will give a substantial subsidy to middle class which are able to cover their water costs. As a result over 80% of households fall into this blocks. Ther are no charge for wastewater services. Water rationalization plans, as mentioned earlier, started since 1985. Public Education to raise awareness to necessity of water saving methods and devices…etc. However, the results of such action are still not gratifying. For example, conservation campaigns are expensive, yet tend to have their peak effects upon incipient and then will diminish

Therefore, water pricing reform is seen as powerful tool to cut the lavish spending of water. It gives a strong signal to user in such a way that reflect value of scarcity of water which is usually delt with as inferior commodity.

9. Water Tariff Reform

It is obviouse that price reforms are necessary for Saudi Arabia for the following reasons:

1. It is the right and strong massage for consumers to use water more effeciently and thus adopt water saving thinking.
2. It is an important step to facilitate private sector participation.
3. The current tariff is the lowest among GCC countries which have similar economical and social conditions.
4. The average collected tariffs (SR 0.70) are only a small fraction of the average cost of water production and distribution (SR 4.0).

Ministry of Water have estimated average water use 200 l/c/d which gives 36 m^3/ month for average family of 6 members.

The major catagorial water user is the household (76%) followed by institutional (18%); Figure 1. Based on that, there are two options for water pricing reforms as shown in Tables 8a and 8b; while Table 9 suggests tariffs for commercial, industrial, and institutional water uses.

Table 8a Suggested Water pricing for household use (Applied as step function)

Blocks m³	**SR / m³**
0 – 30	0,10
31 – 75	1,00
76 – 200	4,00
> 200	6,00

Table 8b Suggested Water pricing for household use (As increasing rate)

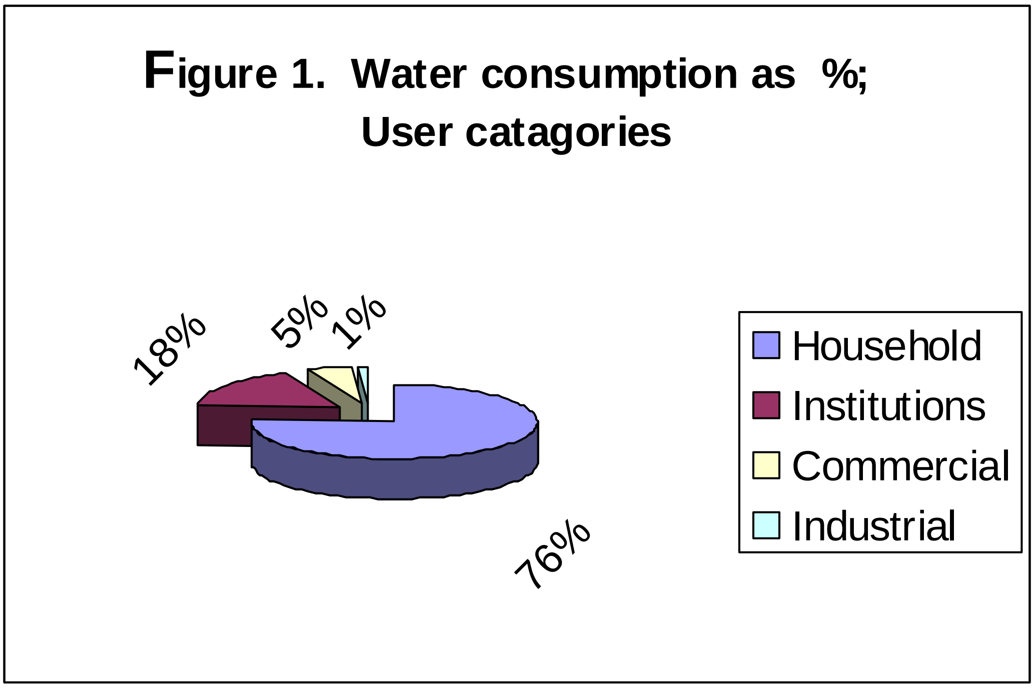
Blocks m³	**SR / m³**
0 – 50	0,10
51 – 75	1,00
76 – 200	4,00
> 200	6,00

Table (9) suggested tariff for Industrial, Commerical, and institutional uses

Range	**SR/m³/month**
1 – 200	4
> 200	6

As mentioned earlier, there is no charge for wastewater services. This practice is considered unfair to areas that are not serviced. It is ,therefore, suggested to add aditional (SR 1.0) for each m^3 of wastewater produced; flat rated. The amount can be easily estimated as 70-80% of total water consumed of house.

It is strongly advised that this price reform should starts immediately after selection of proper system. Suggested tariff for Industrial, Commerical, and institutional uses should be investigated further. It is recommended to apply the new tariff system for aperiod of 7 years then reformed again accordingly.



Conclusions

Saudi Arabia face a severe deficit in the water balance each year. The shortage is entirely supplied from the fossil ground water reserves. About 80% of the total water demand is drawn from this diminishing water sources. Although magnitudes of groundwater are high, the ever increasing demand will ultimately exhaust these reserves. At an abstraction rate is currently about 10 folds higher than the recharge, the situation is critical.

Domestic water constitutes only 5-20% of total national water while industrial demand is between 1-5%. In contrast, agriculture consumption accounts for 70-90% of TWD. Domestic water conservation is part of the solution but agriculture as the largest water sink is much more important. Unfortunately most of the conservation plans and measures, such as tariffs, are directed to domestic water while rationalization of irrigation water use is the key issue in the whole picture of the water map.

The current water tariff gives a substantial subsidy to middle class which are able to cover their water costs. As a result over 80% of households fall into the first block. The average collected tariff (SR 0.70) is only a small fraction of the average cost of water production and distribution (SR 4.0). The current tariff is the lowest among GCC countries which have similar economical and social conditions to Saudia Arabia.

Therfore, price reforms are necessary for Saudi Arabia for two main reasons:
It is the right and strong massage for consumers to use water more effeciently and thus adopt water saving thinking.. Secondly, it is an important step to facilitate private sector participation. The study suggested two tariff systems either step function with base line 30 cubic meters (Table 8a) or an increasing rate with base line being 50 cubic meters (Table 8b). The study suggests additional SR 1.0 for each cubic meter of wastewater as a flat rate wich can be calculated as 80% of the amount of water consumed. It also suggest the application of the new tariff system for a period of (7) seven years then should be reviewed. Pricing of water used for irrigation must be looked at seriousely.

Groundwater Demand Management: an Electricity Quota Approach

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Abstract

Groundwater over-abstraction is a major problem in Oman and in several countries around the globe. In the Batinah coastal area in Oman groundwater over-pumping is accompanied by seawater intrusion. The Government tackled the problem since the beginning of the 1990's and implemented a set of recommendations. However, fifteen years after the recommendations have been sketched the seawater intrusion in the Batinah aquifers is still advancing at an alarming pace. The current paper analyzes a set of scenarios based on water quotas through an annual electricity quota. Results showed the cost of damages to the community if no active policy is implemented amount to (-$288) million. Since water metering in dug wells is not possible then scenarios 2 and 3 consist in analyzing the control of groundwater pumping through energy prices and/or energy quotas instead of the water quota. The results showed that increasing the cost of energy and imposing a dissuasive electricity price after a given quota will result in a net present benefit of $211 million. The introduction of prepaid electricity meters with a management system by internet or SMS will result in a lower net present value of $194 million. However, the difference in the net present value is easily justified by the easiness of the implementation of the prepaid meters. In fact prepaid meters are setup with a credit limit. The credit limit is simply the electricity quota. Prepaid meters allow also to detect frauds and cheating at no cost and do not need any public intervention except the determination of the water and electricity quota.

Keywords: Oman, Water Quota, Prepaid Electricity Meters, Electricity Quota, Economic feasibility

Introduction

Excessive groundwater pumping is a major problem in Oman, primarily in the coastal areas where it results in seawater intrusion. Groundwater monitoring in Oman dates back to the 1980s. In 1991 the National Water Resources Master Plan (NWRMP, 1991) called for a reduction of 215 million m^3 of water pumping, nationwide. However, despite the implementation of several measures groundwater deficit is exacerbating and seawater intrusion is steadily progressing. None of the measures implemented were a demand side measure or a measure leading to a direct change of farmers' behavior in relation to groundwater pumping. This paper considers control of the demand for groundwater in the Batinah coastal area of Oman by limiting the access to electricity. Seventy four percent of the farmers use electricity as a source of energy for water pumping in the Batinah. The electricity quota could be made effective by charging a dissuasive price for electricity use beyond the allowed limit or by introducing prepaid meters. The main objective of this paper is to evaluate the feasibility of controlling and limiting access to electricity as a mechanism to reduce groundwater pumping and ensure that the benefits of controls outweigh the costs. A cost benefit approach is used over a period of 25 years. The relative merits of the two strategies are compared from a practical and organizational point of view. These two strategies are then compared to a "business as usual" strategy where the costs of the falling water table and consequent groundwater salinization are estimated.

The water electricity connection in groundwater pumping

Groundwater and electricity prices are interlinked and several studies proposed electricity pricing or limiting as a proxy to control groundwater pumping. Scott and Shah (2004) considered the case of Mexico where the reduction of groundwater over-pumping could be achieved through a block tariff and electricity quota. However the second block tariff is set to a low level and is unlikely to dissuade farmers from over-pumping. Shah et al (2003) proposed the rationing of electricity coupled with a gradual and regular increase in electricity price to save both energy and groundwater.

Groundwater users in India pay a flat tariff for electricity, based on the capacity of the pump. Historically, the adoption of a flat tariff was motivated by the high cost of metering compared to the revenues generated from meters' installation, reading, billing and fee collection in India where more than 20 million scattered wells are in operation. The flat electricity pricing resulted in groundwater over-pumping and to the unsustainable financial results of the power industry. Recently, Zekri (2007) considered taxing or imposing a quota on electricity in the Batinah area of Oman as an instrument to reduce groundwater pumping by 30% and minimize seawater intrusion. The needed tax on current electricity price to achieve water saving is 212%, is politically unfeasible. Another option considered was the elimination of subsidy coupled with a dissuasive electricity price beyond the quota. This later option is economically feasible but has the inconvenience of increasing electricity prices by 100% which is unlikely to be adopted given that electricity is subsidized for all users not only for agricultural uses. In other terms, a policy change on electricity pricing is unlikely to be driven by groundwater conservation objectives. In this paper the adoption of modern technologies to control electricity use is proposed. Prepaid electricity meters were invented in South Africa with the objective of improving cost recovery and minimizing billing costs. Their use spread to developed and less developed countries mainly for property investors and rented units. The prepaid meters are operated with tokens, magnetic cards, prepaid scratch cards or recharged digitally through internet and SMS. Meters are setup with a credit limit. The credit token may be obtained for any amount equal to or lower than the available credit. When managed through SMS and internet funds must be deposited into the farmer's bank account and then credited to the meter. Once the funds are credited to the meter a 20 digit credit token is sent via SMS or internet to the beneficiary. The first and most important feature of the prepaid meter in relation to groundwater management is the ability to set a credit limit or electricity quota that could not be exceeded by the farmer. This mechanism is thus perfectly adapted to the objective of electricity quota we want to implement for groundwater pumping.

The second and not less important feature is the low cost of the meters which vary between US$65 and US$ 150 and the nil cost of meter reading, billing and fee collection (http://www.prepaidmeters.co.za/component/option,com_docman; http://www.hxgroup.cn/productclass.asp). In fact the high cost of groundwater control is frequently mentioned as the major reason for the non feasibility of control of pumping (Koundouri, 2004). The third advantage of the prepaid meters is ability to implement a specific quota per catchment's area or aquifer instead of a unified quota for the whole region. The fourth advantage of the allocation of a water quota and an electricity quota is the possibility to trade the excess water via selling the excess electricity quota. Since prepaid electricity meters are localized by area then they can be distributed according to specific aquifers and trade allowed exclusively among farmers pumping from a given catchment's area. Last not least is that the Government can buy at any time through the water market parts of water quotas or electricity quotas to protect the aquifer from seawater intrusion during prolonged periods of drought.

Methodology

We examine the costs and benefits of policy alternatives designed to manage the demand for groundwater. In particular, we consider implementing a water rights system, precisely water quotas and extraction control through the electricity metering and limitation. We consider an annual energy limit based on the annual water. The Net Present Value (NPV) of each one alternative is computed using equation (1).

$$NPV_S = \sum_{t=1}^{n} \frac{B_{ts} - C_{ts}}{(1+r)^t} \qquad (1)$$

Where,

B_{ts} are benefits in year t and scenario s ($),

C_{ts} are costs in year t and scenario s ($),

N is the life span of the project (years),

r is the discount rate (%), and

s = 1…3 corresponding to the three scenarios described below.

The expected benefits refer to:

1) Stopping the water table decline, which will result in energy cost savings from pumping;
2) Preventing the traditional irrigation systems of Aflaj from drying up, due to over-pumping;
3) Protecting both farmers and domestic users of groundwater from further degradation of water quality due to seawater intrusion and increased salinity;
4) Ensuring sustainability for future generations; and
5) Energy saving due to the reduction of volume of water pumped.

The costs are mainly related to:

1) The investment and operating costs of groundwater pumping control and the installation of water meters on tubewells;
2) The financial losses of farmers due to the introduction of restrictive water quotas;
3) The cost of creating appropriate institutions to monitor the reforms;
4) The implementation of a participatory approach and an extension program for stakeholders; and
5) The cost of modern irrigation systems subjected to water quotas or an annual energy limit.

We consider three scenarios. Scenario 1: business as usual, with no implementation of any control, surveillance or economic instruments. The objective of this scenario is to estimate the present value of the expected economic losses due to over-pumping. Scenario 2: enforcement of an annual energy limit for all wells using electricity, a subsidy for improved irrigation systems, and the removal of electricity subsidy and pricing at $0.052 per kWh or 0.02 Rials/kWh. Scenario 3: The installation of prepaid electricity meters on all wells and the implementation of an electricity quota.

Results

Water over-pumping in the Batinah region is estimated at 177 million m^3 (MWR, 2000), which represents 30% of total pumped water.

The current average groundwater pumping is 20,765 m3 per ha per year (Al Suleimani, and Al Wohaibi, 2006). Thus the water quota should be established at 14, 535 m^3 per ha per year. We assume a linear relationship between electricity consumption and water pumping. The overall pump efficiency is taken at 50%. On average the well depth is 35 meters. The electricity consumption is estimated at 0.0055 kWh per m^3 per meter of well depth.

Scenario 1 is the "business as usual" scenario. The estimated net present value of total losses over a 25-year period is (-$288) million, using an 8% discount rate. These losses are distributed as follows:

(-$27) million lost due to salinization in the agricultural sector;

(-$59.6) million increase in the costs of energy and of making wells deeper, due to the progressive decline of the water levels in more than 100,000 wells in the Batinah region;

(-$7.6) million lost due to *aflaj* drying up—taking account here only of losses to agriculture;

(-$52.3) million lost to domestic water users who need to shift to other sources of fresh water;

(-$141.6) million lost due to the irreversible loss of the aquifer as a receptacle for fresh water.

Abandoned land is estimated to be 5,995 ha and another 5,000 ha will be moderately affected by salinity. This will cause a loss of 20,000 jobs, one third of them affecting expatriates from neighboring countries. The job losses are estimated by calculating the average number of employees per hectare, multiplied by the area abandoned due to salinization.

Importantly, almost 50% of the losses accrue to future generations rather than to current users of groundwater. The losses to future generations are due to the irreversible salinization of the aquifer and the loss in perpetuity of the aquifer as an underground storage reservoir.

Scenario 2 would have a net present benefit of $211 million and depends on the imposition of an annual energy limit. Such a limit would be made effective by the enforcement of $1.00 per kWh as a dissuasive price to bring the cost of water to its opportunity cost, which we consider to be the cost of recharging aquifers from recharge dams. The regular price would be $0.052 per kWh, double the current price. The annual energy limit would actually be an energy quota which would be estimated based on the current cropping area, well depth and the water quota per ha of cropped land. The objective would be to control groundwater pumping through energy quotas, instead of water metering and water quotas.

The present value of Government expenditure would be $13 million, due to a policy of more generous subsidies for modern irrigation systems—the increased subsidies could be financed by the revenue gained by removing the electricity price subsidy. Farmers would not have to pay any annual license fees because monitoring would be ensured by the electricity meters already in place. The electricity price would be doubled, leading to a higher water cost and thus water savings. Farmers would be persuaded not to exceed their electricity quota by charging a high price for use of electricity beyond the allowed limit. On the other hand, farmers would benefit from the subsidy for modern irrigation systems, which would offset part of their losses generated by the annual energy limit. However one inconvenience of this scenario is the fact the electricity meters are used for domestic use and water pumping purposes. In other terms each farmer does have one electricity meter only. Thus the electricity at the well level is not metered separately.

For Scenario 3 the cost of prepaid electricity meter is $150 plus $30 for installation. The installation of the meters will be undertaken in two years. The meters will be replaced every ten years. The software and the digital system will cost $260,000 and paid only once. The resulting net present value is $192 million. Observe that the NPV is lower than the NPV of scenario 2 estimated at $211 million. However, the difference in the benefit is easily justified by the easiness of the implementation of the prepaid meters. In fact prepaid meters are setup with a credit limit. The credit limit is simply the electricity quota. This is the major advantage of the prepaid meters. It is recommended that after prepaid meters installation to to run them without any electricity quota for one year. One year data collection allows the Ministry to have a full detail of how much electricity is being used by each farmer. Only during the second year should the quota be introduced. This should be done mainly to avoid cheating and illegal connection of the water pumps to the non-controlled electricity. In this paper we do not consider the possibility of trade of the electricity quota. This is an important advantage of prepaid meters as we expect the more efficient farmers to buy electricity from the less efficient farmers which will increase the economic return

Conclusions

It has frequently been argued that controlling groundwater pumping is too costly compared to the expected benefits. In this paper we showed empirically that groundwater could be easily controlled in the Batinah coastal area of Oman where more than 100,000 dug wells and tubewells are operated. The use of modern technology of prepaid electricity meters operated through internet and SMS is an optimal choice that not only reduces the cost of control and management but also allows detecting cheating and frauds at no cost. The cost of the prepaid meters could be easily paid by the Ministry of Water Resources to encourage farmers for the adoption. However, it should be recognized that water regulations should be amended to consider the introduction of a water quota and to link the water quota to the electricity quota.

The results obtained for Oman could be easily extended to countries with similar environments such as Bahrain and Saudi Arabia as well as to any other country where the government or the farmer can afford paying for the $150 cost of the prepaid meter.

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Affordability of Household Water and Sewerage Services in Waitakere City– A Case Study

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Abstract

Anything scarce and in demand commands a price; this is one of the basic principles of economics. Water is scarce in some contexts (drought, degraded quality), so water pricing is increasingly seen as an acceptable instrument of public policy. One particular area of water policy that has become increasingly subject to pricing principles is that of public water supply and wastewater services. The issue of "affordability" needs a degree of prominence by policy makers in the water industry. The average water and sewerage bills have gone up in the Waitakere city. The extent and pace of these price rises has had an impact on the budgets of low and medium income households, many of whom may be dependent on a range of social security benefits to enhance their income. Therefore, essential water and wastewater services must be affordable and the New Zealand Government needs to review the ways in which lower or medium income households can be helped with water and sewerage charges. This paper briefly covers the definition of affordability and how it can be measured, and briefly discusses the OECD (Organization for Economic Cooperation and Development) and New Zealand water pricing systems. This study analyses the water and sewerage services charges affordability in Waitakere City, focusing exclusively on the domestic or household sector. The aim of the study was to assess or establish an affordability benchmark for household water and sewerage charges in Waitakere city. The data relevant to population, number of dwellings, annual water and sewerage charges per household, and annual income per household in Waitakere city was obtained for 1996, 2001 and 2005 years from Waitakere city council and Statistics New Zealand. The data obtained was analysed to assess or establish the affordability benchmark for household water and sewage charges in the city.

In this study, the threshold for the percentage of disposable income above which water and sewerage charges may represent hardship was taken for illustrative purposes to be 3%. The study showed that the annual mean water and sewerage charges have gone up from $616 to $982 during the period 1996 to 2005. The percentage of the lowest household income spent on water and sewerage charges increased from 2.97% to 3.66% during the same time period. The percentage proportion of household spending more than 3% of their income on water and sewerage charge was just above 13.54%, and proportion of household falling into this category has declined by 0.02% since 1996. The results showed that a higher number of household may have faced a financial hardship, since 1996. In order to make the government and water industries aware of this problem, the term “affordability” needs to be taken into account as an assistant of the assessment of household water and sewerage services in Waitakere City or wider over New Zealand.
Keyword: Affordability benchmark, Water and sewerage charges, Water industry.

1. INTRODUCTION

1.1 Defining and measuring affordability

Although now widely used of political and media commentators, the term 'affordability' has come to enjoy this degree of prominence in the context of the water industry in many OECD countries, only within the last decade. The reasons for this are the beyond the scope of this paper. Huby (1994) and Herbert and Kempson (1995) employed the terms "water poverty" and "water affordability" in analyzing links between these phenomena and household incomes. As yet, full consensus has not emerged over whether the word "poverty" or "affordability" is most appropriate when discussing the issue in the context of the water industry. Authors such as Huby (1994) and Fitch (2002) have favored the former: the Organization for Economic Co-operation and Development (OECD, 2003); Watervoice (2004) and Scotland's Water Customer Consultation Panels favored the latter. Although the terminology remains disputed, the fact that households will not be physically deprived of water services in the case of non payment (as the disconnection of household water in no longer permitted in England – DEFRA, 2004). Therefore, the term "affordability" is more favored chosen in the category of water supply. That is the reason why OECD (OECD, 2003), in seeking to measure and calibrate, interpret "affordability" as "ability to pay". Superficially this definition is clear-cut. Practically, the difficulties in measuring the phenomenon are considerable.

However, affordability is the social aspect of water service provision that is most clearly and closely linked to pricing policies. Affordability of water service may not be distributed equally across income groups or neighborhoods – a lower income household will inevitably pay a higher proportion of their income for water services than a higher income household does (OECD, 2003). In fact, one thing needs to be noticed is that there is no equivalent standard as fuel poverty (i.e. a fuel poor household is the one which needs to spend more than 10% of its income on all fuel uses and to heat its home to an adequate standard of warmth – Sawkins and Dickie, 2005) has been set for water, although an indicative affordability benchmark for water rates has been reported by many governments and international organization, for example, 3-5% by World Bank, 3% by UK government, and 2.5% by US government (Fankhauser and Tepic, 2006).

There are two classification concepts for water affordability measurement. One is focusing on aggregate, called macro affordability measures, and the other is disaggregated or micro affordability measure. Macro measures relate average household water charges to either average household income or average household expenditure for whole countries. Its main flaws lie in the failure to convey any significant information about the situation of low income households, it is not with regard to regional, company or municipal variation, and its conflating of essential and luxury water use. It is sometimes not good to be used to approach to the analysis of low income households because this measurement is not taking account of any specific variation. Whereas, micro affordability measures on the other hand allow disaggregating in various ways: by income group, by region, by family type or by a particular burden threshold. It concerns the situation from low income to high income families, and it just fills the part that might be missed while taking the macro measures (Sawkins and Dickie, 2005).

1.2 OECD Countries Pricing System

Anything scarce and in demand commands a price; this is one of the basic principles of economics. Water pricing is increasingly seen as an acceptable instrument of public policy. Water-use charges, pollution charges, tradable permits for water withdrawals or release of specific pollutants, and fines are all market-based approaches that can contribute to making water more accessible, healthier and more sustainable over the long term. For this reason, OECD countries (New Zealand is a member of it) are working toward the goal of "internalising" the full marginal costs (including environment costs) into decisions that affect water use and water quality.

Efficient and effective water pricing systems provide incentives for efficient water use and for water quality protection. OECD member countries also generate funds for necessary infrastructure development and expansion, and provide a good basis for ensuring that water services can be provided to all citizens at an affordable price. The metering of water consumption is a prerequisite for the application of efficient water pricing policies. About two-thirds of OECD member countries already meter more than 90% of single-family houses, although universal metering remains a controversial issue in some contexts (Jones, 2003). The pricing systems for wastewater treatment are rather more complicated than they are for water supply. This is partly because responsibility for sewerage, sewage treatment, and drainage is typically held by different bodies, each with their own principles and practices.

Jones (2003) reported that water charge levels have been rising in most OECD countries in recent years. One reason for this is that water quality is often getting worse as a result of over-consumption. Moreover, government budgets have been stretched to the limit, putting upward pressure on charges. Indeed, there is a demand for more efficient and equitable approaches than across-the-board subsidies for achieving social goals, like affordability. Concern about the affordability of household water services for vulnerable groups, such as low-income households and retired people, has led to the development of a range of policy measures aimed at resolving affordability problems, while still meeting economic and environmental goals. In general, policies that target specific vulnerable groups – such as through income-related support – have been found to be more efficient at achieving their objectives than across-the-board subsidies.

While pricing structures for municipal and industrial water services increasingly reflect the full costs of providing the services, agricultural water use – primarily for irrigation – remains heavily subsidised, which encourages inefficient use of often scarce resources.

Recent OECD reports indicate that industrial and household water users often pay more than 100 times as much as agricultural users, although comparisons of this type are difficult because of the differing water quality needs and conveyance standards of different users. Nevertheless, it is clear that water prices are significantly lower for agriculture than for other user sectors in most OECD countries. OECD countries are working towards more complete recovery of infrastructure and operating costs from users, although rather slowly. Greater transparency, including in the level of implicit subsidies provided through undercharging for infrastructure use, could help build public support for further reforms (Jones, 2003).

1.3 New Zealand Water Price System

The household water and sewerage services charges cover what are, in reality, four different water services provided to households: water supply, sewage disposal, rainwater disposal from buildings, and rainwater disposal from highways. There are two fundamentally different ways in which the cost of providing any one - or all four - of these services can be met, i.e. providing funds from local or national taxation; and making direct or indirect charges on households and others (Palmer, 2005). Current pricing and charging approaches for water and wastewater vary between different territorial authorities and different cities and towns. Charges based on property rates, uniform annual charges (UACs), and flow based or consumption charges are used individually or in combination for water supply. Property rates based charges or uniform annual charges are used for wastewater. Property rates based charges are used to finance stormwater management. With uniform annual charges and charges based on property rates there is no economic incentive for consumers to reduce their water consumption through efficiency measures. Where meters and flow based charges have been introduced, both in New Zealand and overseas, there has been a significant change in behavior and a decrease in demand on a per capita basis (PCE, 2001).

Palmer (2005) reported that if customers are expected to pay for their water services through charges that reflect the costs of making these services available, it is essential to be as clear as possible about how those costs are built up. Hitherto there has been little in the way of published analyses of the separate costs of each major component of these services. However, an analysis making use of the detailed published accounts of one water company whose tariff structure best separates the charges for each of the four water services suggests that: (i) Over half of the average household bill is for sewage and rainwater disposal services; and (ii) Costs associated with local pipe networks account for half or more of total costs. The greater part of total costs is for making services available 24 hours a day, irrespective of actual use, and bears no proportional relationship to the volume of water consumed by individual households.

Mason (2006) reported that too often water services are taken for granted until there is a failure, or a need to increase the price. He mentioned that the Auckland water industry is under particular pressure for a host of reasons, including the threat of climate change, continuing population growth and urbanizations, increasingly stringent environmental standards, and the everyday need to maintain and renew our assets, worth well over $8 billion, or $6000 for every man, woman and child in the region (big Auckland). Across the region the price of drinking water, for example has increased at less than the CPI (The Consumers Price Index, which is a measure of the price change of goods and services purchased by private New Zealand households) for the past five years, but with the start of a number of very large capital projects, this cannot last (Mason, 2006).

The main reason lie behind the importance of affordability issues is the recent large and sustained rise in the average water and sewerage charges of Waitakere city households, which need to develop its water and sewerage pricing system. However, the higher investing causes the higher rate of increasing water and sewerage service price.

Therefore, adequacy of adjusting the household water and sewerage services prices is very important to get the balance of the water industry performance and the public benefit. This paper discusses the meaning of affordability, how it can be measured, and analyses the issue of water and sewage service charges affordability in the Waitakere city.

2.0 METHODOLOGY

2.1 Waitakere City Overview

Waitakere is one of the major cities of the Auckland Region. It is the fifth largest city in New Zealand. Waitakere City is in the west to Auckland City. It has, approximately 190000 people, in a region of 1.2 million. All of them need water and wastewater facilities – most of them have them provided by the council. This population may be doubled in 50 years. Indeed the population of the Auckland Region will increase by 20,000 people every year. For number of reasons, the cost of water and wastewater services may rise in the foreseeable future. **Table 1** below provides an overview of the water services provided to the residents of Waitakere city (during 2003 and 2004).

Table 1: An overview of water services provided to the residents of Waitakere city (*Sources: Auckland Water Industry Annual Performance Review, 2003/04*).

Population served	189,932
Total properties served	63,359
Residential properties served	60,224 (95%)
Business properties served	2,745 (4%)
Other properties served	390 (1%)
Total water serviced area (ha)	16,028
Water serviced area within MUL (Metropolitan Urban limits - ha)	8,228 (51%)
Bulk water supplied to operators (m^3 /annually)	16,302,198
Water consumed per property (l/day)	628
Length of water mains (km)	1,295
Water meters (no.)	63,307
Water pumping stations (no.)	19

2.2 Data Collection and Analysis

The population, annual gross income for different income groups, and number of household for each income group data was obtained from

Waitakere City Council (WCC) and Statistics New Zealand for 1996, 2001 and 2005. The annual quantity of water supplied, price of unit water supply, and average annual sewerage service's charges data was also obtained from WCC for the reporting years. The households were grouped by their average income levels from lowest to highest (i.e. 1 to 9) for each reported year.

The income distribution concept (Scott, 1999) was used to calculate the affordability. In this study, the micro affordability analysis was used, which is more suitable than its macro counterpart. The annual water charge per household was estimated by multiplying the annual water quantity supplied to the whole Waitakere City and the price of unit bulk water, then dividing by the number of household in Waitakere City. In this study, the issue of affordability is analysed in a way that water and sewerage service are banding together, because it can give a direct assessment of affordability of the residents of Waitakere City to pay the water and wastewater service's charges. Therefore, the annual water and sewerage charges were added to get the total annual water and sewerage service charges. The annual values were converted to weekly values. The financial condition and residential situation are more similar between New Zealand and Scotland, than U.S.A. Therefore, a 3% value was assumed as a benchmark (which is same as for Scotland) to assess and analyse an affordability benchmark for household water and sewerage charges in the Waitakere city.

It should be noted that there were few problems to contend with in drawing general conclusions about household water and sewerage affordability issues. For example, the data that is available for the purposes of analysis was not detailed and lacks in household composition and water consumption patterns, especially, of the lowest to medium income households. Further, there is wide variation in individual circumstances. Consequently it is not good practice to draw detailed general conclusions from information on a small number of particular cases. Having acknowledged these problems it was, nevertheless, possible to draw together the data in a way that enables a preliminary analysis of particular circumstances, and from there to draw general (not detailed) conclusions.

3 RESULTS AND DISCUSSION

3.1 Population and Household Growths

The Waitakere city's population growth rate is one of the highest in New Zealand, averaging at 2.3% each year (compared to the national average of 1.0%). The population is expected to grow 20.2% by 2016, from its current level of 190,000 (approx.) to a "low projection" to population of 202,900. Growth projections for 2016 may reach to 229,900 depending on the level of migration and of natural increase (the excess of births over deaths). The results showed that the total numbers of household in the city were 41625, 43644 and 60224 in 1996, 2001 and 2005, respectively (including parents with and without children).

3.2 Income Distribution in Waitakere City

Based on the income distribution principle, the lowest income household was defined as the household whose income is less than 40 percent of the median income (Scott, 1999). Hence, for example, in 1996 the lowest income set was $16598.8, which was 40% of the median income, whereas in 2001, the lowest income set was $19801.6, and for 2005 the lowest income set was $21632. The details of average annual income within each income group for 1996 and 2001 are given **Table 2**.

The results showed that the percentage of income spent on water and wastewater service charges from highest to lowest income group varies between 0.55% and 2.97% in 1996. Whereas for 2001, the percentage of income spent on water and wastewater service's charges varies between 0.73% and 3.31% (from highest to lowest income group – **Table 2**).

3.3 Water and Sewerage Charges

Figure 1 shows the trend of unit drinking water price in different cities or districts of Auckland Region from 1990 to 2006. The line with squares in this chart shows the trend of the price in Waitakere City. The results showed that unit price for drinking water for the Waitakere area remains below $1.0 per cubic meter during 1990-96. However, the unit price for drinking water increased from $0.8 in 1996 to $1.5 in 2005 (**Figure 1**) i.e. an increase of 87.5% since 1990, and 76.5% since 1996. The household water bills have risen substantially, but unevenly since 1990. This increase can be attributed to an accelerate increase of population, urbanisation in Waitakere City (over the last ten years), and water quality & increasing stringent environmental standards. Therefore, the government and water industry have to invest more in order to meet the standards and the demand of the growing population.

Table 2: The percentage of income spent on water and sewerage service's charges by each income group for 1996 and 2001 (as the household number data could not be obtained for 2005).

Income groups	1996				2001			
	Annual income ($)	Household %	Household number	% income spent on water & wastewater	Annual income ($)	Household %	Household number	% income spent on water & wastewater
1 Lowest	16598.8	13.54%	5637	2.97%	19801.6	13.52%	5901	3.31%
2	20000	7.97%	3318	2.46%	25000	3.96%	1728	2.62%
3	25000	4.57%	1902	1.97%	30000	7.01%	3060	2.18%
4	30000	8.40%	3495	1.65%	40000	7.86%	3429	1.64%
5	40000	12.40%	5163	1.23%	50000	9.21%	4020	1.30%
6	50000	11.20%	4662	0.99%	70000	17.84%	7788	0.99%
7	70000	19.35%	8055	0.74%	90000	13.29%	5799	0.79%
8	90000	12.34%	5136	0.59%	100000	9.52%	4155	0.73%
9 Highest	100000	7.35%	3060	0.55%				

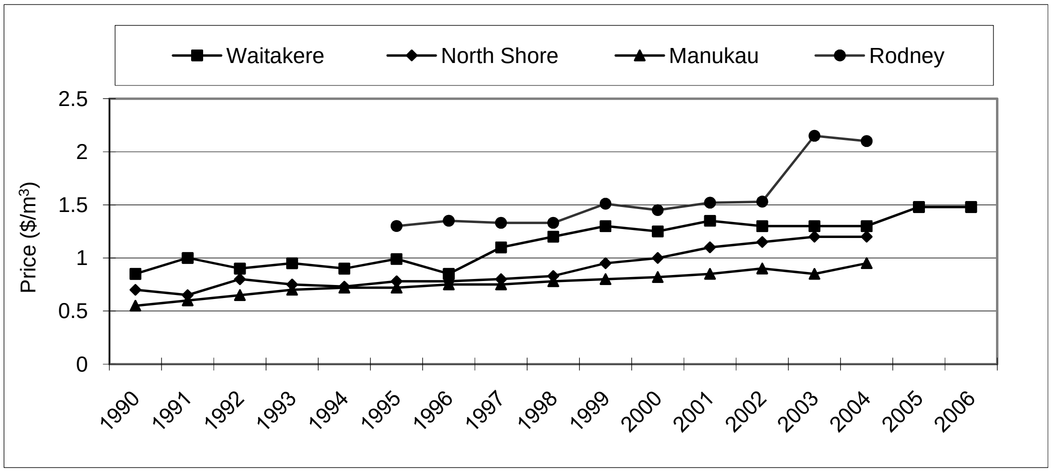

Figure 1: The unit price of drinking water for the main cities of the Great Auckland Region from 1990 to 2006 (***Data sourced**: Watercare, 2005*).

The annual mean water and sewerage service charges per household in the Waitakere city are given in **Table 3**. As no data could be obtained for water consumption per household in the city, therefore, it was assumed that that the daily consumed water per household is stable (i.e. 680 litres per day per household) since 1996 for convenience of calculations. Therefore, there was no significant difference in the water consumption between low and high income households, except the luxury water use such as swimming pool and spa. Especially in the three highest income groups, the excess was at least 13% of the water used in the lowest income family. This difference only appeared in the water charges, and the sewerage charges do not vary (the sewerage service's charges were calculated as 75% of the water charges from 2001 to 2005). The mean weekly water and sewerage charges were slightly higher for the 3 highest income groups, which was basically due to the 13% extra luxury use of water by those income groups (**Figure 2**).

Since 1996, the drinking water price increased at a higher rate (i.e. 76.5%) than sewerage charges (i.e. 41.5%) in Waitakere City. The results showed that the annual water and sewerage charges (combined) have gone up by 59.5% since 1996 (i.e. increased from $616 in 1996 to $982 in 2005). It should be noted that the annual average income increase was 38.2% (i.e. from $47423 to $65520) over the same period of time (i.e. from 1996 to 2005) in the Waitakere area. The results showed that the both water supply and sewerage services charges have increased faster than the annual income increase, since 1996.

Table 3: Mean annual combined water and sewerage charges per household for the reporting years.

Year	Water consumed per household (m^3/d)	Weekly Water consumed per household (m^3)	Water price ($/$m^3$)	Weekly Water price ($/$m^3$)	Annual water charges per household ($)	Annual sewerage charges per household ($)	Total Annual Charges ($) per household
1996	0.628	4.40	0.85	5.95	309	306	616
2001	0.628	4.40	1.35	9.45	491	360	851
2005	0.628	4.40	1.5	10.50	546	436	982

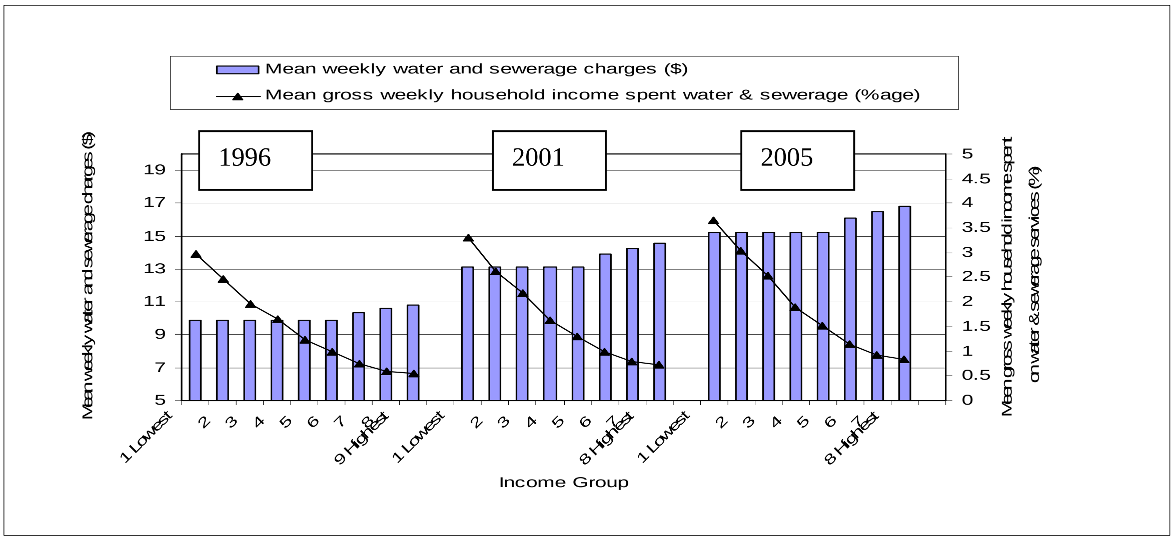

Figure 2: A comparison of mean weekly water & sewerage charges and the percentage of weekly gross income spent by each income group on water and sewerage services in 1996, 2001, and 2005.

The mean weekly gross income and the percentage of mean gross weekly income spent on water and sewerage charges within each income group are shown in **Figure 2**. The results showed that mean weekly gross income varied between $319 and $1923 (from lowest to highest income group) over the past 10 years. The percentage of mean weekly gross income spent on water and sewerage charges (within each income group) varied between 0.55 and 3.66 %. The lowest income group spent 2.97%, 3.31%, and 3.66% of their mean gross weekly income on water and sewerage charges in 1996, 2001, and 2005, respectively (i.e. 23.23% increase for the lowest income group, since 1996). Similarly, the highest income group spent 0.55%, 0.73%, and 0.84% of their mean gross weekly income on water and sewerage charges in 1996, 2001, and 2005, (also mentioned earlier) respectively (i.e. 52.7% increase for this group since 1996). This shows that the lowest income groups are spending a big slice of their income on water and sewerage charges than that of highest income group.

The results showed that the lowest income household group paid 2.97% of their income into water and sewerage service weekly in 1996, which was close to the assumed benchmark 3%. While in 2001 and 2005, it increased to 3.31% and 3.66%, respectively, (i.e. an excess of 0.32% and 0.66% over the assumed fixed benchmark of 3%). This means that water and sewerage service charge has been unaffordable for the lowest income group in 2001 and 2005. This group was taking 13.52% of Waitakere city households.

The results suggested that the percentage of household spending more than the assumed affordability bench mark of 3% was 13.54% in 1996 and 13.52% in 2001. In other word, the percentage of household spending more than the assumed affordability bench mark has reduced by 0.02% from 1996 to 2001. The household number data could be obtained for 2005 year.

4 GENERAL DISCUSSION - Towards an Affordability Benchmark

The way to establish water affordability benchmark is similar to that employed in the context of fuel. A 10% fuel poverty threshold has been embedded within various government energy policy statements for several years (DEFRA 2001). The details of which can be found in Sawkins and Dickie (2005).

In this study, the threshold for the percentage of disposable income above which water and wastewater charges may represent hardship was taken for illustrative purposes to be **3 percent** (as mentioned earlier). The medians of spending by households on water and sewerage charges as a percentage of gross income were 1.23%, 1.47%, and 1.71% for 1996, 2001, and 2005 years, respectively. The choice of 3% appears to be reasonable as it was above the average median value of 1.47% (which is less than 1.5% i.e. half of the assumed benchmark). Sawkins and Dickie (2005) reported that there is no commonly agreed affordability benchmark in the UK. For England and Wales an indicative water affordability measure has been adopted by DEFRA (i.e. 3% of household income).

Concerning the water affordability benchmark debate, another view point is taken by the Congressional Budget Office (CBO). According to CBO report on future investment in drinking water and wastewater infrastructure (CBO, 2002), EPA has never adopted a measure to indicate how much an individual household can pay for water services before they become unaffordable. Yet participants in the current debate use (and attribute to EPA) the assumption that any household with water bills in excess of 4 percent of its income is experiencing a hardship. In adopting that notion, they mistakenly apply to individual households "affordability criteria" that the agency developed for whole water systems. The distinction is important because EPA's criteria compare the revenues collected by a water system to the median household income (MHI) in a service area, not to individual household income. Certainly, average household costs that correspond to 4 percent of a community's MHI represent an even higher percentage of the income of an individual household earning less than the median. Thus, EPA's (subjective) judgment that 4 percent of MHI is a reasonable ceiling on a water system's yield does not translate into a judgment that each individual household served by that system should pay no more than 4 percent of its income for water services. The 4 percent benchmark reflects EPA's separate figures of 2 percent each for wastewater and drinking water. The origins of those individual figures highlight the subjectivity inherent in setting affordability criteria. EPA recently decided to raise the value to 2.5 percent of MHI, which highlights the subjective underpinnings of the agency's affordability criterion.

Turning, briefly, from domestic to international experience of affordability policies and practice it is clear that there is considerable variation even between member countries of the OECD. In countries such as Spain, Portugal and Turkey a progressive system of charging is used - the increasing block tariff - in which unit charges rise with water consumption. In Belgium this system is combined with a free allowance of water for households; a measure designed to guarantee universal access to water for basic needs. Luxembourg has a number of 'social tariffs' and Australia an elaborate series of concessions. Whilst in the Republic of Ireland domestic water charges were abolished in 1996 and consolidated into general taxation (Sawkins and Dickie, 2005). Fankhause and Tepic (2006) have also reported the affordability benchmark for electricity, heating and water services for the lowest income deciles of different countries.

5 SUMMARY AND CONCLUSIONS

In this paper we have looked at household income of different income groups and how much each household within each income group is spending on water and wastewater service's charges in the Waitakere city. The aim was to analyse and understand better to what extent low income households can afford these services. The last 10 years have seen a marked increase in water and wastewater service's charges. While there were important data limitations (as mentioned earlier in the methodology section), these estimates suggest that affordability is indeed a problem for lowest to median income groups. Based on the findings of this study the following conclusions can be drawn:

- The study showed that the Waitakere city's populations, number of houses, and average household income have increased by 22%, 45%, and 38%, respectively since 1996.
- The study showed that since 1996 the average annual water and wastewater charges increased by 77% and 42% (a combined increase of 59.5%), respectively.
- The percentage that the lowest income group's income spent on water and wastewater service's charges increased from 2.97% in 1996 to

3.66% in 2005 (i.e. an increase of 23%). The affordability of household water and sewerage service of lowest income group in Waitakere City has been over the assumed benchmark in 2001 and 2005. This showed that lowest income groups have spent a big slice of their income on water and sewerage services than that of highest income group. The percentage that the highest income group's income spent on water and wastewater service's charges increased from 0.55% in 1996 to 0.84% in 2005 (i.e. an increase of 53%).

- To the best of our knowledge, there is no information available on an affordability benchmark for household water and sewerage charges for New Zealand. Measuring the affordability of water and wastewater service charges is complex and inexact; household composition and choice are significant factors. For example, as the composition of households varies, so does their ability and desire to spend large proportions of their income on housing costs (including water, wastewater, power, telephone, food, etc). Households with dependent children, for instance, may be less able to spend more of their income on housing costs than households with no dependent children. Furthermore, households with higher incomes are able to exercise more choice over how much they spend on housing costs. No data could be obtained for household composition and amount of water used by each household.
- Affordability can play an important role to analyze the water charge, and check if the water and sewerage service's charges are at a reasonable level. Therefore, introducing the issue "affordability" into the water and wastewater service's charges concepts is necessary.
- This paper has tried to identify some of the issues, but it has not reduced the need for further, more detailed analysis of the household composition and water consumption patterns of the lowest to median income households.

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Optimizing the Water Allocation System at Jordan Valley through adopting WEAP Model with emphasis on Financial and Economic implications

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ABSTRACT

The Jordan Valley Basin is considered as the backbone of Jordan Development sectors and has remarkable activities in terms of water demand and supply; the demands which comprised Agricultural and domestic uses.

The current status of the Jordan Valley is the sufferance of enough and affordable water for the different uses, which invite the essentiality of adopting a water allocation and management model to develop a number of water demand/supply scenarios which will be considered as a lateral thinking towards bridging the deficiency.

Water Evaluation and planning system Model (WEAP) is considered as one of the effective management tools in allocating the water resources under increasing competitiveness and shortage of water for the different uses.

The model was tested and adopted for the current status of the valley. Future scenarios were considered in running the model and testing the water demand/supply system. These scenarios were focused on reuse of treated wastewater in the North regions for irrigation practices; raising the efficiency in the irrigation practices mainly in the middle Ghors and using 50 MCM from the Unity Dam to cover part of Amman city domestic demand.

Results of the WEAP were in the form of

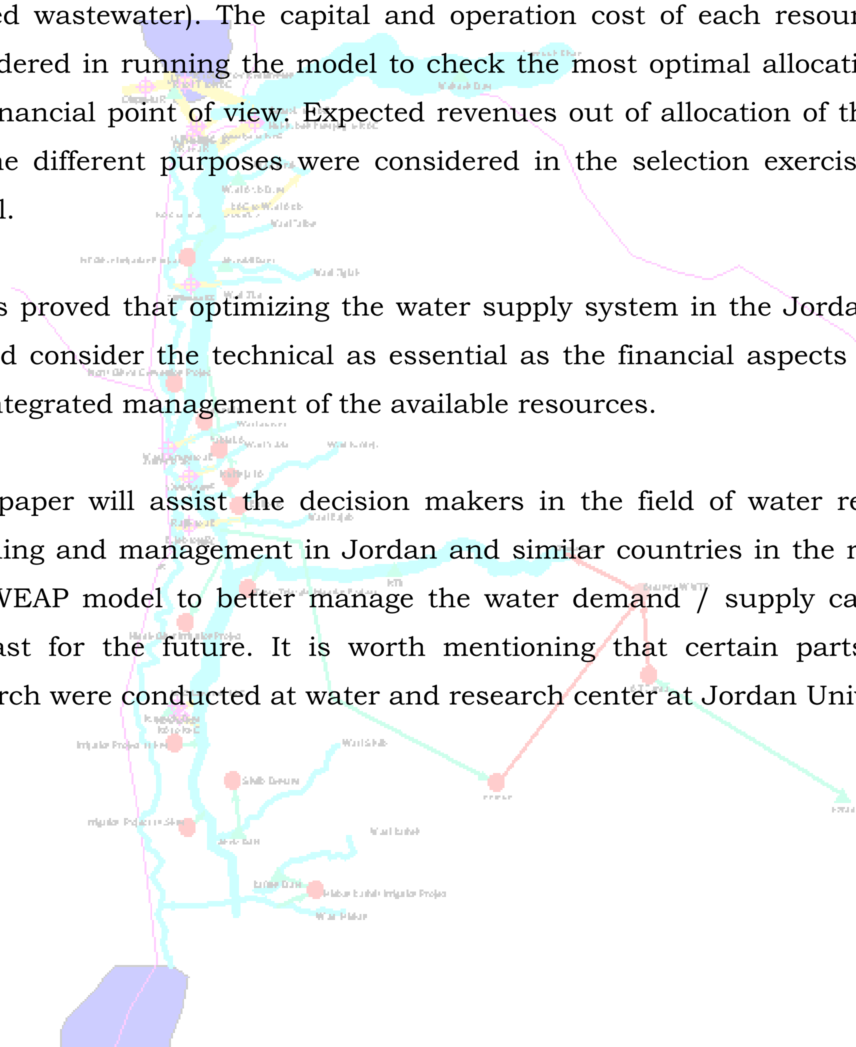
- Stream flow (below node or reach listed)
- Inflows and Outflow to Area
- Reservoir Inflows and Outflows
- Transmission Link Flow
- Costs of delivering the water to the targeted demand
- Expected revenues
- Return Link Inflows and Outflows

- Surface Water Quality (TDS, BOD, and pH)
- Unmet Demand
- Water Demand (not including loss, reuse and DSM)
- Demand Site Coverage (% of requirement met)T

Water Quality constraints were considered in the system (pH, BOD, and TDS) where three types of water were considered; fresh water (without any treated wastewater), blended water (fresh and treated wastewater) and (only treated wastewater). The capital and operation cost of each resource were considered in running the model to check the most optimal allocation from the financial point of view. Expected revenues out of allocation of the water for the different purposes were considered in the selection exercise of the model.

It was proved that optimizing the water supply system in the Jordan valley should consider the technical as essential as the financial aspects to fulfill the integrated management of the available resources.

This paper will assist the decision makers in the field of water resources planning and management in Jordan and similar countries in the region to use WEAP model to better manage the water demand / supply cases and forecast for the future. It is worth mentioning that certain parts of the research were conducted at water and research center at Jordan University.



I. Water in Jordan

Water problems in Jordan are diverse and changing as the gap between supply and demand widens. Water issues are linked to scarcity, mal-distribution, and sharing. The development and management of water resources in Jordan presents a challenge for water managers and experts.

The adoption of new water allocation policies in Jordan is crucial for sustainable water development. This strategy should focus both on demand management and development of non-conventional water resources. With the same trends in population growth and water use, the gap between water supply and demand will continue to widen. The objective of this paper is to present the adaptation of " Water Evaluation and Planning Model" named WEAP for analyzing the available water resources and demands for the different purposes and best manage the water demand and supply under the most technical and financial conditions. The model was applied in the Jordan Valley Basin which is considered as the backbone of the agricultural sector in Jordan and one of the main surface water resources for domestic purposes in Amman.

Water Supply and demand in Jordan

In Jordan, the gap between available water supply and demand was first observed in the domestic sector. The gap is more likely to widen further in the municipal, agricultural and industrial sectors unless adequate measures are taken.

Jordan's water resources are composed of surface water, groundwater and reclaimed wastewater. Total available water amounts to 1050 million cubic meters (MCM) in 1998 (MWI, 2006). Surface water contributes 470 MCM and reclaimed wastewater amounts to 70 MCM. Groundwater makes the largest contribution of 510 MCM/yr. Groundwater abstraction is 450 MCM from renewable aquifers and 60 MCM from non-renewable basins. The safe annual yield from the renewable aquifers is estimated to be 280 MCM, which means that about 170 MCM are being over pumped (i.e. the annual abstraction is 161% of the safe yield). This over exploitation of ground water resources imposes a major constraint on sustainable water development.

Municipal uses represent around 21% of the total consumption and irrigation uses represent around 69% of the total consumption. Ground water is considered the main source for irrigation and municipal uses followed by surface water. With the current trend in water use, it is anticipated that within the next decade, Jordan will have utilized all the potentially available conventional water resources. By 2020, the population of Jordan is projected to become 10 million. The demand in the municipal sector will be about 700 MCM and in industry about 150 MCM. Based on projections of water supply and demand, Jordan is likely to face a potable water crisis by 2010.

Table (1): Current Water Uses in Jordan in 2006 (Unit: MCM/year)

Resource / **Uses**	**Surface water**	**Groundwater**	**Reclaimed Wastewater**	**Total**
Municipal	65	170	-	235
Irrigation	350	313	60	723
Industrial	3	22	10	35
Others	52	5	-	57
Total	**470**	**510**	**70**	**1050**

Table (2): Water Demand, Supply and Deficit of Jordan for the period (1995-2020)

Item	**1995**	**2000**	**2005**	**2010**	**2020**
Population (millions)	4.4	5.2	6.1	7.0	10.0
Water resources (MCM/yr)	832	902	1042	1092	1150
Water demand (MCM/yr)	930	1050	1375	1570	1800
Deficit (MCM/yr)	**98**	**148**	**333**	**478**	**650**

Available Water Resources in Jordan

Groundwater Resources

Jordan's water resources, surface and groundwater, depend mainly on rainfall which is estimated at a long term average value of 8532 MCM/year (MWI). Moreover, the former figure is subject to substantial variations with the nature of rainfall patterns in the country. Variation may fluctuate at ± 4 averages as will be described later.

Groundwater constitutes the most important available resource that can be tapped in over 80% of the country in varying quantities and qualities, and at varying depths ranging from a few meters to more than 1000 meters. Groundwater in Jordan is of two types, renewable and fossil. The latter constitutes 5% of the total groundwater storage of most hydro-geological regimes in Jordan. Estimates of the groundwater safe yield are around 280 MCM/year.

For the fossil water quantities, found in the south eastern part of the country, estimates depend on the exploitable depth and other hydro-geological factors, however this reserve is estimated at 90 MCM/year for a period of 100 years. Quality of groundwater varies from one aquifer to another; salinity ranges from 170 ppm to 3000 ppm in some places.

Surface Water Resources

Surface water resources in Jordan comprise two principal parts; base flow and flood flow. Base flow is derived from groundwater drainage through springs. Surface water is developed through 13 water basins distributed all over the country. In 1998 the actual supply of surface water was 470 MCM/year (MWI) and this number is expected to increase to 550 MCM/year by the year 2010. This increase is due to the construction of Unity Dam at Yarmouk River and other side Wadis reservoirs.

The main surface resource is the Yarmouk basin in the north which contributes almost 45% of base flow and flood flow waters in Jordan. Eleven dams with a total safe yield of 130 MCM/year have been constructed along the main rivers and streams of the Jordan valley.

Non-conventional Water Resources

Different non-conventional water resources are considered as potential water resources. These include reclaimed waste water, ground recharge, water harvesting, desalination of brackish and sea water and importation of water across national boundaries. A brief description of these resources follows:

A. Reclaimed Waste Water

Reclaimed wastewater is an important non-conventional source in Jordan. Currently, there are 21 operating plants of which Khirbit Al Samra is the largest with effluent volume corresponds to about 75% of the effluent volume nation wide. Plans are underway to construct 23 more treatment plants to serve an additional 34 towns and villages in Jordan. These plants will have a combined treatment capacity of 90 MCM in the year 2007 and 110 MCM in the year 2010 (MWI).

Extensive plans and studies are underway to assess the feasibility of using reclaimed water for irrigation in areas adjacent to the treatment plants. The current policy of Water Authority is to consider the reclaimed wastewater as a valuable commodity and should be utilized efficiently close to the treatment plants or at the potential areas. About 70 MCM/year is used currently for restricted irrigation purposes.

Recent studies at Water Authority showed that the average unit cost of treating one cubic meter of wastewater in Jordan is 0.52 $.

B. Water Harvesting

Two types of water harvesting applications are considered for the case of Jordan; urban water harvesting such as the roof harvesting, and the agricultural water harvesting such as the cases of artificial recharges at potential catchment areas.

C. Desalination

Desalination of brackish and sea water seems to offer a sound alternative to arid lands bordering seas or salt lakes; desalination plants producing up to several million gallons per day are commercially available and already used for domestic and industrial purposes in some arid regions.

Figures show that a total desalination capacity of 15 million m^3/day is expected to be installed within the Arab World during the next 25 years. With present capital required for erecting desalination units ranging between $ 1000-2000 per (m^3/day) installed capacity, it is estimated that 15-30 billion US$ would be needed for such a purpose.

In Jordan, two main sources are available to be desalted: the red sea at the Gulf of Aqaba and brackish groundwater in Jordan Valley basins. Preliminary studies show that by the year 2010 more than 20 MCM/year could be developed in the Central Jordan Valley. This figure may reach 70 MCM/year by the year 2040 (JICA,1995).

For the case of seawater desalination at Aqaba, the transportation cost of fresh water from Aqaba to the capital Amman may add big burden on the total unit cost.

D. Importation of Water

Preliminary studies have been conducted to assess possibilities for importing water to Jordan, and sources have been identified in Turkey, Lebanon and Iraq (GTZ, 1999). Conditions which are necessary for the success of such options are (a) the enforcement of regional monitoring of water resources and uses and (b) the establishment of a regional water commission to ensure sustainable water management.

E. Mega-scale projects

Two mega-scale projects are considered in the Jordan water sector investment plan. These projects are the Red-Dead project and Disi-Amman project.

The first project is a multi-purpose scheme that entail a conduit that convey the water from the Dead sea towards a desalination plant using the difference in elevations that will generate electricity, and then to the Dead Sea. The desalinated water will be conveyed again to Amman and other potential demand centers. The second project, Disi-Amman project entails a conduit that convey the fossil groundwater from Disi aquifer towards the north up to Amman city.

II. Future Scenarios for Sustainable Water Development

The approaches for dealing with water issues in Jordan are characterized by challenging management. This was evident in three major areas of water management:

1. Rationing and interruptions of water supply for many users during summer times.
2. Water quality deterioration for both domestic and irrigation.
3. Delays of tariff adjustment after opposition from farmers are voiced.

Dealing with management of water resources under severe shortages created an overburden over the responsibilities of the decision makers in Jordan. The following issues in water management have been identified. These include problems related to fluctuations of supply, water pricing, water quality and user's participation.

Uncertainty and Fluctuations in Water Supply

Surface water resources depend on base flow and flood flow. Due to the erratic distribution of rainfall from one year to another, potential water supply in Jordan is uncertain and the range of fluctuations from year to another are high (above 25%) of the average annual figure. During the period of (1998-2000), rainfall experienced about 35% reduction in comparison to the long term average. This was repeated in the years 2004/2005 with less reduction ratio.

Subsequently, rationing of domestic water supply has been practiced. In addition, during the second Gulf war, an emergency plan was implemented to supply water for the domestic users especially after receiving more than 700,000 Iraqi residents to live in the country.

Over-exploitation of ground water in the Jordan Valley basin is taking place. In 2003, the extraction rate was about 42 MCM while the safe yield was only 21 MCM/year. As a result, water quality deteriorated and moreover some aquifers faced mining. Therefore, preventive measures must be taken to ensure the sustainability of water development in Jordan.

Water Pricing

A tariff of 0.2 cents per m^3 of irrigation water in the Jordan Valley was first introduced in 1961. In 1966, this rate was raised to 0.4 cents for water consumption exceeding 1800 m^3 per 1000 m^2 of irrigated land. This rate was increased again to 0.6 cents per m^3 with no limit of water consumption in 1974 and to 1.2 cents per m^3 in 1989.

Tariffs are usually opposed by users, especially farmers. The ability and willingness-to-pay for water are usually evaluated prior to any increase in water pricing.

Water quality

One major environmental problem in Jordan is related to water pollution. Such a problem is caused by water resources contamination with inadequately treated waste water, cess pools and other environmentally-hostile practices. Deterioration of the quality of Zarqa river water course and King Talal Reservoir water is a representative example as of the above causes.

User's participation

Efficient and sustainable development in the Jordan Valley requires participatory irrigation management. This means joint involvement and shared responsibility by both the Jordan Valley Authority (JVA) and the users in the operation of an irrigation system. This requires a revision of relationships and involvement of users in the decision-making process.

The JVA is in the process of modifying its law to open the door for private sector participation in operation and management of irrigation activities.

III. National Water Policy Formulation in Jordan

The formulation of coherent water policies would help guide strategic decisions regarding water priority allocation, water rights, efficiency of service, and environmental protection.

Recently, a national water program was developed. The overall objective of the program was to formulate water policies for the sustainable development of water resources in Jordan. Moreover, the program aimed to build consensus within the water sector and stakeholders. The program was characterized as a participatory approach where various groups (public officials, private sector consultants, and NGO's) were involved in the entire process.

A summary of the major water policy issues and their corresponding policy components is presented in Table (3). Critical policy issues include allocation priorities, investment options, conservation and efficiency measures, and privatization.

To achieve the above proposed water policies, a coherent institutional framework is needed to ensure access and accountability. Such institutions should be characterized by a distinct separation between the management of water resources (regulatory functions) and the delivery of water services (functional activities). The introduction of a mathematical and management model was essential to achieve the transformation from the traditional thinking into the lateral thinking and adopting a coherent model that will consider the different water resources at the Jordan Valley and the demand centers for the different uses followed by simulating and optimizing these resources to be best allocate for the demand centers. The following sections will elaborate more about the conceptual framework of the model "(WEAP) which stands for "Water Evaluation and Planning System Model".

Table (3): Summary of water policy issues and their components

Water policy issues	Water policy components
Water resources assessment and monitoring	- national monitoring program - central entity for integrated management - water sustainability
Rehabilitation versus new investments	- criteria for project priorities
Regional and shared water resources	- principles to reach agreements - mechanisms for cooperation and trust
Standards and guidelines	- quality control program - standardized procedures
Water rights and water markets	- define water rights - examine possibilities of water markets
Water pricing and cost recovery	- coverage of O&M cost - differential water pricing
Intersectional allocation	- highest priority to domestic uses - adopt water productivity criteria, employment generation and socioeconomic development
Waste water management and reuses	- treatment and reuse of effluent in accordance to standards
Pollution prevention	- integrated environmental management program
Conservation and efficiency measures	- measures to improve efficiency
Privatization and private sector participation	- private sector participation should be pursued to improve efficiency and accountability
Stakeholder Participation and public awareness	- promote participation at planning and operation levels - educate the public about water issues
Research and Development	- encourage research in all related water issues

IV. PREFACE OF JORDAN VALLEY BASIN

As discussed in the previous chapters, Jordan Valley Basin has remarkable activities in terms of water demand and supply and is currently witnessing a shortage of fresh water resources. The demand which comprised Agricultural activities in the valley and Domestic uses in the main cities. The following sections describe the building steps of WEAP over the JV basin model, testing and running the model for the current status and future scenarios. Results were presented after each of the proposed scenario.

WEAP Structure: Building Steps over JV Basin Model

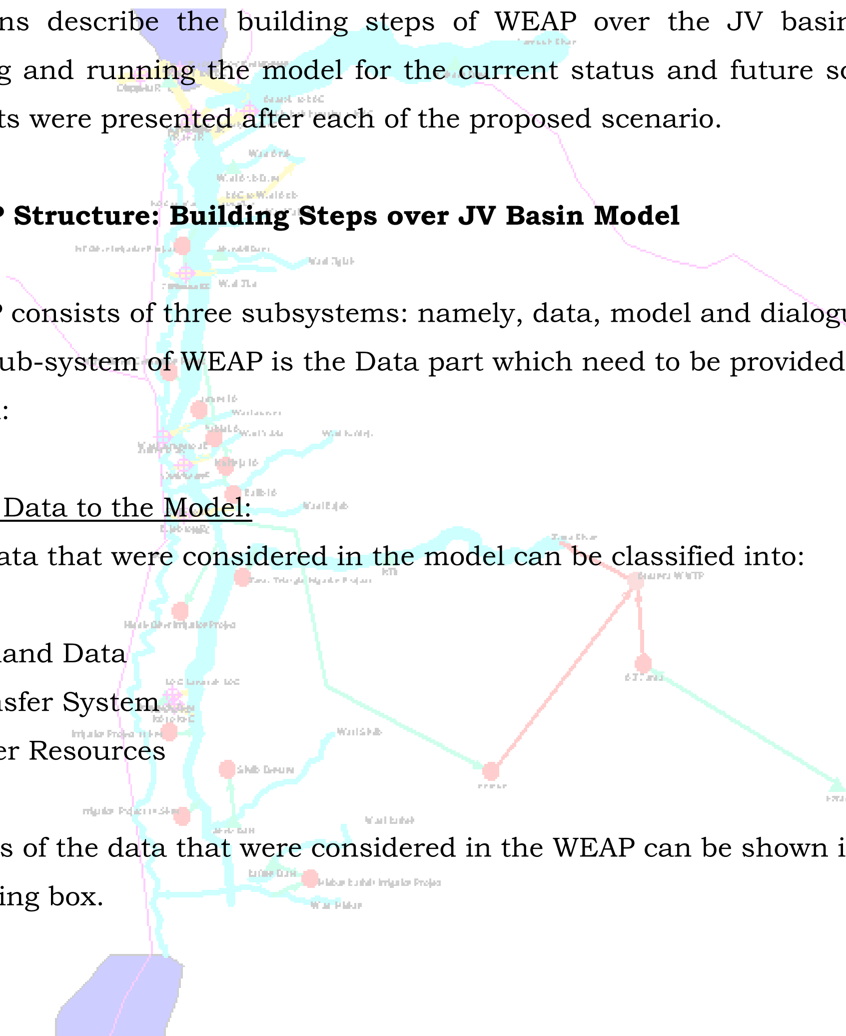
WEAP consists of three subsystems: namely, data, model and dialogue. The first sub-system of WEAP is the Data part which need to be provided to the model:

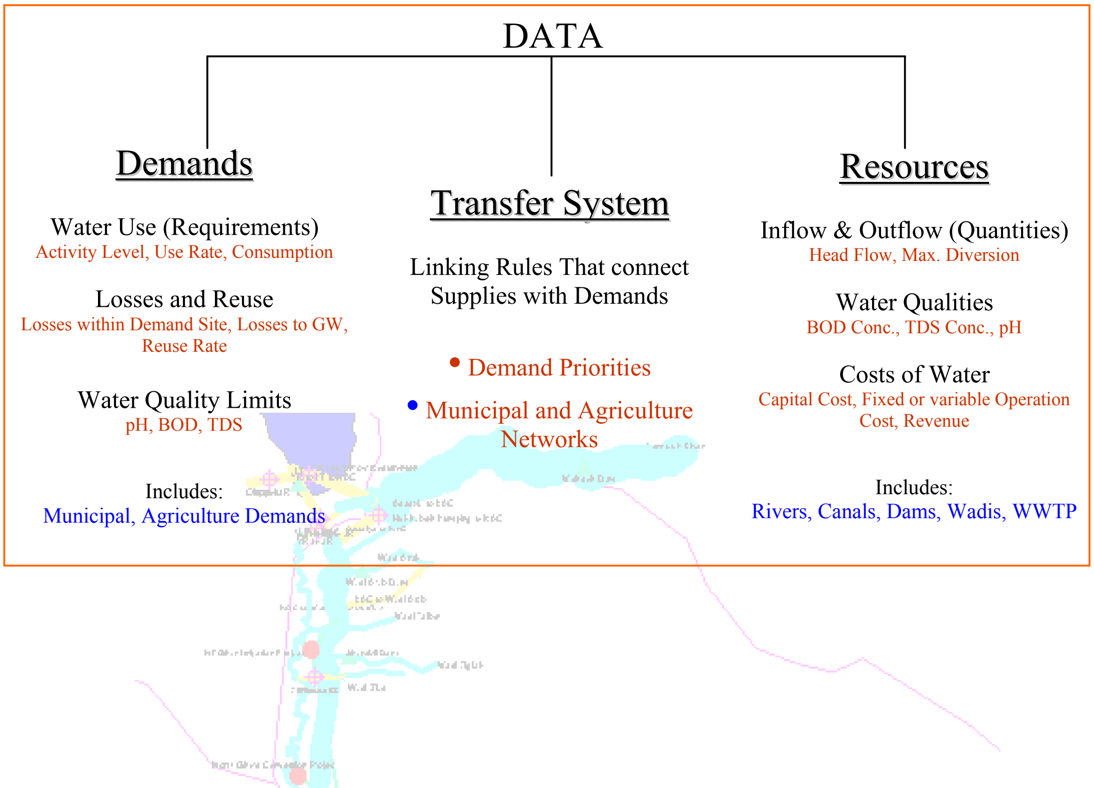
<u>Input Data to the Model:</u>

The data that were considered in the model can be classified into:

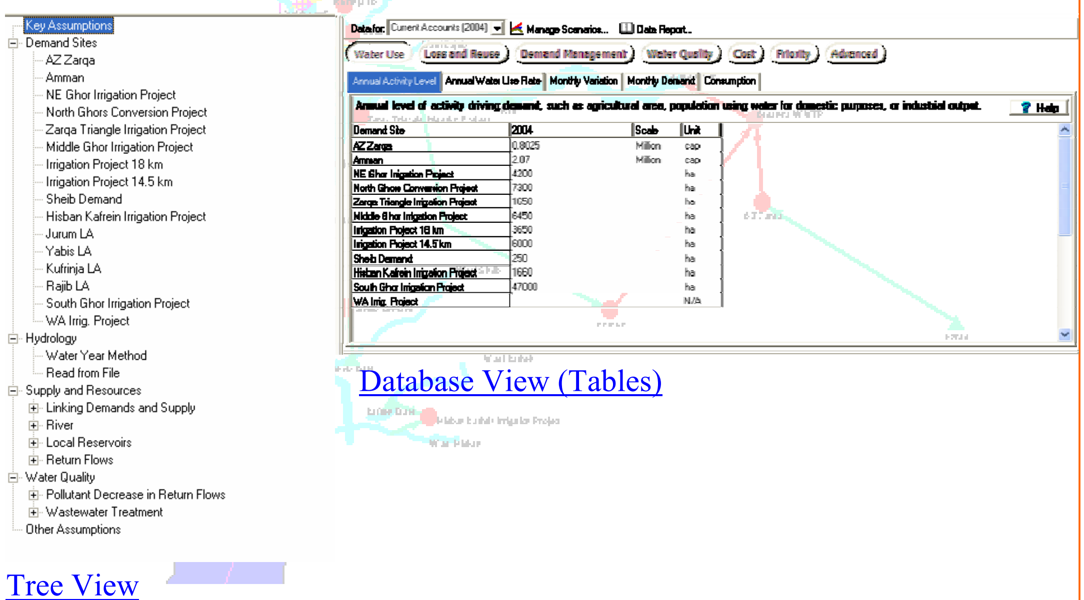
- Demand Data
- Transfer System
- Water Resources

Details of the data that were considered in the WEAP can be shown in the following box.





Figures Represent the input data on the system

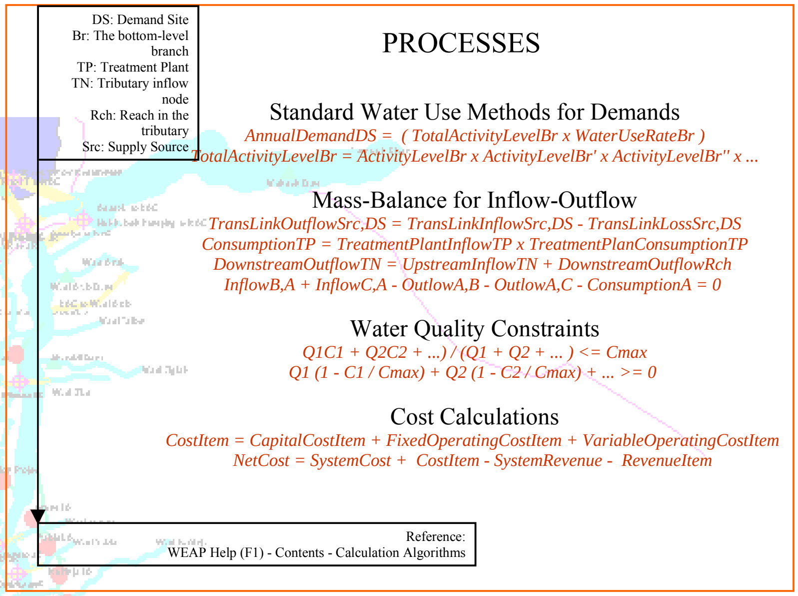


Model Subsystem

The second subsystem is the model subsystem which entails all the mathematical processes that will take care of all the necessary calculations.

Processes of WEAP

The processes that are embedded in WEAP which will enable the model to do the necessary calculations such as mass balance and water allocation. Processes entails water qualities, quantities and financial aspects in terms of capital and operation cost of the available resources.



Dialogue Subsystem

Dialogue subsystem is the third part and was presented through simulating the results and changing in the input data.

Results of the model can be presented in the form of Charts, tables and maps. Description of such results can be shown in the following box.

E4

RESULTS

Charts

Many Relations between the water system variables will present an overview and comparison into forms of :
Area charts, Line charts, pie charts, Bar charts, column charts

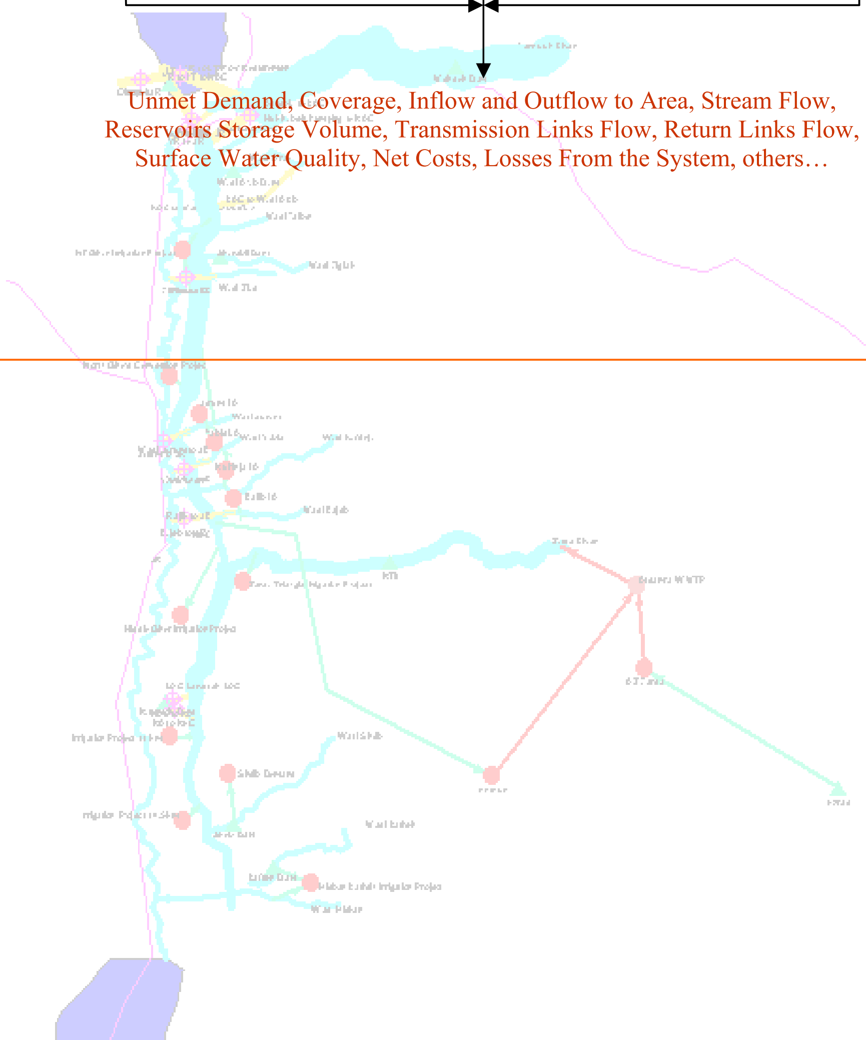
Tables

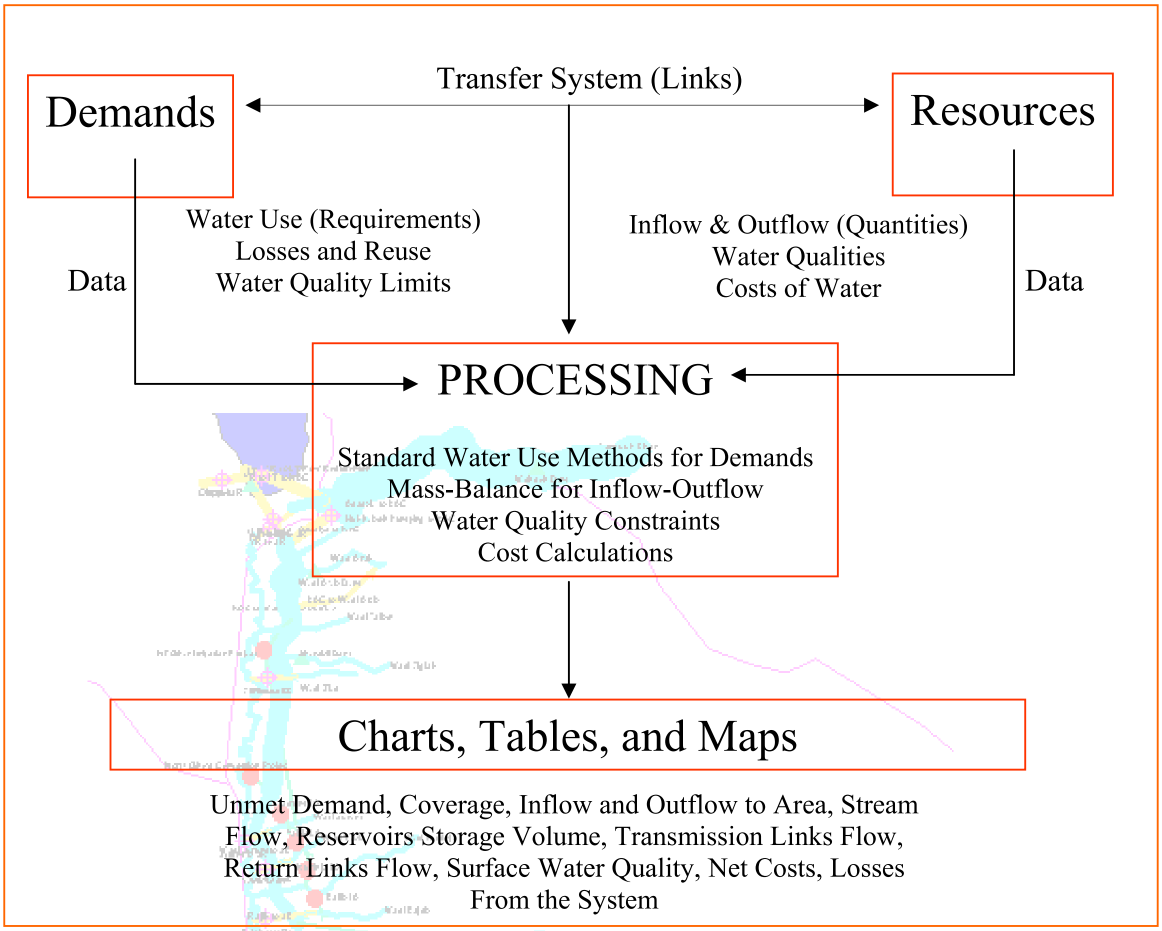
Summarizing final readings of data and make general statistics:
Sum, Min., Max., Percentage

Maps

Spatial distribution of the water system components and its structure, on other hand geographic classifying based on the results

Unmet Demand, Coverage, Inflow and Outflow to Area, Stream Flow, Reservoirs Storage Volume, Transmission Links Flow, Return Links Flow, Surface Water Quality, Net Costs, Losses From the System, others…





V. ACTUAL IMPLEMENTATION OF THE MODEL

Used Data for the Water Resources:

The following data were considered as an input data for the available water resources in the JV:

- Three Rivers (Yarmouk, Zarqa, and Jordan River)
- One Canal (King Abdullah Canal)
- Eleven Wadi (Valley) (Wadi Arab, Wadi Taibeh, Wadi Ziglab, Wadi Abu Ziad, Wadi Jurum, Wadi Yabis, Wadi Kufrinja, Wadi Rajeb, Wadi Shueib, Wadi Kafrein, and Wadi Hisban)
- Eight Surface Water Reservoirs (Unity Dam, Lake Taiberia, Arab Dam, Shurabil Dam, KTD, Karameh Dam, Shueib Dam, and Kafrein Dam)
- One Groundwater Reservoir (Azraq GW)

Used Data for the Demand Areas:

The following demand areas were identified in the model, based on the real conditions in the JV:

- Agriculture Demands (NE Ghor Irrigation Project, Wadi Arab Irrigation Project, N Ghor Irrigation Project, M Ghor Irrigation Project, Zarqa Triangle Irrigation Project, Irrigation Project 18.5 km, Irrigation Project 14.5 km, South Ghor Irrigation Project, and Hisban-Kafrein Irrigation Projects)
- Domestic Demands (AZ Zarqa, and Amman)
- Local Areas and Rights (Jurum LA, Yabis LA, Kufrinja LA, Rajeb LA, and Shueib Demand)

Building the Scheme for JV Basin

This process was based on the WEAP capabilities to simulate and draw the Water System Features through the legend tools and its functionality, thus the following assumptions were considered:

1. King Abdulla Canal (KAC), All Wadis, and the official Rivers drawn as Rivers in the Scheme at WEAP Model.
2. Lake Taiberia (LT) and all Dams in the Basin will be Surface Water Reservoirs.
3. Mukhaibeh Ground Water (GW) is simulated as River to transfer water to KAC.
4. One GW source (Azraq GW Reservoir)
5. Some connection points between the resources are simulated by Diversion tool (Wadis to Jordan River (JR), Pump water from Yarmouk to LT then Pump Water from LT to KAC, Pump Water from KAC to Karameh Dam then Pump Water from Karameh Dam to KAC)
6. Other connections are built directly like Wadis to KAC (River connects to other)
7. One Wastewater Treatment Plant (WWTP).
8. Transmission and Return Links for Amman city, Zarqa city, and Assamra WWTP
9. Transmission links to cover the irrigation projects.

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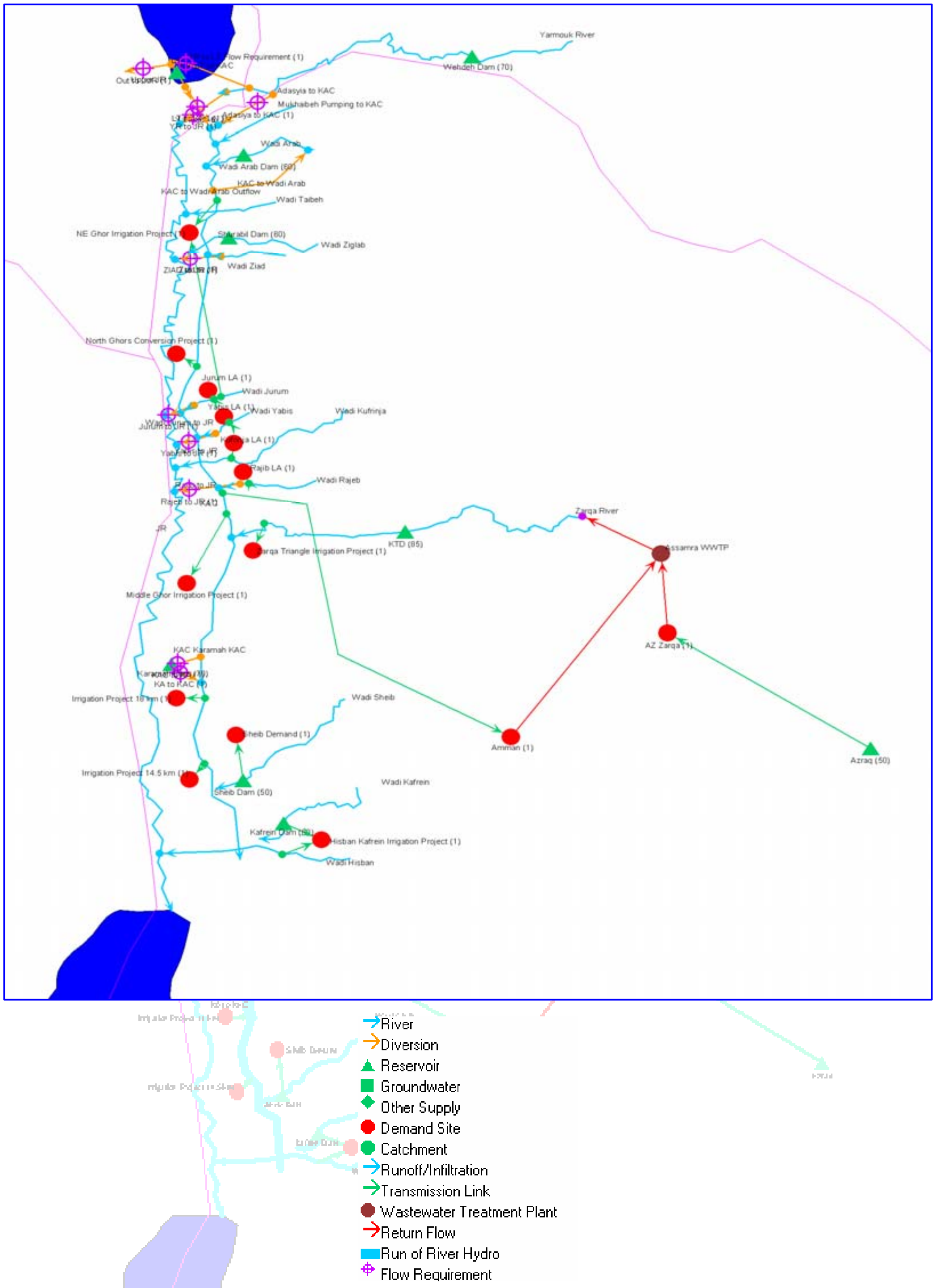


Main Schematic: contains all the water system features

Filling out the Data gap:

In order to bridge the gap related to the availability of data, some of the parameters were considered to ensure the functionality of the model, there parameters that were performed are as follows:

1. Mass Balance Requirements (inflow-outflow) and water volumes
2. Percent of reuse and consumption for Demand Nodes
3. Losses at each Demand and Supply Node
4. Water Demand Requirements for agriculture and domestic use.
5. Water Amounts that returns to WWTP.
6. Water Quality constituents in the system (pH, BOD, and TDS). Where three types of water were considered; fresh water (without any treated wastewater), blended water (fresh and treated wastewater) and (only treated wastewater).

Other parameters which are related with the unit cost of water were considered such as (Capital cost, Variable and fixed cost, and revenues). These financial parameters were essential to decide on the most financially and economically resource that could be allocated to the defined demand center.

Financial Data:

The financial implications of delivering certain resource to a demand area were based on the unit cost of delivering the water to the target. This unit cost is calculated based on the capital, operation and maintenance costs of the said resource. The capital cost is the investment cost which entails

- Equipment
- Construction costs (civil, electromechanical and others)
- Labor costs
- Interests on debts
- Contingencies

The financial cost for the existing resources are the true values, where the investment costs of the future projects / resources should be the discounted costs based on the starting year of construction. The operational and maintenance costs of the existing resource will be based on the actual monthly or yearly spending on delivering the water to the targeted demand centers. The operational costs which may range from 2-5% of the capital costs may entail the following:

- Labor costs
- Energy sources
- Spare parts
- Maintenance costs
- Consumables such as chemicals and others.

For the projects which are under construction or that will be constructed in the future, the expected O&M costs will be adopted.

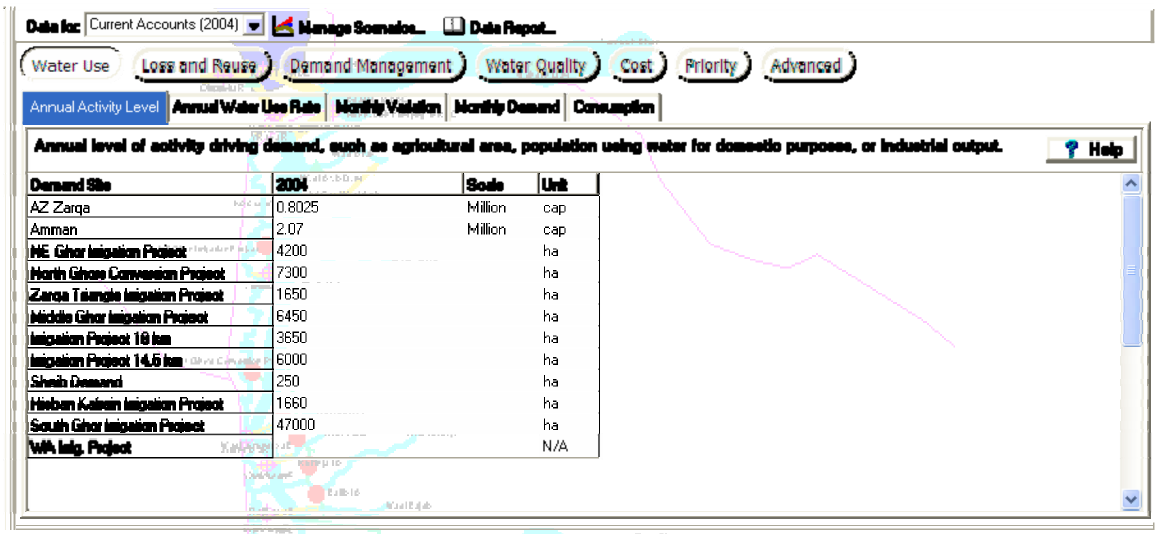
In order to calculate the unit cost of the resource, both capital and O&M costs need to be considered. Each project should have a life period and the discount rate should be defined. Life spans of the water projects ranges from 10-15 years for the case of pipe works up to 25 years for the case of pumps up to 50 years for the case of dams and reservoirs. The investment cost will be divided all over the operational period (life span of the project) with application of a defined discount rate which can range from 5% up to 15% for the cases in poor and developing countries. The yearly share of the investment cost will be added to the O&M in order to get the total yearly cost per resource. This total yearly cost will be divided by the total generated quantity of water per the said year; the result will be the unit cost of water for that resource at that year.

Each resource with its related unit cost can be added to the WEAP model on yearly basis to encounter the financial and economical aspects of allocating certain resource to defined demand center.

The other part of the financial implications is the calculation of the expected revenues out of the project. Revenues of water supply project for municipal uses will be calculated based on the current water tariff and the expected billed quantities during one year. The same is applied for the industrial uses. For the case of the irrigation projects, it will be more difficult. The cropping patterns need to be defined with the areas, expected market prices for each product with the expected production per defined period such as one year. For the existing projects, real financial data can be collected, where for the new projects; an anticipation of the expected income can be calculated.

The income of selling the water to the farmers needs to be considered accordingly. The revenues for the future projects need to be discounted like the case for the capital and O&M costs.

The following chart shows the page of the data entry where the different data bases can be established. Cost is one of the bases for running the model.



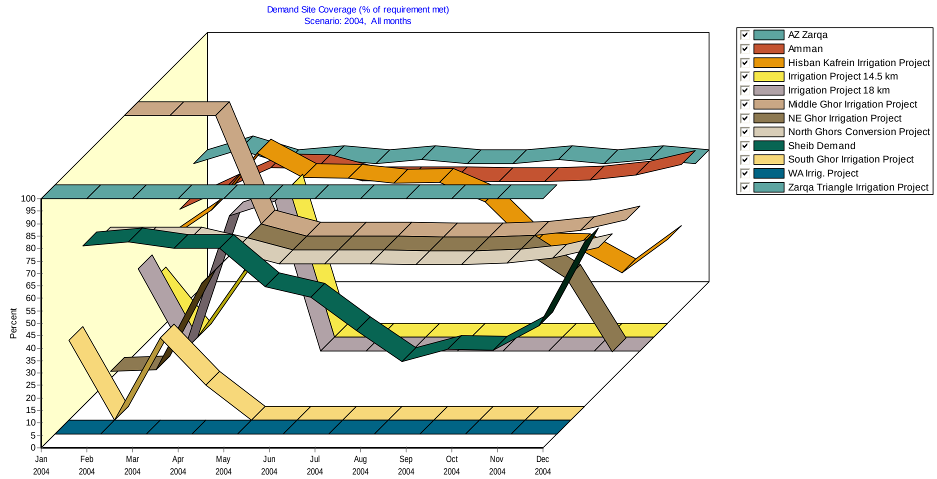
[The data entry tables are used to enter expressions that define Current Accounts and Scenario values of variables.]

Running the model and conceived Results

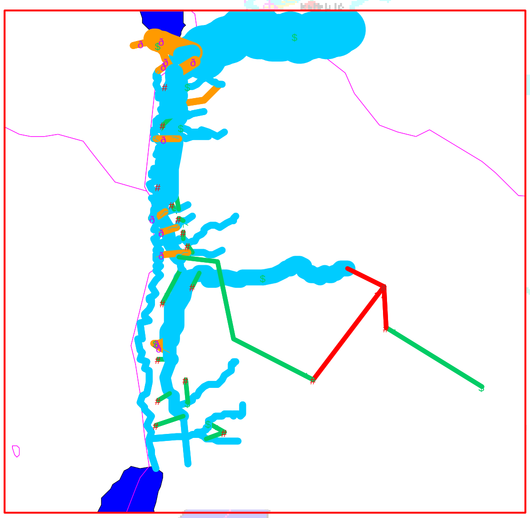
After running the model with the previous assumptions in terms of water balance, water quality and related unit costs, the following results were noted:

A. Good Views and summaries over the basin as a whole system.
- Stream flow (below node or reach listed)
- Inflows and Outflow to Area
- Reservoir Inflows and Outflows
- Transmission Link Flow
- Return Link Inflows and Outflows
- Surface Water Quality (TDS, BOD, and pH)
- Unmet Demand
- Water Demand (not including loss, reuse and DSM)

- Demand Site Coverage (% of requirement met)
- Cost of delivery for each selection



Demand Site Coverage (% of requirement met)



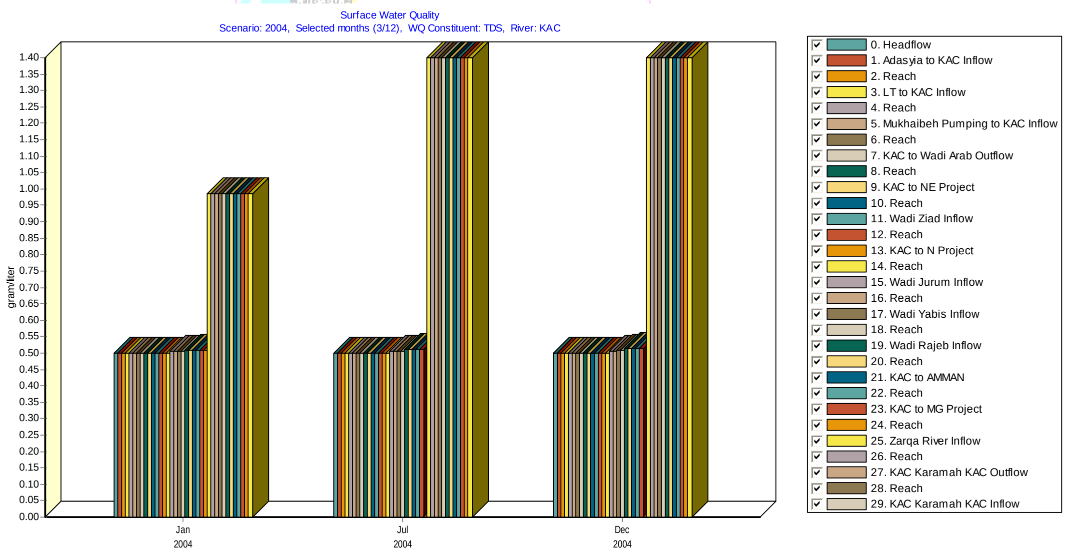
Stream flow (below node or reach listed)

`

Surface Water Quality
milligram/liter

	Jan-04	Feb-04	Jun-04	Jul-04	Nov-04	Dec-04	**Min**	**Max**
0. Headflow	60	60	60	60	60	60	60	60
1. From Assamra to Zarqa River	95	99	121	119	95	110	95	121
2. Reach	95	99	121	119	95	110	95	121
3. KTD	50	50	50	50	50	50	50	50
4. Reach	50	50	50	50	50	50	50	50
5. Zarqa River to Zarqa Triangle	50	50	50	50	50	50	50	50
6. Reach	50	50	50	50	50	50	50	50
Min	50	50	50	50	50	50	0	0
Max	95	99	121	119	95	110	0	0

Surface Water BOD at Zarqa River

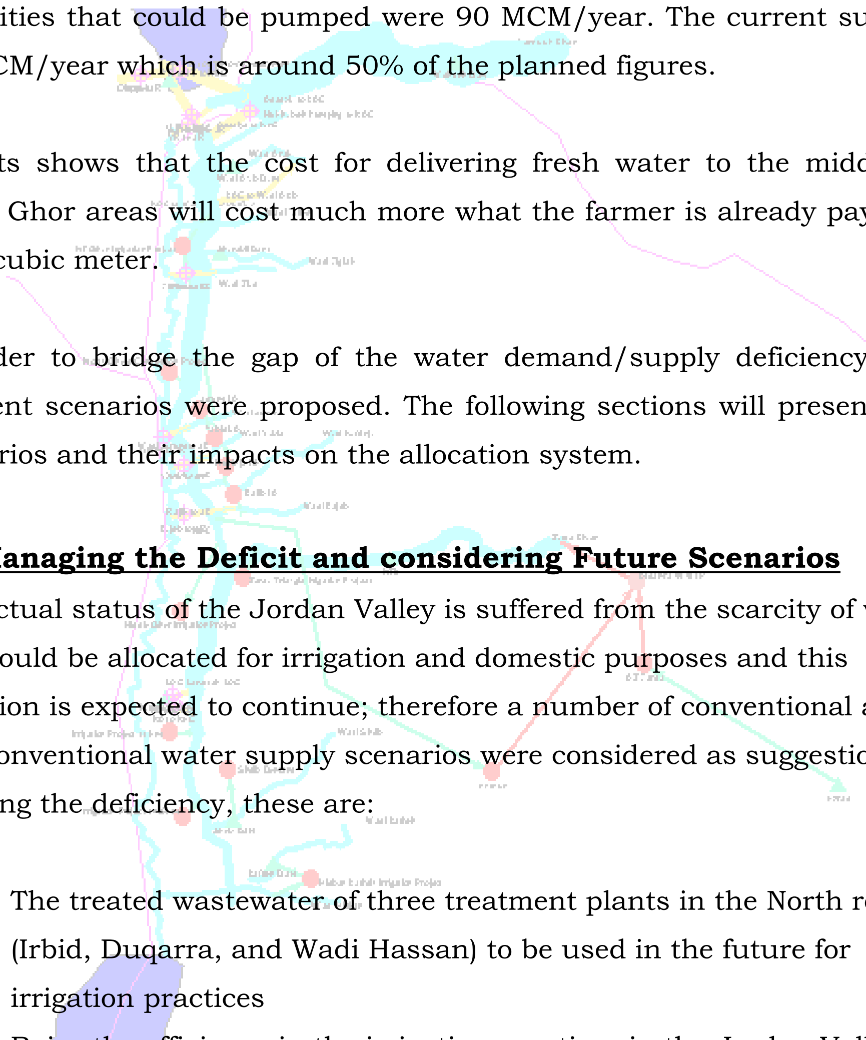


Surface Water Quality (TDS) Declination at KAC in Jan, July, and December

Running the model using the actual data shows that the water qualities will not sufficient to cover all the purposes for irrigation at the Jordan Valley. Around 70% of the actual water demand was met with the available resources. This will be reflected on scaling down the production of agricultural sector. For the domestic uses in Amman, the anticipated quantities that could be pumped were 90 MCM/year. The current supply is 45 MCM/year which is around 50% of the planned figures.

Results shows that the cost for delivering fresh water to the middle and south Ghor areas will cost much more what the farmer is already paying for each cubic meter.

In order to bridge the gap of the water demand/supply deficiency, three different scenarios were proposed. The following sections will present these scenarios and their impacts on the allocation system.



IV. Managing the Deficit and considering Future Scenarios

The actual status of the Jordan Valley is suffered from the scarcity of water that could be allocated for irrigation and domestic purposes and this situation is expected to continue; therefore a number of conventional and non conventional water supply scenarios were considered as suggestions for bridging the deficiency, these are:

1. The treated wastewater of three treatment plants in the North regions (Irbid, Duqarra, and Wadi Hassan) to be used in the future for irrigation practices
2. Raise the efficiency in the irrigation practices in the Jordan Valley by 10%.
3. Using 50 MCM from the Unity Dam to cover Amman city domestic demand.

In order to run the model with respect to the different scenarios, the following assumptions were considered:

- In terms of climatic conditions and rainfall changes, three cases were adopted to simulate lower JR Basin:

- ❑ Base Year (Current Account)

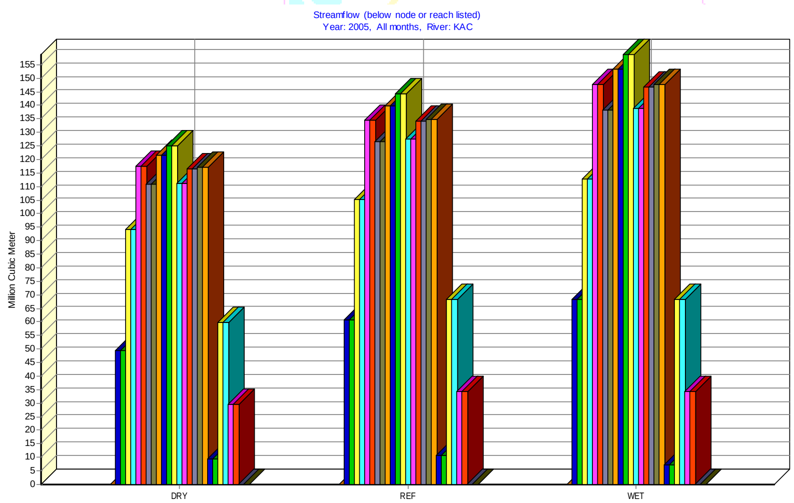
  Average year of 2004 reflects normal distribution of water budget

- ❑ Wet Year

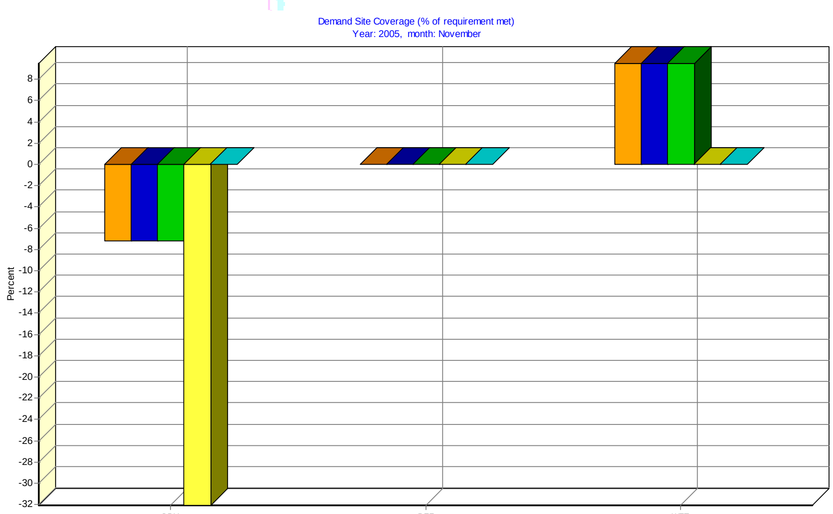
  A prediction of increasing 20% of water income

- ❑ Dry Year

  A prediction of decreasing 20% of water income



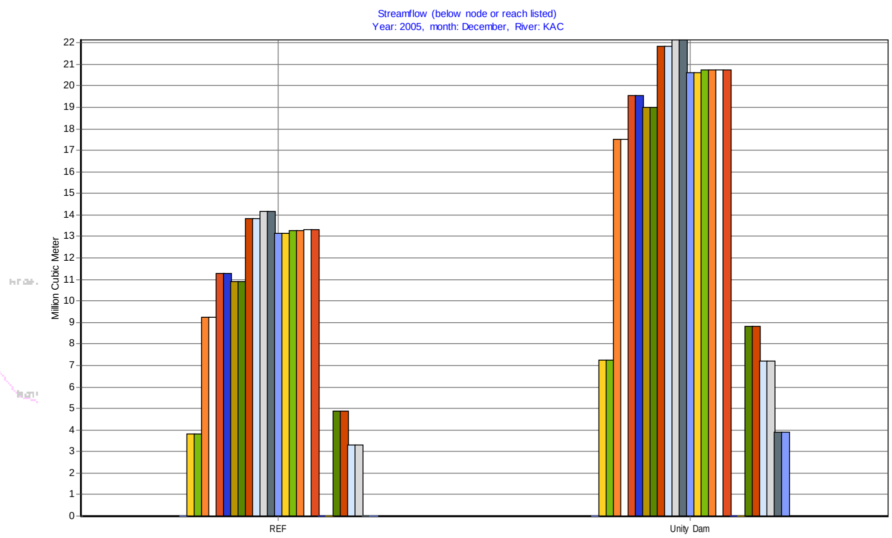
Stream-flow distribution in KAC through three cases of water budget, (it is clear to distinguish that wet account has maximum water abundant in KAC as well as in all stream along JV system).



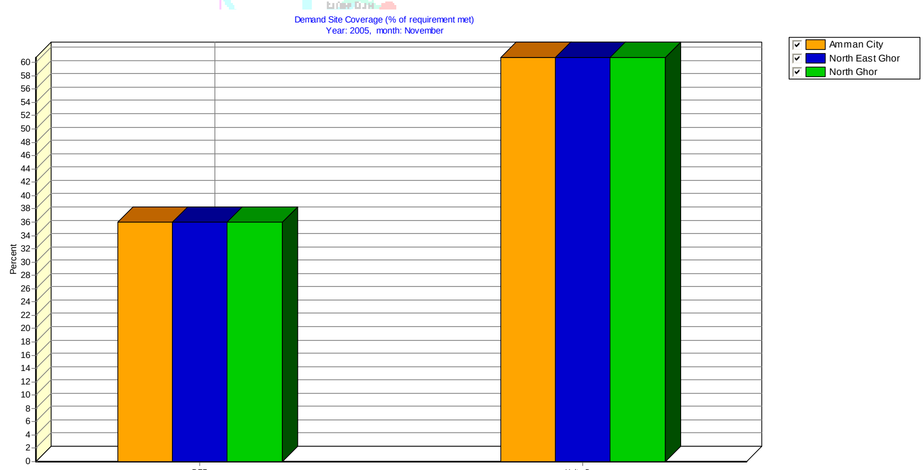
Demand Site

Coverage (% of requirement met) the middle bar in this chart shows the base values in the normal water account, in the right hand the bars represents raising of coverage weights in positive trend and the opposite is observed in dry account in the left hand.

Water Balance after considering the Unity Dam scenario:

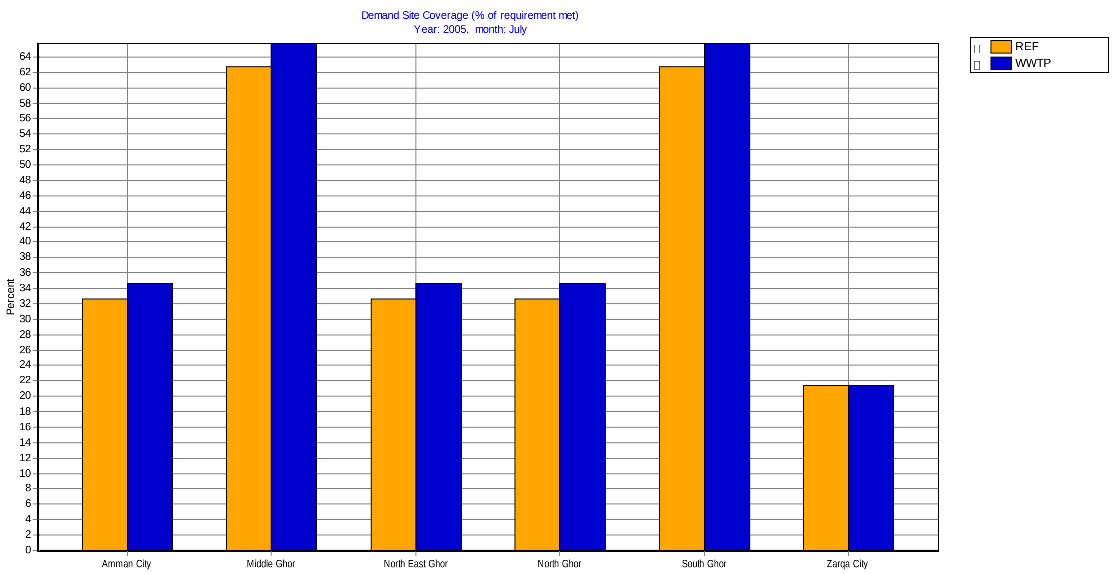


Stream-flow in KAC in comparison with unity Dam scenario (these amounts of water that increase in the right bar of figure will be allocated to Amman city and to north irrigation projects as 50% equally likely)

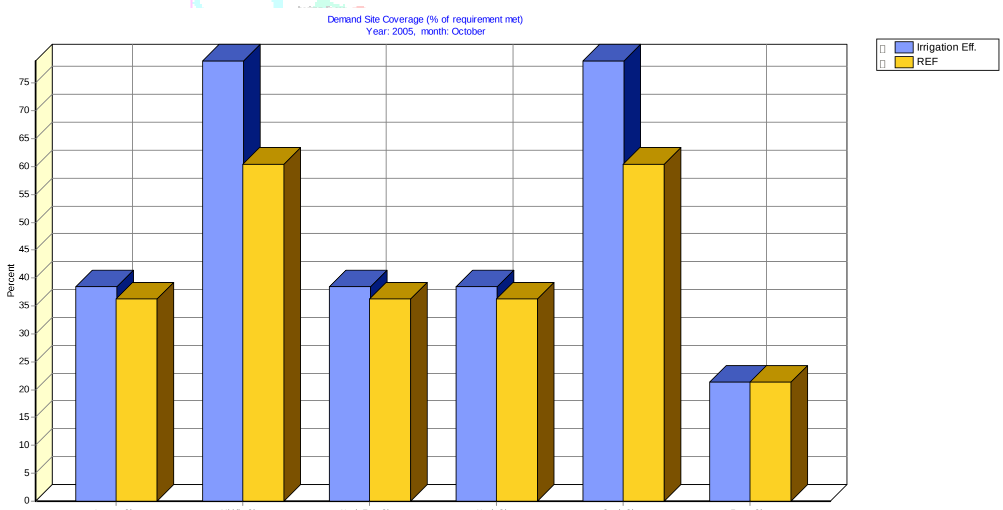


Demand Site Coverage (% of requirement met), notice that coverage for north irrigation projects and for Amman city is going to be better in Unity Dam Scenario.

Results of water balance after considering the reuse of the three wastewater treatment plants in the North.



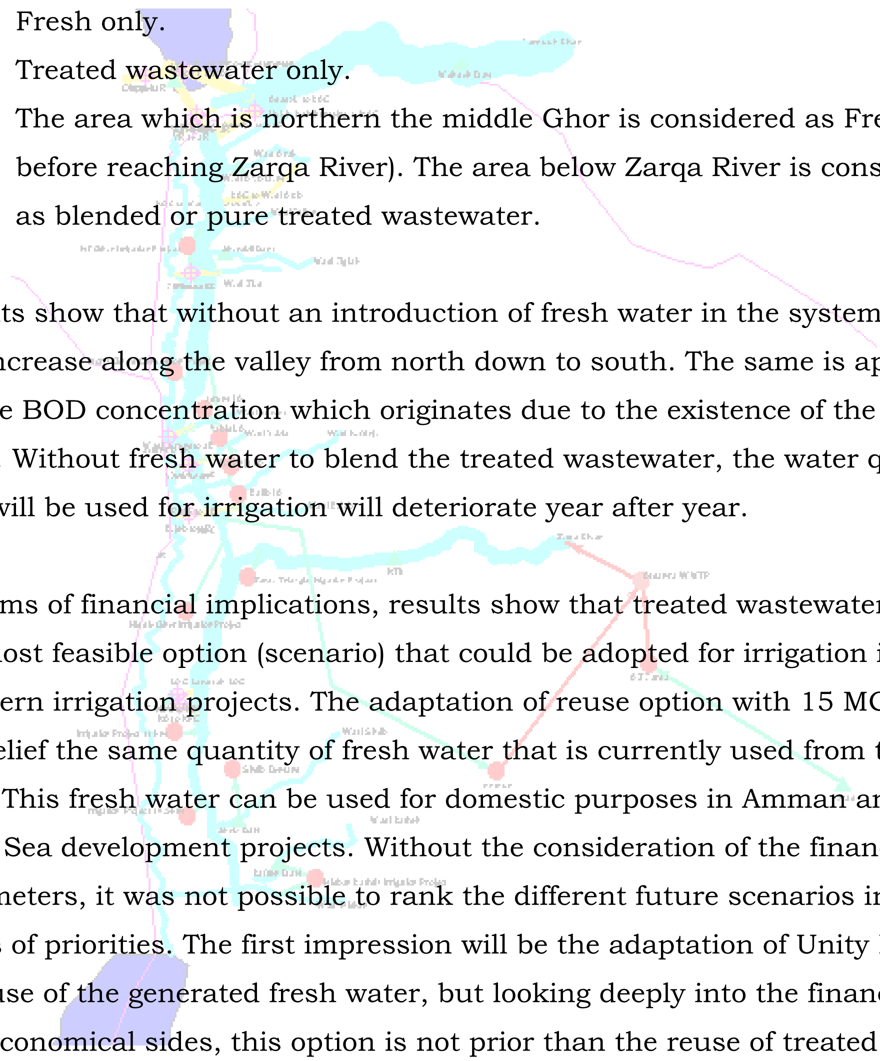
Raising the Coverage% (Water Reuse-WWTP Scenario) this is reflected as a result of finding new water source and ready to serve the north irrigation projects and so raising the coverage percentage.



Results of raising the Coverage% (Irrigation Efficiency), by using new techniques in irrigation method

BOD parameter as a key element to determine the water quality in the JV. Three different types were considered for the different sources:

- Blended water (Fresh and treated)
- Fresh only.
- Treated wastewater only.
- The area which is northern the middle Ghor is considered as Fresh (before reaching Zarqa River). The area below Zarqa River is considered as blended or pure treated wastewater.



Results show that without an introduction of fresh water in the system, TDS will increase along the valley from north down to south. The same is applied for the BOD concentration which originates due to the existence of the Zarqa River. Without fresh water to blend the treated wastewater, the water quality that will be used for irrigation will deteriorate year after year.

In terms of financial implications, results show that treated wastewater is the most feasible option (scenario) that could be adopted for irrigation in the northern irrigation projects. The adaptation of reuse option with 15 MCM/a will relief the same quantity of fresh water that is currently used from the KAC. This fresh water can be used for domestic purposes in Amman and the Dead Sea development projects. Without the consideration of the financial parameters, it was not possible to rank the different future scenarios in terms of priorities. The first impression will be the adaptation of Unity Dam because of the generated fresh water, but looking deeply into the financial and economical sides, this option is not prior than the reuse of treated wastewater option.

Results and Conclusions

As a result of adopting three different future scenarios and running the model on these scenarios, it can be concluded that **WEAP** has the ability to represent the actual status of the water systems and able to be supplied by new sources (quantity, quality and cost).

With respect to relevance for future water use and/or availability in the Jordan River region; WEAP examined to apply three Scenarios, to carry and calculate options which assist Decision Makers in finding alternative or enhancing water plans. Results were promising and prove that WEAP can be used efficiently and effectively for the case of JV and other similar cases in the region. From the purely technical aspects (quantity and quality), adaptation of supplying the system with 50 MCM of fresh water from the Unity Dam proved to be the best scenario. Raising the efficiency at the irrigation facilities will increase the available water and scale down the unmet fraction by 10% was the second option. Utilization of the treated wastewater in the north will add 15-20 MCM/year to the system but certain but ranked technically as the third. With the application of the unit costs only, the reuse of treated wastewater was selected as the first, raising the efficiency is the second and the Unity Dam is the third. With considering the necessary precautions to avoid any blending of the treated water with the fresh water before reaching the point of pumping the KAC fresh water to Amman for domestic uses, the reuse option is the first option. A separate water irrigation system can be introduced to separate the fresh from treated wastewater.

Looking into the three options from the economical point of view and the fact that the 50 MCM/a from the Unity Dam is fresh water that can be used directly for municipal purposes in Greater Amman, and the expected revenues out of that in comparing with the irrigation option. The Decision maker will select the Unity Dam as the preferred option from the technical and economical points of view.

It can be seen that WEAP was able to consider the financial implications of the different scenarios in parallel with the technical aspects. This is necessary in the water management of the Jordan Valley to satisfy the integration of utilizing the available water sources.

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حماية المياه الجوفية في دولة قطر

الدكتور/طارق بن موسى الزدجالي
مكتب مدير عام الإدارة العامة للبحوث والتنمية الزراعية
وزارة الشئون البلدية والزراعة
دولة قطر

الخلاصة:

يستهلك قطاع الزراعة في دولة قطر ما يقارب 99% من الكميات المسحوبة من المياه الجوفية حاليا وتتعرض المياه الجوفية إلى مخاطر متزايدة من الاستنزاف جراء الممارسات غير الرشيدة في الري والزراعة والتي تؤدي إلى تدهور كمياتها ونوعيتها على حد سواء.

وتتناول هذه الورقة ما أتخذ من إجراءات جادة خلال عام 2007م -من قبل الجهات المختصة في وزارة الشئون البلدية والزراعة بدولة قطر- لوقف تدهور المياه الجوفية والعمل على ترشيد مياه الري، والتي يمكن تلخيصها في الآتي:

1. إصدار قرار وزاري بشأن وقف الترخيص بحفر أية آبار مياه جوفية إضافية.
2. اعتماد تنفيذ مشروع يختص بدراسة عن المياه الجوفية وتنميتها بغية تأسيس نظام معلومات مياه جوفية شامل يساهم بشكل رئيس في التخطيط لهذا المورد بما يحقق الاستخدام المستدام له.
3. إجراء دراسة بشان دعم وتطوير الأجهزة المعنية بالمياه الجوفية باستحداث إدارة بمسمى "إدارة موارد المياه الجوفية".
4. إجراء مراجعة شاملة لقانون تنظيم حفر أبار المياه الجوفية واستبداله بقانون "حماية المياه الجوفية".
5. مشروع التغذية الاصطناعية للأحواض الجوفية بمياه الأمطار بواسطة آبار التغذية.
6. المشروع الرائد للتغذية الاصطناعية للأحواض الجوفية باستخدام مياه الصرف الصحي المتقدمة المعالجة.
7. اعتماد تنفيذ البرنامج الوطني لتطبيق أنظمة الري الحديثة في كافة المزارع القطرية.
8. التوصية بالتركيب المحصولي الأمثل الذي يحقق أكبر عائد اقتصادي بأقل كمية مياه ممكنة.
9. التوصية بكميات وجدولة الري للمحاصيل المختلفة.
10. تشجيع استخدام التقنيات الزراعية التي من شأنها ترشيد ورفع كفاءة استخدام المياه.
11. العمل على تعزيز الكوادر البشرية الفنية المتخصصة في مجالات تقييم الموارد المائية وإدارتها وكذلك الإدارة الحقلية لمياه الري وتركيب أنظمة الري الحديثة.

مفاتيح كلمات: إدارة موارد المياه، قانون المياه الجوفية، التغذية الاصطناعية، البرنامج الوطني لتطبيق أنظمة الري الحديثة.

المقدمـة:

تعتمد الزراعة القطرية على الري الذي مصدره الرئيس هو المياه الجوفية إلى جانب (33) مليون متر مكعب سنويا من مياه الصرف المعالجة التي تستخدم في مزرعتين فقط لري مساحة (1005) هكتار من المحاصيل العلفية منها (320) هكتار مزروعة بالبرسيم بالإضافة إلى كميات أخرى من مياه الصرف الصحي تستخدم في الزراعات التجميلية.

ونتج عن الاستخدام المتزايد للمياه الجوفية في الأغراض المختلفة في الدولة خلال الفترة 1975-2004م، ظهور وتفاقم مشاكل العجز المائي نظرا لزيادة سحب المياه في موسم 1976/75م من (50) مليون متر مكعب إلى حوالي (180) مليون متر مكعب في موسم 2003 / 2004م كما ارتفع عدد الآبار من (660) بئر إلى أكثر من (3100) في الفترات نفسها، علما بأن متوسط التغذية الجوفية تقدر بحوالي (60) مليون متر مكعب في السنة التي يكون فيها متوسط هطول الأمطار (84) مليمتر، أي أن العجز المائي السنوي في موسم 2004/2003م يقدر بحوالي (113) مليون متر مكعب.

وأدى تراكم العجز جراء استمرار أسلوب استغلال المياه الجوفية إلى تدهور نوعية ومناسيب المياه وتداخل المياه من البحر وكذلك من الطبقات المائية السفلى، الأمر الذي أثر سلبا على الإنتاج الزراعي واستدامته. ومن أسباب تفاقم العجز المائي هي الممارسات غير الرشيدة في الإدارة المزرعية والتي يأتي على رأسها استخدام نظام الري السطحي التقليدي ذو الكفاءة المنخفضة والذي يغطي ما يقارب (38%) من المساحة المروية حاليا وكذلك عدم وجود التربة الجيدة في المزارع وعدم الاهتمام بالعمليات الزراعية التي من شأنها زيادة قدرة التربة على الاحتفاظ بالمياه إلى جانب غياب العمالة الزراعية الماهرة.

تشخيص مشكلة العجز المائي يكثر ويتكرر الحديث عنها في العديد من الدول وعلى مدار سنوات قد تطول، ولكن لا يتبعه إجراءات عملية من شأنها التعامل مع المشكلة لسبب أو آخر غالبا ما يكون المسئول عنها السياسات والإجراءات الخاطئة التي انتهجت في شأن المياه الجوفية واستخدامها والسياسات الزراعية التي لم تراعي مبدأ الاستدامة، وفي حالة اتخاذ إجراءات للتعامل مع حدوث تدهور ما في المياه الجوفية تكون في أكثر الأحيان متأخرة أو متأخرة جدا.

إجراءات حماية المياه الجوفية:

قامت وزارة الشئون البلدية والزراعة في دولة قطر في عام 2007م باتخاذ خطوات جادة من اجل التعامل مع مشكلة العجز في المياه الجوفية بهدف وقف وتقليل التدهور في هذه المياه وعلى المدى البعيد الوصول للتوازن. وفيما يلي يتم تسليط الضوء على هذه الإجراءات:

1- قرار بوقف حفر الآبار:

صدور القرار الوزاري رقم (20) لسنة 2007م بشأن ترشيد استخدام المياه الجوفية ومنع تدهورها وتضمن مواده أحكاما مفادها:

- وقف الترخيص بحفر آبار جديدة في دولة قطر ما عدا آبار المراقبة، وآبار تغذية الخزان الجوفي، وآبار الحقن، وآبار المنفعة العامة.
- ربط حفر بئر بديلة عن البئر القائمة وتنظيف الآبار القائمة في حالة المزارع بتركيب أنظمة الري الحديثة وبمعيار " بئر واحد يكفي لري (40) دونم".

2- مشروع دراسة وتنمية التغذية الطبيعية والاصطناعية للمياه الجوفية في دولة قطر:

البدء في تنفيذ مشروع يختص بدراسة المياه الجوفية وتنميتها بغية تأسيس نظام معلومات مياه جوفية شامل يساهم بشكل رئيس في التخطيط لهذا المورد بما يحقق الاستخدام المستدام له بالإضافة إلى دراسة التغذية الجوفية الطبيعة وكذلك الاصطناعية. ويمكن الأهداف في الآتي:

- مسح كافة الآبار في دولة قطر بهدف الحصول على معلومات حديثة حول التواجد المكاني للمياه الجوفية ومناسيبها ونوعيتها ومعدلات سحبها متضمنة ترقيم كافة الآبار.
- دراسة ميكانيكية التغذية و المشاكل التي تواجه التصميم والكفاءة المتوقعة من آبار التغذية.
- تقييم شبكة آبار التغذية القائمة حاليا والتي تبلغ (341) بئر ودراسة أثر التغذية الاصطناعية عليها.
- تأسيس نظم معلومات مياه جوفية للبيانات الجغرافية والهيدرومترية والجيولوجية والهيدروجيولوجية وربطه بمركز المعلومات الجغرافية وشبكة بالمحطات القائمة للرصد الآلي الكامل ذات التحكم عن بعد.

3- إدارة موارد المياه الجوفية:

دعم وتطوير الأجهزة المعنية بالمياه الجوفية باقتراح استحداث إدارة بمسمى "إدارة موارد المياه الجوفية" حيث أن التقسيم الإداري المعني بالمياه الجوفية حاليا هو عبارة عن وحدة للمياه الجوفية بقسم البحوث المائية في إدارة البحوث الزراعية والمائية التي تتبع الإدارة العامة للبحوث والتنمية الزراعية في وزارة الشؤون البلدية والزراعة. ويعتبر استحداث إدارة تعنى بشئون المياه الجوفية – في حالة الموافقة عليها- دعما هاما للبناء المؤسسي المعني بالمياه الجوفية في دولة قطر ويمكن من خلالها القيام بمهام واختصاصات أكبر من شأنها المساهمة في حماية وتنمية وإدارة موارد المياه الجوفية. وفيما يلي اختصاصات إدارة موارد المياه الجوفية المقترح استحداثها:

- وضع الخطط والبرامج المتعلقة بتقييم وضع موارد المياه الجوفية في دولة قطر، وإدارتها وتنميتها وحمايتها وفقا لإستراتيجيات وقوانين تعتمد في هذا الشأن.
- تشغيل وتطوير وصيانة شبكات المراقبة في الدولة وتسجيل البيانات المتعلقة بها وتحليلها للاستفادة منها في تقييم وإدارة الموارد المائية الجوفية للاستخدامات الزراعية وغيرها.
- تقدير الميزان المائي لمختلف الأحواض بالدولة.
- اقتراح القوانين والتشريعات المتعلقة بإدارة وتنمية موارد المياه الجوفية ومراجعة وتحديث اللوائح المطبقة حسب الوضع المائي ومتطلبات التنمية المستدامة.
- تنفيذ الخطط الخاصة بإدارة وتنمية موارد المياه الجوفية في الدولة والعمل على تحديثها وتطويرها وفقا للأهداف المعتمدة في هذا الشأن.

- دراسة وإصدار التراخيص ذات العلاقة بموارد المياه الجوفية ومتابعة تنفيذها وفق معطيات الوضع المائي في إطار القوانين والأنظمة والإجراءات المتعلقة بموارد المياه الجوفية.
- القيام بالبحوث والدراسات المتعلقة بموارد المياه الجوفية وإدارتها وتنميتها.
- متابعة التطورات المتعلقة بالبحوث والدراسات الخاصة بتقييم موارد المياه الجوفية وإدارتها وتنميتها.

4- قانون المياه الجوفية:

إجراء مراجعة شاملة لقانون تنظيم حفر آبار المياه الجوفية الصادر في عام 1988م واقتراح استبداله بقانون "المياه الجوفية". إن القانون الحالي قد ساهم في الحد من الحفر العشوائي للآبار ونظم إجراءات الحفر وساهم بالتالي في الحد من تدهور المياه الجوفية إلا أن الحاجة أصبحت ماسة لقانون أشمل وللوائح تفصيلية من شأنها حماية المياه الجوفية والمحافظة على الزراعات القائمة وتقليل معدل زحف الملوحة إلى الخزانات الجوفية العذبة وحماية المياه الجوفية من الممارسات التي من شأنها تلويثها. وتتناول أحكام مواد القانون المقترح موضوعات عديدة تهدف إلى حماية المياه الجوفية في دولة قطر وهي :

- ملكية المياه الجوفية للدولة.
- تضع الوزارة الخطط والضوابط اللازمة لاستخدام المياه الجوفية.
- عدم جواز الترخيص بحفر آبار مياه إضافية في مناطق العجز المائي.
- تحديد مناطق حماية مصادر المياه الجوفية وإمدادات المياه العامة وحظر مزاولة أعمال من شأنها تهديد جودة وكمية المياه العذبة المتوفرة فيها.
- تحديد القواعد والضوابط المنظمة لحفر الآبار واستبدالها وإدخال أي تغييرات عليها وصيانتها واستخدام مياهها، وشروط الترخيص بالحفر ومزاولة الحفر.
- إلزام الوزارة باتخاذ ما يلزم للحد من التدهور في كمية ونوعية المياه في حالة حدوث ذلك والعمل على معالجته بما في ذلك حق الوزير في إيقاف سحب المياه الجوفية في أي وقت.
- تحديد القواعد والضوابط المنظمة لتركيب واستبدال المضخات على الآبار، و نقل وبيع المياه، و تركيب وتشغيل و استبدال وحدات تحلية المياه على الآبار و حفر بئر التخلص من نواتج تحلية المياه.
- حظر القيام بأعمال تؤثر سلبا على التغذية الجوفية للخزان المائي.

5- مشروعات تنمية المياه الجوفية:

إقرار مشروعين لتنمية موارد المياه الجوفية ليتم تنفيذهما خلال الأربع إلى خمس السنوات القادمة وهما:

أ- **مشروع التغذية الاصطناعية للأحواض الجوفية بمياه الأمطار بواسطة آبار التغذية** ويتكون المشروع من حفر (1500) بئر تغذية بتكلفة إجمالية تقدر بحوالي (37,5) مليون ريال تتوزع على مدار خمس سنوات ابتداء من السنة المالية 2008-2009م. ويعتمد تنفيذ هذا المشروع على البيانات والنتائج التي سوف يتم الحصول عليها من مشروع دراسة وتنمية التغذية الطبيعية والاصطناعية للمياه الجوفية الذي تم الإشارة إليه

في البند الثاني أعلاه. ويستهدف المشروع زيادة متوسط التغذية الطبيعية بحوالي (30) مليون متر مكعب سنويا.

ب- **المشروع الرائد للتغذية الاصطناعية للأحواض الجوفية باستخدام مياه الصرف الصحي المتقدمة المعالجة** والتي يتوفر منها حاليا ما يزيد عن 160 ألف متر مكعب يوميا. ويتكون من :

- دراسة الجدوى فنية للمواقع المناسبة لحقن كميات من مياه الصرف الصحي المتقدمة المعالجة تقدر بحوالي (20) إلى (30) ألف متر مكعب في اليوم على أعماق قد تصل إلى (70) متر في أوقات الوفرة خلال فصل الشتاء وكذلك دراسة إعادة سحب هذه المياه لاستخدامها لأغراض زراعية.
- حفر آبار الحقن على أعماق تتصل إلى (70) متر.
- حفر أبار مراقبة بأعداد مناسبة.

وتقدر التكلفة التقديرية للمشروع بحوالي (10) مليون ريال تتوزع على مدار سنتين ابتداء من السنة المالية 2010-2011م.

6- البرنامج الوطني لتطبيق أنظمة الري الحديثة:

على الرغم مما تحقق في مجال تطبيق أنظمة الري في المزارع بدولة قطر حيث أنها تغطي ما نسبته (62%) من المساحات المزروعة إلا أن الحاجة ما زالت قائمة للاستمرار في بذل المزيد من الجهد بغية ترشيد كميات أكبر من مياه الري ورفع العائد من استخدامها وذلك لمساهمة في معالجة الخلل في الميزان المائي وتحقيق توازن يهدف إلى استدامة هذا المورد ورفع الكفاءة الإنتاجية وتحقيق قدرا مناسبا ومستداما من الإنتاج الزراعي المحلي.

ويتوقع من خلال تعميم تطبيق أنظمة الري الحديثة في كافة المساحات المزروعة في دولة قطر توفير كميات من المياه قد تصل إلى (10) مليون متر مكعب سنويا جراء التطبيق المباشر للأنظمة إلى جانب توفير كميات إضافية نتيجة إتباع جدولة مناسبة موصى بها للري.

ومن هذا المنطلق قامت وزارة الشؤون البلدية باعتماد تنفيذ البرنامج الوطني لتطبيق أنظمة الري الحديثة و الذي يهدف إلى الآتي:

1- تطبيق أنظمة الري الحديثة لري المساحات الزراعية القائمة في كافة مزارع دولة قطر.
2- بناء قواعد بيانات دقيقة عن استهلاك المياه الجوفية.
3- متابعة وتقويم أنظمة الري الحديثة القائمة في المزارع والتوصية بتطويرها وصيانتها إذا ما أستدعى الأمر.
4- التوصية بكميات ومواعيد الري.

ويستهدف البرنامج تركيب أنظمة الري الحديثة على مساحة من الأرض المزروعة تقدر بحوالي (30) ألف دونم على مدار (6) سنوات وتركيب عدادات على كافة الآبار في

المزارع وعددها (3300) بئر على مدار (4) سنوات، وذلك بكلفة تقديرية إجمالية قد تصل إلى (60) مليون ريال.

7- إجراءات بشأن ترشيد استخدام المياه الجوفية:

إن ترشيد استخدام المياه الجوفية لا يقتصر على تطبيق أنظمة الري الحديثة فقط فهناك حاجة فعلية لتنفيذ مجموعة من الإجراءات التي من شأنها المساهمة في الترشيد قد يكون بعضها ذات تأثير إيجابي أكبر من تطبيق أنظمة الر ي الحديثة . لذا بدأت الإدارة العامة للبحوث والتنمية الزراعية بوزارة الشئون البلدية والزراعة في دولة قطر مراعاة الآتي:

أ- **تحديد التركيب المحصولي الأمثل:**

للتركيب المحصولي علاقة مباشرة بكميات المياه المسحوبة من الخزان الجوفي للاستخدامات الزراعية بل ربما تكون أحد أهم العوامل التي من شأنها المساهمة بفعالية إما في الحد من تدهور المياه الجوفية أو تفاقم تدهورها، لذا كان من الضروري مراعاة هذا العامل عند التخطيط لحماية موارد المياه الجوفية في دولة قطر حيث أن التركيب المحصولي القائم وفقا لإحصائيات عام 2004م هو على لنحو التالي:

- 14023 دونم من الخضروات.
- 13338 دونم من الحبوب أكثر من 50% عبارة عن شعير.
- 17053 دونم من النخيل والفاكهة منها 14535 دونم نخيل.
- 25441 دونم من الأعلاف الخضراء تروى 10050 دونم منها بمياه الصرف الصحي المعالجة.

ويتضح من الإحصائيات أنه يمكن النظر في تقليص مساحات الأعلاف الخضراء التي تروى بالمياه الجوفية والتي تقدر بحوالي 15391 دونم عند تتوفر موارد مياه بديلة كمياه الصرف الصحي المعالجة التي يتوقع أن يزيد كمياتها في السنوات القادمة لتزيد عن 250 ألف متر مكعب في اليوم وتبذل الوزارة جهود حثيثة للحصول على كميات إضافية تقدر بحوالي 9 مليون متر مكعب من مياه الصرف الصحي لكي تستخدم في زراعة مساحة 3000 دونم من الأعلاف الخضراء.

كما أن الوزارة تعكف حاليا على إجراء دراسات بشأن التركيب المحصولي الأمثل الذي يحقق عائد اقتصادي مناسب ويلبي احتياجات السوق المحلي ويتناسب مع الموقف المائي من حيث الكم والنوع وذلك توطئة للتوصية بالتركيب المحصولي الأمثل الذي يحقق أكبر عائد اقتصادي بأقل كمية مياه ممكنة ووضع الآليات التي من شأنها تحقيق ذلك.

ت- **التوصية بكميات وجدولة الري للمحاصيل المختلفة:**

لا يمكن الحديث عن ترشيد مياه الري دون إعطاء توصيات للمزارع بشأن كميات المياه الواجب استخدامها لري المحاصيل المختلفة وعدد مرات إضافتها خلال شهور العام ووفقا لنوعية المياه، كما لا يمكن الحديث عن الترشيد بترك القرار في هذا الشأن للعامل الزراعي. ومن هذا المنطلق أجرت الوزارة اتصالات مع بيوت خبرة عالمية لوضع برنامج متكامل يعنى بحساب المقننات المائية ونقل هذه المعلومات وتوفيرها

للمزارعين وأصحاب المزارع من خلال أنشطة إرشادية وإعلامية تتزامن مع تنفيذ البرنامج الوطني لتطبيق أنظمة الري الحديثة.

ث- استخدام التقنيات الزراعية التي من شأنها ترشيد ورفع كفاءة استخدام المياه الجوفية:

وتركز الوزارة في هذا الشأن على البيوت المحمية المبردة وغير المبردة في إنتاج الخضروات وتهدف إلى تقليص مساحات زراعة الخضروات في الحقول المفتوحة والتي تبلغ 14023 دونم وزيادة مساحة زراعتها في البيوت المحمية والتي تبلغ 572 دونم. وتعمل في سبيل ذلك على الاتصال بالجهات المختصة في شأن منح قروض ميسرة للمزارعين لتركيب بيوت محمية في مزارعهم وبدون فوائد وفترة سماح سنة واحدة من أجل تشجيعهم على تبني هذه التقنية. كما تعمل الوزارة على تشجيع استخدام الأسمدة والمواد الحافظة للرطوبة التربة و تغطية سطح التربة بأغطية متعددة إدخال محسنات التربة المختلفة والأهم من هذا وذاك دعم البحوث الزراعية بالكوادر البشرية القادرة على تنفيذ برامج بحثية من شأنها دراسة وتقييم ملائمة التقنيات الحديثة للظروف القطرية.

8- تعزيز الكوادر البشرية:

تعمل الوزارة على تعزيز الكوادر البشرية الفنية المتخصصة في شئون موارد المياه الجوفية وإدارتها وكذلك الإدارة الحقلية لمياه الري وتركيب أنظمة الري الحديثة وذلك بزيادة عدد الهيدروجيولوجيين والهيدرولوجيين ومراقبي الآبار وأخصائي نظم المعلومات الجغرافية و أخصائي تصميم أنظمة الري الحديثة والفنيين المساعدين . كما تعمل الوزارة على تشجيع الفتيين الوطنين العاملين في مجال المياه الجوفية على استكمال دراستهم الجامعية على نفقتها.

<u>الخاتمــة:</u>

إن الإجراءات الجادة التي اتخذتها وزارة الشئون البلدية والزراعة بدولة قطر في عام 2007م والتي تهدف إلى وقف تدهور المياه الجوفية وترشيد استخدام مياه الري، سوف تواجهها تحديات كبيرة وبحاجة إلى المتابعة والتقويم ويقترح لاستكمال ما تم البدء به ولبلورة الرؤية العامة لإستراتيجية الحفاظ على الموارد المائية الجوفية وتنميها في دولة قطر، الشروع في إعداد خطة وطنية لإدارة وتنمية موارد المياه الجوفية في دولة قطر إلى عام 2025م تسعى إلى إعادة التوازن المائي والتنمية المستدامة للمياه الجوفية وفي الوقت نفسه كون القطاع الزراعي يستهلك ما نسبته 99% من إجمالي الكميات المسحوبة من المياه الجوفية فإنه يقترح بضرورة تحديد سياسات زراعية واضحة الملامح يتبعها تنفيذ خطط تراعي مبدأ الاستدامة.

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An Advanced Technology for Groundwater Treatment in the Northern Aquifer of the State of Qatar

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ABSTRACT

At present, a significant number of Qatar greenhouses employ pad-and-fan cooling systems. Groundwater is used as the water source for the cooling system. However, this water contains high concentrations of scale-forming substances such as calcium, magnesium, sulfate, silica, carbonate, and phosphate. These solids cause plugging of the greenhouse pads due to the formation of the scale on the surface. Sulfate and silica scales are harmful and they are difficult to remove. This research investigates the feasibility of using an advanced softening process called the ultra-high lime with aluminum process (UHLA) for Qatari groundwater treatment to remove sulfate. Equilibrium model of the chemical processes in the UHLA was developed to predict final concentrations and chemical behavior of the treated water using information on the chemical doses and initial concentrations in the feed water. Equilibrium results indicated that the UHLA can remove sulfate efficiently.

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Keywords: Sulfate, UHLA, scale, softening

INTRODUCTION

Groundwater is almost the only source for irrigation in Qatar, with the exception of few farms which are using treated sewage effluent for producing fodder crops. Drip, sprinkler and flood irrigation systems are used in those farms. Groundwater from the Dammam, Rus, and Umm er-Radhuma formations is used to provide water. Water quality in some locations is good, and ranges between 800 and 2000 mg/L as Total Dissolved Solids (TDS). However, for most of the aquifer, water quality ranges from 2000 to 6000 mg/L (UN 2001). There are two separate and distinct groundwater provinces: the northern province, where groundwater occurs as a freshwater 'floating lens' on brackish and saline water and the southern one where no such lens exists and where water quality is generally brackish with only a thin veneer of freshwater at the top of the water table. Representative groundwater sample from the freshwater lens at the northern aquifer at one of the greenhouses locations in northern Qatar is given in Table 1.

Protected agriculture, greenhouses, in Qatar was introduced in 1976 in cooperation with Food and Agriculture Organization (FAO) of the United Nations. By 1998, the areas of greenhouses were about 65 hectares and continue in growing (Al Mohammadi and Moustafa, 1998). The temperature inside a greenhouse is higher than the ambient temperature outside it (hence, the greenhouse effect). Such high temperatures reduce crop quality and worker productivity. Because of this fact, greenhouses may require both summer and winter cooling systems. Evaporative cooling is the most common method for reducing the temperature inside the greenhouse. Evaporative cooling is a process that reduces air temperature by evaporation of water into the airstream. As water evaporates, energy is lost from the air causing its temperature to drop. Currently, the majority of greenhouses located in Qatar employ pad-and-fan cooling systems (Figure 1).

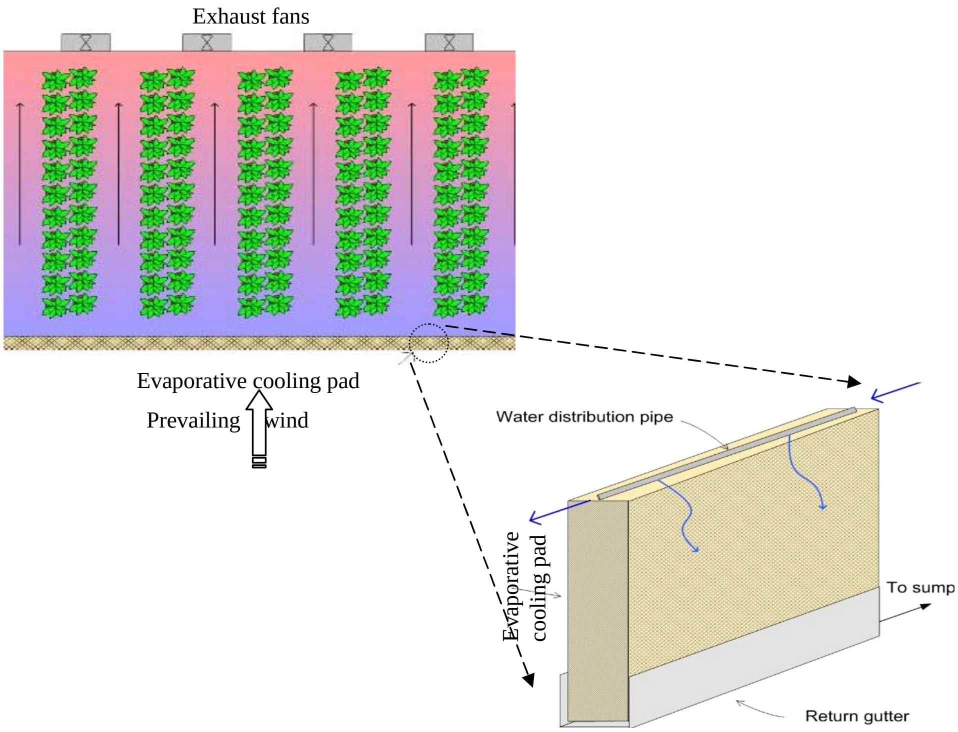

Figure 1. Typical pad-and-fan greenhouse cooling system
(modified from Bucklin et al., 2004).

For pad-and-fan systems, an evaporative cooling pad is installed in the ventilation opening, ensuring that all incoming ventilation air travels trough the pad before it can enter the greenhouse. The pads are typically made of a corrugated material that is glued together in such a way as to allow air to pass through it while ensuring a maximum contact surface between the wet pad and the air. Water is pumped to the top of the pad and released from the supply pipe through small openings along the entire length. At the bottom of the pad, excess water is collected and returned to a sump tank so it can be reused. The sump tank is outfitted with a float valve allowing for make-up water to be added. Since a portion of the recirculating water is lost through evaporation, the salt concentration in the remaining water increases over time (Bucklin et al., 2004).

Pads are susceptible to clogging when the concentrations of scale-forming materials are high in the feed water. Such clogging and scaling can substantially decrease the heat transfer efficiency of the system and shorten the equipment life. In addition, the recycling of cooling water can be limited by decreased water quality resulting when dissolved solids are concentrated by evaporation in the system. An attractive approach for maximizing the efficiency of the cooling system while avoiding the problems of scale inhibitors, is to remove the scalants from the feed water. Sulfate and silica are the most common and aggressive scale forming materials. Sulfate exists in high concentrations in the central and northern groundwater aquifers in Qatar. Reverse osmosis, ion exchange, or electrodialysis (Matson and Harris,

1979) can be used to remove sulfate. However, these technologies are expensive and have many operating problems. The unit price of water treatment using reverse osmosis is about three times the price of lime softening (You et al., 1999). Additionally, theses technologies produce brine that needs to be disposed off. An advanced softening process called the ultra-high lime with aluminum process (UHLA) was initiated (Abdel-Wahab and Batchelor, 2007, 2006a, 2006b; Abdel-Wahab et al., 2005) and it is an innovative modification of high lime softening, in which aluminum is added with lime. It has the ability to remove sulfate, silica, and chloride, in addition to the majority of scale-forming compounds, such as calcium, magnesium, carbonate, and phosphate.

In an effort to investigate the feasibility of using UHLA process to treat groundwater for the cooling system of Qatari greenhouses, a chemical equilibrium model of the chemical processes that was developed by Abdel-Wahab et al. (2005) was used herein. The specific goal was to study the techno-economic feasibility of sulfate removal from the feed groundwater using UHLA process.

METHODOLOGY

A fundamental model of the chemical processes in the UHLA process was used to predict final chemical concentrations in the treated groundwater in central and northern parts of Qatar. Representative composition of feed groundwater for Qatari greenhouses in northern areas was used as an input to the equilibrium modeling. The configuration of the UHLA process that was modeled in this study is shown in Figure 2. The treatment process consists of two stages. In the first stage, lime and sodium aluminate are added to remove sulfate and silica as calcium sulfoaluminate and calcium aluminisilicate. In the second stage, carbon dioxide is added to adjust pH.

Precipitation was assumed to be the mechanism that controls the solubility of the species in the system. PHREEQC software (Parkhurst and Appelo, 1999) was used for equilibrium modeling. PHREEQC is a computer program written in the C programming language PHREEQC is a computer program for simulating chemical reactions and transport processes in natural or polluted water. The program is based on equilibrium chemistry of aqueous solutions interacting with minerals, gases, solid solutions, exchangers, and sorption surfaces, but also includes the capability to model kinetic reactions with rate equations that are completely user-specified in the form of basic statements. The flexible format of the PHREEQC input file allows models to be built and used to simulate a wide variety of aqueous-based scenarios.

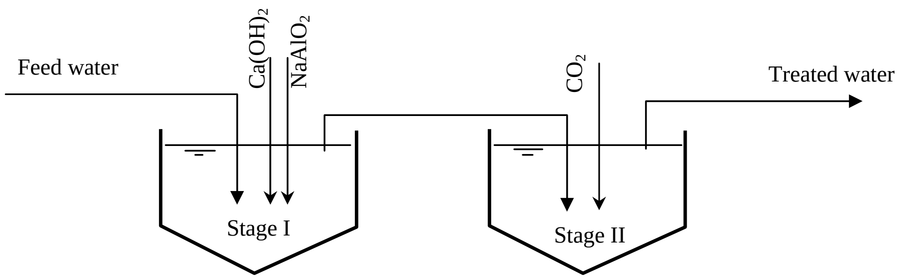

Figure 2. Configuration of two stages UHLA process.

A series of simulations were conducted to evaluate the feasibility of UHLA process in removing sulfate form the groundwater. Influent water quality shown in Table 1 and various lime doses were used as input data to the model. Sodium aluminate doses were chosen to be one-third of lime doses which is the ratio that was recommended by Abdel-Wahab and Batchelor (2007). Reaction temperature was kept constant at the feed water temperature of 35^{o}C. The database of PHREEQC was modified to include new solids and their solubility products, new aqueous species and solid solution formations. Table 2 shows the solubility products (Ksp) for the new solids that were included in PHREEQC database using stoichiometric reactions reported by Abdel-Wahab and Batchelor (2007).

RESULTS AND DISCUSSIONS

Figure 3 shows the effect of lime doses on final concentrations of sulfate as predicted by the model and indicates that sulfate concentration decreased with increasing lime doses at fixed aluminum dose of 0.33 g/L.

Predicted results indicate that sulfate can be removed very efficiently with reasonable doses of lime and sodium aluminate. The final effluent concentrations of the treated water when using 0.9 g/L lime and 0.33 g/L sodium aluminate and after adjusting pH to pH 7 using carbon dioxide following the precipitated process are shown in Table 1. Table 1 shows significant decrease not only in the concentration of sulfate but also the concentrations of other scale-forming materials such as calcium, magnesium, and carbonate. Carbonate is believed to be removed as calcium carboaluminate solid. This consumed some of the lime and aluminum doses added to remove sulfate. An alternative configuration, in order to minimize the use of the chemical doses, is to remove carbonate in a stage prior to the UHLA process by precipitation as calcium carbonate using lime only without the need for sodium aluminate. This will minimize the amount of sodium aluminate dose required to remove sulfate.

Table 1. Comparison between raw water quality and predicted treated water quality.

Constituent	Raw water quality (mg/L)	Predicted treated water quality (mg/L)
Calcium	86	1.25
Magnesium	94	0.05
Sodium	86	171
Potassium	2	2
Total Carbonate	226	92
Sulfate	509	82
Chloride	149	149
pH	7.13	7.50

Table 2. New solids and their solubility products used in equilibrium modeling.

Solid name	Ettringite $Ca_6Al_2(SO_4)_3(OH)_{12}$	Monosulfate $Ca_4Al_2(SO_4)(OH)_{12}$	Tricalcium hydroxyaluminate $Ca_3Al_2(OH)_{12}$	Tetracalcium hydroxyaluminate $Ca_4Al_2(OH)_{14}$
Log (Ksp)	-44.55	-29.43	-19.72	-25.02

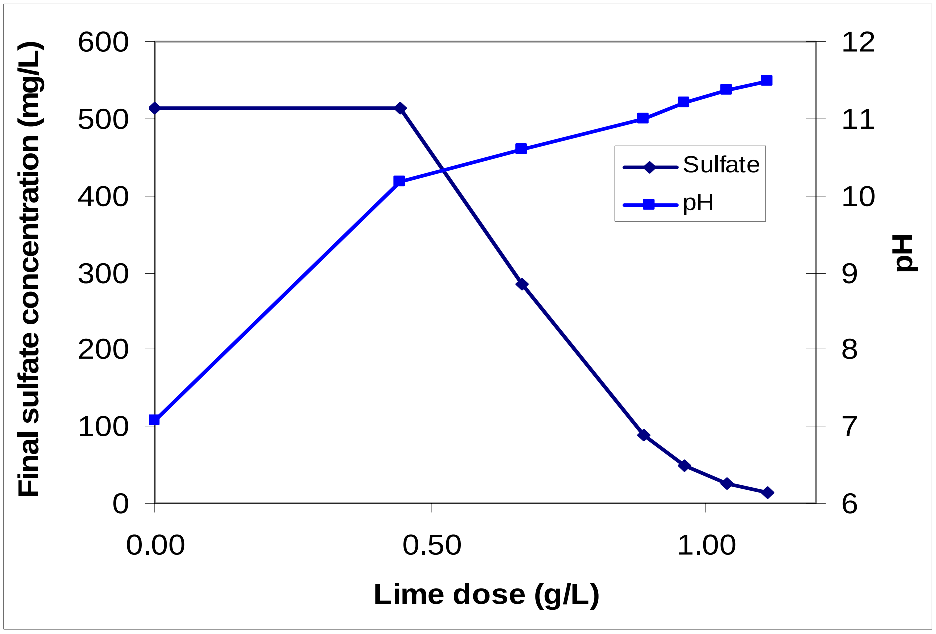

Figure 3. Effect of lime dose on final sulfate concentrations.

CONCLUSION

The feasibility of using a two-stages UHLA treatment process to remove sulfate from the Qatari greenhouse cooling water was evaluated. Equilibrium modeling was applied to predict final sulfate concentrations and chemical behavior in the system using information on the chemical doses and initial concentrations in the feed groundwater. Results of the model indicate that sulfate can be removed efficiently at reasonable doses of lime and sodium aluminate. The amounts of lime and sodium aluminate that needed to be applied depend on the required removal efficiency of sulfate.

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Density – Dependent Flow and Transport Model of a Carbonate Aquifer

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Abstract

This carbonate aquifer is a major groundwater resource for some industrial and domestic activities in a remote region. Although the aquifer is under flowing conditions, its water is saline to very saline. This condition requires a proper groundwater management and planning strategies.

A 3D geostatistical model was constructed to characterize the pre-development groundwater quality condition in the aquifer. The model shows vertical stratification of TDS concentrations and indicates that water quality deteriorates with depth and toward the northern part of the aquifer.

A 3D variable density flow & transport model was also developed to assess the impact on water availability and quality due to long-term aquifer exploitation. The model shows that the aquifer will sustain the required water demand but that water salinity will increase from 9,500 mg/l to about 11,300 mg/l. The modeling approach applied to this case can be utilized in modeling and managing other salinity-threatened aquifers in the GCC countries.

Keywords: Aquifer management, salinity, geostatistics, numerical model, SEAWAT-2000

Introduction

Aquifer modeling techniques like geostatistical procedures and numerical simulators provide good management tools to predict groundwater hydrodynamics and salinity distribution. The objective of this study is to develop a quantitative understanding of the aquifer's hydrodynamics that will be used as a basis for sound development strategies, management implementation, and decision-making procedures. This objective will be achieved by assessing the existing groundwater resource condition and its ability to supply water for different purposes, defining water quality deterioration patterns, and evaluating the existence of saline water upconing. The tools used in this study are the lognormal geostatistical model of WinGSLIB 1.3 and the density-dependent flow and transport simulator (SEAWAT-2000 of Visual MODFLOW PRO 4.1). Results of this study can be utilized to understand the long term behavior of head and salinity distribution when the aquifer is subjected to some proposed pumping scenarios. In addition, the results can also be used to support decision-makers in selecting the locations of newly installed pumping and monitoring wells.

Due to lack of detailed water quality data from different vertical sections in water wells, a 3D geostatistical model was constructed to substitute for this deficiency. The model generated the initial distribution of salinity prior to aquifer development. Furthermore, the density-dependent flow & transport model was developed using historical data and the initial TDS concentration condition estimated by the geostatistical model.

Although no simulator can depict nature precisely, results obtained from this study compare well with the limited field observations. This indicates that the model is an adequate tool to simulate aquifer's hydrodynamics; hence it could be employed to test different futuristic management and planning scenarios. In addition, this attempt to use density-dependent simulators could be repeated and used to simulate flow & transport in other aquifers.

Hydrogeologic Setting and Water Quality

The aquifer is found in a carbonate rock unit. Conceptually, the aquifer is subdivided into three layers on the basis of hydrogeologic importance. Water gradient is S-SW to N-NE. The flow pattern is affected by local variations in thickness and permeability due to fracturing and cavities.

Groundwater quality in the aquifer is characterized by the total dissolved salts (TDS) values of water. Although the aquifer is considered saline to very saline, different studies indicated the presence of an acceptable water quality (9,000 – 14,000 mg/l) at the middle eastern aquifer's section. The water quality in the northern part of aquifer deteriorates rapidly and an increasing trend of salinity is observed with depth.

Salinity Geostatistical Model

A Geostatistical model was developed to characterize the salinity behavior at different aquifer layers. The tools utilized in constructing this model are the semivariogram of salinity and Kriging estimation procedure. The software employed to perform this task is WinGSLIB (Deutsch and Journal, 1998). The theory of geostatistics and its applications to hydrogeologic problems is discussed in details in Kitanidis (1997).

A power model semivariogram $\gamma(h) = 0.0009\ h^{1.35}$ was utilized to build a Kriging model for aquifer's salinity spatial distribution. $\gamma(h)$ is the modeled semivariogram value at lag distance h. The Kriging plan was designed using power model parameters of 0.0009 to represent model slope and 1.35 for model power value. Horizontal and vertical search radii of 10,000 m and 10 m respectively were used in estimating salinity values at unsampled locations. A 3D salinity model of 51,920 blocks was generated using lognormal (logarithmic) Kriging procedure.

Figure 1 shows an example of N-S vertical cross section extracted from the Kriging model output. A combination of these cross sections was used later on to assign the TDS initial conditions for the numerical simulator.

A clear representation of the mixing / fingering front in the flow regime is shown in the figure. Contacts between relatively fresh (TDS ≤ 10,000 mg/l – black) and brackish (TDS between 10,000 and 50,000 mg/l - gray) waters represent a scheme similar to traditional coastal fresh–saline water system with an advancing-mixing front. As relatively fresh water flows from the south, the mixing front pushes more saline water towards the north. The fingering between different types of water is due to variable water densities, flow rate of fresh water entering the field from the S and SW, and aquifer heterogeneity.

SEAWAT-2000 Simulator

A 3D variable density ground water flow & transport model of the aquifer was developed to aid in water management. Due to aquifer's high salinity, accurate representation of variable-density groundwater flow is necessary to characterize and predict the hydrodynamics of the system. Model results will be used to define long-term plans and optimize locations for additional water supply wells for future development projects.

SEAWAT-2000 simulator, a Visual MODFLOW Pro 4.1 USGS numeric engine (Waterloo Hydrogeologic Inc., 2005), was used to model the aquifer. This simulator is used to model 3D variable-density transient flow & transport in saturated porous media. It combines MODFLOW and MT3DMS codes into a single program that solves the coupled flow and solute transport equations. SEAWAT-2000, which is based on the concept of equivalent fresh water head in a saline aquifer, assumes that density is a function of solute concentration only. It assumes also that viscosity and compressibility differences between fresh and saline water are negligible (Oude Essink, 2001a, Guo and Langevin, 2002 and Langevin et. al., 2003).

The governing variable-density flow equation used in SEAWAT-2000 is expressed as follows:

$$\frac{\partial}{\partial \alpha}\left[\rho K_{f\alpha}\left(\frac{\partial h_f}{\partial \alpha}+\frac{\rho-\rho_f}{\rho_f}\frac{\partial Z}{\partial \alpha}\right)\right]+\frac{\partial}{\partial \beta}\left[\rho K_{f\beta}\left(\frac{\partial h_f}{\partial \beta}+\frac{\rho-\rho_f}{\rho_f}\frac{\partial Z}{\partial \beta}\right)\right]+$$

$$\frac{\partial}{\partial \gamma}\left[\rho K_{f\gamma}\left(\frac{\partial h_f}{\partial \gamma}+\frac{\rho-\rho_f}{\rho_f}\frac{\partial Z}{\partial \gamma}\right)\right]=\rho S_f\frac{\partial h_f}{\partial t}+\theta\frac{\partial \rho}{\partial C}\frac{\partial C}{\partial t}-\rho_s q_s$$

where:

α , β , γ are the orthogonal coordinate axes

h_f is fresh water head (L)

ρ and ρ_f are saline water and fresh water densities (M/L^3), respectively

K_f is equivalent fresh water hydraulic conductivity (L/T)

S_f is equivalent fresh water specific storage (1/L)

t is time (T)

θ is porosity

C is solute concentration (M/L^3)

ρ_s is fluid density source / sink (M/L^3), and

q_s is volumetric flow rate of source / sink per unit volume of aquifer

The governing solute transport equation used in SEAWAT-2000 is

$$\frac{\partial C}{\partial t}=\nabla .\left(D .\nabla C\right)-\nabla .\left(\vec{v} C\right)-\frac{q_s}{\theta}C_s+\sum_{k=1}^{N}R_k$$

where:

D is the hydrodynamic dispersion coefficient (L^2/T)

V is the fluid velocity (L/T)

C_s is the solute concentration entering from source / sink (M/L^3) and

R_k is the reaction term (M/TL^3) of N different reactions

Both governing equations are coupled in SEAWAT-2000 by a linear equation of state that represents fluid density as a function of solute concentration (Langevin, 2003). The current simulator does not consider the effects of pressure and temperature on fluid density during execution. It utilizes the following equation of state:

$$\rho = \rho_f + \frac{\partial \rho}{\partial C} C$$

where:

$\frac{\partial \rho}{\partial C}$ is the density / concentration gradient that is calculated from a range of field values.

SEAWAT-2000 solves the governing flow equation by either explicit or implicit Finite Difference Method (FDM) and solves the governing solute transport equation by either FDM or Method of Characteristics (MOC).
One of the important features of SEAWAT-2000 is that the head input / output should be / is written, respectively, in terms of aquifer heads although the flow equation is written in terms of equivalent fresh water head. This means that the program converts automatically the actual aquifer head data into equivalent fresh water head during the computational process and does the reverse before writing heads to the output files (Langevin et. al., 2003). Equivalent fresh water and actual water head equations used in the program are:

$$h_f = \frac{\rho}{\rho_f} h - \left[\left(\frac{\rho - \rho_f}{\rho_f} Z \right) \right]$$

$$h = \frac{\rho_f}{\rho} h_f + \left[\left(\frac{\rho - \rho_f}{\rho} Z \right) \right]$$

Model Design and Calibration

The entire modeled system consists of a 3D grid and it is divided into 70 columns by 98 rows by 3 layers. Model cell sizes vary in the horizontal plane from 1000 m X 1000 m near the boundaries to 200 m X 200 m near the pumping wells. The grid consists of 20,580 active elements.

Initial condition for hydraulic heads, in meters, was entered in the model from pre-development wellhead pressures measurements. The Geostatistical model slices were utilized to define the initial condition for solute concentration in mg/l. Good estimate of concentration initial condition, which was computed by geostatistics in this case, is considered a very important model input when dealing with 3D problems (Oude Essink, 2001b). Both heads and TDS concentration initial conditions were considered from dates prior to the actual abstraction date. Distant no flow boundaries were considered in all vertical sides of the model. They were selected, based on an analytical solution, such that the heads and concentrations in the vicinity of the boundaries will not be affected during the simulation as explained in Anderson and Woessner (1992). Top and bottom of the model were also no flux boundaries to reflect the confined nature of the aquifer.

The calibrated hydraulic conductivity varies in the aquifer from 1.25 X 10^{-7} m/s to 6.25 X 10^{-5} m/s in its upper productive parts. The bottom layer is assumed to have a constant value of 2 X 10^{-10} m/s. The ratio of vertical to horizontal hydraulic conductivity was assumed to be 0.1. Calibrated storage coefficient varies between 1.03 X 10^{-7} (in the lower part of the aquifer) and 3.3 X 10^{-6} (in the upper units of the aquifer). A constant value of porosity of 0.30 was considered for the entire modeled system.

Due to lack of information and after several trail and error procedures, a longitudinal dispersivity (α_L) and molecular diffusion (D_m) values of 27m and $6.6X10^{-2}$ cm^2/s were assumed, respectively, to represent the hydrodynamic dispersion part of the solute transport equation. α_L value is close to the one computed by Schulze-Makuch and Cherkauer (1997) for large scale carbonate aquifers. The linear relationship between density and TDS concentration obtained from field data show that the density / concentration slope is 0.743. The minimum and maximum temperature & pressure compensated density values used in model execution were 1007 and 1060 kg/m^3, respectively. These density values were estimated by Kutasov equation (1989) to account for pressure and temperature effects on density in aquifers. The NaCl-dominated fluid was treated as a conservative solute with no reaction or sorption.

The root mean square error (RMSE) for heads was about 0.9 m. This means that about 70% of the head differences were between ME + 0.9 and ME – 0.9 m. Because of its sensitivity to density differences, the model was calibrated with respect to TDS concentration distribution to reduce uncertainty. This task was performed on a trail and error basis. The concentration ME, MAE, and RMSE were -12, 12, and 17 mg/l. These values were considered satisfactory indicators for a calibrated model taking into consideration the large range of and differences in TDS concentrations in this aquifer.

Model Results

To simulate the behavior of aquifer's hydrodynamics, a transient simulation period of 9125 days (25 years) was selected. Different stress periods were selected to approximately reflect the anticipated changes in well production rates. SEAWAT-2000 was run by solving the flow equation conditioned to a forward in time and central in space mathematical solution.

A 3rd Order Total Variation Diminishing (TVD) approach was coupled with an implicit solution and utilized to solve the advection / dispersion term of the solute transport equation. This approach minimizes solution instabilities associated with 3D complex problems like variable-density flow and transport simulation (Gottlieb and Shu, 1998).

At the end of simulation period, the model illustrated that a regional water level decline and directional deviation will affect the domain although most of the wells were used for only a short period of time (Fig. 2). Only one cone of depression will be developed near the permanent abstraction center. The estimated head drop will approximately be 60 m by the end of simulation as indicated in Fig. 3. Rapid decline in head during the period extended from 1,200 days to 2,000 days is due to high combined production rates from the pumping wells in abstraction center.

Fig. 4 shows the salinity trend during the simulation period. As expected, the trend reflects a salinity increase over the 25 years period. Concentration increase by about 1,600 mg/l will affect wells in the water abstraction center. Concentration increase may be mostly due to the horizontal migration of saline water in the aquifer and upconing of lighter-density fluid toward the well as shown in Fig. 5. Moreover, it is expected that density difference between saline and very saline waters retards the brine from transporting upward to the producing wells. Under natural flowing conditions, very highly saline water remains practically horizontal and does not upcone toward the well (Zhou et. al., 2005).

CONCLUSIONS

- The conceptual model of the aquifer is similar to traditional coastal aquifer saline water intrusion model. However; the minimum TDS concentration is in the range of 10,000 mg/l and above.
- The 3D salinity model, generated by geostatistics, indicates that the aquifer has less mineralized water in its eastern and southeastern zones. However, TDS concentration tends to increase moderately towards the west and severely in the northern direction. The model also shows that water salinity increases with depth.
- The model shows that better quality water (TDS ≤ 10,000) could be extracted from the eastern part of the aquifer from the middle layer. This section of the aquifer is believed to be the most productive unit.

- Simulation of variable density groundwater flow & solute transport is a viable technique for characterizing the behavior of groundwater in a fresh-saline or saline–very saline aquifer systems. Analyzing more than a single process (i.e. flow, transport, and density vs. flow only) at a given site provide different information, new insights, and better understanding of the flow regime.
- SEAWAT-2000 is a conceptually straightforward and easy to use density-dependent groundwater flow and solute transport simulator. It uses the existing user-friendly Visual MODFLOW family interface to input / output modeling requirements / results. The model utilizes mathematical methods to minimize numerical dispersion and solution instabilities effects like the Method of Characteristics (MOC) and TVD, respectively.
- The numerical simulator suggests that the aquifer will be able to cover water demands for the about 20-25 years with relatively acceptable salinity increase in the vicinity of producing wells. However, head drop in the producing water well fields may require the installation of pumps to enhance water abstraction.
- The model showed that TDS concentration increase is most probably due to upconing of saline waters at the lower part of the middle layer. More dense saline water is expected to reside at the bottom layer of the aquifer without tendency to upcone.

Acknowledgment

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Fig. 1 N-S salinity distribution cross section through aquifer. Black: TDS<= 10,000 mg/l and Gray: TDS = 10,000 – 50,000 mg/l

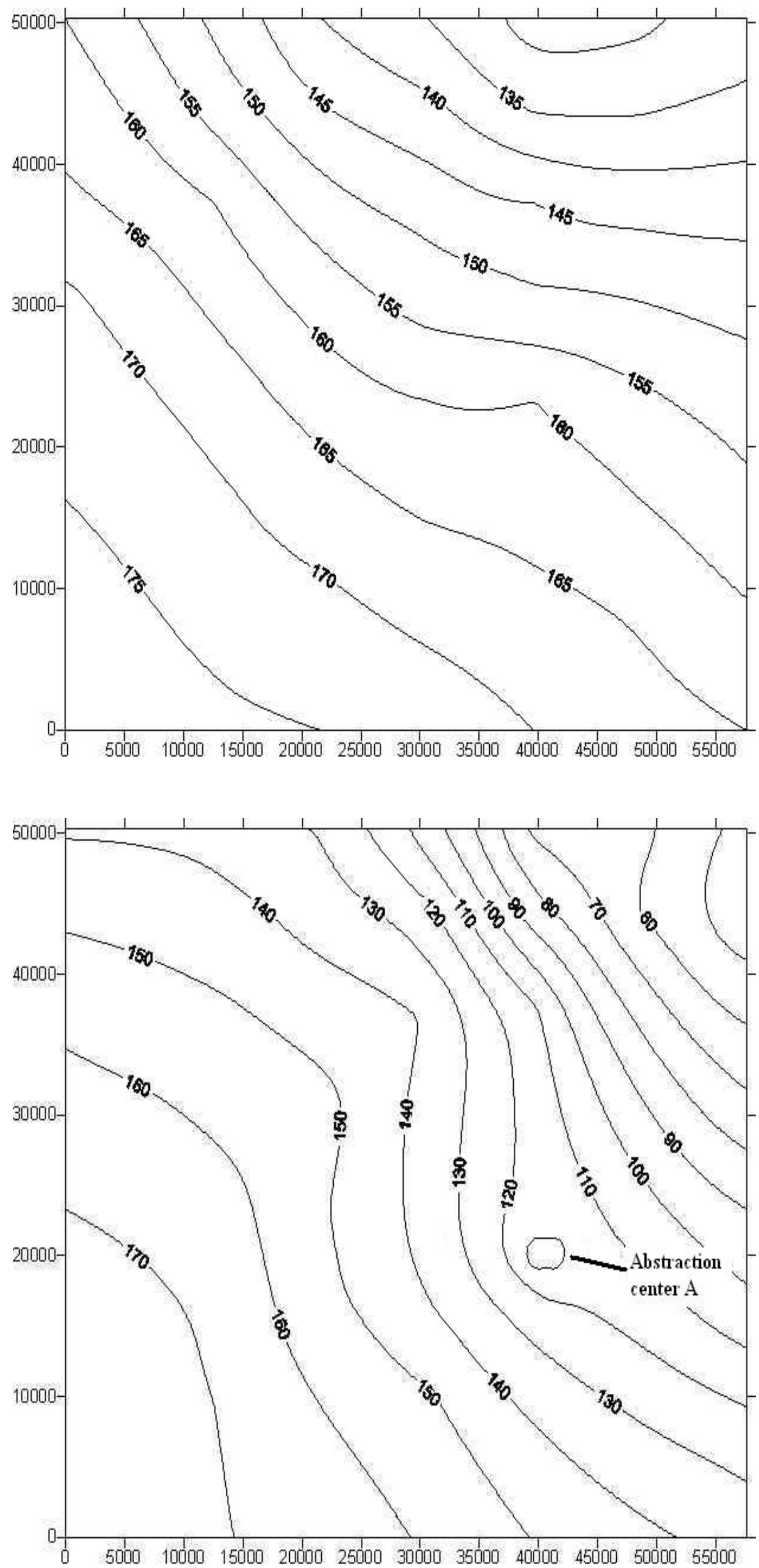

Fig. 2 Potentiometric surface. Initial (upper) and at the end of simulation period (lower).

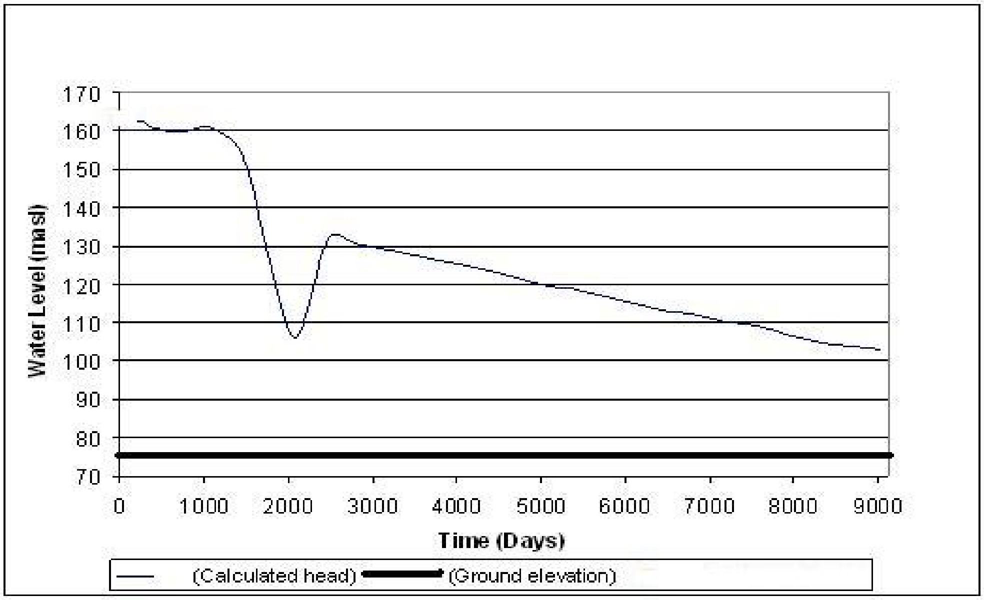

Fig. 3 Predicted water level at the end of simulation period in a monitoring well in abstraction center A.

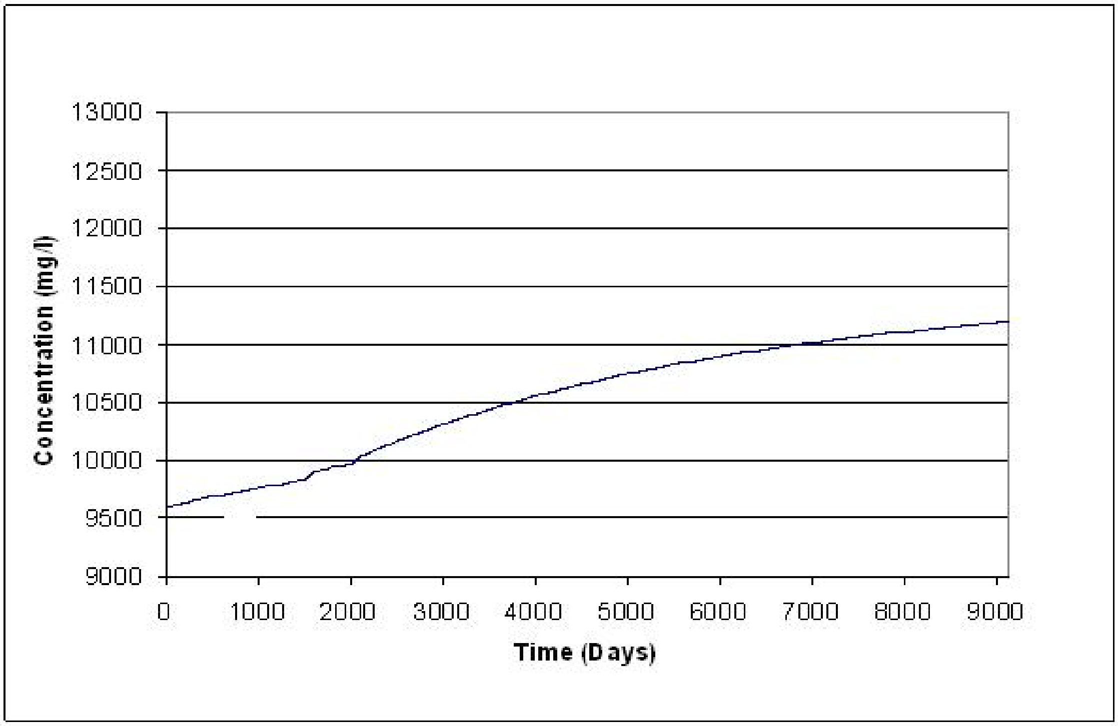

Fig. 4 Predicted TDS concentration during the simulation period in a monitoring well in abstraction center A.

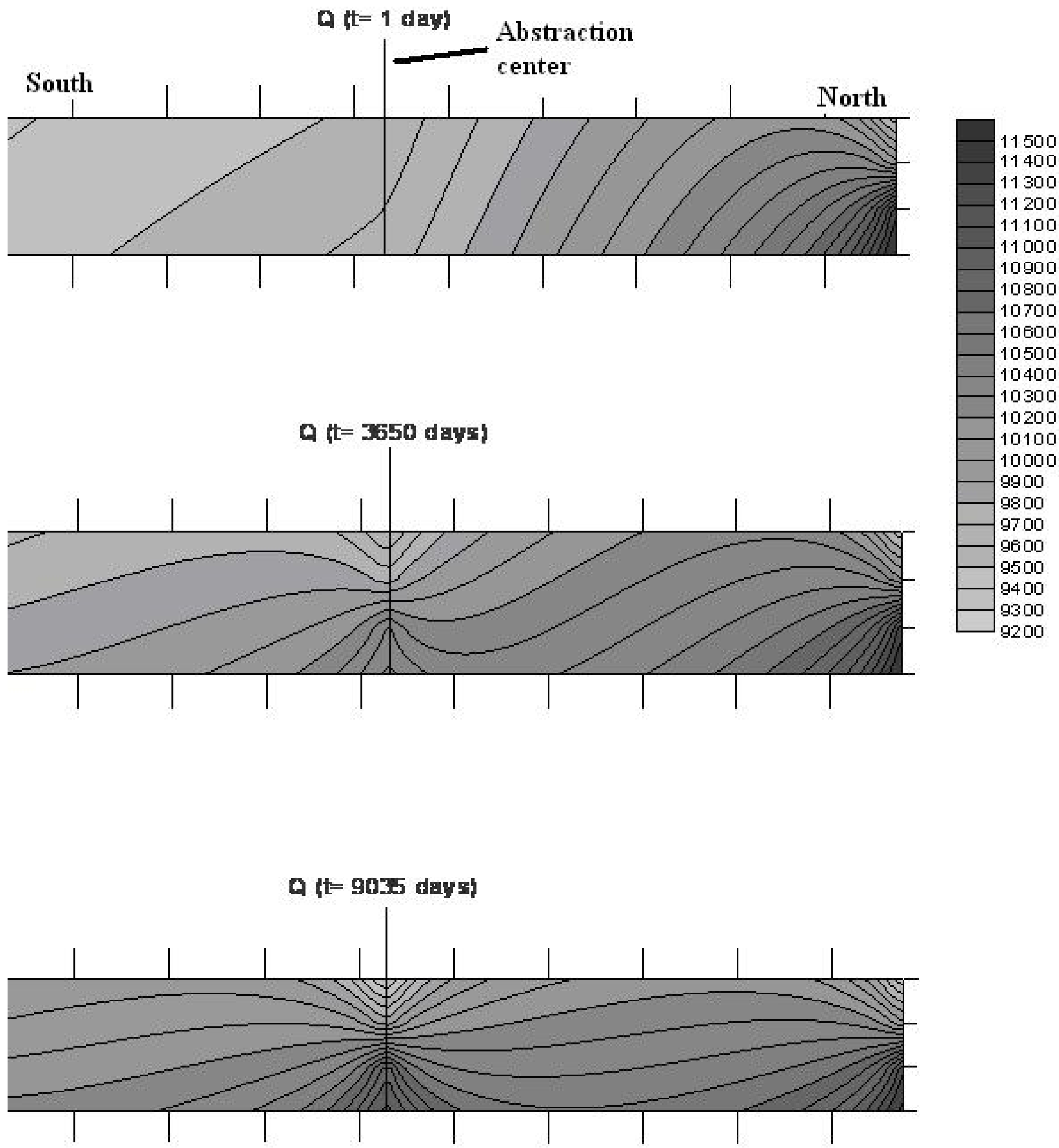

Fig 5 Schematic diagram for upconing that affected a monitoring well in the abstraction center A during different simulation times. Darker colors represent higher TDS in mg/l

Assessment of Groundwater Aquifer Recharge in some wadis by

Using Different Isotope Methods in UAE
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ABSTRACT

Due to recharge – discharge imbalance severe depletion of ground water table has occurred in most of aquifers in The United Arab Emirates. This problem has severe negative environmental impact like salt water intrusion dewatering of shallow aquifer. To minimize this impact the UAE government has built more than 114 refutation and definition dams . To assess the increase in ground water recharge increase from these dams, Isotopes Methods were used to calculate such increase in three major wadies named as Wurrayah and Tawean dams. Hydrochemical and Isotopes data (^{18}O, ^{2}H and ^{3}H) have clearly showed a meaningful contribution to the recharge through the dam A tentative Isotopic balance based on stable Isotopes of rains water stored by these dams drove to a quantification of the artificial recharge ranging from less than 10% in wadi Taween up to 40% in wadi al Wurrayah.

Keywords: Isotopes hydrology, Wadi Wurrayah , Wadi Tawean, Hydrogeochemical Aspects

1. Introduction

The United Arab Emirates (UAE) lies in the southwestern 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 Sultanate of Oman and the Gulf of Oman and on the South and west by the Kingdom of Saudi Arabia. The total area of the United Arab Emirates is about 83,600 km^2. Most of the land is desert and characterized by predominance of aeolian landform system. The geomorphologic features include mountains, gravel, sand dunes, coastal zones and draining basins. Renewable water recourses in the UAE are very limited. No surface water in the form of rivers & lakes is available. The rainwater is very scare, random and infrequent. The average rainfall is in the order if 110 mm/yr. However, this number of rainfall is mostly encountered in few events .

The UAE is divided into two distinct zones: the larger low-lying zone and the mountains zone. The first covers over 90% of the country's area, extending from the northwest to the eastern part of the country where it is truncated by mountains zone. The low-lying zone ranges in altitude from the sea level up to 300 meters. Its major part is characterized by the presence of sand dunes which rise gradually from the coastal plain reaching their highest elevation of 250 m above sea level (amsl). Along the coast of the Arabian Gulf, the low-lying land punctuated by ancient raised beaches and isolated hills which may reach up to 40 m in some locations .

Due to the recharge-discharge imbalance, a distinctive depletion of groundwater table has occurred in most aquifers in UAE. The existing imbalance has originated as a consequence of lack of natural recharge and extensive groundwater abstraction. Groundwater recourses in the UAE have been over exploited to meet the increasing water demands, especially for agricultural purposes, during the last two decades. The classical result of such over-pumping practices is the depletion of and quality degradation of groundwater recourses. Evidences indicated that groundwater levels have declined sharply in the farming areas over the last three decades.

For example, an average drawdown of 100 meters was calculated for the period 1969-2005 in Al Dhaid area (Akaram and others, 2008 in the same volume)

Detention dams are designed to retard the flow velocities and allow appropriate time fore the recharge process to take place. Retention dams are designed for water storage with large quantities and relatively high hydraulic heads. On the other hand, water might be used directly from the storage for irrigation purposes. During the last two decades the UAE government has built more then hundred dams. In addition to the numerous dams, several observation wells have been installed to monitor the subsurface water levels as well as changes in water quality.

Within this framework, the current study aims to develop a better understanding of the recharge mechanisms and groundwater flow patterns in the hydrological systems of two selected dam sites, namely Wadi Wurrayah and Wadi Tawiyaen sites (Fig. 1 and 2). The main objective of this study is the evaluation the effectiveness of dams in recharging shallow groundwater aquifer by using geochemical and isotopic techniques.

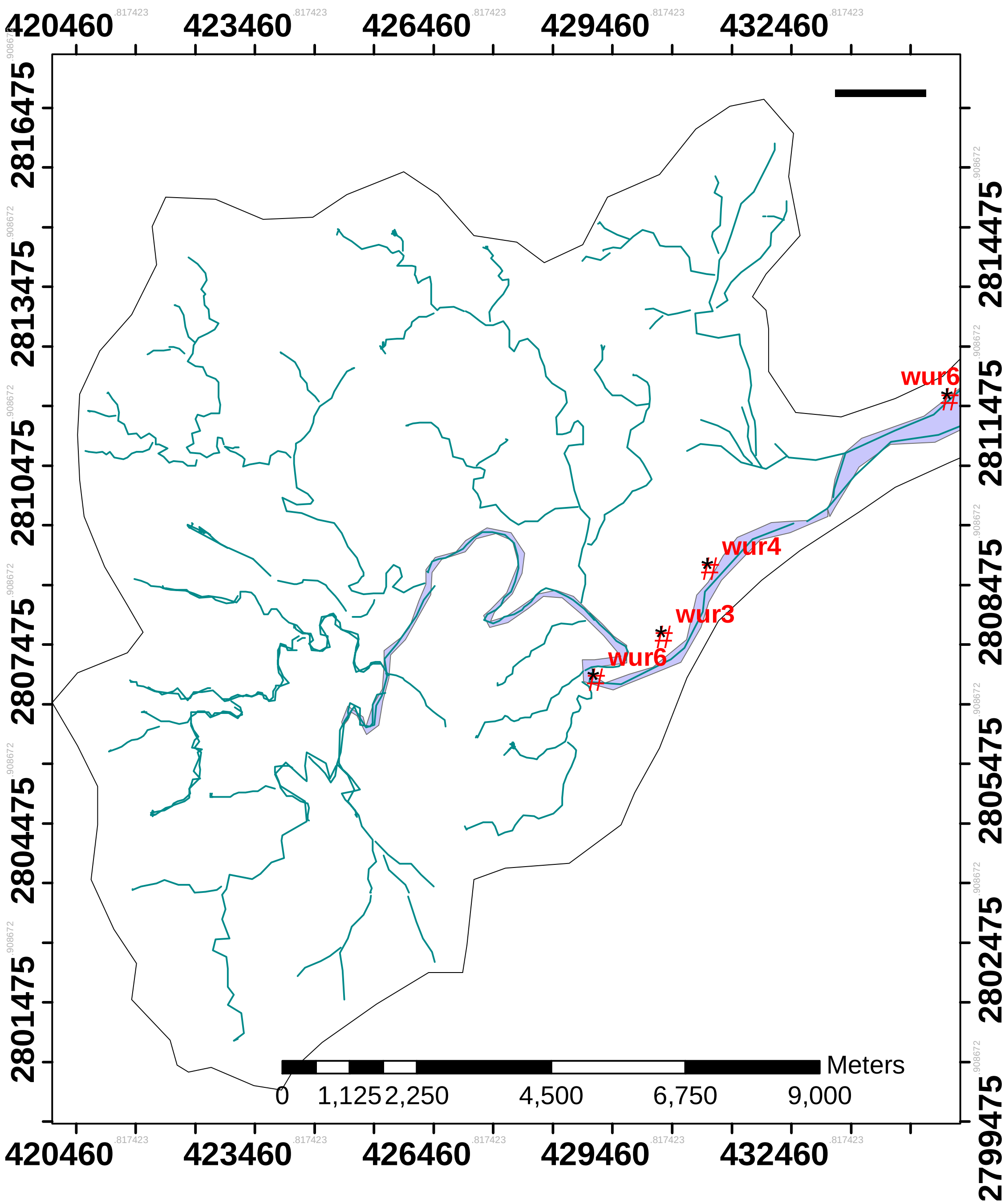

Fig. 1 Catchment area of wadi Wurriah. Locations of monitoring wells are also shown.

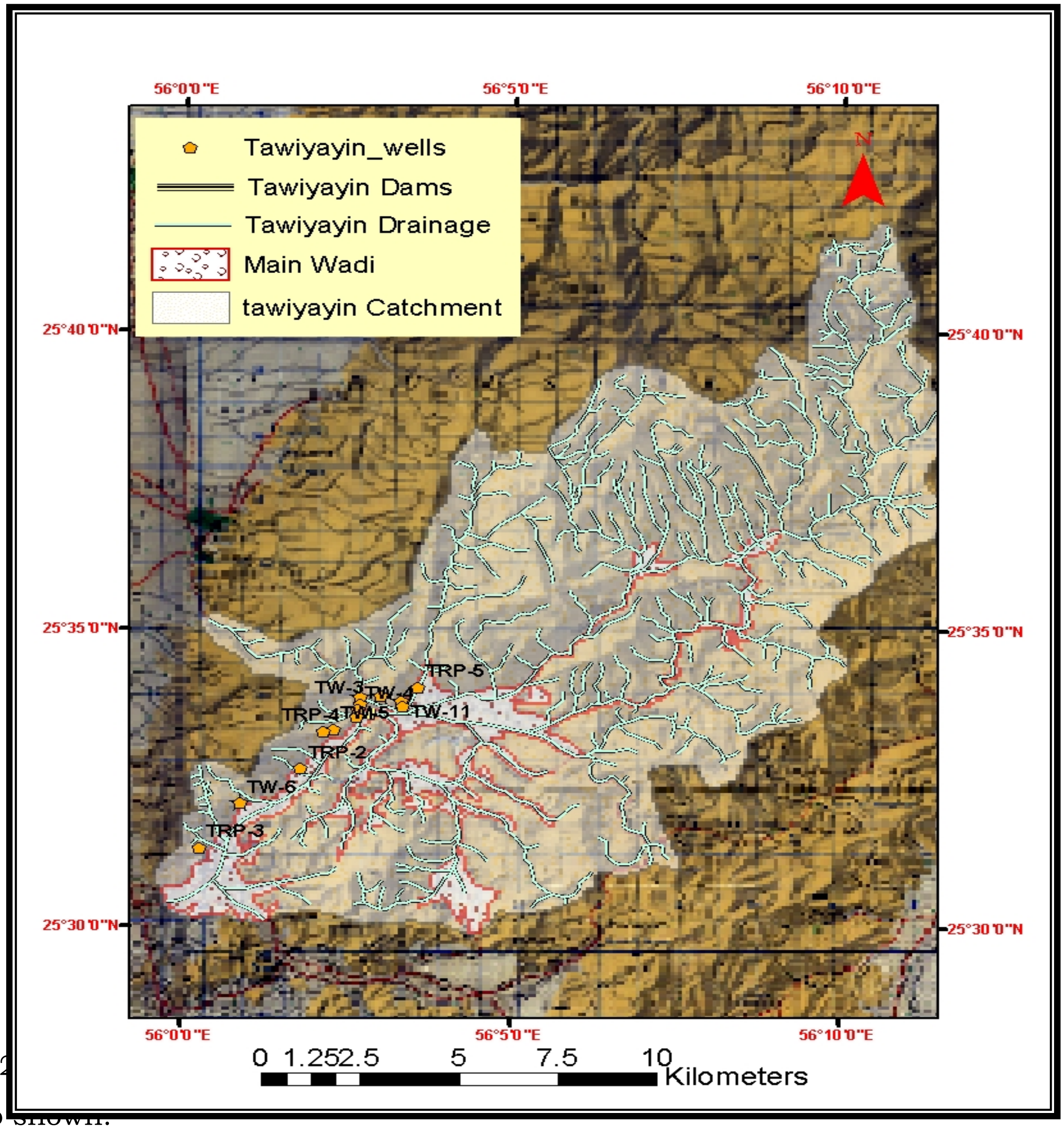

Fig 2

also shown.

2. Hydro geochemical Aspects of Groundwater in the Shallow Aquifers

2.1 Local meteoric water line.

During this study data collection of rainfall water have been assured to define a local meteoric line using isotopic data obtained in the framework of an other study realized in UAE between 1984and 1990.

The analysis of these data reveals the following

- In The $^{18}O^{2-}H$ diagram of the obtained data about 80% of the sample fall between the global meteoric line (CRAIG,1961) and the East Mediterranean meteoric line (NIR,1967).The rest of the sample exhibit an evaporation effect which concern especially the sample collected during the rainy season (March and April (Fig. 3).

- Considering only the non evaporated sample, susceptible to assure a refill of the shallow aquifer, the representative points plot on a line close to that of the East Mediterranean meteoric water, with the equation: $^{2}H = {}^{18}O + 17$. This line reveals the significant effect of the vapour masses coming from the oriental Mediterranean on the regional precipitation (Fig. 3)

- This line is agreement with the one of North Oman defined by Dansgaard (1964), using data from rain events characterized by a significant amount (say> 20mm).which can saturate the air column and minimize evaporation of droplets. The slope of this line is close to 8, and excess in deuterium is about 16 (Fig. 3).

2.2. Wurrayah Wadi basin, Eastern region,

The Wurrayah dam was constructed in 1997, approximately 5km North-west of Khor Fakkan town, on the Samail Ophiolite bedrock, which comprises fractured and mineralized assemblages of serpentenite and gabbroic rocks. The catchment area covers 129 km^2 .

2.3 Discussion of geochemical data of the Wurrahya Wadi basin

The measured values of the TDS and major elements concentration in the sampled wells are represented in the Table 1 , The mean TDS value in the dam reservoir water was 119 mg/L. Water samples collected from the shallow wells located near the dam are characterized with Low TDS value(WUR 3-6) This may indicate that the recharge of these wells is probably from the dam reservoir. This hypothesis is confirmed by the Schoeller-Brerkal off diagram (Fig.4) which shows practically the same water families .

However the slight differences in Ca^{+2} and Mg^{+2} concentrations in the dam water and the control wells groundwater can be explained by the cation-exchange with clay minerals in the shallow aquifer. The piper diagram (Fig.5) also confirm this

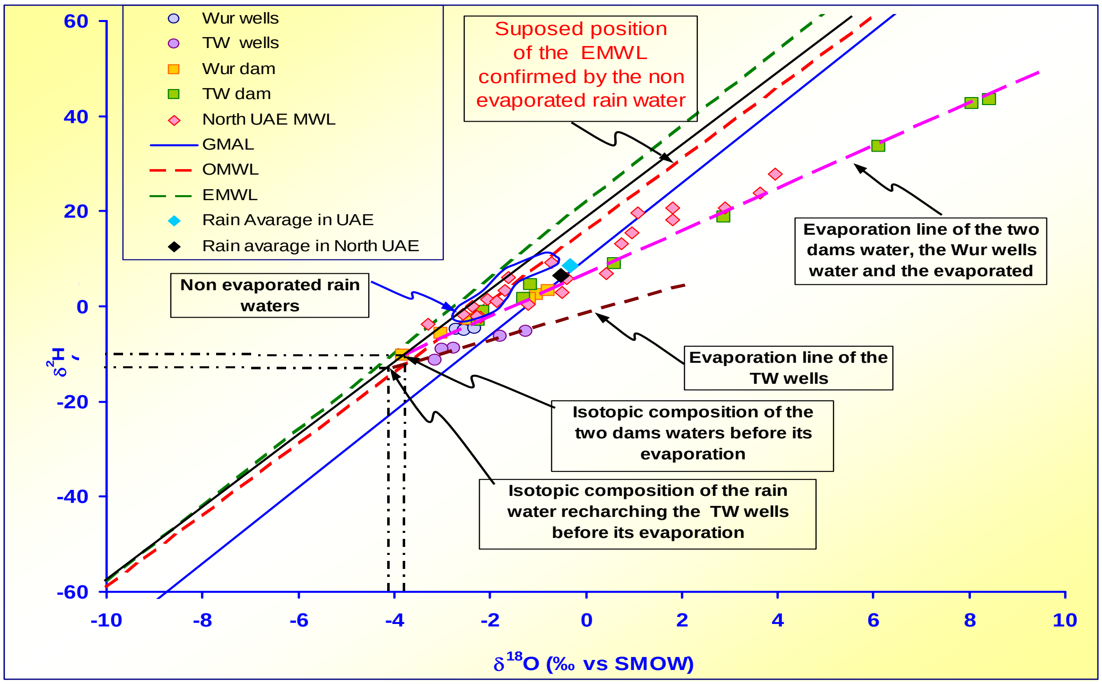

Fig. (3) ^{18}O / ^{2}H Diagram of Wurrayah , Tawyeen Dams and shallow wells

suggestion and indicates comparative water types for the dam reservoir and control wells, especially Wur 3 and Wur5. This also agree with the bivariate diagram between Cl^- and Na^+ (Fig 6) which shows that the water samples of observation wells plot on the same line with the dam reservoir water sample.

Position of each groundwater sample in this line is proportional to the distance from the dam, indicating probably the same origin as the dam reservoir water or varying mixture of dam water with the original groundwater.

Table 1 : Mean values of the TDS and major elements concentration in the Wurryiah dam reservoir and the Observation wells

Mean	TDS	Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	$CO3^{-2}$	$HCO3^{-}$	Cl^{-}	$SO4^{-2}$	$NO3^{-2}$
Wur – 3	257.36	6.23	40.09	23.44	2.04	5.96	109.29	48.34	23.19	6.81
Wur – 5	258.50	3.50	32.00	25.50	3.50	4.50	83.50	65.50	65.50	29.00
Wur – 6	278.50	3.70	21.11	49.87	6.15	7.43	92.04	72.27	19.49	3.24
Wur Dam	119.00	16.82	8.68	6.28	1.84	0.00	62.50	21.40	6.56	6.78

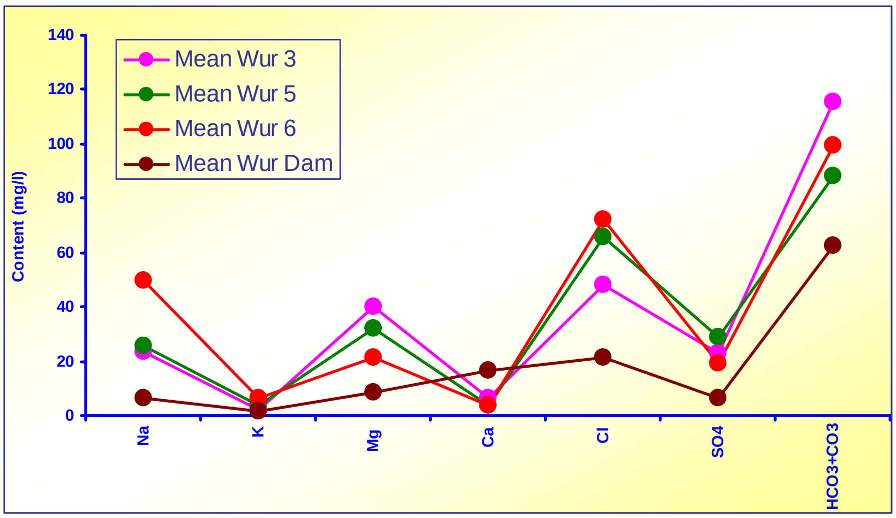

Fig (4)   : Schoeller-Berkallof diagram of Tawiyaen Obser. wells and Dam reservoir water

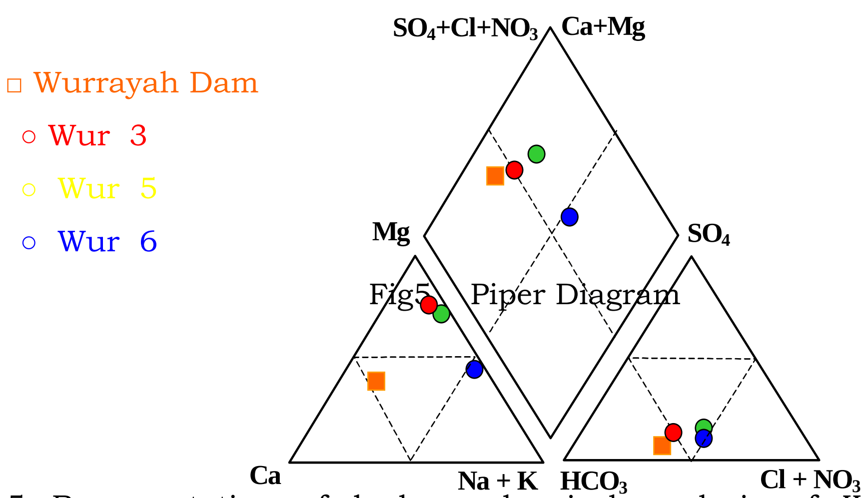

Fig.5 Representation of hydrogeochemical analysis of Wurrayah water samples on Piper Diagam.

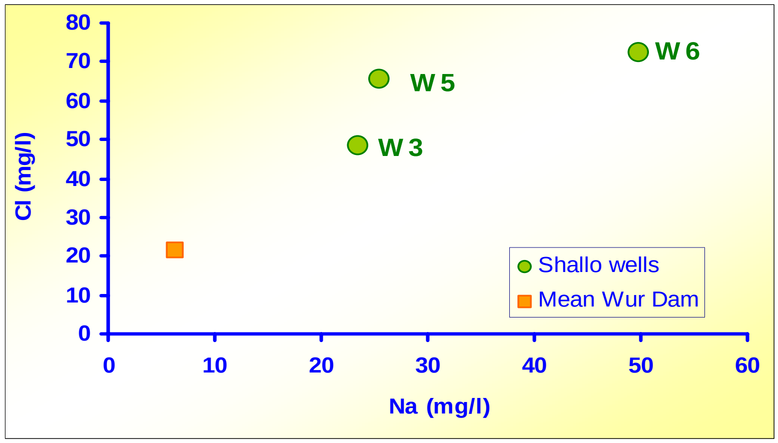

Fig.6 Bivariate diagram between Cl^{-} and Na^{+} concentration in Wurrayah water samples.

2.4 Discussion of isotopic data

The observation wells and the Wurayah dam reservoir were sampled for the stable isotopes (^{18}O,^{2}H) analyses in the period December 2002 to June 2003 . The wells Wur3 and Wur6 were sampled 14 times while the well Wur5 and the dam reservoir water were sampled two times and sex times respectively . the maximum and the minimum as well as the mean values for each sample are represented in the table 2

Table (2) Maximum and minimum Values of stable isotopes in Wadi Wurayah

	$^{2}H^{+}$	$^{18}O^{-2}$	$^{2}H^{+}$	$^{18}O^{-2}$	$^{2}H^{+}$	$^{18}O^{-2}$
Wur 3	- 5.90	- 2.86	- 3.60	- 2.58	- 4.81	- 2.71
Wur 5	-2.86	- 2.82	- 2.54	- 2.54	- 5.05	- 2.53
Wur 6	- 2.82	- 2.38	- 3.32	- 2.22	- 4.54	- 2.32
Wur Dam	- 3.83	- 3.30	- 3.30	- 0.78	- 1.83	- 2.04

Mean values of stable isotopes contents in observation wells groundwater are represented in the $^{18}O/^{2}H$ diagram together with oxygen 18 and deuterium contents of the dam reservoir water and the rainwater samples collected between 1984-1990 in the North and the East of the UAE

2. In Wurayah case the trend constituting by the evaporated samples of precipitation and dam reservoir waters coincide completely with the evaporation line of the control wells (groundwater). This evidenced clearly indicates that these waters have the same origin. Thus, the control well groundwater seems to be recharged by the dam reservoir water

In order to evaluate the dam reservoir water contribution in the shallow aquifer in the Wadi Wurayah basin an isotopic balance model has been tentatively established using stable isotopic data and their relationship.Computed values of the dam reservoir contribution to the shallow aquifer vary from 22 to 43% (Table.3).

Table.(3) : Dam reservoir contribution estimated by the isotopic balance.

	Average ^{18}O	Dam reservoir contribution (%)
Wur no .3	-2.71	43.02
Wur no .5	-2.53	34.1
Wur no 6	-2.32	22.09

The result of this isotopic balance evidenced that groundwater in the observation wells represents a mixture between the dam reservoir water and the present rainwater. Indeed , the computed values of dam reservoir water confirm the important contribution of this water in recharging the control wells aquifer , especially in the case of the wells wur3 and wur 5, which are more closer to the dam.

2-5. Tawiyean Wadi basin, Northern region.

The dam in Wadi Tawiyean was constructed in 1992 on the bedrock consisting of Jurassic to Cretaceous limestone. The capacity of the dam is 18.4 mcm. Its catchment area covers 198 km^2 (Fig 2).

5-3 . Discussion of geochemical data of the Tawiyean Wadi basin

The mean value of salinity and (TDS) major elements concentration in the sampled wells are reported in the Table 4 The TDS mean value in the dam reservoir water was 253 mg/1. In the shallow wells (groundwater). This value varied from 222 mg/1 measured in the well TW2, to 1044 mg/1 measured in the well TW9.

The wells TW2, TW6, TW8and TW9, located downstream of the dam, showed a T DS values higher than the salinity of the dam water. These wells are logically recharged by the dam reservoir water, since the TDS values increase in the same direction of the groundwater flow.

Table (4): Mean values of the TDS and major elements concentration in the Tawiyean dam reservoir and the Observation wells

Mean	TDS	Ca	Mg	Na	K	Co3	Hco3	CI	SO4	NO3
TW2	221.83	29.17	16.33	12.00	3.00	2.17	137.00	22.171	14.50	8.50
TW6	504060	48.60	18.60	83.80	4.80	1.40	213.00	81.40	72.20	22.60
TW8	934.50	22.33	12.83	265.83	5.00	5.83	236..17	248.17	126.50	11.17
TW9	1044.5	39.25	19.23	200.83	4.80	0.08	234.52	168.86	156.20	27.94
TW DAM	253	6.14	3.57	41.00	1.14	2.00	27.14	37.00	35.57	7.57

5-4 Discussion of isotopic data

The observation wells and the Tawiyean reservoir were sampled during the summer and the spring of 2002 and 2003 for stable isotopes (^{18}O . ^{2}H) analyses . The maximum and the minimum as well as the mean values for each sample are represented in Table (5).

Similar to Wadi Wurayah different a graphical presentations of the hydro geochemical analysis results have been made for Wadi Taween as depicted in Figures 7-9.

Table (5) : maximum and minimum values of stable isotopes

	Mean values		Maximum values		Minimum values	
	^{2}H	^{18}O	^{2}H	^{18}O	^{2}H	^{18}O
TW 2	-3.14	-11.24	-1.84	-5.55	-3.42	-12.70
TW 6	-2.75	-8.69	-2.67	-6.65	-2.84	-9.60
TW 8	-2.99	-8.07	-2.92	-1.00	-3.11	-11.70
TW 9	-1.79	-6.19	-1.42	-4.40	-3.27	-11.80
TW Dam	2.13	16.62	8.43	43.40	-2.25	-2.85

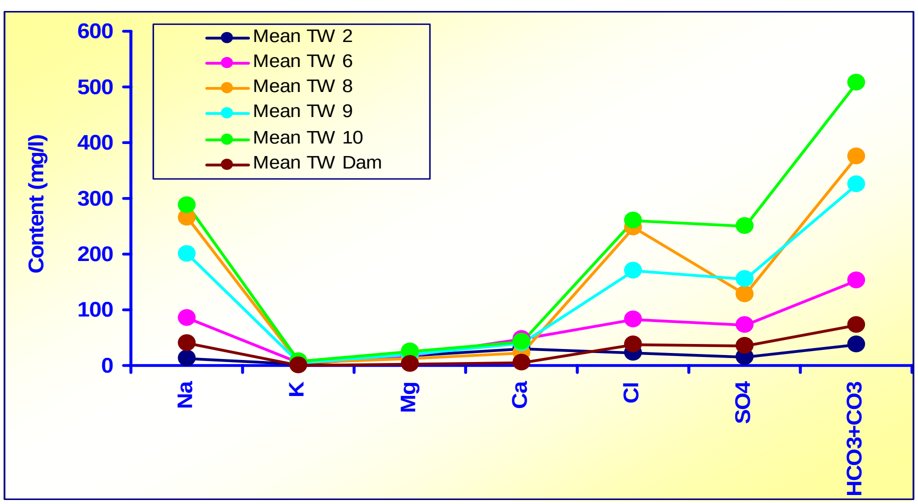

Fig (7) : Schoeller-Berkallof diagram of Tawiyean Obser. wells and Dam reservoir water

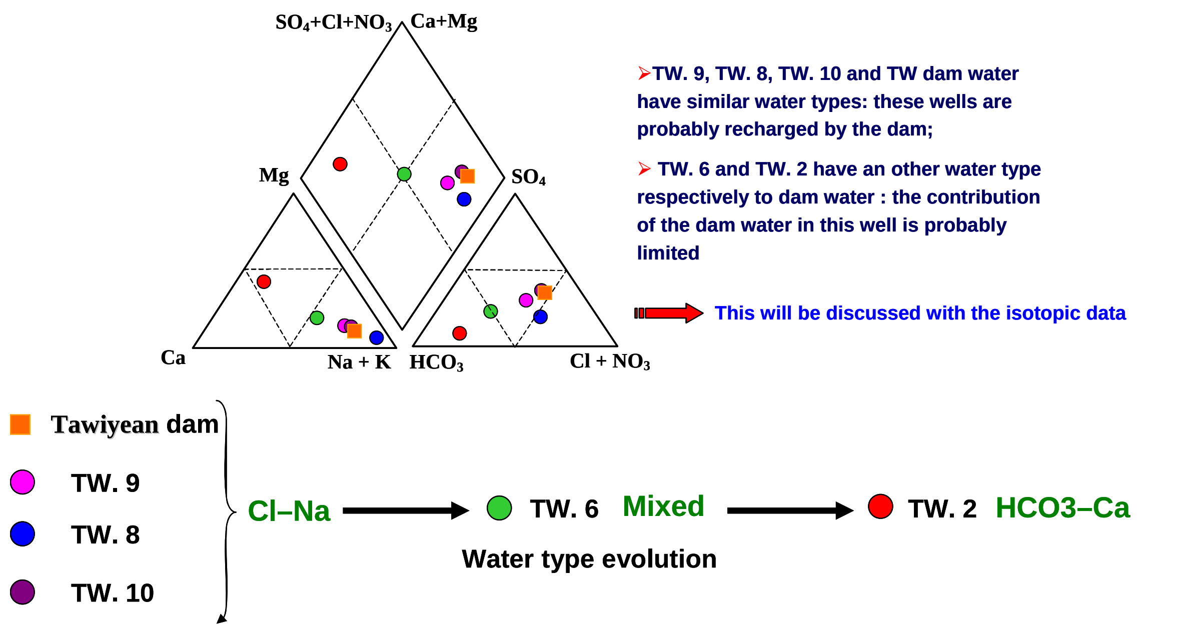

Fig.8 Representation of hydrogeochemical analysis of Wurrayah water samples on Piper Diagam

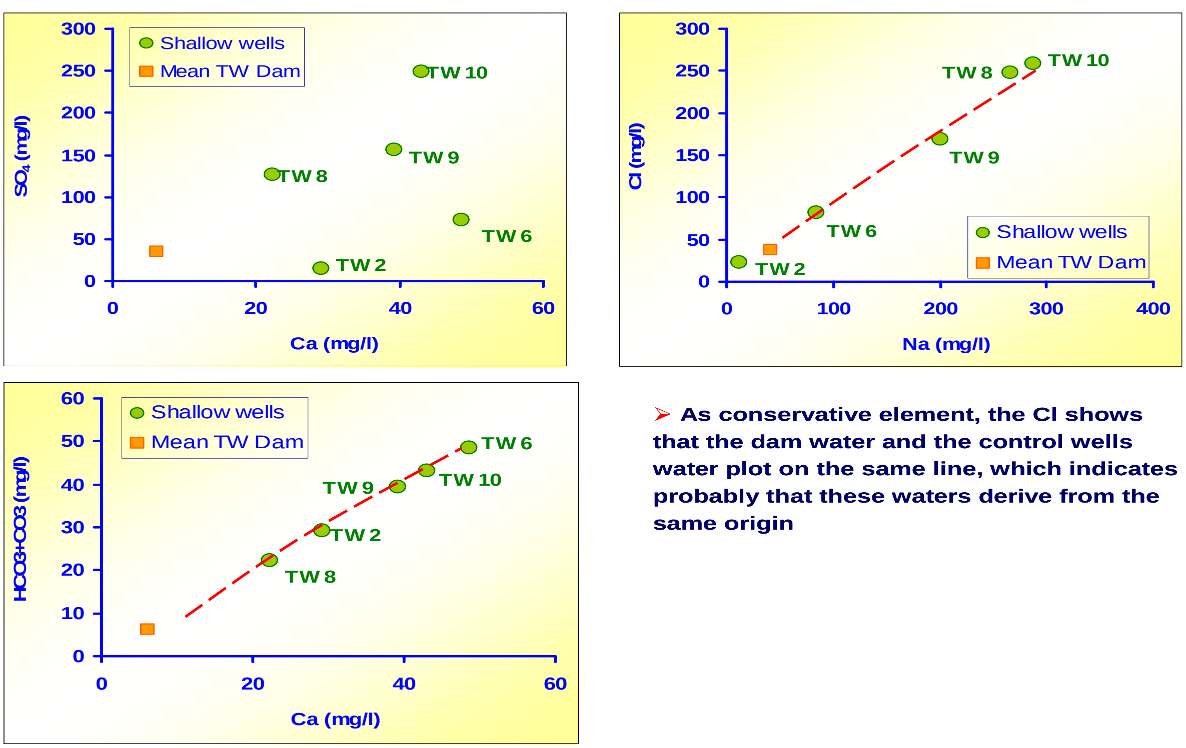

Fig. 9 –major elements relationships for the water samples collected from Taween Dams

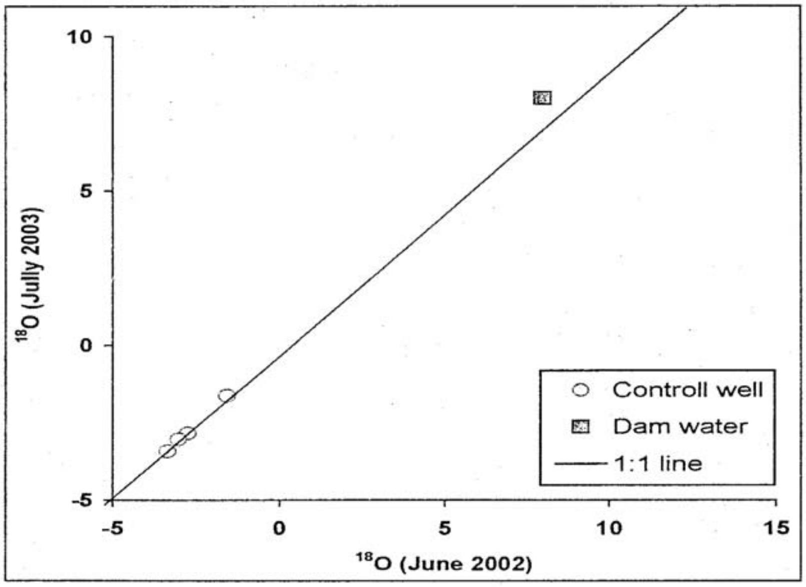

Fig. 10 Annual variation of 18 O content in the observation wells groundwater and the Tawiyeen dam reservoir dam water.

Temporal variation of stable isotope contents

Measurements made on samples collected during two different campaigns at a one – year interval (June 2002 –July 2003) do not show any marked variations of the oxygen-18 and deuterium (not shown) contents of the control wells groundwater (Fig 10) ,However some discrepancy in these isotopic contents is observed for the Tawiyean dam reservoir water from a campaign to another. Indeed, the dam water sample collected in June 2003 is relatively more evaporated than that collected one year before. This unbalance dissemblance between stable isotopes contents of groundwater and the dam reservoir agree with the hypothesis of different origins of these resources suggested according to the hydro chemical data.

9) Tritium data

In the Wadi Tawiyean basin, tritium analyses were performed during the winter and the summer 2002 and 2003.

The tritium concentrations (Table 6 , Fig.11))have a limited effectiveness in the determination of the origin of recharge in our case of study, since they present practically the same range of variation, either for the dam water or for an other recent recharge water derived from the present-day precipitation.

Table(6) : Mean values of tritium contents in the Wadi Tawiyean Basin

	^3H content
Tw 2	2.72
Tw 6	4.4
Tw 8	4.18
Tw 9	3.42
Tw 10	2.93
Tw Dam	3.96

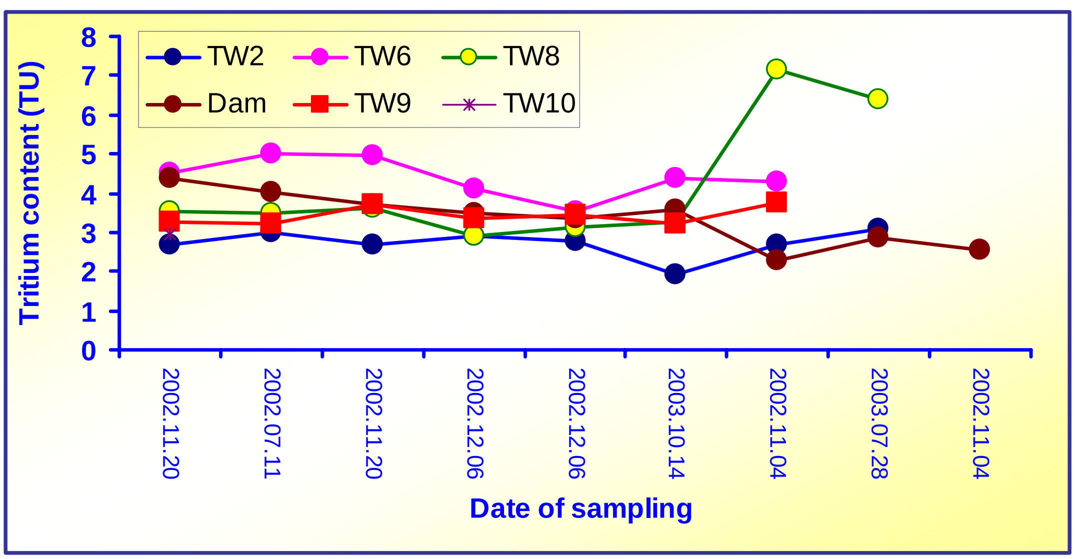

Fig. (11)-variation of ^3H content in the Dam water and obser.wells in Wadi Tawiyean

CONCLUTION and RECOMMENDATIONS

This present study aimed at aims quantifying natural recharge through two dams (Wurrayah and Tawiyean). Results achieved during this survey allow to highlight the contribution of dams to the recharge of surface aquifer. Indeed, hydrochemical and isotopic data (^{18}O ,^{2}H and ^{3}H), especially those gotten on the Wurrayah basin, clearly show a meaningful contribution to the recharge through the dam. An tentative isotopic balance based on stable isotopes of rains, water stored by this dam and wells drove to a quantification of the artificial recharge ranging from 20 to40%.

However, chemical and isotopic data obtained on the Tawiyean basin have not permitted to clearly show recharge from this dam. A recent infiltration seems to exit at the observation wells as shown by tritium content. On the other hand, considering the scarcity of available data and the inadequate distribution of the sampled wells., it is very difficult to determine how this infiltration takes place, as was the case for the Wurrayah dam.

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Application Of 2d Earth Resistivity Imaging Tomography And Gis For The Sustainable Management Of Water Resources In Northern Emirates, Uae

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Abstract

The 2D earth resistivity tomography methods and The Geographic Information System (GIS) were used to evaluate the available water resources in the Northern Emirates of UAE. The spatial analysis of GIS was used for analyzing the hydrogeological data to determine the quantity and quality of the available groundwater resources and to define the data gaps locations where further studies are needed. The GIS graphic capabilities were used to produce different types of digital geopotential maps necessary for the sustainable management of these precious resources. The developed hydrogeological map gave a clear picture about the available groundwater aquifers and their physical settings. To determine the groundwater potentiality of the Quaternary Aquifer which is solely used for irrigation, the contours of water table depth, saturated thickness were overlaid on the hydrogeological map. In the same map, the groundwater salinity contours of year 2005 were overlaid on the hydrogeologcal map to define the relation between groundwater salinity and aquifer's lithology as well as the present extraction rates. The 2D earth resistivity tomography method was used to determine the potentiality of the Quaternary aquifer and its approximate groundwater salinity in the areas where there is no drilling information as well as the locations of fractures and karst features in the Hajar aquifer in the mountainous area.

Keywords: Quaternary aquifer, Northern Emirates, GIS, water resources management, groundwater depletion, saltwater intrusion, 2D Earth resistivity imaging

Introduction

Quaternary aquifer in the Northern Emirates (Fig. 1) is the major groundwater aquifer in this area. It is composed of alluvial gravels and sands. The saturated part of the alluvial gravels in this aquifer at the foot of Oman Mountain is directly recharged from the infiltration of rainwater. Since the early seventies, water has been pumped from this aquifer for irrigation and domestic uses. With the introduction of deep drilling and powerful pumps, groundwater exploitation started to exceed groundwater recharge in the early eighties, and in year 2005, it was estimated to be in the order of twelve folds (MAF, 2005). Groundwater depletions and in some areas the complete dewatering of the Quaternary aquifer has caused some environmental problems. Along the coasts of Oman and Arabian Gulfs, the balance between the aquifer recharge and the saline water body intruding from the sea has been upset due to the excessive pumping to meet the rapid increase of water demands for agriculture purposes during the last three decades. On the other hand, drought conditions prevailed in the period 1997-2004, more groundwater was exploited to encounter the lack of surface water. Records indicate that groundwater has reached its lowest ever level in 2004. Many wells have dried up and several farms have been abandoned. This severe decline in the groundwater levels is naturally associated with a significant deterioration in the groundwater quality. The seawater has migrated into the aquifer causing a considerable increase in the groundwater salinity.

Geophysical methods and Geographic Information System have been recognized as the most efficient techniques for the quantitative and qualitative assessment of groundwater resources and thus used to study the present situation of water resources in the Northern Emirates. Geoelectrical methods, in particular, earth resistivity methods have a wide application on shallow groundwater resources. For example, the application of surface resistivity methods to delineate the contaminated zones has the following advantages: (1) reduced need for intrusive techniques and direct sampling

(2) relatively inexpensive and can be used for rapid and economical monitoring of large areas and optimization of the required number of monitoring wells; and (3) electrical conductivity/resistivity are intrinsic properties of ground-water chemistry that are readily interpreted in terms of the degree of groundwater contamination (Ebraheem et al. 1990; Ebraheem et al. 1997). The electrical conductivity of water, which is controlled by the concentration of dissolved ions, shows how well the groundwater conducts electricity.

The available Hydrogeological data in the period 1969-2005 in the Northern Emirates was critically reviewed and analyzed, and then used to build a GIS database for the study area. The spatial analysis of GIS was used to analyze this data to determine the quantity and quality of the available groundwater resources in the Northern Emirates as well as to determine the data gaps and thus orient &control the needed geoelectrical survey

After conducting the needed geoelectrical survey to bridge out the gaps in the hydrogeological data, the interpreted results were used to update the GIS data base and then the spatial analysis component of GIS was reused to reanalyze the updated data. The main objective of this paper is the application of earth resistivity imaging methods along with GIS techniques to study the groundwater potentiality of the Quaternary and karistified limestone aquifers as well as to identify and classify the dispersion zone, where the groundwater salinity/resistivity varies gradually, in the coastal areas. The 2D earth resistivity imaging technique was very useful in tracing the saturated fractures and cavities in the limestone aquifer and thus to determine its potentiality. The GIS was used to produce hydrogeological map, groundwater contours, and salinity map which have been very useful in finding solutions for the sustainable water resources management challenges in this area.

Geological and hydrogeological setting

The graphic capabilities and spatial analysis technique of the GIS was used to construct the updated geological and hydrogeological maps shown in Figures 2 and 3 respectively. The geological map shown in Figure 2 indicates that the northern part of UAE is geologically located in the Eastern Mountain Region, which includes two types of Allochthonous and para_autochthonous units. They are both strongly influenced by the orogenic activity. The Allochthonous Unit contains Hawasina Grcup and Semail Series. The Para-autochthonous Unit mainly includes limestone facies from Rus Al Jabal massif. These mountains are c1early divided into three tectonic lines (Fig.2). They are the Diba zone, Wadi Ham line and Wadi Hatta zones (JICA, 1996).

The Diba Zone extends to the south of Diba and consists of a low-lying region dominated by a fault (fractures marked with green color in Fig. 2) which cuts south-west through folded limestones and deep-sea argillaceous sediments along the chert as well as volcanics belonging to the Hawasina Series (JICA, 1996).

Wadi Ham Line is a fault zone along Wadi Ham which extends NNW (fractures marked with dark blue colour in upper right corner of Fig. 2) from the area to the west of Fujairah. It is divided into two areas of high ground formed from the basic and ultrabasic rocks of Semail Suit.

The Wadi Hatta Zone lies in the south of the mountain region, north of Masufut. Extending WNW, the zone separates to two areas of Semail rocks and is similar in structure and lithology to the Dlba Zone.

By control1ing the above three structural zones, the northeastern Emirates lying within the Oman Mountains are divided into three regions: (1) the Rus Al Jabal massif, (2) Hawasina Series and Metasediments and (3) Semail Ophiolite Complex. In addition,

(4) Upper Cretaceous limestone is scattered around the base of the mountain to the Bahada Plain. The characteristics of these geological units are described in JICA (1996).

In the hydrogeological map (Fig.3), it is possible to identify the following three regional groundwater aquifers

1) Quaternary aquifer which is composed of the gravel plain of Recent silts and conglomerates and meets the mountain front at a high angle. In the area extending from Oman Mountain to the Arabian Gulf ,this layer is overlying the thick Juweiza formation which is generally of low permeability and thus acting as aquitard rather than an aquifer (Figs. 4&5). Electrowatt (1981) subdivided sediments of the Quaternary aquifer into recent sediments, being slightly silty sand gravel with some cobbles and boulders, and old sediments, which are silty sandy gravels with many cobbles and boulders which are weathered and cemented. The hydraulic conductivity of the recent sediments tends to be very high, typically in the range of 6–17 m/day. For the old cemented sediments the hydraulic conductivity is in the range of 0.080–0.86 m/day. In the unconsolidated gravels, the primary porosity is very high compared to the cemented gravels. The storage coefficients typically range from 0.1 to 0.3 (Electrowatt 1981). Seventeen continuous pumping tests (duration ranged from 8 to 300 min) on some of the wells located in the study area were conducted. The results of these pumping tests interpretation are discussed in (IWACO, 1986 and Sherif et al.,2004).

2) **Carbonate aquifer** which refer to the exposed thick Musandam limestone of Jurassic - Cretaceous age in the mountains (Figs.3-5). These carbonate layers are composed of well jointed, karst weathered, thin bedded, nodular, fragmental and porcellanous dolomitic limestones and also limestones interbedded with calcareous shales.

These beds dip at a very high angle, up to 90°, to the west and have been planed off, probably by marine erosion, at about 600 feet above sea level for about 2 kilometers into the mountain front.

Various north-south trending folds can be seen on the aerial photos on the western strip of the main mountain massif. At Khatt village, these beds are linked to the gravel plain layers in the following ways:

a) as the western flank of a north-south trending anticline;
b) as the eastern up throw side of a north-south trending fault bounding the mountain front.
c) as the 'nose' of a thrust of the Mesozoic limestone facies to the west over a serpentinite facies, as exposed in Wadi Hagil.

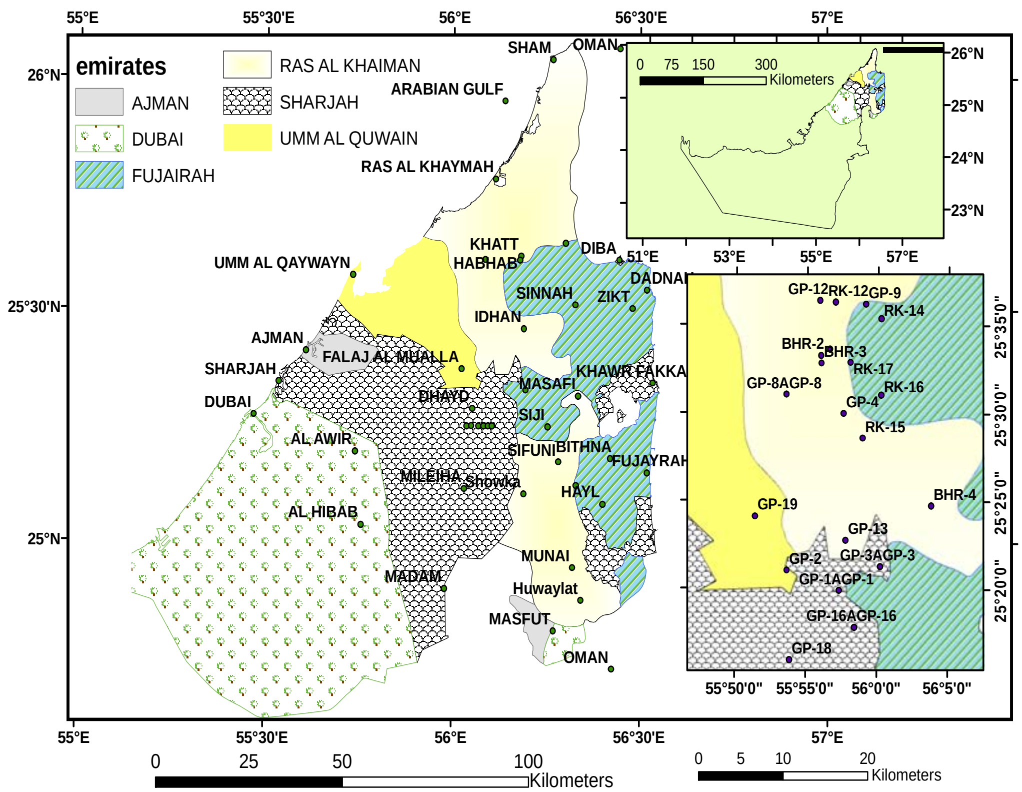

Fig. 1- Location map of the Northern Emirates. Locations of some of monitoring and exploratory wells are also shown.

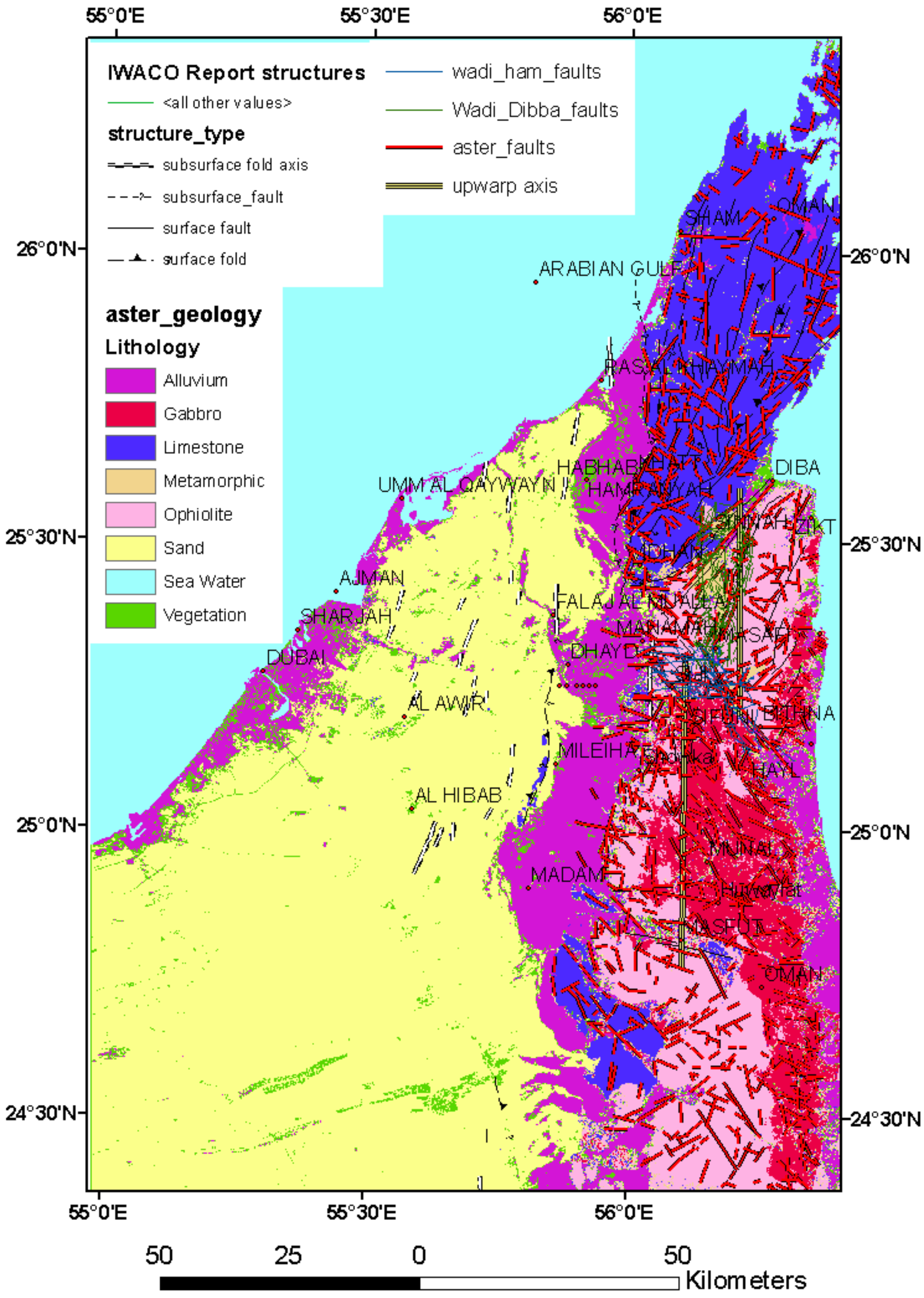

Figure 2-Geological map of the Northern Emirates (modified from IWACO, 1986 and SEWA 2006).

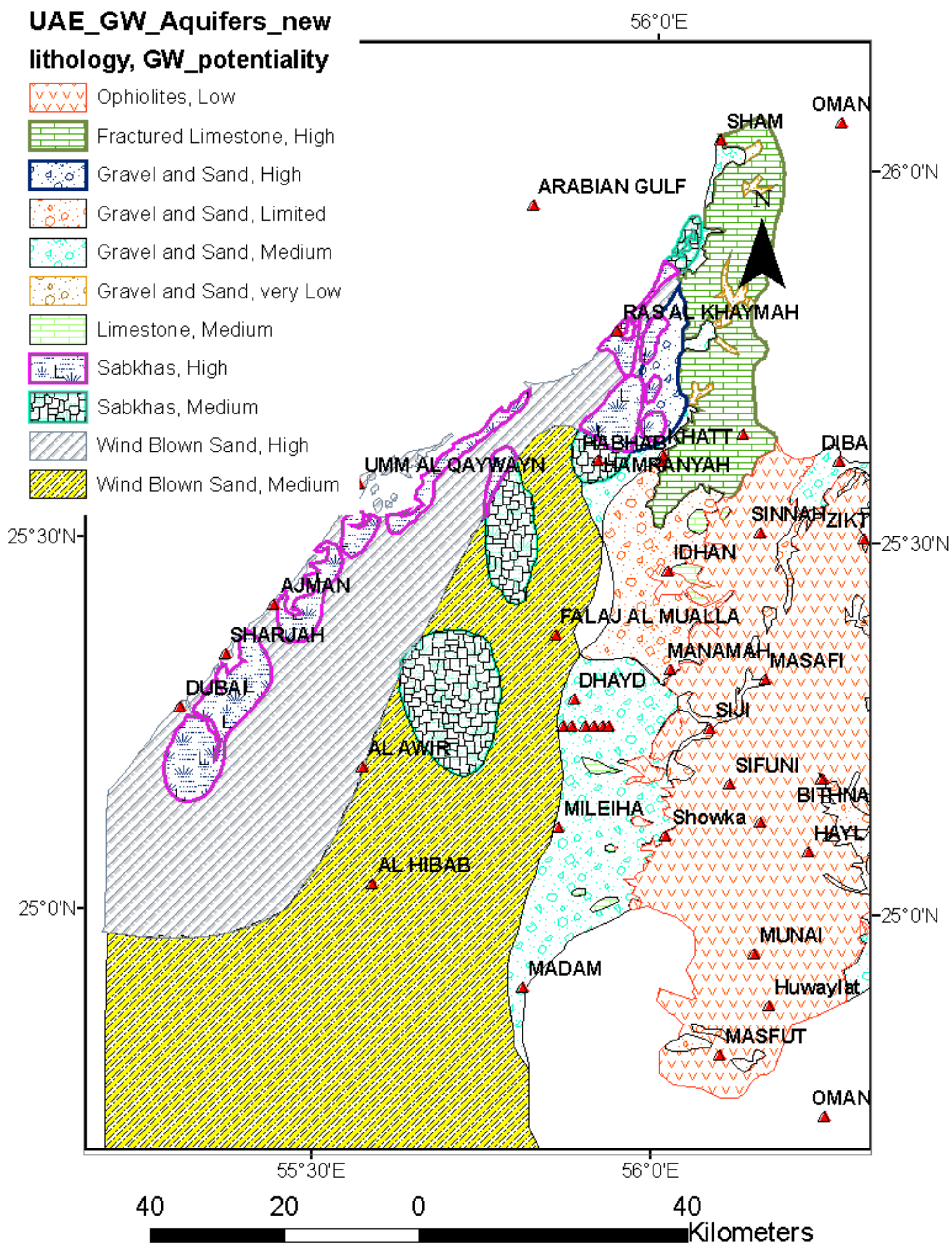

Figure 3- Hydrogeological Map of the Northern Emirates (modified from IWACO, 1986).

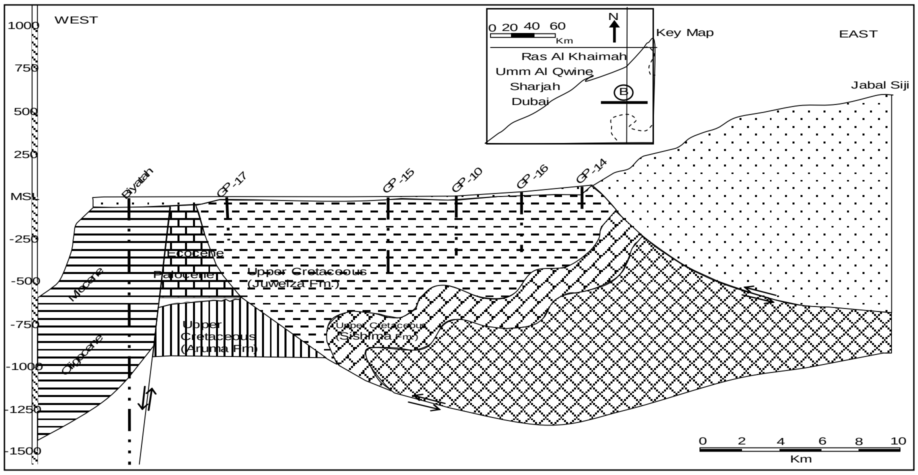

Fig. 4-An East-West substance geological cross section across GP-17 and GP14 wells (modified from IWACO, 1986).

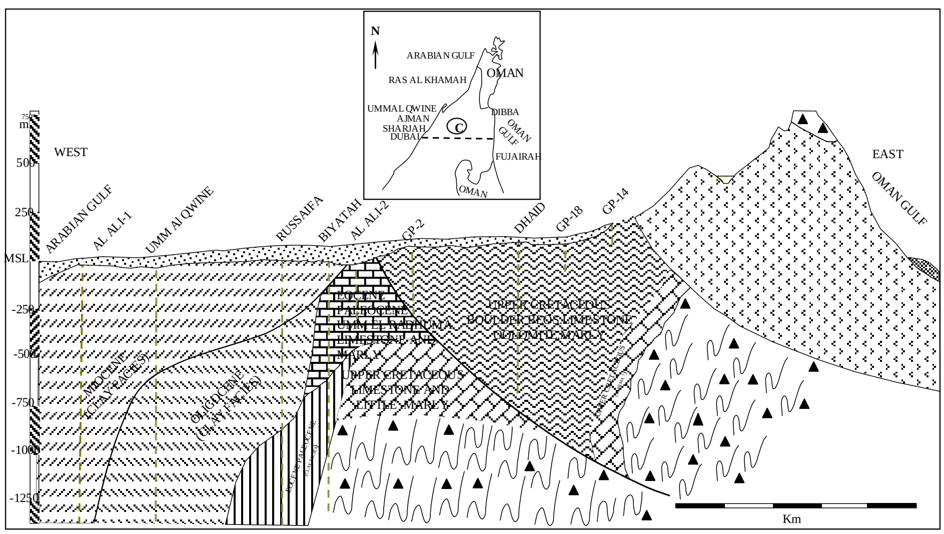

Fig.5-An East-West subsurface geological cross section across the latitude of Um Al Quaeen (modified from IWACO, 1986).

To calculate the hydrogeological parameters of this aquifer, seven pumping tests were conducted by IWACO (1986) and one test by MAF (2005) for well KhSp-1 near the northern Khatt Spring.

Groundwater Depletion in the Quaternary Aquifer

As previously mentioned, groundwater has been exploited from the Quaternary aquifer since late sixties at a rapid increasing pace for irrigation and domestic purposes.

Since early eighties the exploitation rates are far more than the recharge rate and thus cone of depression started to form in several areas (e.g. Al Dhaid, Al Hamraniyah), and continuously increased in size (Fig. 6). Up to late eighties, classic irrigation techniques (flooding) associated with water consuming crops was used in these areas. Starting from year 2000, several irrigation wells in Al Hamraniyuah became dry and there is a persistent threat that the Quaternary aquifer (only source of irrigation water) becomes completely dewatered in few years. Similar problem is encountered in Al Dhaid area, central part of Sharjah Emirate. This intensive groundwater depletion problem has also caused severe saltwater intrusion problem in coastal area and even inland areas by upward coning of deep saline water (Fig. 7). Dradown in the period 1969-2005 reached more than 80 m in several areas (e.g. Jabel Al Heben north of Hayl, Al Dhaid, and Al Hamranyiah ; Fig.6). The associated groundwater salinity increase for the same period reached more than 4000 ppm in the areas south of Idhan and east of Al Hamaraniyah (Fig.7). Almost there a direct relationship between drawdown and groundwater salinity increase (figs. 6 and 7).

Despite the fact that modern irrigation system was introduced in the area in the early eighties and the current percentage of modern irrigation methods is exceeding 86%, it is still not enough solution for the severe groundwater depletion problems in the above mentioned areas. A lot of efforts and budget are needed for the restoration of the Quaternary aquifer via artificial recharge. It is still difficult to convince the farmers about the need to change the crop patterns from the traditional agriculture to less water consuming crops. In this concern there is a crucial need to increase the farmers' awareness about the water shortage problem and develop and implement legislative law that control drilling of water wells and groundwater exploitation from the farms.

Geoelectrical techniques: principles of DC resistivity Method

DC resistivity methods measure the electrical resistivity distribution of the subsurface using current transmitted into the ground from dc- or low-frequency sources by two electrodes (A and B).

The potential difference between a second pair of electrodes (M and N, Fig. 8a), is also measured. The apparent resistivity of the subsurface can be calculated by applying a geometric correction (G) to Ohm's law (R=DV/I, where R is the resistance, DV is the measured potential difference, and I is the injected current), based on the specific electrode spacing and geometry. These geometrically corrected measurements are defined as apparent resistivities rather than true resistivities because a homogeneous subsurface is assumed. Measured resistivity values are controlled by material resistivity, quality, and quantity of groundwater (Haeni et al. 1992; Reynolds 1997). The maximum penetration depth is directly proportional to the electrode spacing and inversely proportional to the subsurface conductivity (Edwards 1977, Mussett and Khan 2000).

The 2D dc-resistivity profiling is carried out by making many measurements at different locations along the profile and at different offsets. The obtained data are inverted to create a tomogram-like model of resistivity along a section of the subsurface that can be used to detect water zones of aquifer in the eastern side of Ras Al Khaimah. The linear array of each profile consisted of 112 electrodes where the distances were controlled automatically controlled by eight channel data switch manufactured by AGI Company. Dipole Dipole and Sclumberger arrays (Fig. 8a) were used in this survey. By using an iterative smoothness-constrained least-squares inversion method (deGroot-Hedlin and Constable 1990; Sasaki 1992), apparent resistivity data collected by the 2D dc resistivity imaging system (Fig. 8b) are inverted to create a model of subsurface resistivity that approximates the true subsurface resistivity distribution (Loke 1997).

In this study, thirty two 2D dc-resistivity profiles were completed with a total length of 45 kilometers. The locations of these profiles were chosen based on the available monitoring wells for calibration purposes.

Figure 9 is an example of an interpreted geophysical profile with a total length of 2220 meters where it was possible to define the areas of saturated cavities and fractures in the Musandam limestone in the area north of Kahtt. The 2D earth resistivity method was also useful for studying the salt water intrusion problem, for example it was possible to identify the three water zones (saline-brackish-fresh) in the true resistivity-depth cross section (results are reported in Sherif et al., 2005).

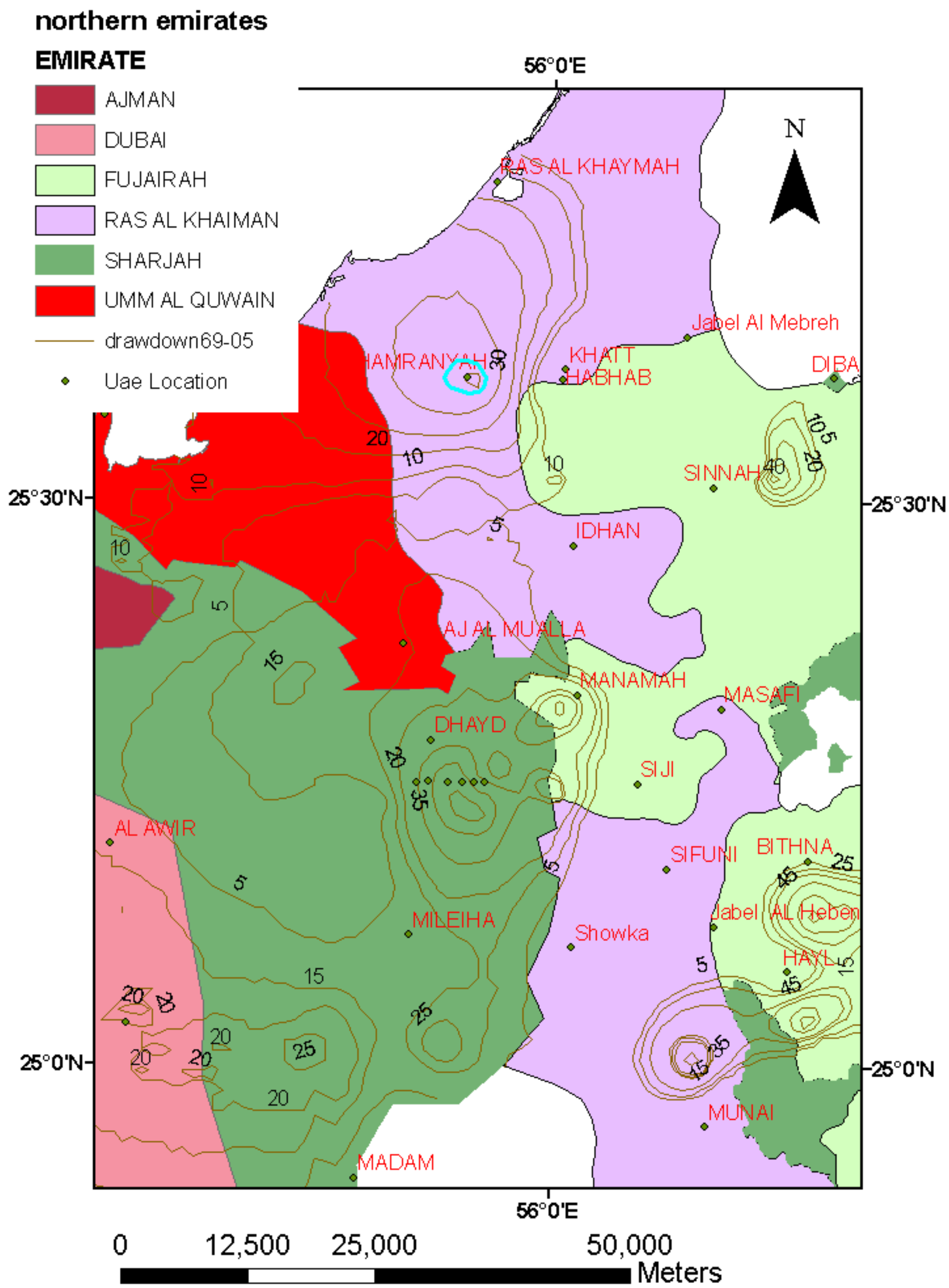

Fig.6- Decline in the water table of the Quaternary Aquifer in the period 1969-2005.

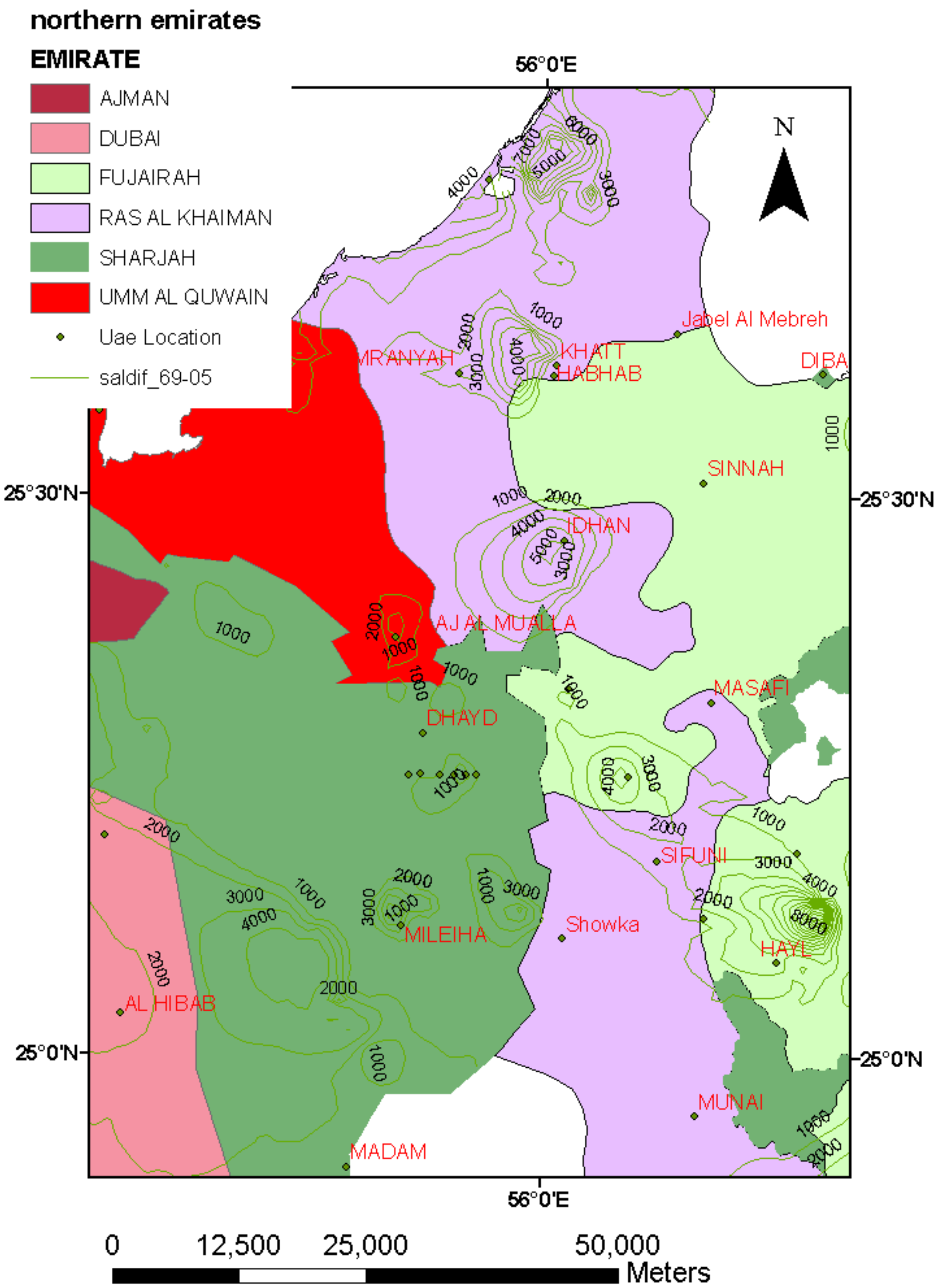

Fig. 7 Salinity increase in the groundwater of the Quaternary Aquifer in the period 1969-2005.

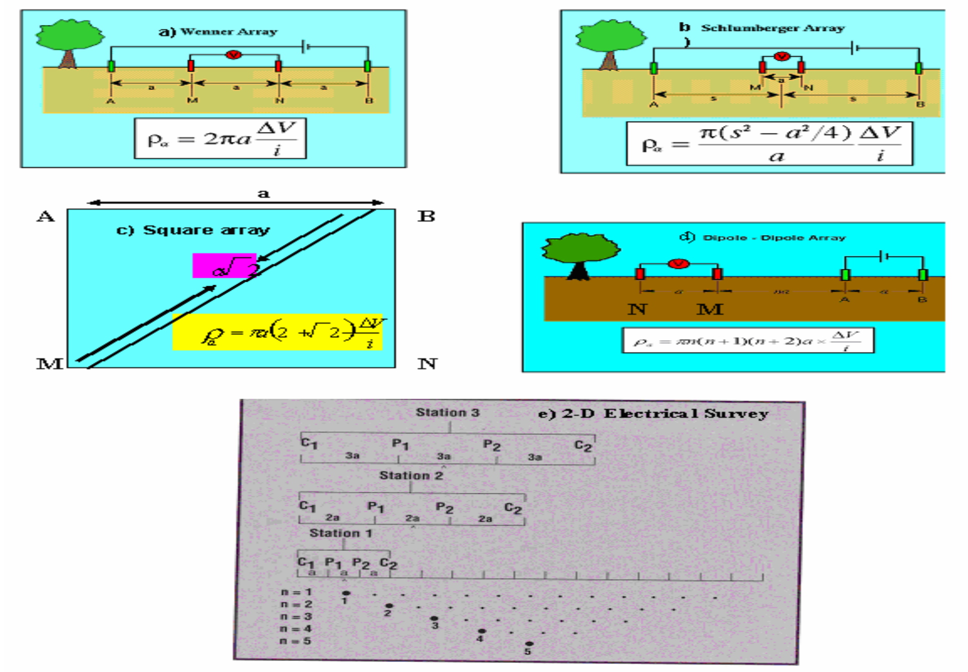

Fig. 8- Common array used in resistivity surveys and their geometric factors (top) , and the arrangement of the electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudo section (bottom) (after Loke, M. H., 1997).

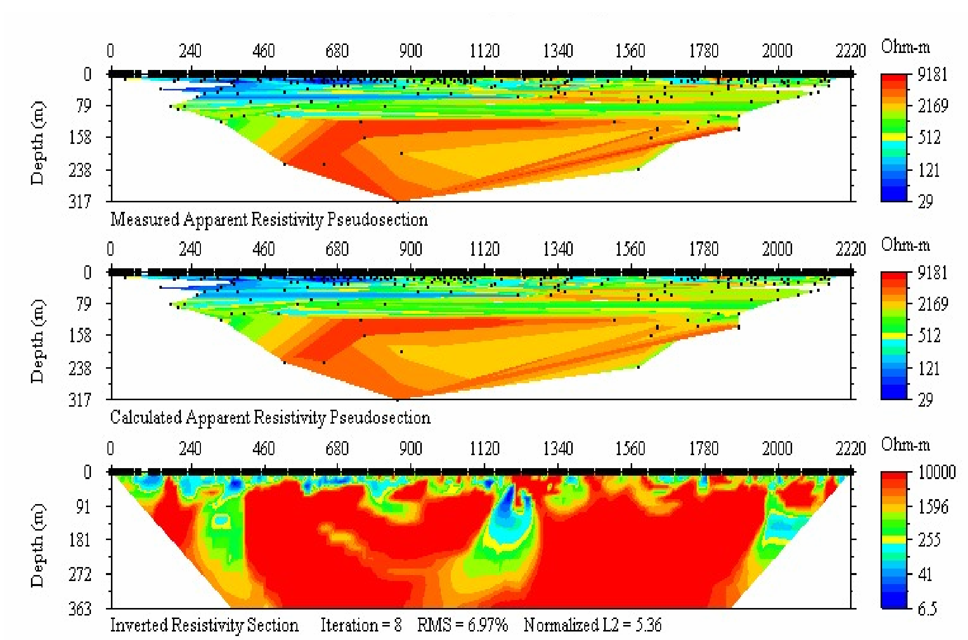

Fig. 9- An example of an interpreted geophysical profile with a total length of 2220 meters where it was possible to define the areas of saturated cavities and fractures in the Musandam limestone in the area north of Kahtt Springs area, Ras Al Khima Emirates.

Conclusions

The GIS was used to store the environmental data available for the period 1969-2006. The spatial analysis and graphic capabilities of GIS were used to analyze the data and define the data gaps were further studies are needed as well to produce geopotential maps (e.g. hydrogeological, groundwater salinity, etc). These maps were then used to study the available groundwater resources of the Northern Emirates and their exploitation problems.

Exploitation of groundwater from the Quaternary Aquifer for irrigation purposes in this area since 1969 has caused sever groundwater depletion and saltwater intrusion in several areas in the Northern emirates. Cone of depression of more than 80 meters associated with salinity increase of 4000 ppm were determined for the area between Al Hmaraniyah and Khatt in Ras Al Khaimah Emirate.

The 2D earth resistivity imaging method was used to determine the locations and depths of the fractures and karsts zones in the western side of Oman Mountain (eastern part of Ras Al khaimah Emirate).The obtained results indicated that the Hajar bedrock (Karistified limestone) aquifer is probably extending for several hundred of meters and thus constitutes a deep groundwater aquifer with high groundwater potentiality in the areas where it is extensively fractured and karistified. The groundwater quality in this aquifer seems to be fresh to slightly brackish. The results also indicated the presence of a subsurface fault extending in the northwest-southeast direction.

The developed GIS database which is continuously updated has been useful in developing sustainable water management schemes, developing groundwater flow models to make informative prediction of the environmental impact of current and planned development projects, and making the necessary environmental impact assessment (EIA) studies for the new engineering projects.

Recommendations

From the technical point of view, artificial recharge of the quaternary aquifer in most of the Northern Emirates and the change from traditional agriculture to the less water consuming and saline tolerant crops (e.g. economical halophytes) are strongly recommended.

From the legislative point of view, drilling of water production wells in UAE must be controlled . Groundwater exploitation rates in the farms should be monitored and controlled.

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NATURAL RADIOACTIVITY LEVELS FOR GROUNDWATER IN AL HASSA, KSA

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Abstract

Al Hassa Oasis is one of the main and old agricultural centers in Saudi Arabia. Al Hassa oasis with an area of about 360 Km^2 and is located 70 km west of the Arabian Gulf. The cultivated area at Al Hassa Oasis is about 80 Km^2 and it is irrigated mainly from Neogene aquifer. Over pumping from the aquifer led to water depletion and deterioration of water quality.

The present work aims to shed lights on the natural radioactivity level of the groundwater in this vital area of Al Hassa and present to what extent this natural resource is radioactively polluted. In this respect, sixty water samples have been collected from different localities of Al Hassa area and its surroundings. The activity concentrations of radionuclides in groundwater samples have been measured. The activity concentrations of ^{234}U and ^{238}U series together with the total of uranium in parts per billion (ppb) are measured. Moreover, α and β particles are measured.

The result of this study reveals that**,** the activity concentrations obtained for ^{238}U and ^{234}U ranged from 0.1 to 0.9 Picocurie/Liter (pCi/L) and 0.16 to 0.81 pCi/L respectively for the collected groundwater samples. The total activity concentrations for uranium in the groundwater samples ranged from 0.21 to 2.12 in parts per billion (ppb). The gross α and the gross β activities in the water samples ranged from 12 to 54 pCi/L, and 167 to 315 pCi/L, respectively.

The high activity concentrations for uranium series in groundwater samples of Neogene Aquifer are attributed to the heterogeneity of the lithology of the aquifer at these particular locations. Also geological phenomena's such as faults, hydrothermal alterations, weathering could have favored further local enrichment of radionuclides in such areas.

These results can be considered as a base monitor for any future variation of natural radioactivity of this part of KSA, especially, the eastern part of KSA is currently witness for many industrial-agricultural development programs. These results are lower than the International Commission on Radiological Protection (ICRP) maximum permitted limit and therefore, have no significance radiological health burden on the environment and the populace.

Keywords:- Natural radioactivity, radiological health Hazard, Uranium, gross alfa and gross beta; Groundwater radiological pollution, groundwater, water quality, Al Hassa, Saudi Arabia.

Introduction

Radionuclides are found naturally in air, water and soil. They are even found in ourself, being that we are products of our environment. Every day, we ingest and inhale radionuclides in our air and food and the water. Natural radioactivity is common in the rocks and soil that makes up our planet, in water and oceans, and in our building materials and homes. There is nowhere on Earth that you can not find natural radioactivity.

Radioactive elements are often called radioactive isotopes or radionuclides or just nuclides. There are over 1,500 different radioactive nuclides. As example, Uranium with the atomic weight of 235 would be shortened to U-235 or ^{235}U.

The major sources of external gamma radiation are ^{238}U, ^{232}Th , their decay products and ^{40}K. External exposures to gamma radiation outdoors arise from terrestrial radionuclides occurring at trace levels in all ground formation. The contribution to absorbed dose in air external gamma radiation emitting from radionuclides change also depending on local geological and geographical conditions.

Natural waters contain several alpha (α) and beta (β), which emit isotopes in widely varying concentrations. The most commonly found radionuclides belong to the uranium and thorium family present in groundwater. The gross alpha activity in the groundwater samples originates from the ^{238}U and its daughter ^{226}Ra, while beta activity is principally from ^{232}Th and ^{40}K (Conthern and Rebers, 1990).

The radionuclide concentrations in groundwater depend on the type of mineral derived from aquifer rocks, the chemical composition of the water and the soil ions retention time (Freeze and Cherry, 1979; Andreo and Carrasco, 1999).

The chemical composition of groundwater is also function of the aquifer rocks, flow conditions and residence time in aquifer.

Aquifers in granitic rocks contain important groundwater resources in many parts of the world. Groundwater derived from granitic rocks are not an unalloyed blessing. It is widely recognized from several studies (Banks et al., 1995 and Banks et al., 1998; Reimann et al., 1996; Apambire et al., 1997; Örgün et al., 2004) that they may contain minerals such as quartz and feldspar, trace elements, such as F and B, some heavy metals (Pb, Cu, Zn, Sb, Hg, etc.) and radioelements (U, Th, Rn, Ra) at levels which may exceed recognized drinking water norms.

The γ-rays due to the ^{238}U series, ^{232}Th series and ^{40}K play an important role in the exposure dose of the public in dwellings (UNSCEAR, 1993).

Increase in the background ionization radiation from numerous sources has various health side effects on the populace. Some of the sources of radiations are cosmic rays and natural radionuclide in air, food and drinking water (NCRP, 1976). Radiation exposure can be external: natural radionuclides and cosmic rays and internal: food, drinking water and the mineral contents of the body. Exposure to excess level of background ionization radiation causes somatic and genetic effects that tend to damage critical and/or radiosensitive organs of the body, which ultimately can lead to death (Ajayi, 1999).

The present work aims to initiate a radiological assessment program at a Al Hassa area , Eastern part of KSA, (Fig. 1) and to establish a baseline maps of radioactivity background levels in the surrounding environment. These maps will be used as reference information to assess any change in the radioactivity background levels due to various geological processes or any artificial influences on the radiation environment.

Al Hassa Oasis is one of the main and old agricultural centers in Saudi Arabia. Al Hassa oasis with an area of about 360 Km^2 is located 70 km west of the Arabian Gulf. The cultivated area at Al Hassa Oasis is about 80 Km^2 and it is irrigated mainly from Neogene aquifer. Over pumping from the aquifer led to water depletion and deterioration of water quality.

The awareness of the potential degradation of the environment by different activities at Al Hassa is on the increase and there have been various claims and counterclaims of degradation of the surface soil and water by the host communities. This study, therefore, determine the level of natural radionuclide concentrations in the soil and water in Al Hassa, estimates the level of degradation of the radioactive equilibrium of the areas and ascertain the radiological health side effects on the populace and the environment.

Nowadays, the local inhabitants are using the limestone and the calcareous layers in cement industry and quarrying the sands for masonry purposes.

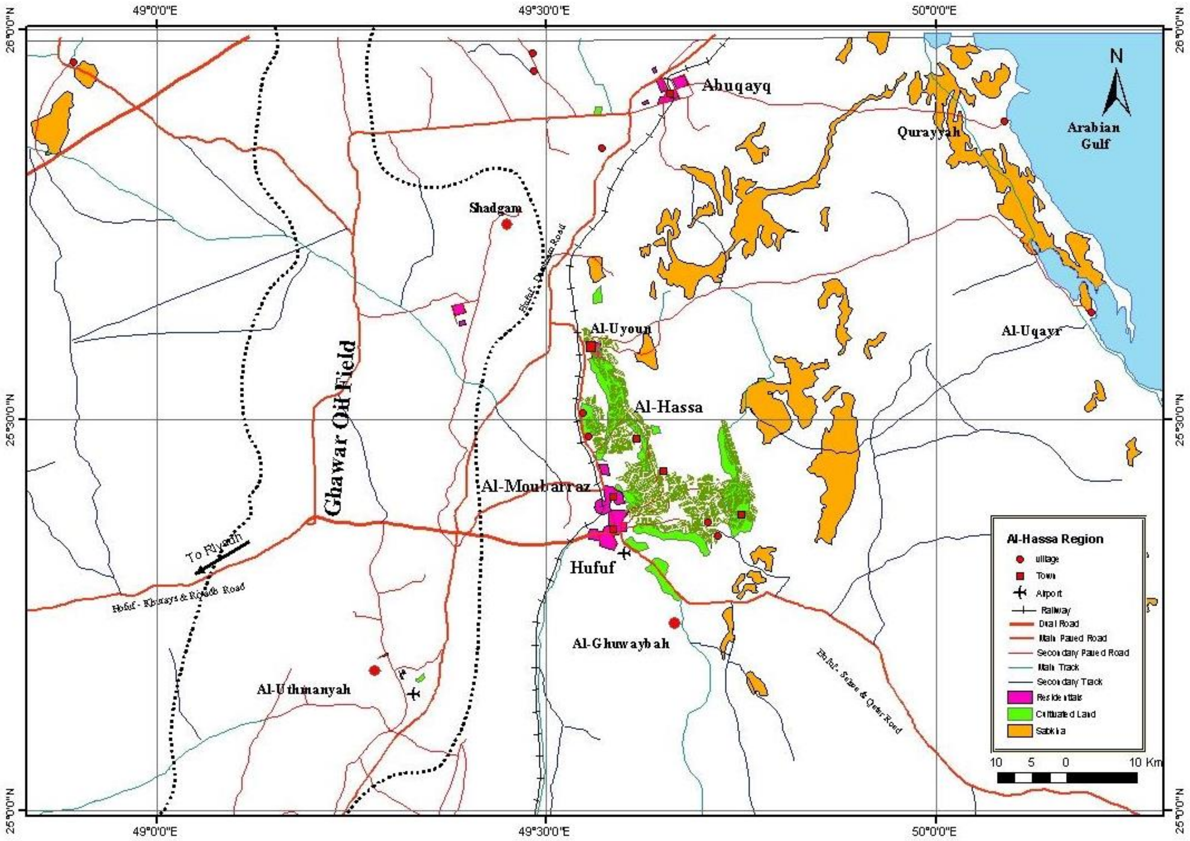


Figure (1) location map of Al Hassa Oasis (modified after WSC, 2004).

The introduction of low level gamma-ray spectrometry technique has become very important in various fields specially in geological and environmental sciences. By applying gamma-ray spectrometry, the various radionuclides in the samples can be identified quantitatively on the basis of their characteristic peaks in their spectra.

Geological and Hydro Geological Setting of Al Hassa Area

The outcrops of different rock units bounding Al Hassa are belong to Pliocene and Miocene are mainly of calcareous sand marine sand, calcareous shale, chert nodules and conglomerate. The Quaternary deposits are spread along the oasis and of thickness of about 10 m and composed mainly of boulders, sands, clays, silts and sabkha.

The groundwater is consider the main source even not the only source for different purposes of Al Hassa Oasis. The main rock of the Neogene is calcareous and characterized by karst and high porosity. Such Karst areas and fractures within Neogene sequence makes a hydraulic connection between the Neogene aquifer and the underlying aquifer of El Dammam formation. The depth of the Neogene sequence ranges from zero to 180 m below ground. The total dissolved salts of the Neogene aquifer ranges from 1570 mg/l to 2500 mg/l (Al Khateeb, 1980). Details about the hydrogeology of Al Hassa area discussed by BRGM,(1977) and (1981), Etewy et .al., (1983), HIDA, (1986), Al- Mahmoud, (1987), Abdurrahman,. (1988), Edgell, (1989) , Al Dakheel & Al Safarjalani, (2005) and Al Safarjalani and Almadini (2007).

The fresh water supply in arid regions is limited due to scarce precipitation and high fresh water demand in these regions due to rapid population growth, it necessitates optimal development and management of groundwater resources which require understanding and identifying the recharge mechanisms to the groundwater system. Delineation of natural radioactivity of groundwater and soils in arid regions has received considerable attention in recent years.

Sampling and Experimental Method

Sample Collection and Preparation:

At the first stage of the survey, Geiger–Mueller counter, (model 6150AD), a dose rate meter for radiation and contamination measurement manufactured by Automess Automation and Messtechnik GmbH in Germany was used first to measure the natural background dose at Al Hassa area.

Sixty groundwater water samples were collected from the area of investigation (Fig. 2). The latitude and longitude of each sample location was measured by using Trimble GPS NAV 5000 PRO. About 20 liters of water was collected for each well location and putted in bottles. The water samples were acidified by addition of nitric acid (at 1%) to the original sample to avoid adsorption on the walls of the bottle and then the water samples were marked and stored in a refrigerator and kept for secular equilibrium to be established before sending to the analysis. The samples were analyzed by Inductively Coupled Plasma-Mass Spectrometry (ICPMS) available in the Space Research Institute, King Abdulaziz City for Science and Technology, KSA.

Experimental Procedure

Gamma spectrometry

Gamma spectrometry measurements were performed using a high purity germanium detector of 20 to 40% relative efficiency. The system also contains the analogue to digital converter (ADC) and 4096-multichannel analyzer. The detector has a resolution (FWHM) of 1.9 keV for the 1332 keV gamma line of 60Co. The detector was shielded in a 10 cm thick lead well internally lined with 2 mm copper and 2 mm cadmium foils. Energy calibration and relative efficiency calibration of the gamma spectrometer were carried out using 1000 ml Marinelli calibration sources (supplied by Isotope Products Laboratories Inc.) which contained ^{133}Ba, ^{152}Er, ^{154}Er,^{241}Am, and ^{226}Ra emitting gamma rays in the energy range between 80 and 2500 keV. The counting time for each sample as well as for background was 50 000 s.

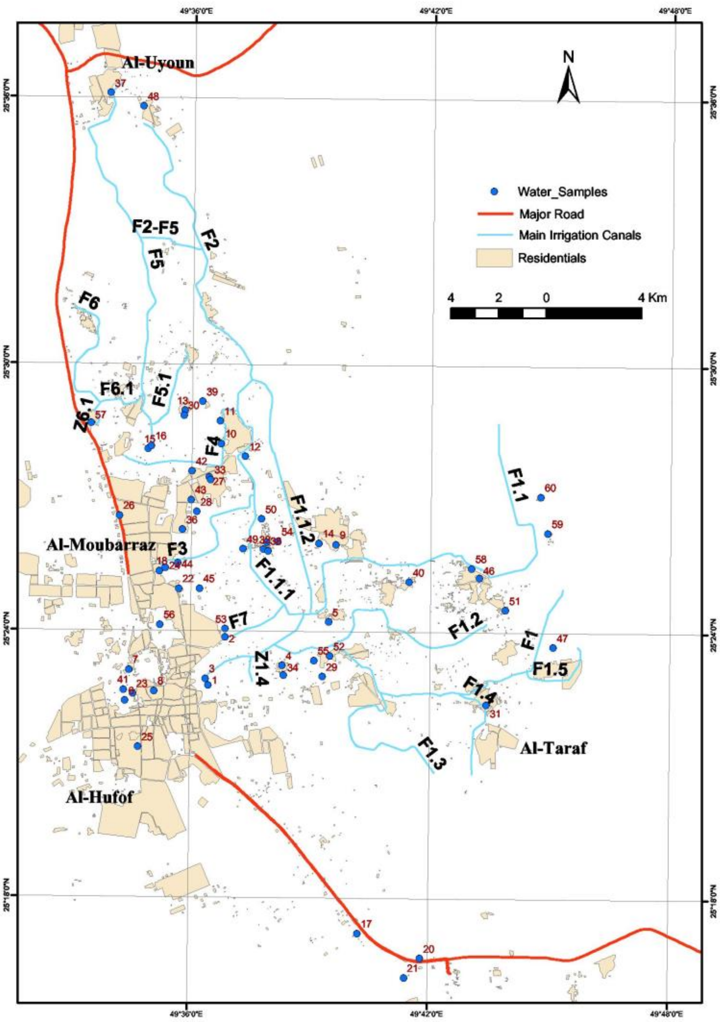


Figure (2) Base map of the Water samples, Al Hassa Area.

Experimental Procedure

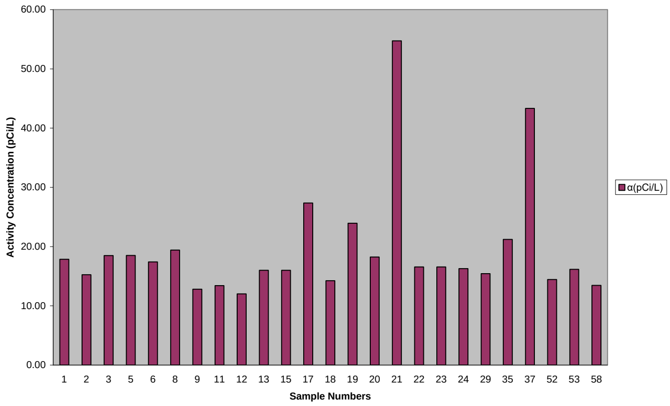
Gamma spectrometry

Gamma spectrometry measurements were performed using a high purity germanium detector of 20 to 40% relative efficiency . The system also contains the analogue to digital converter (ADC) and 4096-multichannel analyzer. The detector has a resolution (FWHM) of 1.9 keV for the 1332 keV gamma line of 60Co. The detector was shielded in a 10 cm thick lead well internally lined with 2 mm copper and 2 mm cadmium foils. Energy calibration and relative efficiency calibration of the gamma spectrometer were carried out using 1000 ml Marinelli calibration sources (supplied by Isotope Products Laboratories Inc.) which contained ^{133}Ba, ^{152}Er, ^{154}Er,^{241}Am, and ^{226}Ra emitting gamma rays in the energy range between 80 and 2500 keV. The counting time for each sample as well as for background was 50 000 s.

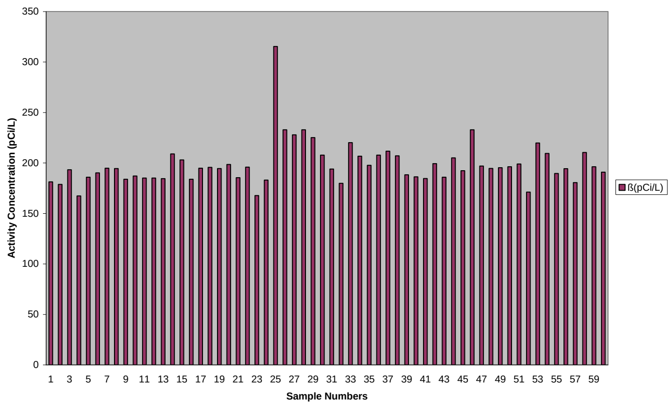
Results and Discussions

The activity concentrations of Uranium series in groundwater samples

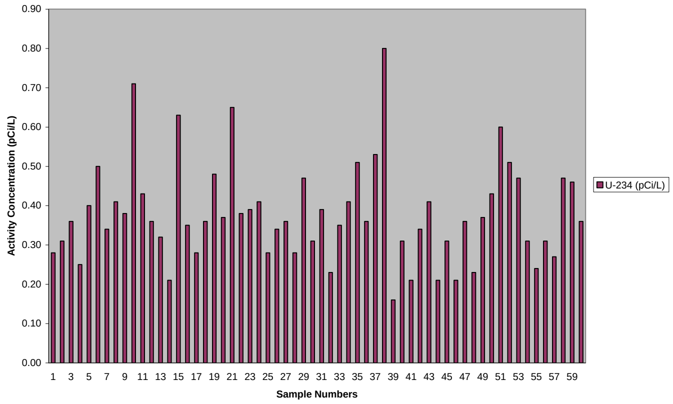
The activities of the radionuclides concentration levels results of the analysis of the sixty water samples collected from the active springs. and from the active wells which withdrawn their water from the dried springs (see Figure 2, for the location). The activity concentrations of ^{234}U and ^{238}U series together with the total of uranium in parts per billion (ppb). Moreover, α and β particles are measured .Figure (3) presents the histograms of these radionuclides concentration levels for the analyzed groundwater samples.



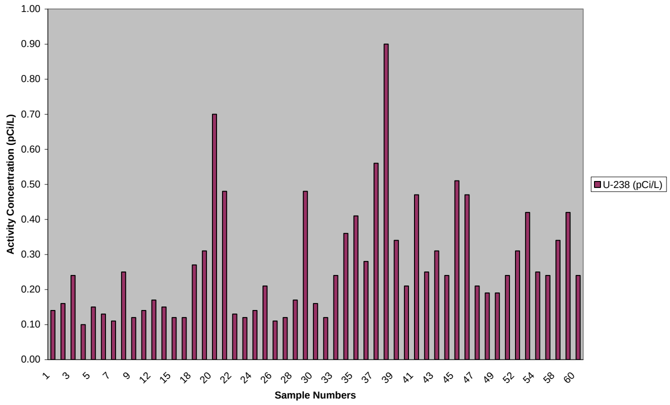
a) The activity concentration of (α)



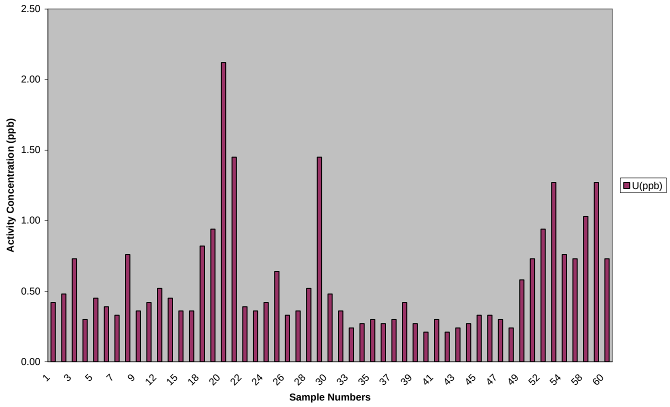
b)The activity concentration of (ß)



c)The activity concentration of ^{234}U



d) The activity concentration of ^{238}U



e) The activity concentration of total uranium

Figure (3) Histograms of the radionuclides concentration levels for the collected groundwater samples, Al Hassa, KSA.

From Figure (3), the following can be noticed:-

1. The samples are generally characterized by low level of radioactivity and the radionuclides concentration are within the acceptable values for water.

2. Radioactivity concentrations of ^{238}U and ^{234}U have almost the same range of concentration while Beta and Alpha particles are much higher than that of ^{238}U, ^{234}U concentration. β activities is the much highest concentration radionuclide.
3. Comparing with the worldwide average concentrations of these radionuclides in this study with which are reported by UNSCEAR (2000), these results show that the radiological health burden due to use of the groundwater on the human populace is very insignificant and has neither health implications nor affect the background ionization radiation and the results obtained could therefore be that due to natural ionization radiation of the environment .

Areal Distribution of the analyzed radionuclides.

To show the spatial distribution of each radionuclides separately, contour maps of the radioactivity concentration of each radionuclide have been constructed using Surfer mapping system software Ver.8.00 (Golden Software Inc ., 2002)

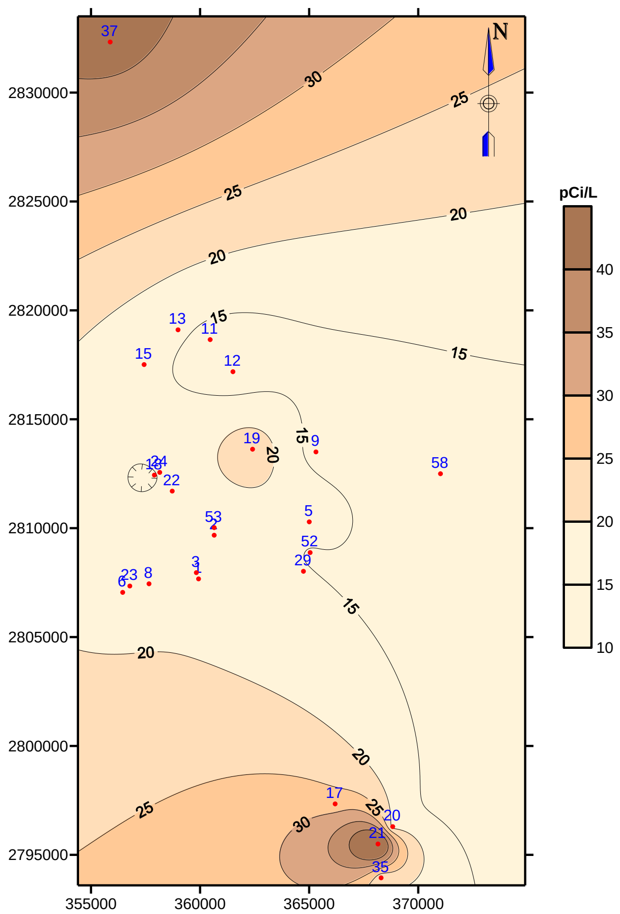
In the following a discussion will be presented for each radionuclide

Areal distribution of the gross alfa (a) activity concentration.

Figure (4) represents the contour map of gross alfa (α) activity distribution in the area of study. The activity concentration of gross alfa ranges between 12 to 52 pCi/L. From this map it is clear that we have two relatively higher zones. The first zone is located to the south of the area (Al Ghweiba, on Qatar road). The centre of this anomaly is the location of sample No.21 and this anomaly is extending to sample Nos. 17 and 35 (see also Figure 3.a). The activity concentration at this site is of more than 40 pCi/L. The second zone is located to the northwest of the area of study around the location of No.37 at Al Uyoun. For the rest of the map, the radioactivity concentrations is relatively low.

The relatively high concentrations are attributed to subsequent hydrogeological processes causing radionuclides solution and precipitation, and geological phenomena's such as faults, hydrothermal alterations, weathering could have favored further local enrichment in such areas.

The gross-α concentrations can be grouped in three different set of concentrations: low, medium and high. In the first set, gross-α concentration range from 12 to ≤19 pCi /L, in the second from >19 to ≤23 pCi/L, and in the third set of more than 23 pCi /L,. The samples (17,21, 37) within the third set were taken from area close to Ghweiba and Al Uyoun.. The maximum gross-α value was measured in the sample No. 21. Otherwise, the samples 8, 19 and 35 within the second set (Fig. 3 a). The rest of the samples within the first set have much lower gross-α concentrations than others



<u>Figure (4).The areal distribution of the gross alfa (α) activity concentration for the collected groundwater samples, Al Hassa, KSA.</u>

Areal distribution of the gross beta (ß) activity concentration.

The activity concentration of gross beta ranges between 167 to 315 pCi/L. gross β activity is the much highest concentration radionuclide comparable to other measured radionuclides of the collected groundwater samples. Figure (5) represents the contour map of gross beta (ß) activity distribution in the area of study. From this map it is clear that some sites are characterized by relatively high concentration of more than 200 pCi/L. It is worthy to mention there is a good match between gross beta and gross alfa at the northwest of the area of study around the location of samples No.37 at Al Uyoun (see Figures 5&6). This confirm that alpha and beta at this area is coming from the same source. The southwest area is characterized by highest beta concentration, where the location of sample No. 25 has of more than 350 pCi/L (see also Figure 3.b). For the rest of the map, the radioactivity concentrations is below 200 pCi/L.

Limit values for gross-α and gross-β radioactivity concentrations in drinking water are 2.7 and 27 pCi/l, respectively (WHO, 1993). As seen from and Figure 3 a and Figure 3b the concentration of gross-β radioactivity higher than WHO-guide limit.

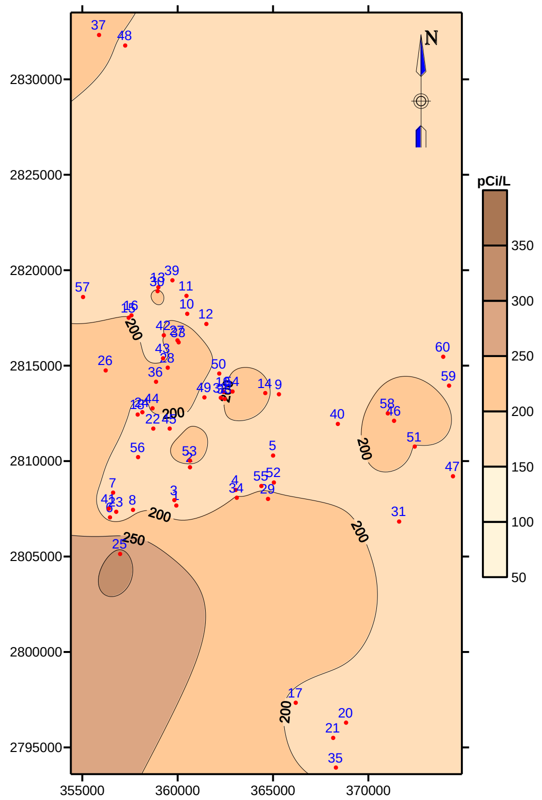


Figure (5).The areal distribution of the gross beta (β) activity concentration for the collected groundwater samples, Al Hassa, KSA.

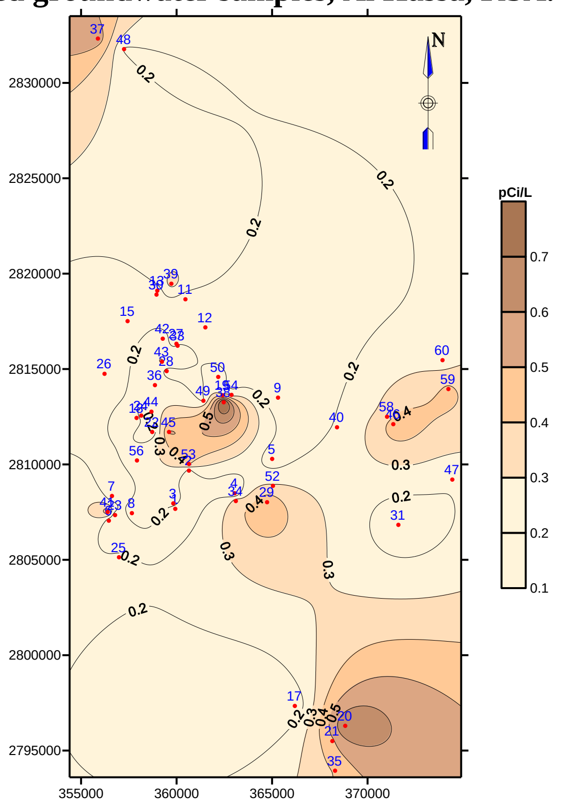


Figure (6).The areal distribution of the ^{238}Uactivity concentration for the collected groundwater samples, Al Hassa, KSA.

Areal Distribution of ^{238}U activity concentration:

Figure (6) represents the contour map of ^{238}U activity distribution in the area of study. The activity concentration of ^{238}U ranges between 0.1 to 0.9 pCi/L. Comparing this map with gross alpha and gross beta distribution maps (Figures 5 &6), it is clear that almost the same locations of high radionuclides concentrations of ^{238}U are the same of the gross alpha and gross beta. The site of Al Ghweiba, on Qatar road (site of sample No. 20) is the highest concentration of ^{238}U. For the rest of the map, the radioactivity concentrations is relatively low.

Areal Distribution of ^{234}U:

Figure (7) represents the contour map of ^{234}U activity distribution in the area of study. The activity concentration of ^{238}U ranges between 0.16 to 0.81 pCi/L with almost of the same range of ^{238}U which discussed above. Investigation of this map indicates that the highest concentration are located at the northwest , middle part and to the south east of the area of study .

Comparing the ^{234}U distribution map (Figure 7 with distribution maps of gross alpha , gross beta and ^{238}U distribution (Figures 4, 5 &6), it is clear that almost the same locations of high radionuclides concentrations of ^{234}U are the same of the gross alpha, beta and ^{238}U. Also the location of No.37 at Al Uyoun is characterized by high concentration.

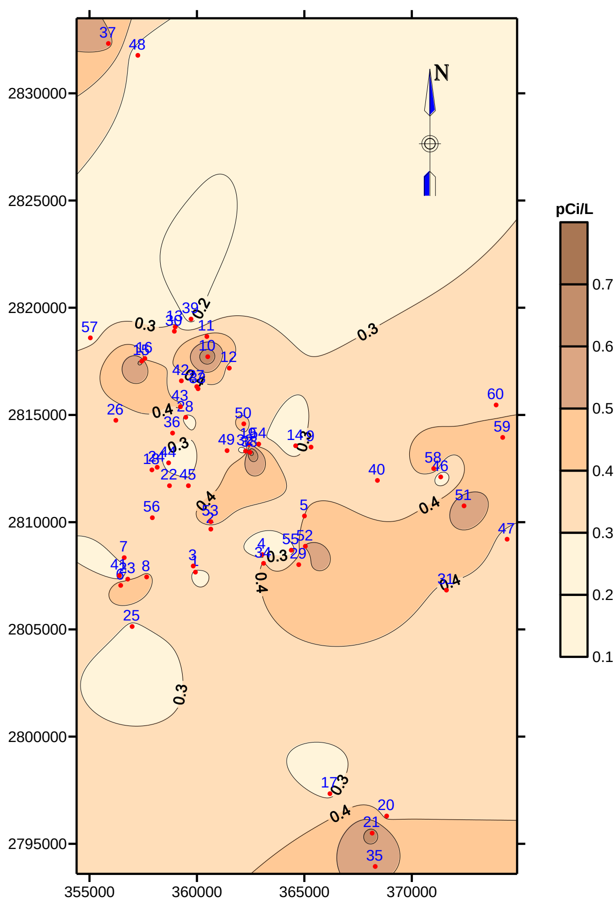


Figure (7).The areal distribution of the ^{234}Uactivity concentration for the collected groundwater samples, Al Hassa, KSA.

The areal distribution of the total uranium activity concentration

The distribution of the activity concentrations of the total uranium measured in part per billion (ppb) is represented in Figure.(8). The activity concentrations of the total uranium ranges between 0.21 to 2.12 (ppb). The relatively higher zones of the total uranium concentration are located at the southeastern part of the area and to the east part at the middle of the study area, at the location of samples numbers 21, 22, 30, 54 and 60 (see also Figure 3, e).

With general inspection of Figure (3) and Figures(4 to 8), it should be noted that almost the same locations of high radionuclides concentrations of gross alpha, gross beta, ^{238}U, ^{234}U and total uranium, are almost of the same location and this confirm that they source causing this relatively high concentration are the same for all these radionuclides.

Also, it worthy to mention all the maps shown in Figures 4 to 8 remarkably indicates two highest zones of radionuclides concentration. The first one is located to the northwest corner of the area the location of sample Nos.37 and 48 at Al Uyoun area. The second one is located to the southeast corner of the area the location of sample Nos.20, 21 and 22 at Al Ghweiba, on Qatar road. The relatively high

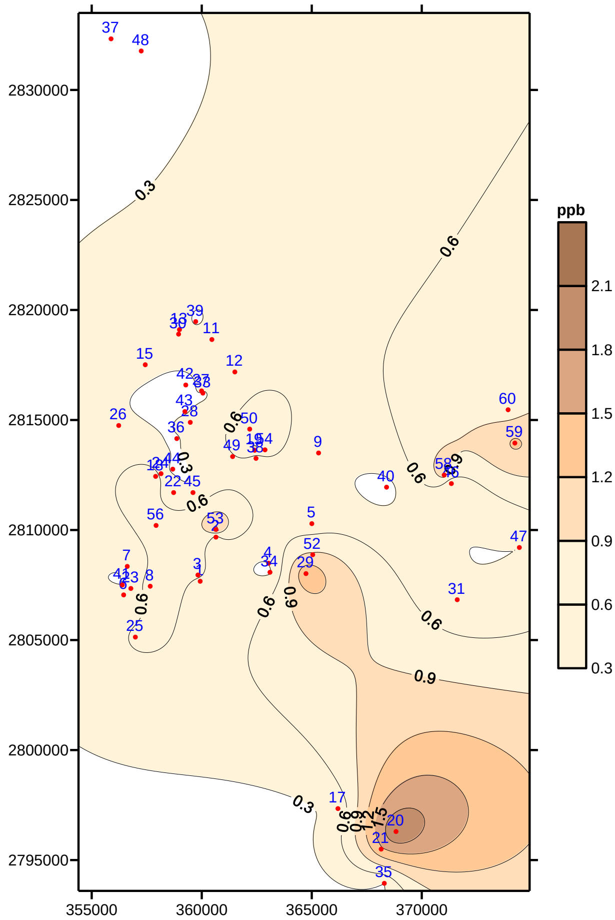


Figure (8).The areal distribution of the total uranium activity concentration for the collected groundwater samples, Al Hassa, KSA.

concentration at these particular areas is attributed to subsequent hydrogeological processes causing radionuclides solution and precipitation, and geological phenomena's such as faults, hydrothermal alterations, weathering could have favored further local enrichment in such areas.

The measurements of the high radioactivity concentration in the groundwaters can be good indicator for the high radioactivity levels in the aquifer rocks. Because radionuclide concentrations in groundwaters depend on the minerals derived from aquifer rocks. Consequently, it is not surprise that the high radioactivity concentrations were measured in groundwater samples draining area close to Al Uyoun and Al Ghweiba areas.

The specific levels of terrestrial environmental radiation are related to the geological composition of each lithologically separated area, and to the content in thorium (Th), uranium (U) and potassium (K) of the rock from which the soils originate in each area (Merdanoglu and Altınsoy, 2006).

Groundwater is heated by subsurface geologic activity and passes through relatively young and uraniferous igneous rock. Radium is dissolved from the rocks by hot ground water. Uranium is not dissolved because the groundwater is anoxic and uranium is insoluble in anoxic waters (Grandstaff 1976). When the groundwater reaches the surface at hot spring locations, travertine, a calcium carbonate mineral, precipitates out of solution with dissolved radium substituting for calcium in the mineral.

External exposures to gamma radiation outdoors arise from terrestrial radionuclides occurring at trace levels in all ground formation. The contribution to absorbed dose in air external gamma radiation emitting from radionuclides change also depending on local geological and geographical conditions (Örgün et al., 2005).

Conclusions

The study of the radionuclide concentration levels in groundwater of Al Hassa area has been carried out. Sixty representative groundwater samples have been collected from different localities at Al Hassa area. The relatively abnormal highs for the analyzed radionuclides are attributed to the heterogeneity of the lithology of the aquifer at these particular locations. Also geological phenomena's such as faults, hydrothermal alterations, weathering could have favored further local enrichment in such areas.

The results indicated that the radionuclide concentration levels are lower than the International Commission on Radiological Protection (ICRP) maximum permitted limit and therefore, have no significance radiological health burden on the environment and the populace However, these values may increase in future with the more water depletion and water quality degradation. However, the concentration of gross-β radioactivity higher than WHO-guide limit in drinking water. Limit values for gross-α and gross-β radioactivity concentrations in drinking water are 2.7 and 27 pCi/L, respectively (WHO, 1993).

This study can be used as a baseline for future investigations. It is safe to use the still flowing springs at Al Hassa oasis as health spas.

Acknowledgment

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30. الملخص العربى

عنوان البحث:– مستويات الإشعاعية الطبيعية فى تربة الأحساء ،المملكة العربية السعودية

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تعتبر واحه الأحساء واحدة من اهم المراكز الزراعية القديمة في المملكه العربية السعودية وتبلغ مساحة واحة الأحساء حوالى 360 كم^2 وتقع إلى الشمال الغربي من الخليج العربي بنحو 70 كيلومترا وتبلغ المساحه المزروعة في واحة الأحساء بحوالى 80 كم^2 وتروى بشكل أساسى من مياه خزان عصر النيوجين .ولقد أدت زيادة معدلات الضخ من هذا الخزان إلى نضوب المياه وتدهور نوعيتها.

وتهدف هذه الدراسة لإلقاء الضوء على مستوى الإشعاعية الطبيعية لمياه الآبار والينابيع فى هذه المنطقة الحيوية بمنطقة الأحساء وتحديد إلى أى مدى هذه المياه ملوثة إشعاعيا. ولتحقيق هذا الغرض تم جمع ستون عينة مياه من مياه آبار وعيون واحة الأحساء وأطرافها. وفى هذه العينات تم تحديد كل من نظير U-238 ونظير U-234 وكذلك تركيز كل من جسيمات ألفا وجسيمات بيتا فى هذه العينات وقدر تركيز النشاط الإشعاعي لهذه النظائر والجسيمات بوحدة بيكو كوري/لتر،كما قدر اليورانيوم الكلي فى هذه العينات كجزء فى البليون.

أظهرت نتائج تحاليل الإشعاعية الطبيعية لعينات المياه المأخوذة من واحة الأحساء وأطرافها تباين فى مقدار الإشعاعية الطبيعية لسلاسل اليورانيوم وتم تمثيل النتائج فى صورة رسوم بيانية وخرائط كنتورية. وقد أظهرت النتائج أن تركيز نظير U-238 يتراوح مابين 0.1 إلى 0.9 بيكوكورى/لتر بينما يتراوح نظير U-234 مابين 0.16 إلى 0.81 بيكوكورى/لتر ووجد أن تركيز اليورانيوم الكلى يتراوح مابين0.21 و 2.12 جزء فى البليون.بينما تراوحت تركيز جسيمات ألفا مابين 12 إلى 54 بيكوكورى/لتر و تراوحت تركيز جسيمات بيتا مابين 167 و 315 بيكوكورى/لتر.

ولقد وجد أن التركيزات العالية نسبيا لنظائر اليورانيوم ولجسيمات ألفا وجسيمات بيتا في عينات المياه الجوفية التى تضخ من الخزان التابع لعصر النيوجين ترجع إلى عدم تجانس أو تغير السحن الصخرية المكونة للطبقات التى يتكون منها خزان النيوجين وأيضا إلى مدى تأثر هذا الخزان الغير محصور بالأنشطه البشرية.

مثل هذه النتائج تعتبر قاعدة بيانات هامة يبنى عليها مستقبلا لمراقبة أى تغير فى الإشعاعية الطبيعية لأهم مصدر طبيعى بواحة الأحساء تلك المنطقة الحيوية من المنطقة الشرقية بالمملكة خاصة وأن هذه المنطقة تشهد كثير من المشروعات التنموية كالمشروعات الصناعية والزراعية .

والجدير بالذكر أنه بالمقارنة بالمعدلات العالمية وتبعا لتوصيات اللجنة الدولية للوقايه من الاشعاعات فنجد أن تركيز هذه النظائر المشعة فى مياه وينابيع واحة الأحساء نجد أنها وفقا لهذه الدراسة مازالت أمنة إشعاعيا ولاتمثل أى خطورة على البيئة المحيطة فى الوقت الحالى.

الكلمات الدالة:– النشاط الاشعاعي الطبيعي ، المخاطر الصحيه للإشعاعية ،اليورانيوم ، جسيمات ألفا وبيتا ،التلوث الإشعاعي للمياه الجوفية ، ،المياه الجوفية ، ونوعية المياه ، ،واحة الأحساء – المملكه العربية السعودية.

MAINTENANCE WORKS OF WATER STRUCTURES, AFLAJ CHALLENGES IN THE SULTANATE OF OMAN

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Saif bin Sulaiman Al Amri[3], Tariq Helmi[4]

ABSTRACT

Water is the backbone of life for every living being, since time immemorial. Almighty God said in the Holy Quran " we made from water every living thing" (Sourat Al Anbiya 30). It is well known that the people of the Sultanate of Oman are faced with some harsh environmental conditions, the salient feature of which is the scarcity of water resources which are restricted to wells and *aflaj*. The traditional construction of, and concern about *aflaj* are integral parts of the heritage which the Omanis feel proud about. In addition *aflaj* have a remarkable socio-economic role and close connection with the local environment where the citizens were dependent on them from ancient times in all aspects of their life. Agricultural production in Oman is almost fully dependent on irrigation in which more than one third of irrigation water is supplied by *aflaj* (singular: *falaj*). Oman has 4,112 *falaj* in which 3,017 are live *aflaj,* producing water about 680 x 106 m^3 year. They supply rural communities with their water requirements for agriculture and domestic uses. 33% of the agricultural land in Oman is irrigated by *aflaj*. *Aflaj* flow rates range between 15 and 60 l/s and the flow of some large *aflaj* may reach up to 1500 l/s in wet periods.

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The falaj is a marvelous engineering work resembling the high-level techniques and skills of the Omanis and the remarkable stage reached by that unique architectural style in the region. *Afalj* have been existed in Oman since ancient times and some of them were built before the advent of Islam. The Sultanate has paid a special attention to *aflaj* throughout various periods of time. This attention reached its climax during the blessed Renaissance period where the State has allotted large funds in the annual budgets for *aflaj* maintenance and introduction of modern maintenance devices such as mechanical shovels which are currently used for *aflaj* channel excavation instead of manual devices, as well as the use of plain and reinforced concrete for *aflaj* channel lining in lieu of stones and Sarooj, a matter which reduced time and effort put in maintenance works.

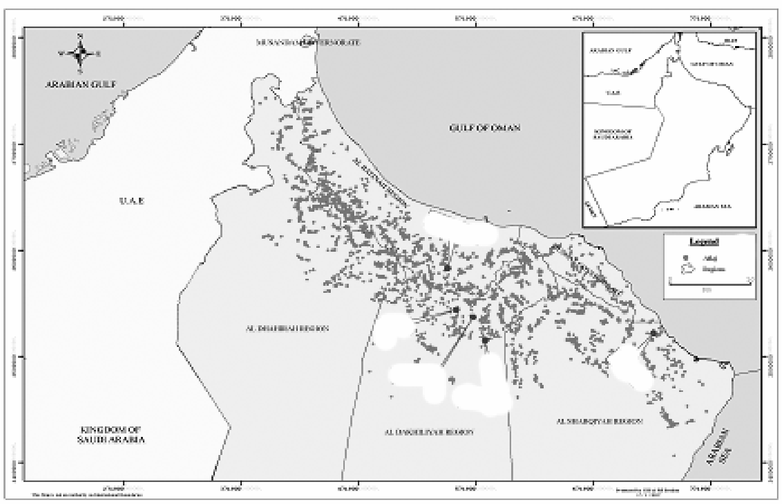
As the Omanis have established the concept of irrigation by *aflaj* a long time ago, their descendants are responsible for keeping this cultural heritage in the present time through maintenance of *aflaj* and avoidance of over-exploitation of their water. This paper deals with *aflaj* and their importance, types and construction. Then it reviews and documents in more details, for the first time the *aflaj* maintenance and repair works. These detailed engineering works were compiled through about 669 project for *falaj* maintenance carried out by the Government since 1989 till the end of 2006.

1. INTRODUCTION

1.1. *Aflaj in The Sultanate of Oman*

Aflaj the singular of which is *falaj*, has a number of meanings. Linguistically the word *falaj* means a fracture or fissure on the ground, a small stream or an irrigation canal. The word *aflaj* is a comprehensive term which means an irrigation system. In classical Arabic *falaj* means to divide property into shares. Thus *aflaj* means an organization for distributing water amongst shareholders and this is the meaning used in the region.

In Oman, there are 4,112 *aflaj*, of which 3,017 were operational. Of the total national cropped area *daudi aflaj* irrigate 22%, *aini* 11%, *ghaili* 8% and wells 59% (Ministry of Water Resources 1997). Most of



them are found at the foothills and low land of the northern mountains (Al Hajar Al Gharbi and Al Hajar Al Sharqi) in Northern Oman as shown on Figure 1.

Figure 1 : The Location of *Aflaj* in The Sultanate of Oman

From engineering point of view, *falaj* means a main well with a number of subsidiary wells dug in a mountainous area and connected by a canal passing across the bottoms of those wells. The canal is constructed with a downward slope which allows a flow of water from the first well to the last well, then to the surface. The ancient Omanis spent a lot of money, time and effort in building engineering structures and the success they achieved in their endeavors is exemplified in the great skill they employed in building those *aflaj* which have immortalized their history.

1.2. *Aflaj and their importance*

Agriculture is a vital economic resource for nations throughout the world. Fresh water resources used for irrigation vary from one region to another, with some regions depending on rainfall and others taking their water from rivers or collecting it in large reservoirs or dams; in addition, many regions rely on underground water which accumulated a long time ago in certain geological formations.

The situation is different in the Sultanate of Oman, which lies within the arid and semi-arid zone where there are no rivers and the rainfall is not sufficient for agriculture. However the Omani people were never helpless; they accepted the challenge and applied their minds and skills to obtain the maximum benefit from the available underground water resources. They found the optimum solution in the *aflaj* system, which enabled them to obtain the fresh water supplies required to ensure continuity of life in Oman. The fruit of their efforts can be seen today in the existing *aflaj* and irrigation canals. *Aflaj* have always played a remarkable role in enabling agriculture to be sustained through water supplies, which represent the basis of life and the stability of human communities. The ancient Omanis excelled in the construction of *aflaj* in spite of their limited capabilities. The *aflaj* demonstrated the unique engineering style of the Omani people who were completely dependent on them in view of the absence of other sources of water.

2. TYPES OF *AFLAJ*

Although similar in some characteristics, there are some basic differences between the different types of *aflaj*, especially in terms of their width, depth and water quality as well as the nature of the land on which they are constructed – though there are also numerous similarities in the method of construction. In addition, there are variations in the quantity of water carried by one *falaj* and another. Such variations are attributable to a number of factors, including the availability of water in the aquifer and the amount of water lost through evaporation and seepage. The most important advantage of *aflaj* is the continuous flow of their water throughout the year without incurring any running costs apart from the cost of construction and maintenance.

A- Iddi* (or *Daudi) Aflaj

It is clear from the name that these *aflaj* are attributed to the Prophet Solomon son of David, upon him be peace, who ordered the jinn to build the *aflaj*, and it is from these that the name *Daudi falaj* derives (Wilkinson 1997). Abundant flow of water is one of the most important characteristics of this type of *falaj,* which is usually affected by changes in the groundwater table (Figure 2). A *falaj* of this type consists of an underground tunnel between 0.5m and 1m in width and 0.5m to 2m in height with a maximum depth of up to 50m below the surface of the ground. These *aflaj* are characterized by their length, which may be as much as 12 Km, and their perennial flow which continues throughout the year. They have branches (*Sa'id*) which increase the *falaj* recharge. Some *aflaj* may have tens of branches; according to the results of the *Aflaj* Inventory Project, *Al Malki falaj* in the Wilayat of Izki is the largest *falaj* in Oman in terms of the number of branches, with a total of 17 branches. *Daudi aflaj* account for about 23.5% of the total number of Oman’s *aflaj*.

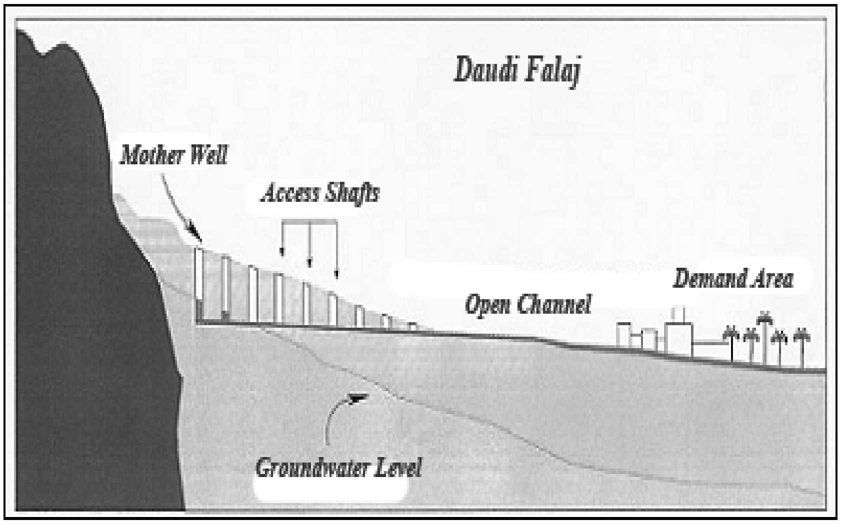
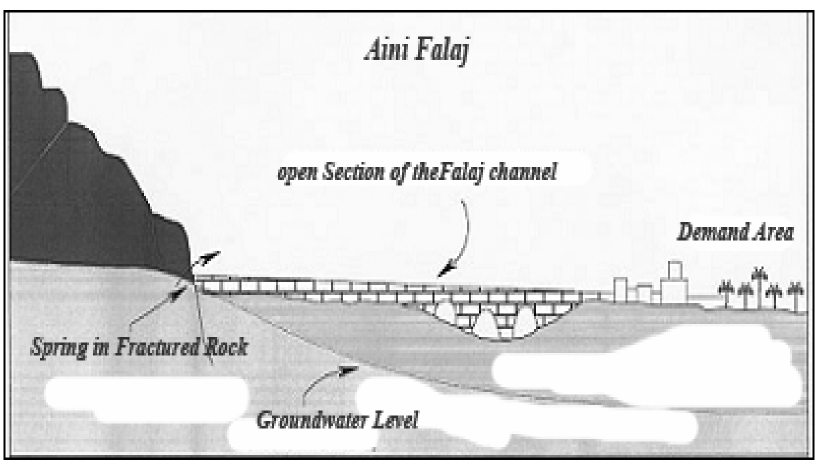


Figure 2: *Daudi* (*Iddi*) *falaj* Type

B- Ghaili Aflaj

They are called *ghaili* because they are seasonal and flow at certain periods determined by the availability of groundwater and rainfall. They draw their water from wadi channels and the lower mountain slopes, which constitute the main sources from which the *falaj* water is derived (Figure 3). They area normally open channels with only small covered sections located within wadi channels. They have a depth of up to 4m below the surface of the ground and are between



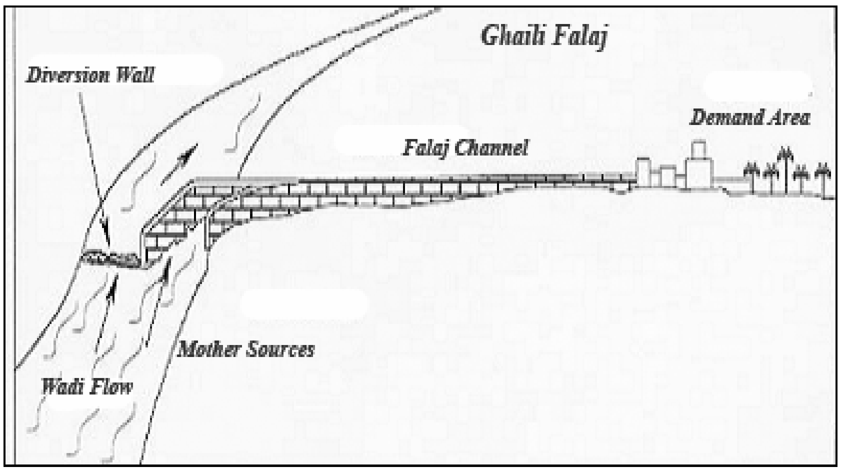
100m and 2 km long. Most of these *aflaj* become dry during the dry periods as a result of their dependence on the water which accumulates in the pools at the downstream of the wadi and base flow. This is the most prevalent type of *falaj* in North Oman and constitutes about 48.5% of the total number of *aflaj* in the Sultanate.

Figure 3: *Aini falaj* type

C- Aini Aflaj

These are fed by springs flowing from the foothills and peaks of mountains where the water runs in open channels (Figure 4).

Water of such *aflaj* flows from deep geological layers formed in ancient times. Such water usually contains sulphur and sometimes it may be hot; therefore it is used to cure some diseases such as rheumatism. There are many such springs in the Sultanate; the most widely known



are Ain Al Thawarah in the Wilayat of Nakhal, Ain Al Kasfah in the Wilayat of Rustaq and Ain Arzat in Jabal Al Qara in Dhofar Governorate. *Aini aflaj* account for about 28% of the total number of *aflaj* in the Sultanate.

Figure 4: Ghaili *falaj* type

3. FALAJ CONSTRUCTION

The *falaj* is a unique system which depends on groundwater. It is a man-made conduit constructed in a masterly engineering style. Groundwater accumulates by seepage into the conduit which is 2 to 4 feet wide, then it flows downward to the end of the conduit. The existing *aflaj* prove that our ancestors did not construct them in a haphazard way; instead, they adopted a scientific engineering approach. We can see this clearly if we take a look at the steps they followed in the building process:

First step: Exploration:

The selection of the proper site for constructing the *falaj* is determined by a range of geographical criteria identified by our ancestors, including:-

A. Existence of a high and wide physiographical and topographical set-up with drainage basins that absorb rain water and ground water flowing towards low lands with suitable soil for agriculture and farming.

B. Availability of sufficient information about an aquifer which is annually recharged by seasonal or intermittent rainfall. Aquifers may not exist in mountain areas of heavy rains and flowing wadis, due to hard rock formations in the area which do not permit any water infiltration but only allow surface flow to remote downstream areas.

C. Areas of clayey or alluvial soils are suitable for the absorption and infiltration of water to form major aquifers where swamps and large plants and trees are frequently found. These areas are suitable for excavating a *falaj* to tap the groundwater and carry it to the desired location for long-term use. The ancient Omanis identified the aquifers by observing large numbers of *prosopis cineraria* trees. When the soil in that area was suitable for agriculture, they promptly started *falaj* excavation to convey the ground-water to the agricultural land for use.

Second Step: Excavation:

The *falaj* excavation phase follows confirmation of the area's suitability and the availability of the required factors. After verification of the above, *aflaj* construction experts undertake many site visits to the selected area and take engineering measurements there. The first issue to be considered is a study of the location from the geographical point of view, including the upstream area where the aquifer is sited and the downstream areas where the ground level is compatible with the groundwater level in the upstream area. Deciding on the mother well is one of the first requirements for *falaj* excavation. A suitable site for the mother well is usually determined by the *"Basir"* or expert (a person with special knowledge in determining the existence of underground water by intuition) before the beginning of the excavation process. Then the expert determines the site at which water will emerge at the surface (*shari'a*). Sometimes two or more experts meet to decide on a suitable site for the mother well.

The mother well is excavated after a suitable aquifer has been identified by the expert. Then four or five test wells are dug at varying distances according to the availability of underground water. The distance between such wells may be as close as seven meters, though sometimes it may be up to fifty or eighty meters. When sufficient stocks of water are reached the dug wells are connected with each other through an underground tunnel locally known as *A'sull*. Then wells of a lesser depth are dug along a straight line. Excavation takes place in two directions and the expert determines the correct direction of the *falaj* and its channel until the required area is reached. If the diggers encounter an obstacle which they can not overcome, they usually go around it. The digging of the wells continues with gradual reduction of the well depths until the water flows on the surface at the *shari'a,* after which a number of internal canals are constructed to convey the water to farms within the catchment area.

***4. AFLAJ* WATER DISTRIBUTION SYSTEM**

The water distribution system is rather complicated and requires comprehensive study because it varies from *falaj* to *falaj* according to the social and economic conditions prevailing in each *falaj* area. The distribution of the *falaj* water is based on complicated calculations involving the positions of stars and the times of sunset and sunrise. The *falaj* water is divided among the people who have participated in the excavation of the *falaj*. Before we proceed with reviewing the methods of water distribution we need to explain some of the locally used terms:

4.1 The falaj agent (Wakeel)

The responsibility for water distribution, time keeping, dispute resolution and management of *falaj* affairs rests with a person called the *Wakeel* (the *falaj* agent) who undertakes such tasks in exchange for a certain quantity of the *falaj* water. The *Wakeel* should have certain qualifications such as knowledge of the stars and an ability to calculate the intervals between the rising and setting of the stars and the seasonal variations of their positions, as well as an understanding of measurements of shadow length etc. When people have confidence in such a person's knowledge and experience, he will be entrusted with the task of distributing the *falaj* water between the shareholders on a rota system. Disputes over the water distribution, of water are referred to the *Wakeel*. The *Wakeel* is assisted by a person called the *Areef* whose main task is to distribute the *falaj* shares.

4.2. The baddah

Falaj water is divided into baddat (plural of baddah), and each baddah is divided into 24 athar; an athar is approximately half an hour, so the duration of one baddah is 12 hours. A quarter of a baddah is known as a ribi'a (3 hours). A baddah can be owned and its owner may offer it for sale or rent. The *Wakeel* knows the exact time at which each baddah or athar begins or ends. The *Areef* relies on the stars at night and the shadows during the daytime to determine water shares. One *atha*r may be equal to 30 feet of the shadow cast by the post. This distance decreases by time because shadows lengthen as the sun goes down, therefore the length of the following athar would be 22 feet and so on. These days people have switched to the hour system instead of depending on the stars and shadows.

4.3. Athar

An athar is divided into 4 parts, each of which comprises 6 kiyas - i.e. one athar is equal to 24 kiyas. A quarter of baddah is called a ribi'a which is equal to six athar.

4.4. Quod

Some shares in the baddah are owned by the farmers and some are offered for rent to those who have no shares in the *falaj* water. This process is known as the Quod. The Quod and the reserve shares in the baddah are considered as endowment to the *falaj* and their rent proceeds are used to cover the *falaj* maintenance costs and other *falaj*-related expenses.

4.5. Water Distribution Methods

There are several methods for distributing the water between shareholders. Some of them involve dividing each shareholder's share by the number of days required to irrigate his farm, with a minimum of four days and a maximum of ten days and nights, though usually the average is eight days. Soil type plays an important part in water distribution. In areas where the weather is hot and the soil is a mixture of sand and gravel, plants can not tolerate more than four days without water. On the other hand where weather is cold and soils are usually thick and not mixed with sand or gravel, so plants can tolerate a period of more than ten days without irrigation. The *falaj* agent (*Wakeel*), who is usually appointed immediately after the construction of the *falaj*, takes care of the water distribution depending on requirements, while taking the nature of the soil into account.

Another *falaj* water distribution system is based on experience and skills acquired by practice. The day baddah is divided into 24 athar using specific time division criteria. Under this system people select a flat piece of land measuring 10 by 10 meters where the sun's rays are not obstructed by any object throughout the whole day. A pole two and a half meters high is anchored in the center. Then the area east and west of the pole is divided into standard divisions and water is distributed according to those divisions. This process is known as "the shadow of the wooden pole".

If the weather is cloudy, the *Wakeel* distributes the *falaj* water by relying on his own expertise in estimating the amount of water of one athar or the amount of water sufficient to irrigate a specific number of palm trees or part of a farm with a specific area.

The night-time distribution of water starts after sunset and the stars are used to calculate the water distribution intervals. The length of the night is taken into consideration in this complicated arithmetical calculation, which requires extensive knowledge of astronomy and an ability to estimate the intervals between the rising and setting of the stars. The movements of the stars are only known to a few people who have studied this science and acquired good knowledge of it by practice and learning from their ancestors. After the advent of clocks and watches all the old problems were resolved and it became easy to keep time to ensure accurate distribution of water among shareholders.

There is also another method for the distribution of *falaj* water, under which the shareholders agree to distribute water on a rotational basis through a ten-period cycle. Each plot of land is allotted a specified period of time in which it receives water depending on the number of shareholders. The best method under this system is to divide the plot into semi-circular portions, each of which is irrigated by a semi-circular canal. This simple system saves water and time and reduces water loss during the process of conveying it to the desired location. In *aflaj* with abundant water the *falaj* channel is diverted directly to irrigate the shareholders' farms on either side of the channel

It is clear from the above that *falaj* irrigation uses a clearly defined system for distributing water among shareholders and farmers. This system is mostly based on the distribution of water over specified periods of time. Each farmer is allowed a period of time to use the *falaj* water to irrigate his farm.

Each *falaj* has its own administrative system for managing the *falaj* irrigation in accordance with local conditions. In small *aflaj* the irrigation system can be easily regulated while in large *aflaj* with many shareholders the irrigation system is rather difficult. Moreover, the regulation of the irrigation system depends mainly on the community served by the *falaj*. The *falaj* administration is usually formed by the

Wakeel who gets a share in the agricultural land in addition to a share in the agricultural produce from some *aflaj*, though usually the *Wakeel* only gets a share in the *falaj* water. Employee numbers and management methods vary according to the *falaj* size and the number of shareholders. In small *aflaj* one person may assume responsibility for all the *falaj* affairs, while in large *aflaj* the work is divided among a number of employees under the supervision of a *Wakeel* appointed by the shareholders. The *Wakeel* is the senior person responsible for financing and organizing the sale of the *falaj* water and he decides whether the *falaj* services are sufficient or not. The *Wakeel* performs his duties without consultation with the shareholders but in a manner that safeguards the *falaj* interests. In cases of urgent matters relating to *falaj* affairs, the *Wakeel* usually invites the shareholders to a meeting to consider the problem. The *Wakeel* and his assistants receive their management fees from the *falaj* income.

5. *AFLAJ* MAINTENANCE OPERATIONS

5.1. Factors leading to aflaj deterioration

Currently there is a total of 4,112 *aflaj* of all types (live and dead) in the Sultanate of Oman with an annual flow of 680 million cubic meters. Of these, 410 million cubic meters are used to irrigate existing farms, while the remaining 270 million are lost as a result of the cracks and ruptures which are to be found in a large number of *aflaj* channels.

Almost one third of the cultivated land in the Sultanate is irrigated by *aflaj*; hence *aflaj* are a source of livelihood for a large sector of the Omani population and they encourage people to become closely attached to their land. Most *aflaj* farmers own small traditional holdings which generate low incomes. Therefore they cannot maintain the *aflaj* they use from their own resources. Moreover rising living standards during the blessed Renaissance and the import of dates from abroad, coupled with their low prices and the fact that most Omanis are no longer dependent on dates as a basic foodstuff, have decreased the revenue of the *aflaj*. Therefore *aflaj* owners have neglected their maintenance and have become largely dependent on the government in this respect.

The increasing importance of *aflaj* and the urgent need for their maintenance is due to the fact that *aflaj* provide many people with water supplies for drinking and domestic uses, in addition to the water required for various public utilities such as mosques and schools. Moreover *aflaj* are considered a major part of Oman's glorious heritage. In many villages and some towns *aflaj* are considered to be part of the infrastructure which needs to be supported and maintained by the government.

Most *aflaj*, especially those lying in wadi courses or on the fringes of plains adjacent to wadis are liable to collapse and their channels tend to be blocked by rocks and silt as a result of excessive rainfall or intrusion of water from the wadis into the part of the *falaj* channel extending from the mother well to the *shari'a*. This blocks the flow of water in the main channel near the area where the water is required. Deep *aflaj* also suffer from the collapse of access shafts, due to erosion and heavy rains which wash stones and silt into the channels, leading to the collapse of their walls and roofs and a consequent interruption of the flow of water to its destination. Prolonged droughts are a further factor that may cause *aflaj* to dry up. The factors that interrupt water flow and require *aflaj* maintenance can be summarized as follows:-

1. Prolonged drought
2. Erosion of old structures
3. Wadi floods
4. Accumulation of lime on the beds of channels
5. Growth of deep-root trees near *aflaj*
6. Collapse of roofs and walls of old channels
7. Channel beds becoming filled by soil and dirt

5.2. The State's contributions to aflaj maintenance

After the blessed Renaissance the State allocated millions of Omani Rials annually for *aflaj* maintenance and for the improvement of maintenance systems. In addition, laws were enacted and regulations and controls were brought in to conserve *aflaj* water resources, while modern maintenance devices such as mechanical shovels were introduced; these are currently used for *falaj* channel excavation instead of the old manual devices, and mechanical excavators have replaced manual excavation for breaking up the rock layers which obstruct the course of the *falaj*; in addition, plain and reinforced concrete is now used in lieu of stones and *sarooj* to line the *falaj* channels. All these measures have reduced the time and effort required for maintenance works. While earlier generations of Omanis established the principle of *aflaj* irrigation a long time ago, their descendants have now been assigned responsibility for the *aflaj* maintenance. Hence *aflaj* maintenance operations are restricted to Omani contractors.

5.3. Aflaj maintenance techniques

The State has spared no effort or money on the maintenance of the country's *aflaj*, which are not only part of Oman's heritage reflecting its ancient civilization, but also a major water resource. The State has provided technical and financial support for *aflaj* maintenance and has improved maintenance techniques in accordance with available financial resources at each phase of the Renaissance, as shown below:-

A. From the beginning of the Seventies up to the year 1994

- Local people would submit a *fala*j maintenance application approved by the Sheikh and the Wali.
- A field visit would be made to the *falaj* site in coordination with the *Wakeel* and the local population.
- Technical specifications and financial estimates would be made and put out to public tender; alternatively, quotations might be obtained from contractors.

- Initial approval for the work would be obtained from H.E the Undersecretary.
- work implementation contract would be drawn up and a notice to proceed would be issued in the light of instructions and financial allocations.
- The contractor would implement the required work under official supervision.
- Upon satisfactory completion of the work a completion certificate would be issued and the contractor would be paid the amount due to him

B. From 1994 up to now

- Local people submit *falaj* maintenance applications to the Regional Directorates.
- Regional Directorate staff inspect the *falaj* and prepare an initial report about it, including its structural and hydrological conditions, the works required and assistance previously extended to the *falaj*
- The criteria and standards set by the Ministry are applied to enable staff to decide on the eligibility of the *falaj* for maintenance work.
- The *falaj* owners are briefed on the inspection result and their *falaj*'s maintenance status.
- Maintenance priorities are given to *aflaj* on the basis of availability of funds and in line with the *Aflaj* Department's annual *aflaj* maintenance program.
- Staff prepare the technical specifications and financial estimates and the required maintenance work is put out to a public tender
- The bids received are analyzed and the tender is awarded to the appropriate contractor.
- A contract is drawn up and approved by H.E the Undersecretary, then a notice to proceed is issued.
- The supervising engineer at the Directorate undertakes regular supervision of the implementation work.

- Upon satisfactory completion of the work the supervising engineer issues a work completion certificate. The amounts due to the contractor are paid after deduction of a sum equal to 5% of the contract value, which is retained for a period of one year as a performance guarantee.

5.4. Aflaj maintenance works

There is little difference between one type of *aflaj* maintenance operation and another. The main types of maintenance work are listed below:

A- **Extension of new channels** this takes place through construction of new channels by using equipment suitable for the required depth. Channel construction works comprised:
  - Plain concrete (sand + small stones + cement) floors 10-15 cm thick
  - Plain concrete or plain concrete and stone walls, or walls built of stones and cement mortar with a thickness of 30 to 40 cm and a height of 120 cm.
  - Roofs made of reinforced concrete or *Omani Salafa* (flat stones)

B- **Maintenance of tunnels** This is done by enlarging existing channels and supporting the weak sections with stones and cement after removal of sand and dirt. Roofs are supported by prefabricated concrete slabs or by *Omani Salafa*

C- **Construction of new diversions of courses of *aflaj*** This is done using the same method used in extending new channels.

D- **Maintenance of open channels** through repair of old channels or through construction of diversion channels parallel to the old channels with sections proportionate to the size of the *falaj* discharge. The floors of such channels are built of plain concrete of thickness ranging between 10 and 15 cm Walls are built with a thickness of 30 to 40 cm with elevations varying according to the volume of the discharge and the level of the adjacent land.

E- **Maintenance of access shafts** This is done by removing old access shafts down to the hard rock base. Then an access shaft measuring 60 by 90 cm is rebuilt at a height of 50 cm above ground level. In fast flowing wadis such access shafts may be built below ground level. In such cases they are usually provided with a staircase made of steel or stones projecting out of the wall of the access shaft. Access shafts are either covered with slabs made of reinforced concrete or with *Omani Salafa* (normally flat stones, though sometimes they may be cylindrical).

F- **Construction of crossings beneath roads** Bridges made of reinforced concrete are constructed with sections suitable for the loads expected to pass over the road. Sometimes a complete section of the *falaj* channel is constructed under the road where the structure of the old channel is weak.

G- **Construction of Siphons** *(gharraq falah)*: Siphons are constructed at points where *aflaj* intersect with wadis. They are usually made of reinforced concrete with sections suitable for the size of the *falaj* flow and the geological characteristics of the site in order to ensure a smooth flow of the *falaj* water from one bank of the wadi to the other.

H- **Construction of bridges to carry *aflaj* channels over wadis** When a *falaj* crosses a wadi channel a conveyance canal is constructed on a supporting bridge extending over the wadi channel.

I- **Protection of *aflaj* channels from erosion** Protective walls are built using stones and cement mortar. The sizes of the walls are determined by the nature of the site and the need to prevent the conveyance channels from collapsing through erosion by wadi water.

J- **Construction of water collection basins** *(lujal)* Basins constructed from plain or reinforced concrete according to the nature of the site for the purpose of supporting low flow *aflaj*. The sizes of these basins vary according to the quantity of water required to be collected during specific period of time.

K- Adjustment of channel water levels The channel gradient is adjusted according to the difference in water level at the mother well and near the demand area in order to allow easy flow of water. Gradient adjustment may require a deepening of the *falaj* at certain positions to increase its flow.

5.5. Construction of support wells

The flow of some *aflaj* may decrease despite the fact that their structural condition is good and none of their parts require any maintenance. In such cases the government constructs a supporting well equipped with pumps and pipes to alleviate water stress.

5.6. Improvement of aflaj maintenance techniques

There are many proposals and actions which should be considered in order to improve *aflaj* maintenance techniques, including:

A) General measures to ensure compliance by *aflaj* maintenance contractors:

- **Project classification**

  Projects are classified into three categories (small, medium and large projects) according to their sizes and the cost of works to be implemented.

- **Classification of the contractors**

  Contractors are classified into two grades (first grade and second grade contractors) according to their capabilities, such as equipment, staff expertise, supervisory body etc. in addition to their records of previous works with the Ministry, their compliance with delivery dates and the quality of implemented works. First grade contractors implement large and medium projects while small projects are left for second grade contractors.

- **Bank guarantee**

  The contractor or company awarded a tender to implement the maintenance works must submit a bank guarantee equivalent to 5% of the contract value, valid throughout the implementation period, to ensure sound implementation of the work within the agreed time.

- **Compliance with the period specified for implementation of the work**

  The implementation period shall be laid down in coordination with the contractors after they are informed of the work that is required and the nature of the area on which it is to be carried out, to enable them to comply with the agreed implementation period.

- **Technical specifications and estimated costs**

  All contractors must abide by the general and special specifications of the maintenance works and the materials to be used. Such specifications shall be considered to be an integral part of the *falaj* maintenance agreement to be signed by the contractor and the Ministry. The contractor must itemize the required maintenance work indicating his price for each item. These prices shall be binding on both parties and final settlement of account must be made upon satisfactory implementation of the project.

- **Contingency allocations**

  A percentage of 10% of the value of the works agreed upon by the contractor and the Ministry shall be retained as a contingency amount which can be used for any necessary works which may arise during implementation. Such contingency amount shall be released upon completion of the works.

- **Standards of *aflaj* maintenance and construction of support wells**

  The standards for *aflaj* maintenance and support stipulated in Ministerial Decision No 64/97.

B) Determination of *aflaj* to be maintained or supported:

- Citizens shall submit their applications to the regional departments. The concerned regional department shall visit the *falaj* site and submit a report to the Department of *Aflaj*. The report will include the following**:**
  - A general description of the *falaj* and the required maintenance work, together with an initial estimate of the cost in accordance with the quantities and price.
  - The structural condition of the *falaj*.
  - The hydrological situation of the *falaj.*
  - The state of existing agriculture and water requirements for all uses.
  - Previous assistance extended to the *falaj.*
  - Social condition of the *falaj* owners cooperation with other concerned bodies should be arranged in this regard.
  - Geographical location of the *falaj* (remote area or urban area).
  - Importance of the *falaj* as a source of water.
  - Recommendation after application of the standards.
- The Department of *Aflaj* shall review the application of the standards and shall prepare a list of the maintenance priorities taking into account the social condition of the *falaj* owners, the geographical location and the importance of the *falaj* as a source of water supply.
- The Department of *aflaj* shall prepare an annual plan for maintenance work and construction of support wells according to funds allocated for each region.
- The *falaj* owners shall be notified of the action taken in respect of their application.

C) Maintenance implementation measures:

- Departmental staff shall prepare the technical specifications and estimated costs of maintenance of *aflaj* and springs.
- The required works shall be put out to tender. *Aflaj* Department staff shall give the contractors an adequate description of the works required and the general and special conditions of the agreements, in order to ensure that the contractors are fully aware of the required works in their entirety.
- ❖ The contractors shall fill in the bill of quantities and prices and the tender shall be prepared on the basis of the prices of the items of maintenance works.

D) Supervision of works implementation

- The contractor or the company shall submit the work implementation schedule.
- The regional departments shall set a schedule for follow-up field visits during the implementation period.
- A qualified person shall be present at the site during the concreting operations to oversee the quality and percentage of the concrete mix and take concrete samples to send to the laboratory at the contractor's expense.
- The contractor shall not implement the reinforced concrete works without first obtaining written approval from the concerned engineer at the regional department effecting receipt of reinforcement steel and adequacy of the brackets.
- The work shall be handed over in stages (Excavation – Foundations – Canals – Roofing). The contractor shall not proceed to the next stage until the preceding stage has been handed over and a written order to that effect has been received from the concerned engineer.
- The regional departments shall submit detailed monthly progress reports on the projects under implementation.

- *Aflaj* Department staff shall make visits to the work sites to check that the work is proceeding in accordance with the program submitted by the contractor.

E) Some *aflaj* maintenance operations

- **Walls**

  Walls of covered or uncovered channels are built either of reinforced or plain concrete with solid stones or of stones and cement mortar as shown in Figure 5 (a), (b) and (c)

- **Roofs**

  Roofs of *aflaj* channels are made of solid stones locally known as (*Salafa*) laid either horizontally or pitched at an angle. Roofs may also be made of reinforced concrete as shown in Figure 6 (a), (b) and (c)

- ***Aflaj* facilities**

  It is recognized that the facilities area in which the *falaj* recharge takes place is the most important area in the *falaj* system. Figure 7 shows how channels are built in this area. The *falaj* may receive its recharge supplies from the bottom or the sides or from both as shown in Figure 7.

- **Intersection of *aflaj* with small wadis (tributary Wadi)**

  The *falaj* may intersect with a small wadi known as a *Sharja*. In such cases the *falaj* channel needs to be extended over the small wadi to avoid damage to the channel when the wadi flows. Figure 8 shows how *aflaj* channels are extended over wadis

- **Siphons *(gharraq falah)*:** When a *falaj* intersects with a large wadi the *falaj* channel needs to be extended beneath the wadi bed through a siphon locally known as a *gharraq falah*. The length and gradient of the siphon bottom depend on the size of the wadi and its discharge. Siphons may be built in various different configurations, as shown in Figure 9 (a), (b) and (c)

- **Road Crossings:** When a *falaj* intersects with a side road, the *falaj* is protected by constructing its channel under the road while taking into account the type of the subsoil as shown in Figure 10
- **Intersection of *a falaj* with a road**

  When a *falaj* intersects a road, the weight of the vehicles passing over the road necessitates construction of a reinforced concrete culvert under the road to allow *falaj* water to flow as shown in Figure 11.
- **Access shafts:**

  The main purpose of the access shaft is to provide access to the deep part of the channel for maintenance and the removal of dirt in order to allow easy flow of the *falaj* water. Access shafts may be constructed on flat land or in a wadi channel. Figure 12 shows sections of access shafts.
- **Protection of channels from wadi erosion**

  The channels of many *ghaili aflaj* pass parallel to wadi channels at levels above or below the wadi bed. Such channels may be subject to collapse due to wadi flow and should therefore be protected. Figure 13 shows how conveyance channels are protected from wadi flows in two cases - (a) when the depth of the rocky wadi bed is less than 2 meters, and (b) when the depth of the rocky wadi bed is more than 2 meters.

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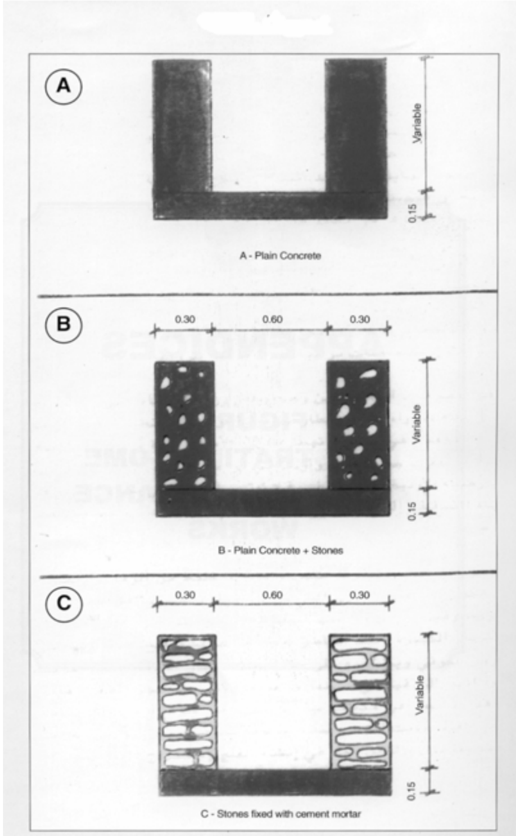
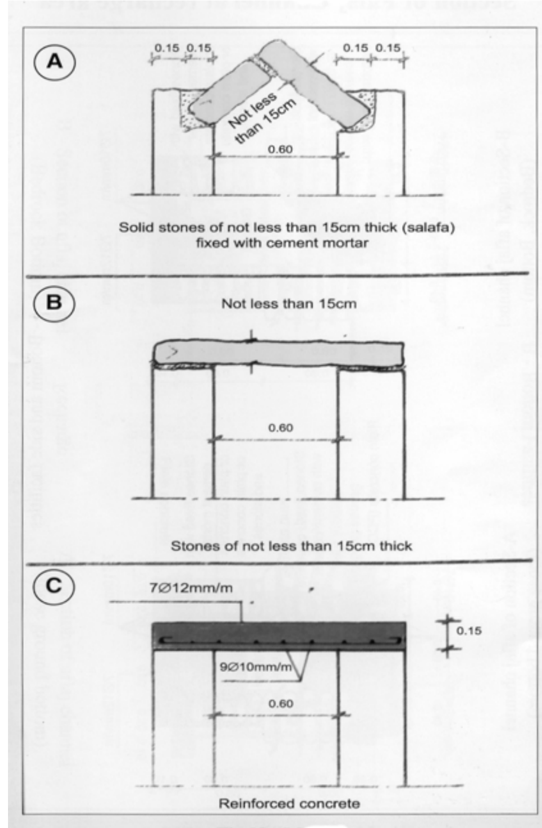
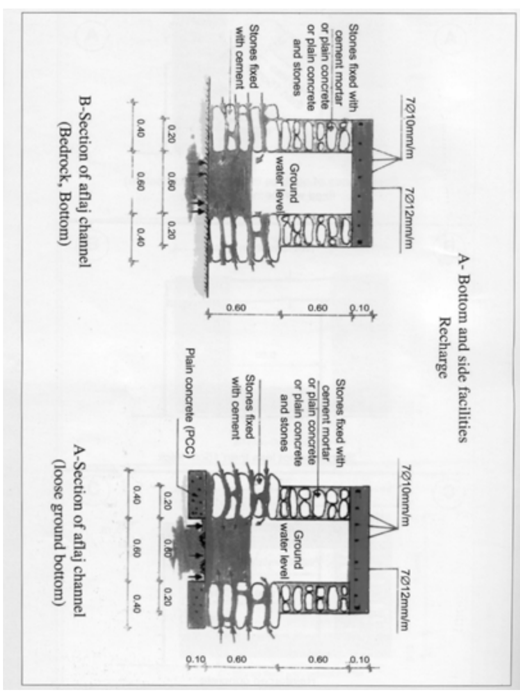
4. GLOSSARY OF THE ARABIC WORDS

Ain	Spring
Aini *Falaj*	Type of *falaj* by spring
Al Hajar Al Gharbi	Western Mountain
Al Hajar Al Sharqi	Eastern Mountain
Dawoodi	Type of *falaj* obtains water from deep aquifer
Falaj (Plural *Aflaj*)	A surface and/or underground channel fed by groundwater/spring or stream built to provide water to communities for domestic and/or agricultural use
Ghaily *Falaj*	Type of *falaj* in which water is derived from wadi base flow
Jabal (plural Jibal)	Mountain
Sharja'h	Small Valley (tributary valley)
Wadi	Stream or river bed which carries flash floods, sediment deposits are usually extremely sorted, literally; valley
Wilayat	An administrative area within the Sultanate of Oman







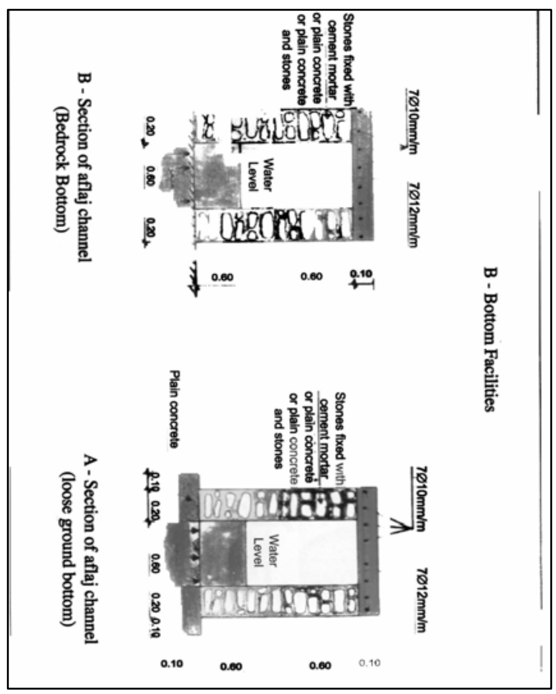


Figure 5: *Aflaj* Walls

Figure 6: Roof Types

Figure 7: *falaj* channel at recharge area with a sharja

Figure 8: Intersection of *falaj*

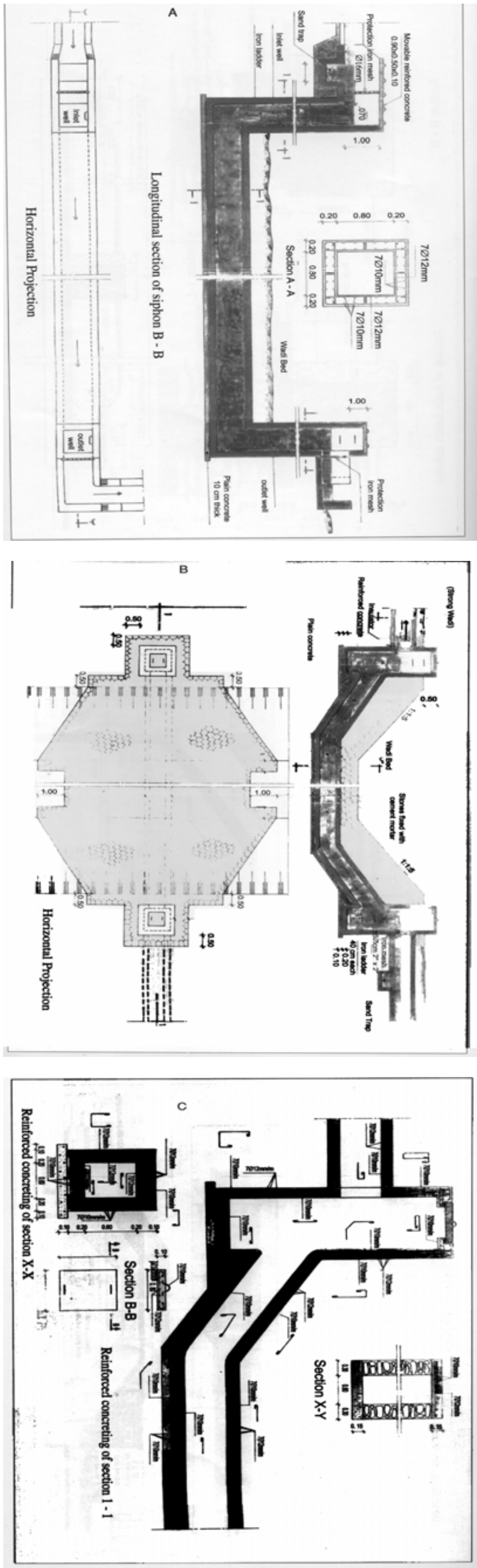


Figure 9: Siphon model (a, b, c)

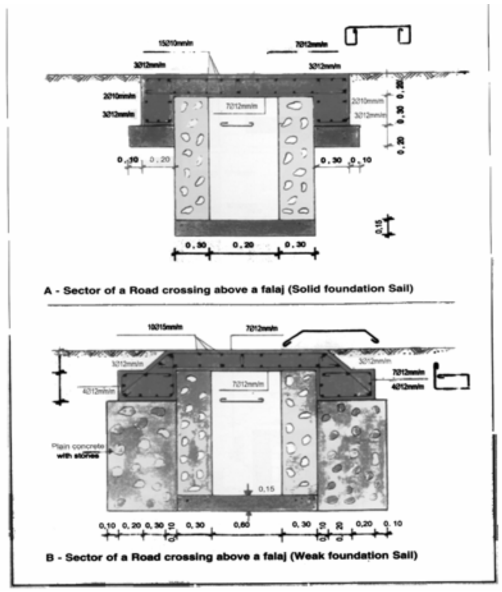


Figure 10: Road Crossing

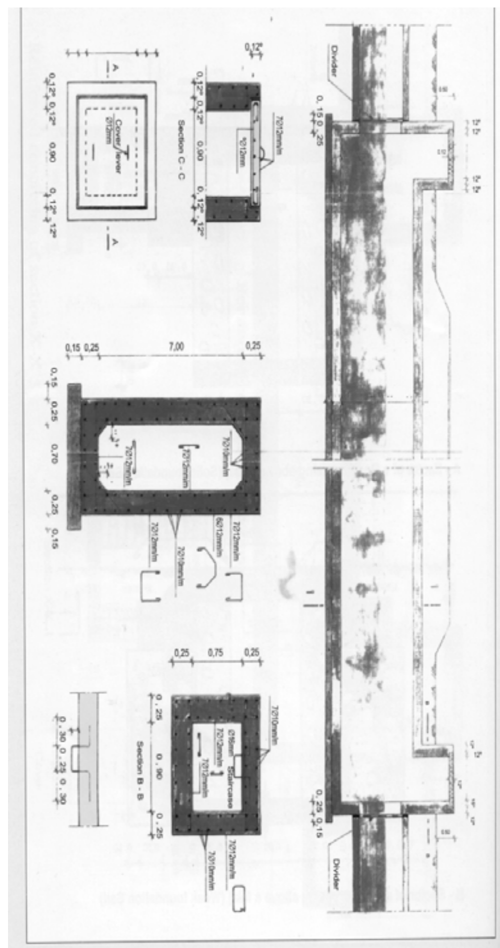


Figure 11: Intersection of *falaj* with road

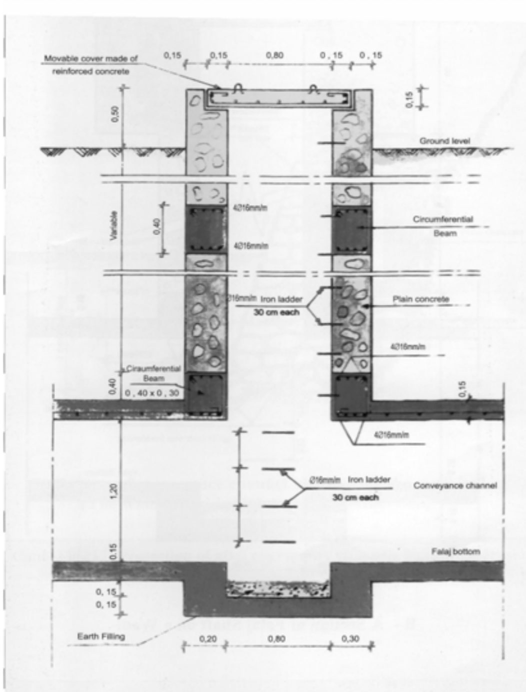


Figure 12: *Falaj* shafts

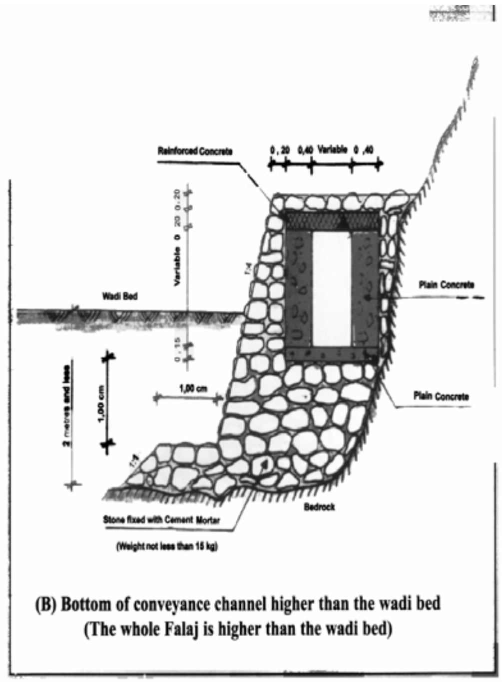


Figure 13: Protection of *falaj* conveyance channels from wadi erosion

Assessment of Rainwater and Run-off Quality at Agricultural and Water Resources Building, KISR, Kuwait: A Case Study

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Abstract

A research study was carried out to determine the quality of rainwater and run-off water from the roof of the agricultural and water resources building at Kuwait Institute for Scientific Research at Shuwaikh area, Kuwait. The rainwater and run-off samples were collected from this site and analyzed for parameters including pH and electrical conductivity (EC), total dissolved solids (TDS), turbidity, major cations (Na^+, K^+, Ca^{+2} and Mg^{+2}), major anions (SO_4^{-2}, Cl^- and HCO_3^-), total hardness, nitrogen compounds (NO_3^-, NO_2^- and NH_3), trace elements (F^-, Cu^{+2}, Fe^{+2}, Ni^{+2}, Pb^{+2} and Zn^{+2}), organic compounds (TOC) and bacterial indicators (total coliform bacteria, faecal coliform bacteria). The laboratory results indicated that TDS values of the rainwater ranged between 41.0 mg/l and 150.0 mg/l with mean value of 93.3 mg/l, while those values for run-off samples ranged between 24.0 mg/l and 753.0 mg/l with mean value of 184.3 mg/l. In general, the water analysis results revealed that the first cycle of rain had the highest concentration of pollutants compared with the next cycles. The presence of pollutants in the run-off samples is probably due to flushing the sediments and dust on the roof of the investigated building. Moreover, the rainwater samples meet the drinking water standards, while the run-off samples need to be treated before being used for drinking. The treatment included removing the dust and sand particles as well as water disinfection. Also, this water can be used without any treatment for other applications such as for agricultural and washing purposes.

Keywords

Rainwater, total dissolved solids, bacterial parameters, pollutants, dust, water disinfection

Introduction

Although the collection of rainwater for potable purposes is an ancient practice and is widespread in many parts of the world today, rain water harvesting systems have largely been viewed as a black box. Research has neglected many important facts of rainwater harvesting including the critical area of process understanding with regard to water quality changes and treatment mechanisms.

In arid areas like Kuwait, the urban run-off should collected separately from the sewage and used directly for groundwater recharge or after the necessary treatment for domestic uses. Although the amount of rainfall is small, heavy run-off can create severe environmental problems for human, plants and soil displacement. Intense rainfall during winter season can create strong run-off water, and this run-off can produce flooding especially if the stormwater manhole system was not designed properly as demonstrated in the run-off flooding in 16 December 2004, Kuwait. Rain water samples collected from direct precipitation of that event indicated that its salinity is about 100 mg/l which is considered a freshwater source. In Kuwait, the final destination of the run-off water in the residential areas is towards the stormwater manholes in the streets, which finally discharges to the sea. Unfortunately, there is no specific run-off collection system available in Kuwait.

Large quantities of run-off can be utilized especially if the certain structures are built to store the run-off water. Run-off can be also be exploited in residential areas and collected in tanks from the roof of the private houses, and used for drinking after treatment, washing and gardening activities. Moreover, the run-off can recharge the groundwater and increase the water table level if it passes through permeable aquifer materials. More studies are needed in Kuwait to determine the quantity and quality of the run-off water. The main objective of the current study is to evaluate the quality of rainwater and run-off water after intense rainfall periods in urban areas of Kuwait.

Methodology

The rainwater and run-off sampling were completed in three months from November 2005 to January 2006. The Agricultural and Water Resources Building (AWRB) at Kuwait Institute for Scientific Research (KISR) in the Shuwaikh area, Kuwait, was selected to represent collection of run-off samples from large roof with area of $2845m^2$. At the same site, direct precipitation was collected to determine the differences in the levels of pollution between the direct precipitation and the run-off.

Samples were collected during heavy rain fall and run-off periods. The samples were transferred from the containers by hand pump to sterilized bottles. The runoff samples form the site was collected directly from the drainage outlet. All samples were collected in sterilized glass bottles and without adding preservatives and were kept cool with ice bricks in the ice box, until these were delivered to the laboratory. Two to three liters of water samples was gathered from the site.

Water samples were analyzed for several parameters for the determination of both rainwater and run-off water quality. The water samples were analyzed for the following parameters; turbidity, Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, NH_3, SO_4^{-2}, Cl^{-}, NO_3^{-}, NO_2^{-}, HCO_3^{-}, F^{-}, Zn^{+2}, Fe^{+2}, Cu^{+2}, Ni^{+2}, V^{+}, Pb^{+2}, total suspended solids (TSS), total dissolved solids (TDS), total hardness (H_T), total organic carbon (TOC), chemical oxygen demand (COD), petroleum hydrocarbon (TPH), total coliform bacteria (T.C.) and faecal coliform bacteria (F.C.). These parameters were analyzed according to standard methods for the examination of water and wastewater (APHA, 2005). These water parameters were selected based on the natural and man made pollution sources and international practice.

Results and Discussions

The chemical, organic and bacterial analysis results for rainwater and run-off samples were compared with the world health organization (1984) guidelines for drinking water standards (Tables 1-7). The water parameters such as pH, salinity, turbidity, major ions, total hardness, nitrogen compounds, organic compounds, trace elements and bacteria content for the site are discussed in separate sections.

The pH values of the rainwater samples collected in KISR site ranged between 5.0-7.6 with mean value of 6.4, while those values for run-off samples ranged between 6.3 and 7.2 with mean value of 6.7 and these pH values are within the limits recommended by WHO drinking water standards. These data indicate that rainwater found is lightly acidic to neutral media. For the same site, the salinity values of the rainwater expressed as TDS ranged between 41.0 mg/l and 150.0 mg/l with mean value of 93.3 mg/l. Those for the run-off samples ranged between 24.0 mg/l and 753.0 mg/l with mean value of 184.3 mg/l (Fig.1). In general, the mean values of TDS of the rainwater were lower than the TDS values of the run-off. The mean values of TSS and turbidity for rainwater at KISR site were found to be 69.5 mg/l and 23.8 nephelometric turbidity unit (NTU), respectively (Fig.2). This high value of TSS was related to presence of dust associated with rain water during rainfall period. This water needs to be treated from suspensions and fine sand particles before it can be used for drinking purposes (Fig.2). In general, as the size of the roof of the building increases the amount of suspensions and dust deposited would increase. Therefore, it is expected the amount of suspension and dust in the run-off samples expected to be higher in big government building compared to those of small public buildings.

Based on the obtained results and according to the concentrations of the major cations and anions, the rainwater and run-off in the study area is dominated with $CaSO_4$ water type (Tables 2-3). The concentrations of the cations (Na^+, Ca^{+2}, K^+ and Mg^{+2}) and anions (Cl^-, SO_4^{-2} and HCO_3^-) of $CaSO_4$ water type increased in the following order: $Ca^{+2} > Na^+ > Mg^{+2} > K^+$ and $SO_4^{-2} > Cl^- > HCO_3^-$. Total hardness ($H_T$) expression is related to presence of calcium (Ca) and magnesium (Mg) ions in the water. The mean total hardness value of the rainwater samples collected at the site was found to be 47.3 mg/l, while the mean value of total hardness for run-off samples was found to be 97.5 mg/l (Fig.3). Based on the available data, the rainwater for this site was classified as soft water (hardness < 75 mg/l).

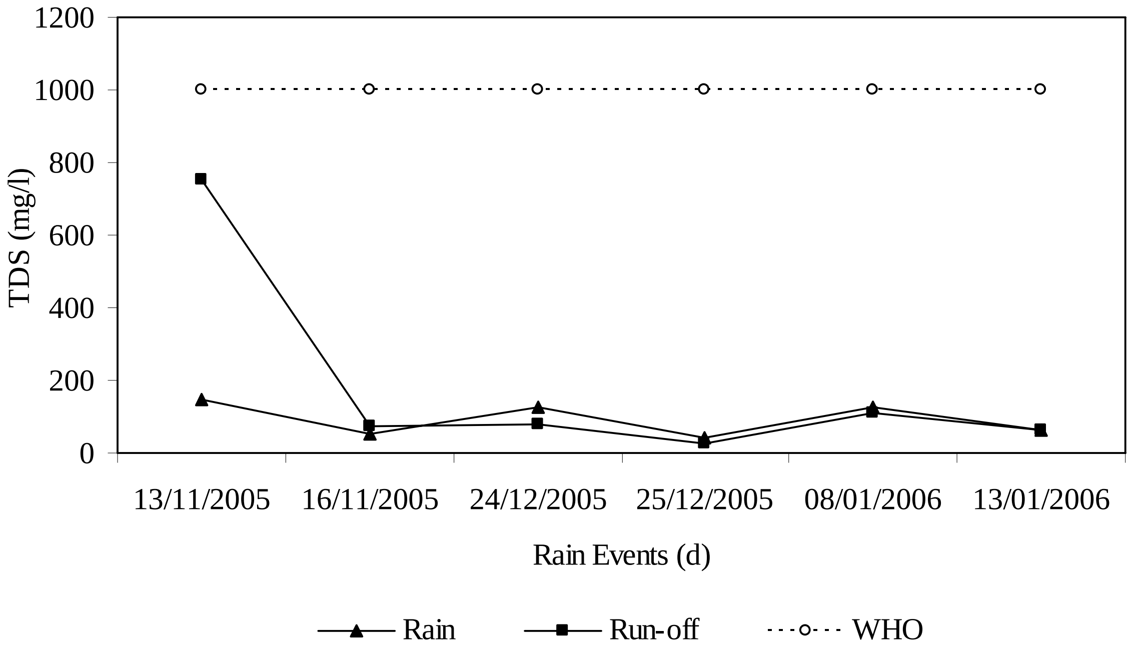

Fig. 1. Salinity concentrations of rain and run-off samples at KISR site.

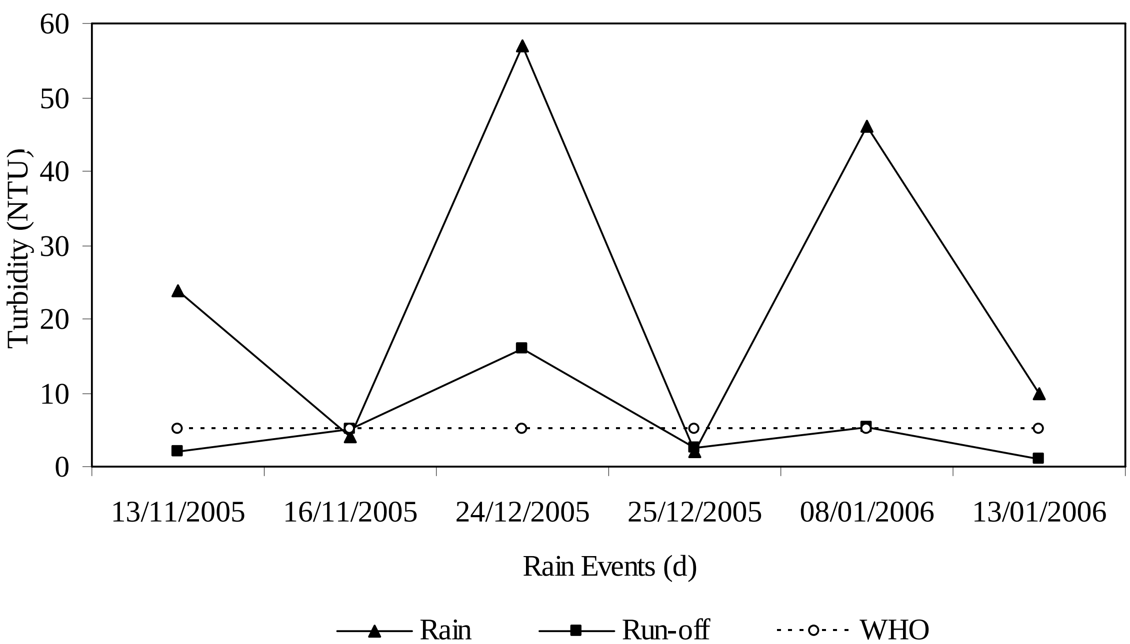

Fig. 2. Turbidity concentrations of rain and run-off samples at KISR site.

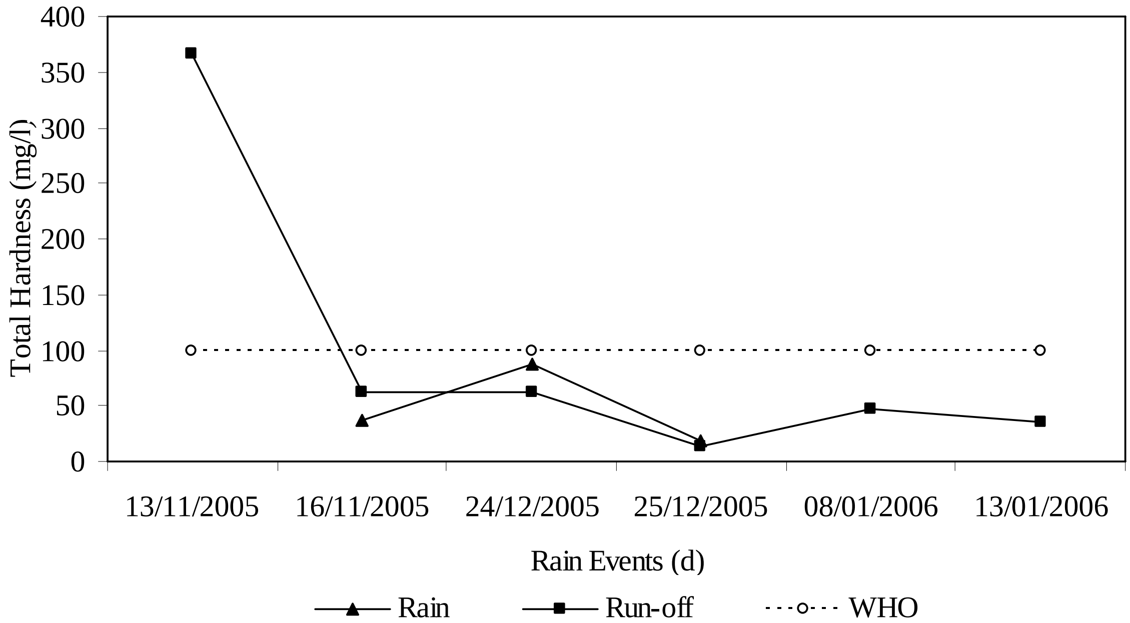

Fig.3. Total hardness concentrations of rain and run-off samples at KISR site.

Three nitrogen forms were studied for the rainwater and run-off samples. These are nitrate (NO_3^-), nitrite (NO_2^-) and ammonia (NH_3). These compounds can be found in the rain water mainly naturally through oxidation and reduction process for the nitrogen gas in the atmosphere, and may also be formed by industrial processes which produce vapors of nitrogen compounds, that pollute the air and rainwater. The mean values of nitrate, nitrite and ammonia for the rainwater samples were found to be 11.7 mg/l, 1.2 mg/l and 0.8 mg/l, respectively, while the mean values for the same parameters for the run-off samples was found to be 16.1 mg/l, 1.2 mg/l and 0.7 mg/l, respectively. Nitrate is the dominant nitrogen form in the rainwater (Fig. 4).

Total organic carbon (TOC) parameter was used in this study to determine the levels of rainwater and run-off samples polluted with organic compounds. American public Health Association (APHA, 2005), suggested that the maximum limit of TOC value should be 25.0 mg/l for drinking purposes. The mean TOC value for the rainwater samples collected at KISR site was found to be 2.0 mg/l, while the mean value of TOC for run-off samples was found to be 2.4 mg/l (Fig.5).

The results of the trace elements are shown in Tables 4-5. These elements compared with the world health organization guidelines for drinking water standards. Drinking water values of 1.5 mg/l, 1.0 mg/l, 0.3 mg/l, 0.02 mg/l, 0.01 mg/l and 3.0 mg/l were set by WHO, for F^-, Cu^{+2}, Fe^{+2}, Ni^{+2}, Pb^{+2} and Zn^{+2}, respectively. All the trace element results of the rainwater collected in KISR area were below the values of WHO drinking water standards.

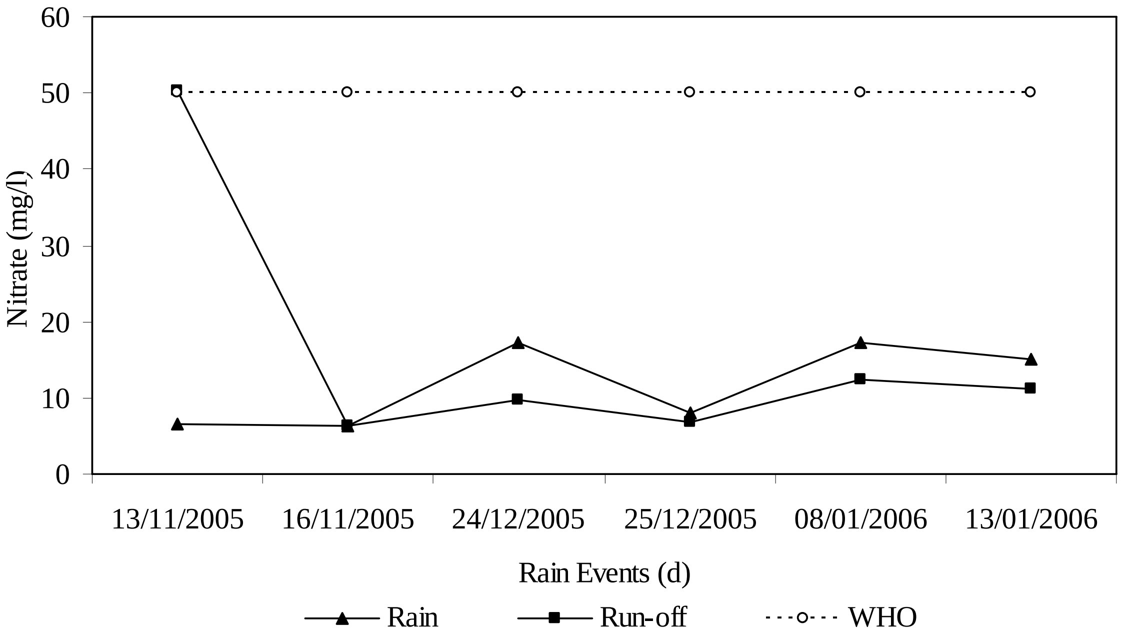

Fig. 4. Nitrate concentrations of rain and run-off samples at KISR site.

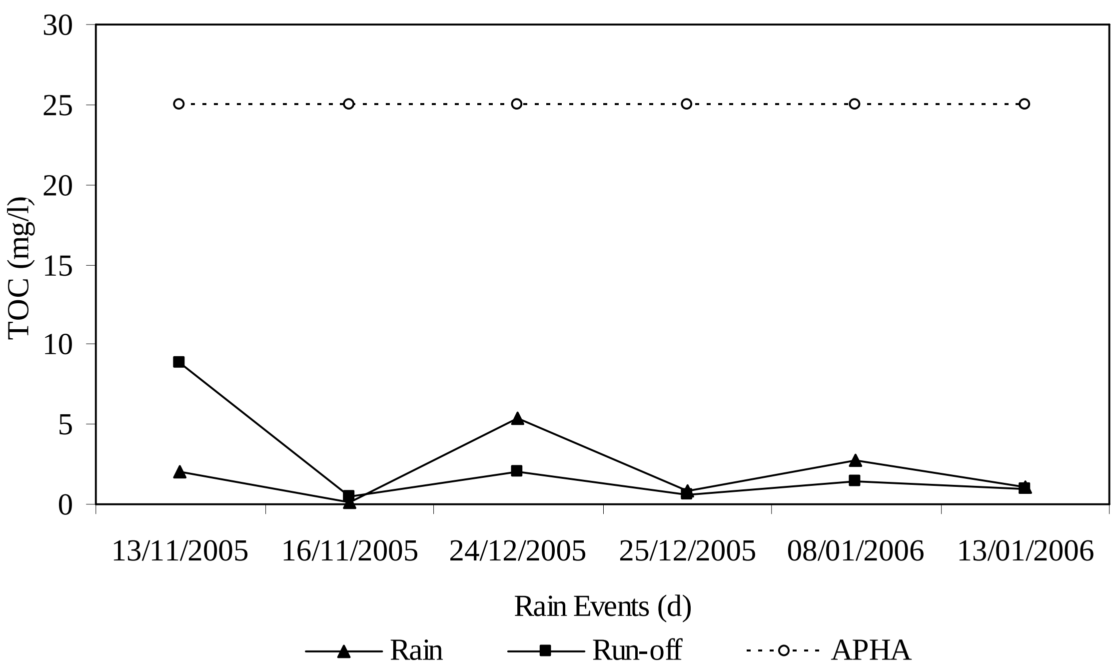

Fig. 5. TOC concentrations of rain and run-off samples at KISR site.

On other hand, the run-off samples collected at the same site revealed that trace element concentrations were below the values of WHO drinking water standards, with the exception of the run-off samples collected on 13 November 2005, where relatively high concentrations of fluoride (0.25 mg/l), iron (0.3 mg/l), nickel (25.2 mg/l), lead (1.5 mg/l) and zinc (0.3 mg/l) were detected as demonstrated in Fig. 6. These positive trace ions probably associated with the negative clay particles (dust) accumulated on the roof of the building for that rain event.

Total coliform bacteria (T.C.) and fecal coliform bacteria (F.C.) parameter were used in this study to determine the bacterial contamination in both the rainwater and run-off samples (Tables 6-7). The drinking water standards set by WHO, recommended upper limits of 10 colony forming unit (cfu) per 100 ml and 0 cfu/100 ml for total coliform and faecal coliform bacteria, respectively. The total coliform bacteria values for the rainwater samples collected in KISR site ranged between 0 and 1733 cfu/100 ml (Fig. 7). Total of 20 cfu/100ml of faecal coliform bacteria was found only in rainwater samples collected on 13 November 2005. These bacteria probably adsorbed to the surfaces of the dust or sand particles during rainfall period. The total coliform and faecal coliform bacteria values for the run-off samples collected at the same site ranged between 27 and 1278 cfu/100 ml, and between 0 and 248 Cfu/100 ml, respectively.

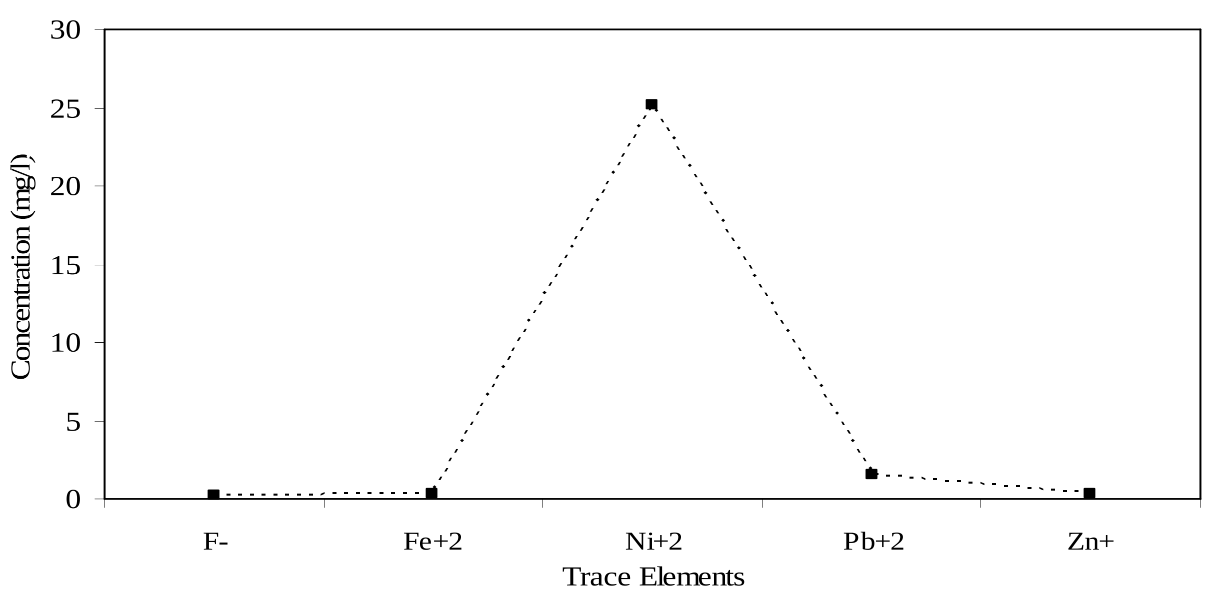

Fig. 6. Trace elements concentrations of run-off samples at KISR site.

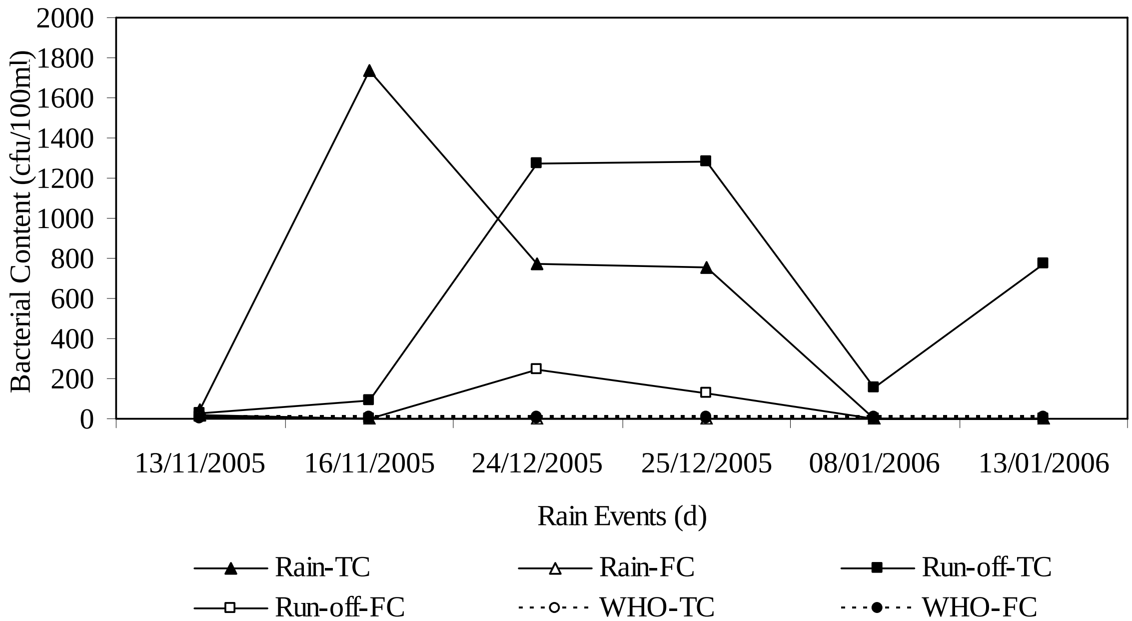

Fig. 7. Bacteria content in rainwater and run-off samples at KISR site.

Conclusions

In general, the rain water samples collected at KISR site indicated high levels of turbidity and total coliform bacteria whereas, the runoff samples including the first cycle of rain event on 13 November indicated high levels of TDS, total hardness, TOC, trace elements, total coliform and faecal coliform bacteria. These high values of turbidity and bacteria in the rainwater was due to the presence of dust and fine sand in the air, and on the surfaces of these particles, bacteria were adsorbed, and all dissolved in the rainwater and formed muddy rain. On other hand, the high values of contaminants in the run-off samples were due to flushing of the accumulated sediments and dust on the roof of the KISR building.

The water quality parameters (turbidity, bacteria) for both the rainwater and runoff samples were above the recommended limits set by WHO drinking water standards. This means that this water should not be used for drinking purpose unless it is treated for these parameters using techniques such as sand filter, activated adsorbed carbon and disinfection. Application of sand filtration through adsorption by activated carbon and chlorination should remove turbidity, TOC and bacteria from both the rainwater and the run-off. Also, this water can be used without treatment for other applications such as irrigation and washing.

Recommendations

Based on the results of the study, following recommendations are made:

- Run-off samples should be collected and analyzed from all types of buildings as well as street run-off collecting points near stormwater manholes from several areas of Kuwait.
- Meteorological station including rain gauge should be installed within the residential areas to estimate rainfall and monitor run-off quantity better.
- Design for a storage tank is needed to capture the roof run-off from different types of buildings.
- The treatment required for the generated run-off to make it usable for different uses should investigated.

Acknowledgement

The Kuwait Institute for Scientific Research (KISR) are highly acknowledged for their funding of this study. Special thanks are due to Dr. Muhammad Al-Rashed, Director of Water Resources Division and Dr. Meshan Al-Otaibi, Manager, Hydrology Department for their encouragement and support throughout the duration of study.

References

APHA, 2005, Standard method for the examination of water and wastewater, American Public Health Association, Washington, D.C., USA.

World Health Organization. 1984, Guidelines for Drinking Water Quality, Vol. 1. Recommendations.

Table 1. World Health Organization Drinking Water Standards.

Parameter	Guideline Value
pH	6.5 – 8.5
TDS (mg/l)	1000
Turbidity (NTU)	5
Alkalinity (mg/l)	100
T. Hardness as $CaCO_3$ (mg/l)	100
H_2S (mg/l)	0.05
Cl_2 (mg/l)	0.2-0.5
Ca^{+2} (mg/l)	75
Mg^{+2} (mg/l)	150
Na^{+} (mg/l)	200
K^{+} (mg/l)	10
SO_4^{-2} (mg/l)	200
Cl^{-} (mg/l)	250
NH_3 (mg/l)	1.5
NO_2^{-} (mg/l)	3.0
NO_3^{-} (mg/l)	50.0
Zn^{+2} (mg/l)	3
F^{-} (mg/l)	1.5
Cu^{+2} (mg/l)	1.0
Fe^{+2} (mg/l)	0.3
Ni^{+2} (mg/l)	0.02
Pb^{+2} (mg/l)	0.01
Total Coliform Bacteria (cfu/100ml)	10
Faecal Coliform Bacteria (cfu/100ml)	0

Table 2. Chemical Analysis Results of Rainwater Samples from KISR Building, Shuwaikh area, Kuwait.

Date	Ph	EC (µs/cm)	TDS (mg/l)	TSS (mg/l)	Alkalinity (mg/l)	COD (mg/l)	TOC (mg/l)	Turb. (NTU)	NO_3^- (mg/l)	NO_2^- (mg/l)	NH_3 (mg/l)	SO_4^{-2} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Cl^- (mg/l)	H_T (mg/l)	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	TPH (mg/l)
13.11.05	7.20	179.00	150.00	224.00	7.00	65.00	2.04	23.80	6.60	-	0.28	11.00	-	-	-	-	-	-	-
16.11.05	6.04	48.00	55.00	0.00	3.00	0.00	0.13	4.00	6.20	1.00	1.03	9.00	0.85	0.05	7.00	37.00	8.00	4.20	
24.12.05	6.62	222.00	124.00	95.00	2.20	32.00	5.36	57.00	17.16	0.00	0.85	9.00	0.45	0.92	-	86.80	3.14	0.20	0.11
25.12.05	5.02	27.40	41.00	12.00	3.70	1.60	0.82	2.00	7.92	2.00	1.04	7.00	0.05	0.05	1.00	18.00	5.20	2.20	2.20
08.01.06	7.60	211.00	127.00	68.00	7.00	13.30	2.8	46.00	17.16	2.00	1.66	12.00	4.00	0.05	0.00	-	-	-	-
13.01.06	5.74	71.00	63.00	18.00	4.90	7.10	1.09	10.00	14.96	1.00	0.09	13.00	0.05	0.05	0.00	-	-	-	0.28

Note: - Parameter not analyzed.

Table 3. Chemical Analysis Results of Run-off Samples from KISR Building, Shuwaikh area, Kuwait.

Date	pH	EC (µs/cm)	TDS (mg/l)	TSS (mg/l)	Alkalinity (mg/l)	COD (mg/l)	TOC (mg/l)	Turb. (NTU)	NO_3^- (mg/l)	NO_2^- (mg/l)	NH_3 (mg/l)	SO_4^{-2} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Cl^- (mg/l)	H_T (mg/l)	Ca^{+2} (mg/l)	Mg^{+2} (mg/l)	TPH (mg/l)
13.11.05	6.38	968.00	753.00	83.50	27.00	78.00	8.79	2.00	50.38	1.50	1.27	400.00	2.30	2.30	60.00	366.00	129.00	11.10	0.61
16.11.05	6.88	78.00	76.00	4.00	14.00	11.00	0.50	5.00	6.40	1.00	0.43	17.00	1.40	0.12	1.50	62.00	12.00	7.70	-
24.12.05	6.27	110.00	80.00	27.90	15.40	10.00	2.00	16.00	9.68	0.00	0.84	20.00	0.14	1.22	3.90	62.00	15.20	5.70	0.11
25.12.05	6.75	30.80	24.00	40.00	7.30	1.80	0.56	2.50	6.82	1.00	0.77	2.00	0.55	0.05	1.00	13.00	1.70	0.60	0.60
08.01.06	7.17	125.00	110.00	11.00	27.00	1.70	1.44	5.30	12.32	1.50	0.74	27.50	0.74	0.08	15.35	46.50	17.18	0.85	-
13.01.06	6.79	71.50	63.00	1.00	10.50	11.25	0.91	1.00	11.20	2.00	0.15	17.00	0.70	0.05	3.30	35.50	9.60	3.85	-

Note: - Parameter not analyzed.

Table 4. Trace Elements Results of Rainwater Samples from KISR Building, Shuwaikh area, Kuwait.

Rain Events No.	Date	F^- (mg/l)	Cu^{+2} (mg/l)	Fe^{+2} (mg/l)	Ni^{+2} (mg/l)	Pb^{+2} (mg/l)	V^+ (mg/l)	Zn^{+2} (mg/l)
1	13.11.05	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05
2	16.11.05	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05
3	24.12.05	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05
4	25.12.05	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05
5	08.01.06	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05
7	13.01.06	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05

Table 5. Trace Elements Results of Run-off Samples from KISR Building, Shuwaikh area, Kuwait.

Rain Events No.	Date	F^- (mg/l)	Cu^{+2} (mg/l)	Fe^{+2} (mg/l)	Ni^{+2} (mg/l)	Pb^{+2} (mg/l)	V^+ (mg/l)	Zn^{+2} (mg/l)
1	13.11.05	0.25	<0.05	0.30	25.15	1.50	<0.05	0.33
2	16.11.05	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05
3	24.12.05	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05
4	25.12.05	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05
5	08.01.06	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05
7	13.01.06	<0.10	<0.05	<0.05	<0.05	<0.10	<0.05	<0.05

Table 6. Microbiological Results of Rainwater Samples from KISR Building, Shuwaikh area, Kuwait.

Rain Events No.	Date	T.C. (cfu/100ml)	F.C. (cfu/100ml)
1	13.11.05	41	20
2	16.11.05	1733	0
3	24.12.05	769	0
4	25.12.05	756	0
5	08.01.06	0	0
7	13.01.06	3	0

Table 7. Microbiological Results of Run-off Samples from KISR Building, Shuwaikh area, Kuwait.

Rain Events No.	Date	T.C. (cfu/100ml)	F.C. (cfu/100ml)
1	13.11.05	27	7
2	16.11.05	93	0
3	24.12.05	1271	248
4	25.12.05	1278	130
5	08.01.06	152	0
7	13.01.06	774	4

Note: T.C and F.C. are total coliform and faecal coliform bacteria, respectively.

THREE-DIMENSIONAL GEOLOGICAL AND GROUNDWATER FLOW MODELLING OF DROUGHT IMPACT AND RECHARGE POTENTIALITY IN KHATT SPRINGS AREA, RAS AL KHAIMAH EMAREATE, UAE

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Abstract

The available hydrogeological data in the period 1969-2005 for Khatt Basin in the Emirate of Ras Al Khimah, UAE was critically reviewed and analyzed, and then used to build a GIS database for this area. The spatial analysis of GIS was used to analyze this data to determine the quantity and quality of the available groundwater resources in Khatt Basin area as well as to prepare the input data for a recently developed digital 3D geological model. The graphic capabilities of GIS were used to produce different types of geopotential maps necessary for the sustainable management of the precious groundwater resource in this area. With the GIS data base, it was possible to build a pioneering 3D geological model for the area that gives detailed information about the subsurface stratigraphy below any point in the model domain. The results of the 3D geological structural model were used to assign the model layers elevations and their hydrogeological properties in a 3D groundwater flow model which is being developed to determine the impact of the present and planned extraction rates on the quantity and quality of groundwater in the Quaternary Aquifer System which is heavily exploited since the beginning of the seventies. The steady state simulation indicated that there is a very close fit between the calculated and observed groundwater contours of 1969 indicating that the Quaternary Aquifer System prior to 1970 was in a steady state condition (i.e. the recharge from Oman Mountain was enough to balance natural and artificial outflow at that time).

Keywords: groundwater, geological model, hydrogeological model, Khatt basin

Introduction

Successful water resources management in arid regions depends largely on the planners and scientists knowledge of the available water resources as well as the capability of using mathematical models to predict the consequences of a certain management option in the short and long run. The validity of using these models for water resources management is depending on the availability of a complete and well documented historical environmental data base (preferably in the GIS format). Also, if the geological setting and structural pattern are complicated, the 3D geological modeling technique should be used to determine and resolve these complications prior setting up the 3D structures and parameters for numerical groundwater flow models (Gossel et al., 2004; Wycisk et al., 2005).

In the last forty years, many of groundwater exploration and evaluation studies were conducted in the northern part of the United Arab Emirates. Most of these studies were for consultancy purposes and missing any scientific interest. Due to the fact that the majority of these studies are only documented as internal reports, their use is limited and probably confined to the purpose and organization paid for that particular consultancy job. In an effort to investigate the current situation of water resources in the Northern Emirates region, all the available drilling information and environmental data from 1979 to 2005 were recently critically reviewed and stored in a GIS data base. Then the spatial analysis algorithm of GIS enhanced with its graphic capabilities was used to analyze and reinterpret these data and preliminary evaluate the current situation of water resources (availability and management challenges) in the Northern Emirates. The results were used to prepare the input data of 3D geological structures model and subsequently a local scale groundwater flow model. The main objectives of the present study are:

a) Determining the geological and hydrogeological setting of Khatt Spring area; emphasis were given to the impact of the geological structures on groundwater accumulation and flow pattern;
b) Evaluating the impact of drought years and groundwater depletion (caused by intensive irrigation) on the flow and water temperature of springs;

c) Using the recently developed software for digital 3D geological structures modeling which utilizes cross-section based networks for subsurface interpolation in heterogeneous aquifers;
d) Using groundwater flow model as a management tool for the sustainable management of water resources in these areas.

Khatt Spring Area

Khatt springs area is one of the most prominent springs inside UAE and situated at the extreme east of the gravel plains where it meets the foot hills of the Oman Mountain range (Fig.1). There are two main springs, Khatt north and Khatt south the flow from which was gauged in February 1966. Khatt north spring emerges about ten yards west of the main limestone foothills; south spring issues direct from the limestone, a bedding plane having been excavated to increase the flow.

The most interesting feature of these springs is the high temperature of the water about 39 °C as compared with a range of 25-32 °C for all other groundwater in the northern Emirates. The temperature of groundwater may be assumed to increase with depth from a level of about 20m below ground at a gradient of about 1°C in 30 m. The difference between the temperature of the spring water and that of groundwater in the surrounding area suggests that the former issues from a considerable depth; perhaps about 300 m below ground level (Sir William Halcrow & Partners, 1969; IWACO, 1986).

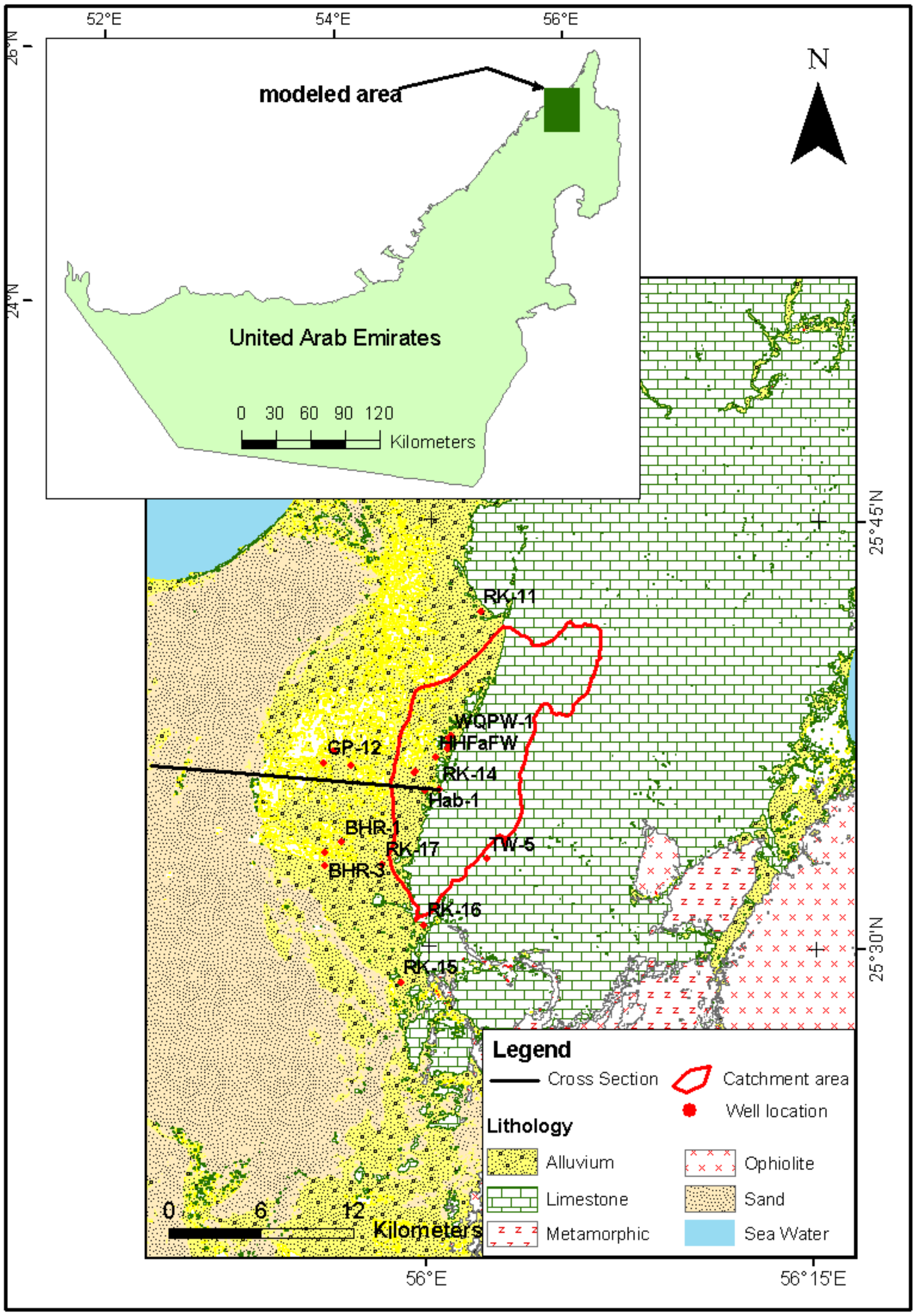

Figure 1: Location map of Khatt springs catchments area (upper right); location of the subsurface cross section (lower right) and geological map of Khatt springs area (left; modified from IWACO, 1986).

Water flowing out from Khatt springs has been used for traditional bathing and medication till 1979 when it further developed to be a major bathing and recreation site in Ras Al Khaimah Emirate (in year 2006, one five stars hotel was launched in this area). The outflow of pools in addition to water flowing from other sources like small springs and hand-dug wells are drained into an intricate system of lined channels and falajs to supports a substantial cultivation of date palms and other market produce (Fig. 2).

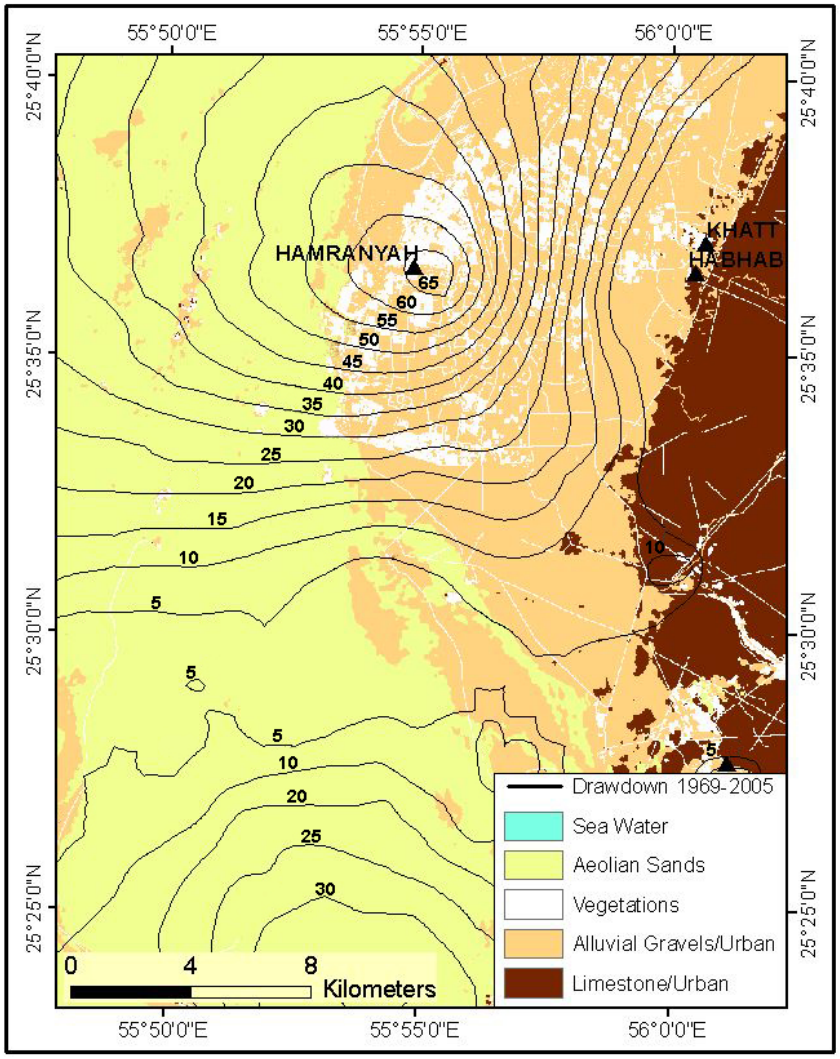

Figure 2: A drawdown of up to 65 meters happened in the period 1969-2005. Major geomorphologic units and agricultural lands are also shown.

Due to the drought conditions prevailed in the period 1998-2004 together with the necessity of intensive groundwater exploitation for irrigation purposes, the outflow from the northern spring was not enough for keeping the temperature in the swimming pools to the desired level due to the relatively long time of water residence time in the pool. This also led to deteriorating the environmental conditions in the recreational park around the pool and the spread of mosquitoes.

Geological and Hydrogeological Setting

The study area lies on the western side of the Northern Oman Mountains (Fig. 1), which are comprised of the Jurassic to Cretaceous Musandam Group limestones. These mountains rise above the western Jiri coastal plain, which consists of late Tertiary to Recent alluvial sediments overlying the late Cretaceous Juweiza Formation (Sir Williams Halcrow & Partners, 1969).

The Juweiza is a flysch-like sequence of marls and shales with varying admixtures of coarse detrital debris of chert, basic igneous rock, and limestone (Fig.1).

The area has been subjected to two major tectonic events. These are the thrusting of the Hawasina Formations and the Samail Ophiolite over the Musandam limestone in the Upper Cretaceous and then the formation of the Oman Mountains due to folding, faulting and thrusting in the mid Tertiary (Fig.1). This resulted in the formation of the major northeast-trending anticlinal structure through the Musandam Mountains, the Hagab Thrust fault along the western edge of the mountains and the Jiri plain, and the Dibba Zone to the southeast, with the Batha Mahani thrust running along the valley of Wadi Tawiyean. Consequently the Musandam limestones are strongly faulted, with major trends running northeast (parallel to the Dibba Zone thrusts), north, and northwest (Robertson et al., 1990).

The drilling information of the available water wells was used to construct several subsurface geological cross sections along different directions. An example of these cross sections is shown in Figure 3.

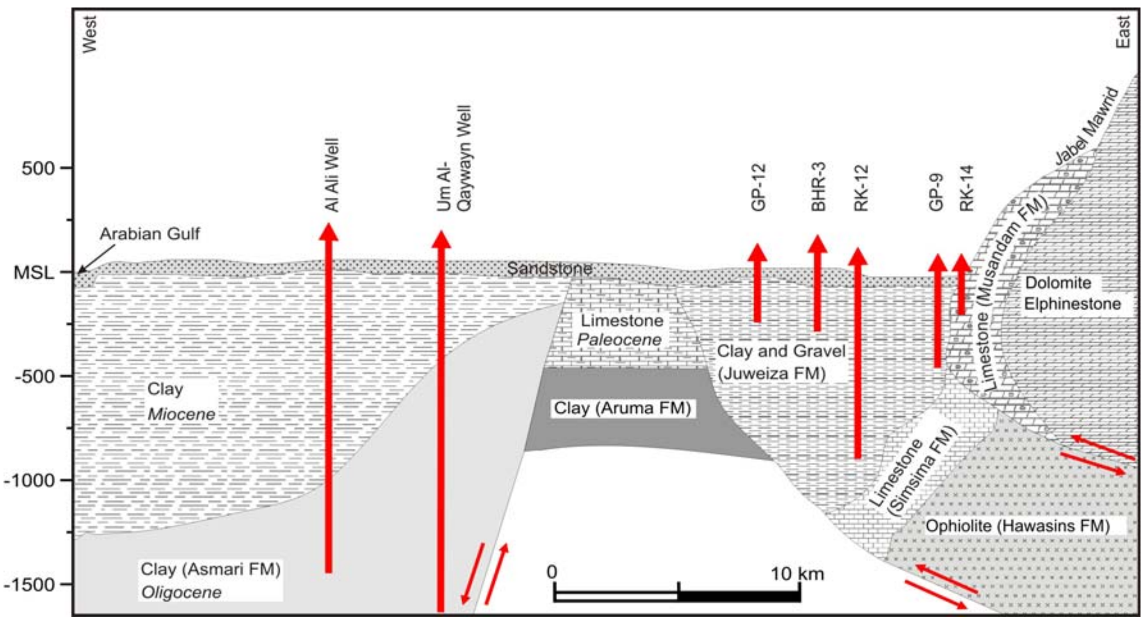

Figure 3: A subsurface geological cross section in the east- west direction (after IWACO, 1986). Location of the cross section profile is shown in Figure 1.

In figure 3, two hydraulically connected groundwater aquifers can be identified as follows:

1) **Quaternary aquifer** which is composed of the gravel plain of recent silts and conglomerates and meets the mountain front at a high angle. This layer is overlying the thick Juweiza formation which is generally of low permeability and thus acting as aquitard rather than an aquifer (Fig. 3).
2) **Carbonate aquifer** which refer to the exposed thick Musandam limestone of Jurassic - Cretaceous age in the mountains (Fig. 3).

These carbonate layers are composed of well jointed, karst weathered, thin bedded, nodular, fragmental and porcellanous dolomitic limestones and also limestones interbedded with calcareous shales. These beds dip at a very high angle, up to 90º, to the west and have been planed off, probably by marine erosion, at about 600 feet above sea level for about 2 kilometers into the mountain front. Various north-south trending folds can be seen on the aerial photographs on the western strip of the main mountain massif. At Khatt, these beds are linked to the gravel plain layers in the following ways:

a) as the western flank of a north-south trending anticline;
b) as the eastern upthrow side of a north -south trending fault bounding the mountain front;
c) as the ‘nose’ of a thrust of the Mesozoic limestone facies to the west over a radiolarite - serpentinite fades, as exposed in Wadi Hagil.

The distribution and groundwater potentiality of these aquifers is shown in the hydrogeological map of northern emirates shown in Figure 4.

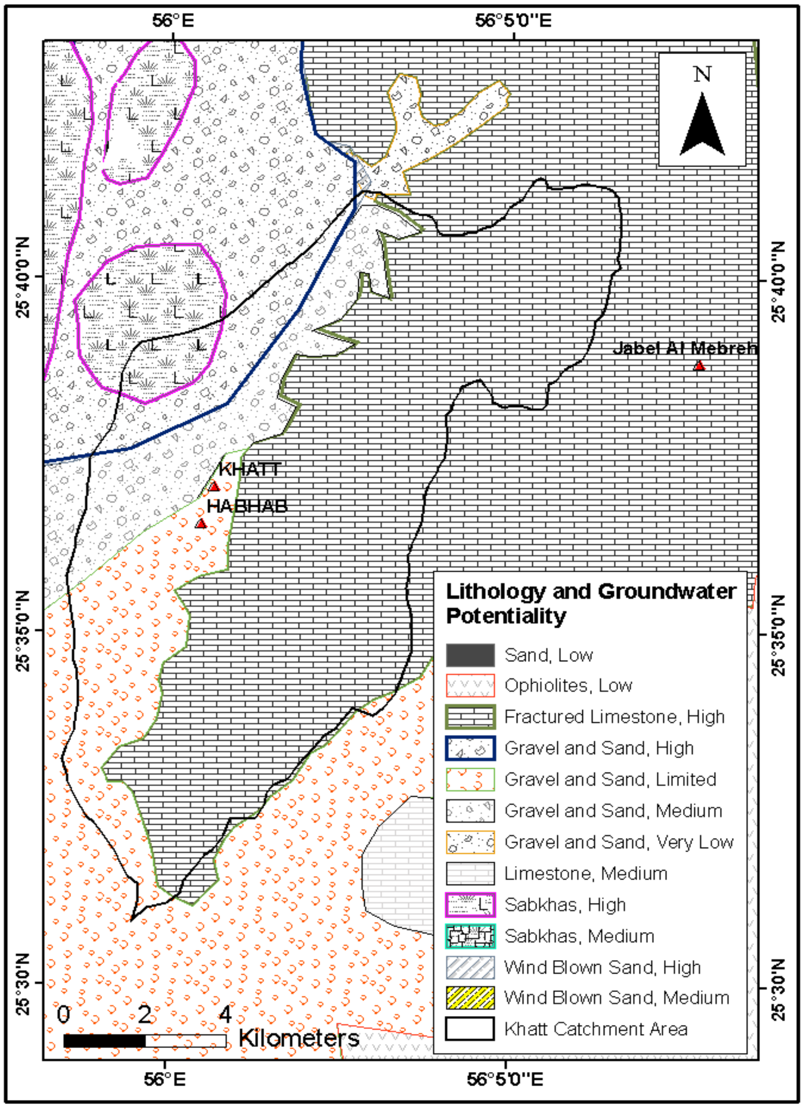

Figure 4: Hydrogeological map of the study area.

Groundwater Recharge and Drought Environmental Impact

Ruus al Jabal Peninsula is formed mainly of permeable limestone and dolomites, of the order of 3000 meters thick (Hudson, 1959). Precipitation entering these beds will be guided by joint and other openings and by the attitudes of the folded beds, which pitch northward outflow of groundwater from these beds will occur either at sea level or through high level overflow springs occurring where impermeable beds pond back the flow into karst zones or joints as at Khatt and Habhab.

In order to assess the effect of rainfall events, monthly groundwater level data for three observation wells in Khatt area have been selected for the groundwater table analysis. There is a significant variation in the groundwater level in response to recharge events.

The maximum groundwater level (approximately 40 masl) was observed on March of 1996 in well Khat-1 which is very close to the southern spring as well as in well RK-14 which is located in Habhab area south of Khatt village (Fig. 5). This also was reflected in the amount of outflow from the northern spring (30 l/s increase; Fig. 6).

The impact of precipitation on the water table level, amount of flow, and temperature of groundwater in the limestone has been studied since 1979 (Figs.5 & 6). It can be deduced that the precipitation rate has enormous impact on the outflow rate from the spring and can be summarized in Table1.

Table 1: Impact of 1999-2004 Drought on Khatt Springs.

North spring situation in the period 1979-1998	North spring situation in the period 1999-2004
Outflow ranged 10-60 l/s	Outflow ranged 1-30 l/s
Rainfall rate ranged 60-450 mm/year	Rainfall rate ranged 20-66 mm/year
Source water temperature ranged 39 - 40 °C	Source water temperature 39 -40 °C
Irrigation falajs are working without pumping	Irrigation falajs are only working with pumping from hand dug wells

During drought years as well as during the summers, over pumping of groundwater for local irrigation purposes has created major cone of depression (Fig 2.) which also lead to a decrease in the springs outflow rates. The following two solutions were suggested to solve this problem.

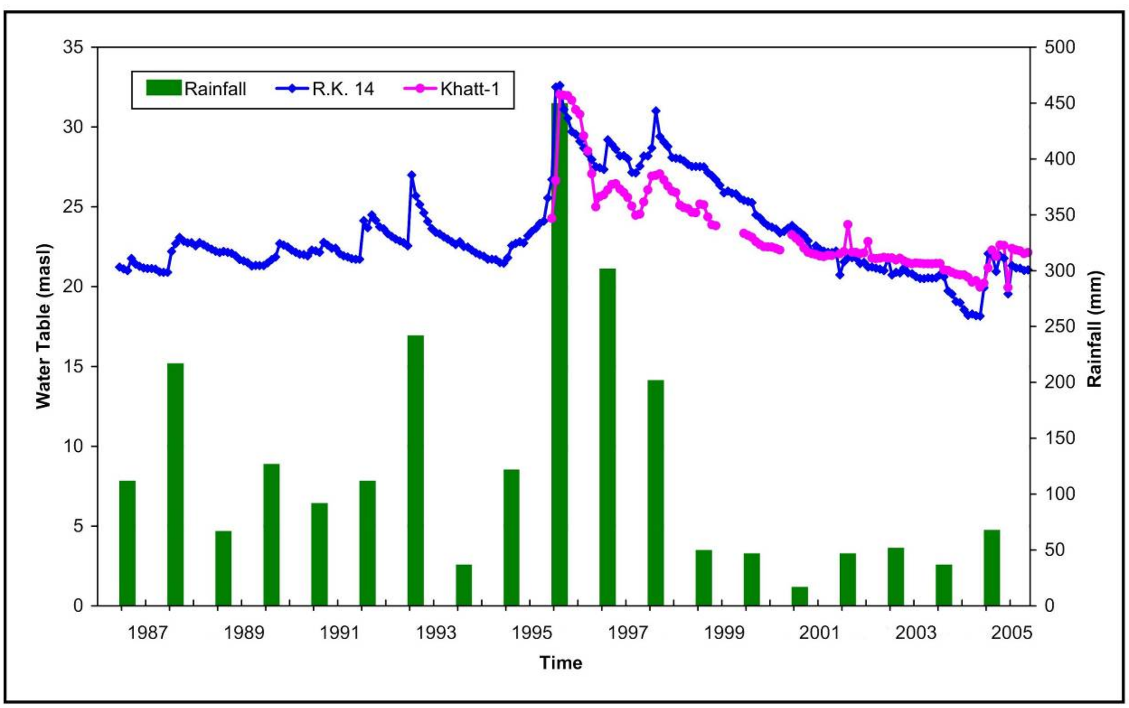

Figure 5: Water table fluctuations in wells RK-14 and Khatt-1 in response to the amount of annual precipitation. The water table measurements are shown as monthly values.

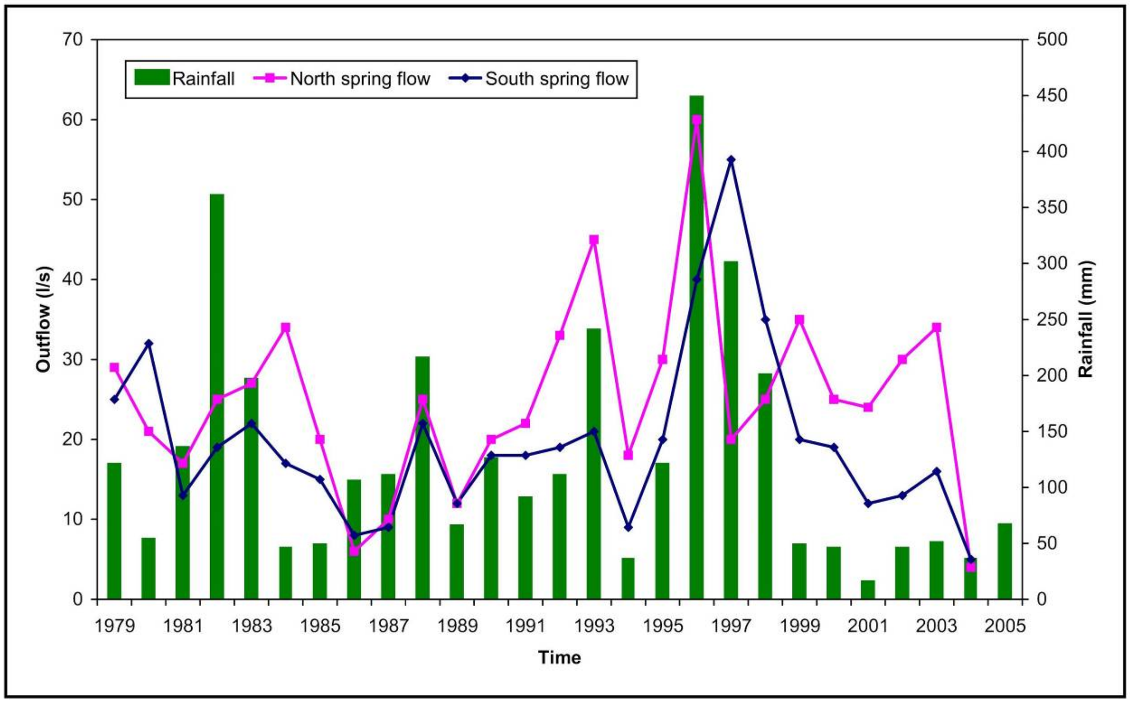

Figure 6: Annual flow rate variations in the north and southern springs in response to the yearly amount of precipitation.

The engineering solution (i.e. deepening the bottoms of pools and the associated outflow falajs) was investigated first but the results indicated that this will only solve problem temporary and thus rejected. Drilling a well which should hit a karst and/or a fracture zone with a special design to prevent mixing of deep hot water with relatively cold water in the alluvial aquifer came out to be the best and sustainable solution for feeding the swimming pools with their need of hot water during drought time (geological solution). The 2D earth resistivity imaging method was used on March 2004 to determine the location of a production well that penetrate the fracture zone and at the same time isolated from the infiltrated return irrigation water. This well was completed on May 2004 and since then it has been used for feeding the swimming pools with hot water during the drought time.

Digital 3D Geological Modelling

Up to now, true 3D modelling of geological structures is not state of the art in regional and local assessment except in the field of economic geology. The required geological information (e.g. drilling information) is not available at least to the desired and appropriate extent for regional statistically based interpolation. The techniques used in most cases for geological 3D modeling are based on statistical or geostatistical interpolation between stratified scattered boreholes.

These methods are in adequate in this specific field because it leads to a reduced heterogeneity and an inadequate loss of the "real world" setting of the lithostratigraphic layers. Even the complex structural setting of the Quaternary sediments can not be represented correctly following the geostatistical approach only (Wycisk et al., 2005). Therefore, a first 3D geological model of about 2000 km^2 was built for Khatt Springs area, southeast of Ras Al Khimah City and is based on a construction of 39 networked cross-sections which are based on 39 borehole records. Beside the drilling information, the following 2d and point information were also used for the 3D-database: a) digital elevation model (DEM), geophysical logging and profiling information, geological and hydrogeological maps. The developed 3D geological model of Khatt Springs area allows different types of visualization (Fig. 7), calculation and predictions as well as the subsequent operation within hydraulic models. The provided information by the digital subsurface 3D models is of specific need in the fields of groundwater flow modeling of water resources management options as well as for environmental impact assessment of any future development type of this area.

Local-Scale Groundwater Flow Model

Numerous models have been successfully developed for water resources management in clastic aquifers (continuous porous media); where the flow is perfectly laminar flow (Anderson & Woessner, 1992; Slade et al., 1985; Ebraheem et al., 2002 and 2003; Gossel et al., 2004). However, application of numerical models in karst aquifers is more problematic due to the following reasons:

a) Karst aquifers are generally highly heterogeneous.
b) Karst aquifers are dominated by secondary (fracture) or tertiary (conduit) porosity and may exhibit hierarchical permeability structure or flow paths.
c) These aquifers are likely to have a turbulent flow component, which may be problematic in those most numerical models which are based on Darcy's law, which assumes laminar flow.
d) Despite the fact that modeling of karstic processes is often possible and numerical flow models can sometimes simulate hydraulic heads, ground-water fluxes, and spring discharge, they often fail to correctly

predict such fundamental information as flow direction, destination, and velocity (Quinlan et al., 1996)

e) Numerical model in karst aquifers often fail to correctly predict fundamental information for solute transport such as flow direction, destination, and velocity modeling (Huntoon, 1995; Quinlan et al., 1996).

f) Accurate transport predictions require in-depth knowledge of the distribution of the subsurface fracture and conduit systems which is not an easy task. Transport of solutes in fractured rocks is an active research area (Bear et al., 1993).

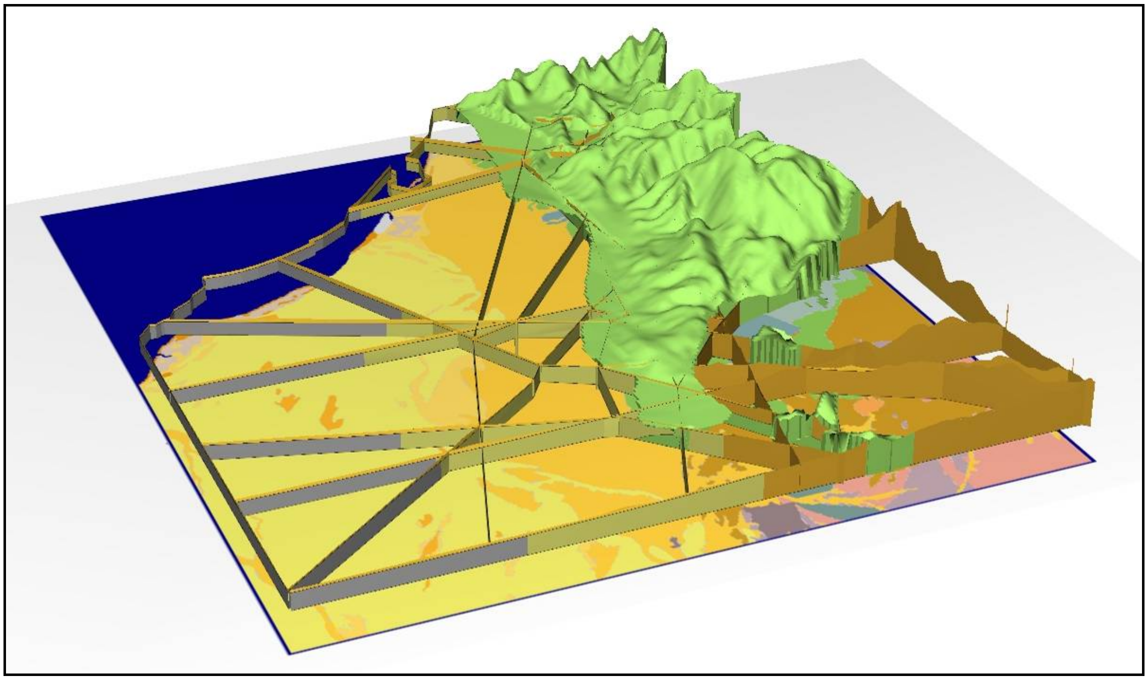

Figure 7: Constructed 3D-geological model for Khatt Springs area.

The availability of a relatively complete GIS data base of the drilling information for the last forty years as well as the flexibility and modular structure of MODFLOW software enabled us to develop, calibrate, and validate a local scale groundwater flow model for the Quaternary aquifer in Khatt Basin area. Since the karstified aquifer is extending for tens of kilometers with a thickness reaching several hundred of meters (IWACO, 1986) and intensively fractured, it possible to approximate it as equivalent porous media (Larocque et al., 1999; Pankow et al., 1986; Neuman, 1987).

Conceptual Model of the Ground Water System

Schematization of the Aquifer Systems

The first step in formulating the conceptual model was to identify the boundaries of the model and its model layers. Geologic information including geological and geomorphological maps (Figs. 1&2) well logs, cross-sections (Fig.3), and statistically-interpolated subsurface stratigraphy using the 3D digital model (Fig. 7) combined with information on hydrogeologic properties (Fig.4) are gathered to define hydrostratigraphic units for the conceptual model. As a part of preparing the water budget, the sources of water to the system as well as the expected flow direction and exit points were also identified for the model. The field estimated inflow such as groundwater recharge from precipitation, overland flow, were identified. Outflows such as spring flow, evapotranspiration and pumping were considered in the model conceptualization. Hydrologic information was used to conceptualize groundwater flow system. Hydrologic information on precipitation, evaporation, and surface water runoff, as well as observation well data is also used (Figs. 5 & 6). Water level measurements are used to estimate general direction of groundwater flow, the location of recharge and discharge, and the interaction between aquifers and surface water systems.

Based on well logs, pumping test results, and hydrogeological cross sections, the Quaternary and karstified limestone aquifers were approximated into a six layers model (Fig. 8).

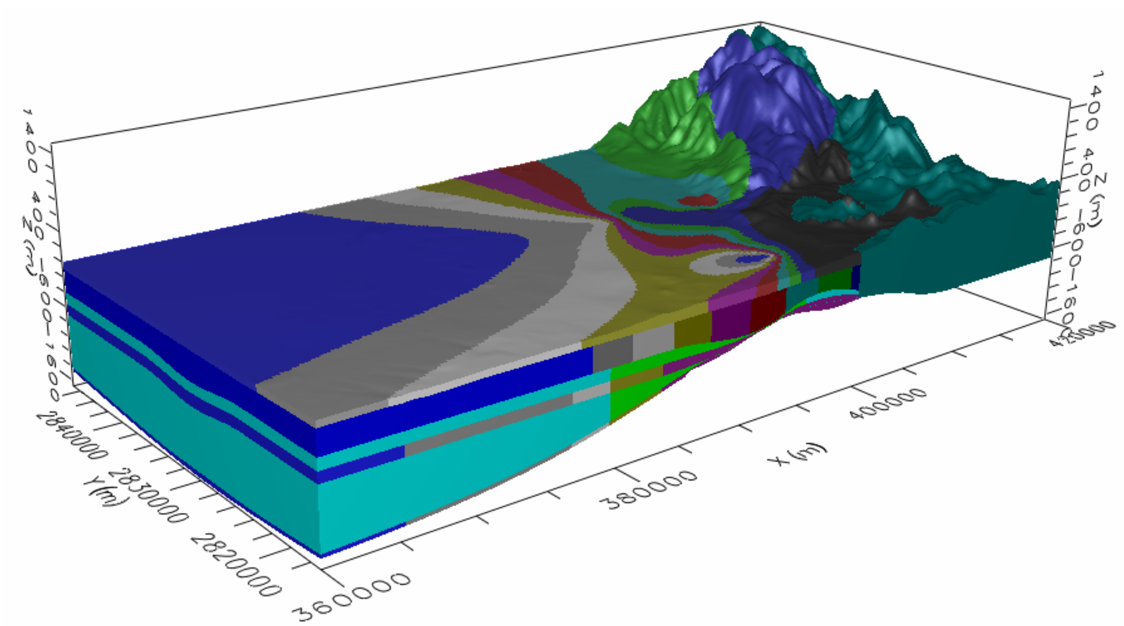

Figure 8: Conceptual model of Khatt springs area in which the subsurface stratigraphy is approximated into six layer model based on vertical hydraulic conductivity variations.

The model design included setting flow domain and its boundary and initial conditions, development of the grid system, selecting time steps, model layers and their preliminary hydraulic parameters values, and hydrologic stresses as discussed below (Fig. 9).

Groundwater flow in the main aquifer layers is governed by conditions at the boundaries of the regional system. These conditions are not well defined for catchment area of Khatt Springs. Therefore, in order to model groundwater flow in the Quaternary and karstified limestone aquifers, the modeled area were enlarged to have some cells in the Arabian Gulf in the west (constant head) and some cells in the impermeable argillaceous limestone layer in the southeast (no flow boundary). The boundary conditions also include known flux in northeast part.

The proper characterization of hydrogeological parameters is crucial for model calibration and validation. Point date feature thematic layers of the available records of the hydrogeologic properties (Table 2 & 3) were created using ArcGIS.

Table 2: Pumping tests results of wells in the karstified limestone aquifer.

Well	Specific Capacity [m³/hr/m]	Transmissivity [m²/day]
RK-5	23	288
RK-6	high	high
RK-9	50	382
RK-11	27	580
RK-14	67	2800
RK-15	26	140
RK-16	11	66
KhSp-1		39.7

Table 3: Pumping tests results of wells in the Juweiza aquifer.

Name	Easting [m]	Northing [m]	Specific capacity [m³/hr/m]	Saturated Thickness [m]	Transmissivity [m²/day]	Storativity	Hydraulic Conductivity [m/day]
GP1/1A	394896	2802122	1.8	142	7.6	0.006	0.0535
GP2	388741	2804271	0.7	105	2.7	-	0.025714
GP3	399780	2804621	3	184	6.1	0.0011	0.033152
GP4	395451	2820702	0.2	312	1	-	0.003205
GP6/6A	385858	2782511	29	123	1166	0.02	9.479675
GP8/8A	388718	2822739	7.6	176	270	0.003	1.534091
GP10/10A	393881	2790978	4.1	320	264	0.001	0.825
GP11	384115	2773198	28	166	480	-	2.891566
GP14	401017	2891573	6.2	126	230	-	1.825397
GP15	391717	2792509	5	126	156	-	1.238095
GP16/16A	396682	2798251	2	143	120	0.003	0.839161
GP17	382413	2790957	10	110	110	-	1

The interpolation capabilities of the program SURFER was used to assign an initial value of each property to each grid cell in the model area. A lot of constrains had to be situated prior to the interpolation procedure to avoid the problem of extrapolation. Among these constrains, the appropriate model of griding was firstly chosen by using the variogram kriging function of SURFER. The variogram is a three dimensional function usually used to match a model of spatial correlation of observed variables. Variogram is a measure of how quickly things changes on average and thus it is used to define the weights of the kriging function (Cressie, 1990).

Steady State Simulation

After assigning the model conceptualisation (Fig.8), the appropriate values of hydrogeologic parameters (e.g. hydraulic conductivity, specific Storativity /specific yield), the hydraulic parameters (e.g. porosity), and initial hydraulic head (water table of 1969) were assigned to each grid cell in the model domain (Fig.9). Then the model was run for the steady state condition using MODFLOW software (McDonald and Harbaugh, 1988) and the simulated groundwater contours were compared into the observed groundwater contours of 1969. A minor modification in the distribution of the hydraulic conductivity parameter spatial distribution was needed to obtain an acceptable fit between observed groundwater contours of 1969 and the simulated steady state groundwater contours. However a deviation of less than 5 meters was measured in the mountainous area in the eastern part of the modelled area where the information about the geological and hydrogeological setting is rather limited. The close fit between the simulated and observed groundwater contours indicated that before 1970, the recharge components of the Quaternary aquifer from Oman Mountain was enough to balance or slightly exceeding the sum of natural and artificial discharge existing at that time and thus the system was in a steady state condition before 1970. The close fit between the two sets of groundwater contours (Fig. 9) is considered as a preliminary calibration of the model and thus the model is being validated by groundwater simulation under transient state for the period 1970 to 1986 as information about water table levels on both years as well as the abstraction rates in this period are available.

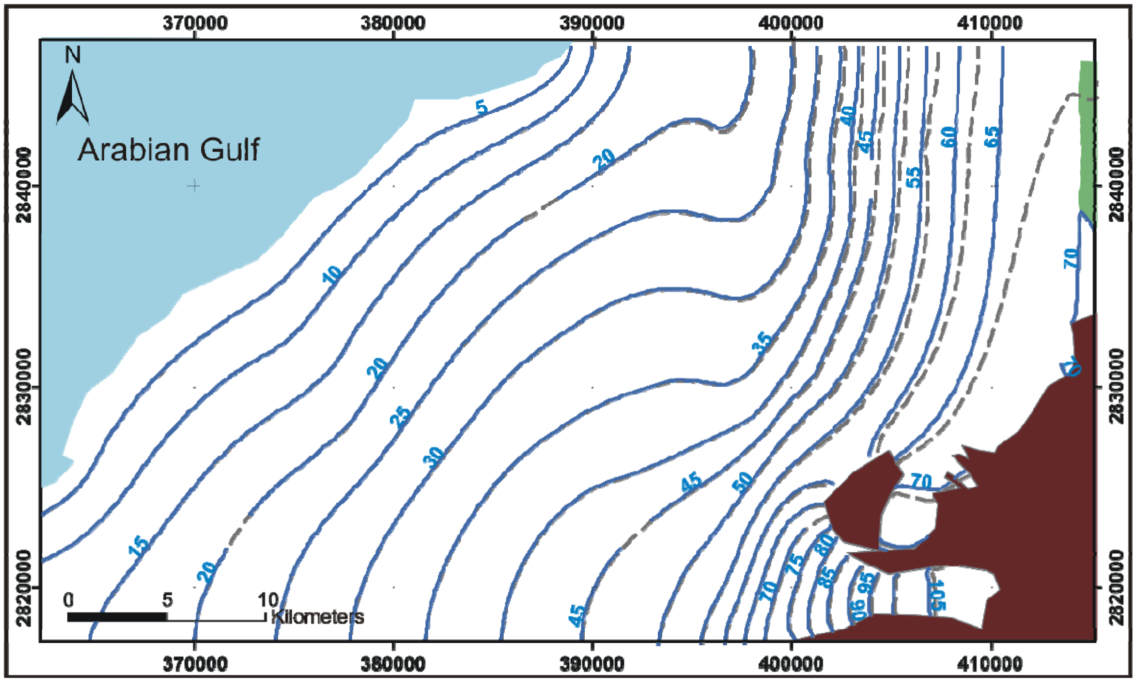

Figure 9: Correlation between observed in year 1969 (dashed lines) and simulated (blue solid lines) steady state groundwater contours.

Results

The drilling information of the drilled wells indicate the presence of two aquifers in the area of Khatt springs, the Quaternary (or shallow) aquifer and the fractured limestone (or deep) aquifer. The deep aquifer in Ruus al Jabal Peninsula is formed mainly of permeable limestone and dolomites, of the order of 3000 meters thick. The Quaternary aquifer is regarded as the main aquifer and is composed of the unconsolidated sediments (mainly alluvium gravel and coarse sand).

Precipitation entering the Musandam limestone beds will be guided by joint and other openings and by the attitudes of the folded beds, which pitch northward outflow of groundwater from these beds will occur either at sea level or through high level overflow springs occurring where impermeable beds pond back the flow into karst zones or joints as at Khatt and Habhab areas (as springs).

Historical observations of outflow from Khatt springs indicated that the amount of flow is strongly affected by the rate and pattern of rainfall. The drought condition prevailed during the period of 1999-2004 has led to a decrease in the amount of flow from the developed northern Khatt spring from 40 liters/second to 5 liters/second which was not enough to support the recreational and irrigational activities in this area.

The hydrological and hydrogeological settings of Khatt Springs area were intensively studied to find a sustainable solution to minimize the drought impact on Khatt spring. The results indicated that drilling of a well hitting a karst zone will be the best solution for feeding the developed spring with its need of hot water. The 2D earth resistivity imaging method was used to determining the location and depth of a karst zone in the nearby of the north spring.

After completing building the GIS data base for the studied area, a GIS-based 3D groundwater flow model was developed and calibrated for the steady state conditions. The simulated steady state contours are in a good match with the groundwater contours of 1969 and this indicate that groundwater exploitation at that time was less than or equal to the natural recharge.

The detailed digital geological 3D model developed for the area is an important need of subsequent grid mesh refinement in the developed groundwater flow model and/or any subsequent models for environmental impact assessment and water resources management in the area. The GIS database has been used for linking the geological and numerical groundwater flow model and thus to allow combining several different thematic layers to get valuable answers to environmental questions, e.g. risk assessment of groundwater contamination, fate and pathway prediction, and land use planning concepts.

Further hydrogeological investigation area needed to evaluate the current status of water resources in the area as well as to get better understanding of the relationship between the karstified limestone aquifer and the Quaternary aquifer in term of hydraulic connection and source of recharge. This is also needed for developing strategies for the sustainable development of these precious natural resources.

Acknowledgement

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Groundwater management in Sana'a Basin – Republic of Yemen (Action Plan Matrix)

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Abstract

Previous Studies in Sana'a indicates that water abstraction has increased dramatically during the recent years where water level drop reached 5m/year. If no action were taken, this will lead to depletion of groundwater within 25 years. A well inventory study was carried out by WEC and concluded that well drilling has been increased where about 14000 well were drilled during 30 years life. This made the situation even worse and in spite of the existence of a water law and many other management measures, the government could not enforce them. The lack or shortages of information due to poor or discontinuity of monitoring systems always leads to poor estimation of water resources and subsequently to any adopted management plan. For better estimation and management of ground water in the basin, an action plan Matrix was suggested. This matrix involves all the relevant governmental bodies and the role to be played in terms of technical, institutional or political actions. Application of this matrix via involving all related water users in dialogue and policy formulation will certainly consolidate the cooperation for policy implementation, water law enforcement and probably to establishing a socially acceptable water cost. This will be the first step towards IWRM and thus towards exploiting the dwindling groundwater source in a more sustainable manner.

Keywords: Yemen, Sana'a basin, groundwater, well inventory, water quality.

1. Introduction

The Sana'a basin (Figure1) is an inter-mountain plain located in the central Yemen highlands. It relies to a large extent on groundwater for both irrigation and the urban water supplies. The commendable groundwater storage of the Sana'a basin to a depth of 250 meters below ground level was estimated at 6050 Mm^3, of which around 50% (3220 Mm^3) was considered usable storage (Al-Hamdi, 2000). Historically, water supplies were obtained from dug wells and ghayls tapping the unconsolidated Quaternary deposits in the plain. Boreholes construction and the introduction of pumps began in 1960's and increased rapidly from the mid-1970. This enabled deeper aquifers to be exploited for irrigation and municipal supplies. The groundwater development has been largely uncontrolled (SAWAS, 1996). As a result, the Basin is experiencing a serious depletion of groundwater resources with an associated alarming degradation in water quality due to spread of wastewater disposal through cesspits Al-Hamdi (2000). The situation is further complicated by the absence of an integrated water resources management plan for the basin including lack of data, a regulatory framework to manage the groundwater extractions and inefficient irrigation practices. It useful then to identity the major considerations required for the management of the available water resources in a sustainable manner.

Objectives of the study

- To identify problems resulting from water scarcity in the basin and the interaction between various users and governmental bodies.
- To identify the data and information gaps and prepare a water resources monitoring strategy for the entire basin.
- To establish the regulatory, legal and institutional framework needed for more sustainable water resources management in the Basin;

2. Approach and Methodology

To meet the objective mentioned above, the following activities were undertaken:

The available and relevant data, water use and sources, and groundwater availability, groundwater depletion and management, crop production areas, soil cover, maps, and meteorological information were gathered from the following sources:

- World Bank (WB) reports, Yemen.
- Water and Environment Center (WEC) reports, Yemen.
- Central Statistical Organization (CSO) reports, Yemen.
- Reports from National Water Resource Authority (NWRA-Yemen).
- Seasonal reports from National Water Supply Authority and Sanitation (NWASA).
- Several reports from Internet

Rapid Rural Appraisal (RRA) approach was used in this study. The fieldwork survey of the RRA consisted of the stakeholder consultations with representatives from different water users.

3. Study Area

The Sana'a Basin a part of Sana'a Governorate is located in Central Highlands of Yemen at an elevation ranging from 2000m to 2200m above mean sea level (MSL) and includes the capital city Sana'a. It covers an area of 3200 sq. km accounting to 6.06% of total area of the country. It has a population of 1.6 million which constitutes 7.8% of the country's total population.

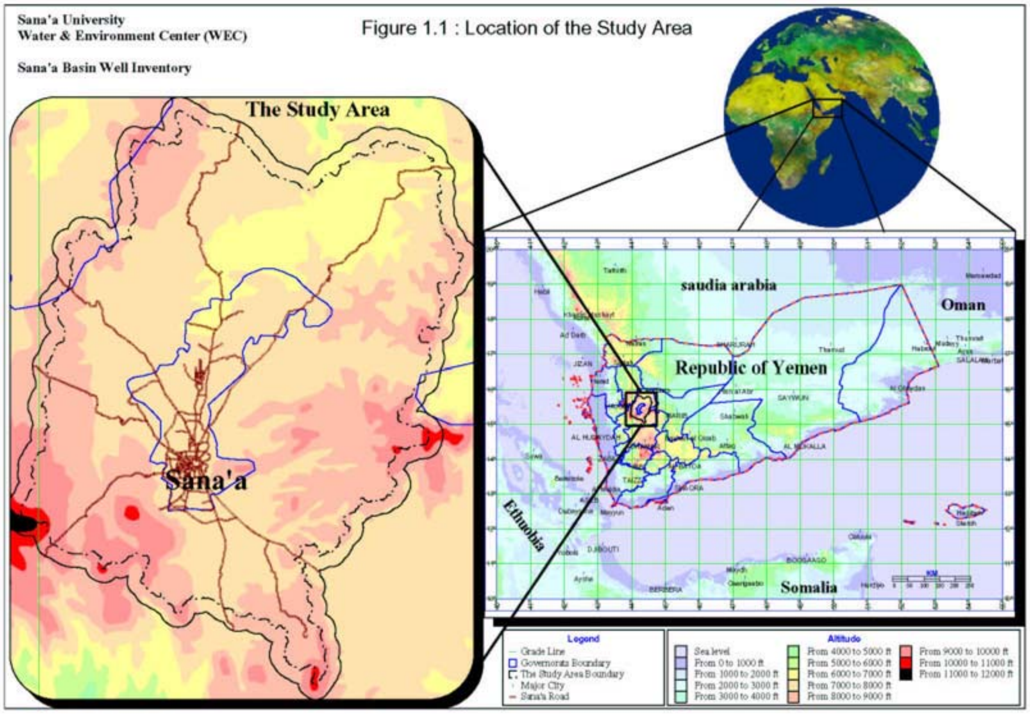

Figure 1: General location of the study area.

4. Characteristics of Sana' Basin

The Sana'a Basin is characterized by a complex ground water system which, in spite of many major studies carried out during the last 30 years (including, Italconsult, 1973; Mosgiprovodkhoz, 1986; Bloemmendaal, 1994a; TS-HWC, 1992, WEC, 2001; WEC, 2002), is only imperfectly known. Figures (2 & 3) give an impression of the geology and Table 1 shows the stratigraphy of Sana'a basin. The important geological units are the Quaternary alluvial deposits, the Tertiary Yemen Volcanics, the Cretaceous Tawilah Sandstones and the Jurassic lime stone which includes Amran and Kohlan Sandstones. Alluvial deposits used to be an important source of ground water in the past but serious declines of the ground water levels have reduced their role. The Tawilah Sandstones have become the most exploited aquifer unit since they were explored in the early 1970s which is between 200 to 300 meters deep (Figure 3). Flow in this aquifer is believed to be through fissures and pores (mixed aquifer type). These sandstones are absent in the northern part of Sana'a basin, probably due to erosion; perhaps the unexplored Kohlan Sandstone may provide water there (GDH & TNO, 1995). South of Sana'a the Tawilah Sandstones dip under a complex of Tertiary Volcanic Rocks and intercalated alluvial sediment. Productive wells have been sunk in the Tawilah sandstone in the southern zones of the urban area, but further south the Vocanic/alluvial complex is the only significant aquifer known. High rates of abstraction through more than 14000 wells have severely affected the piezometric levels in the Tawilah Sandstones with a mean value of 5 meters per year (WEC, 2002). Groundwater quality is generally good in the Sana'a Basin, but polluted zones have been observed in the urban area and north of Sana'a City where untreated sewage water is infiltrating (WEC, 2001b).

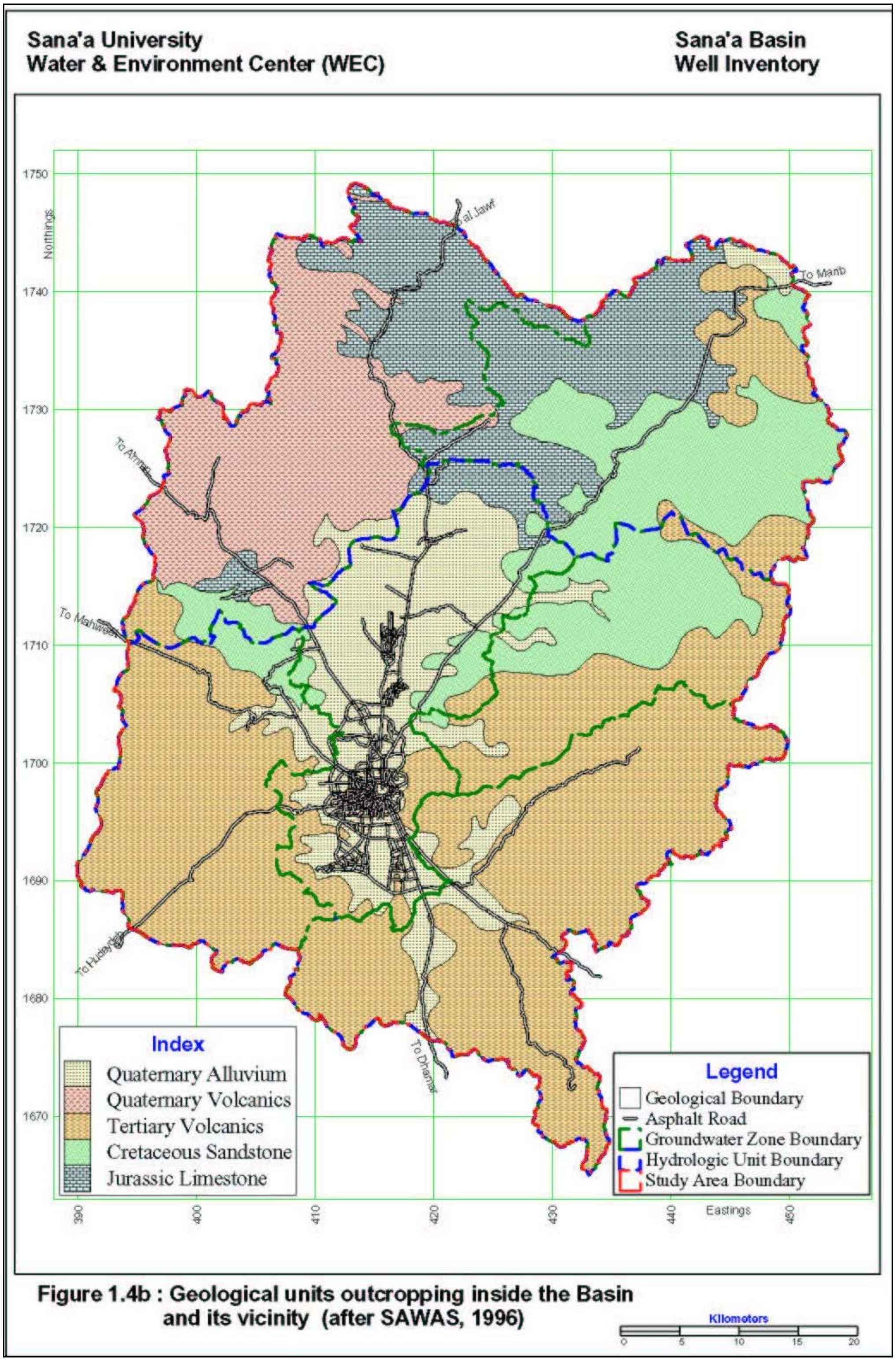

Figure 2: Geological units outcropping inside the Basin and its vicinity (after SAWAS, 1996)

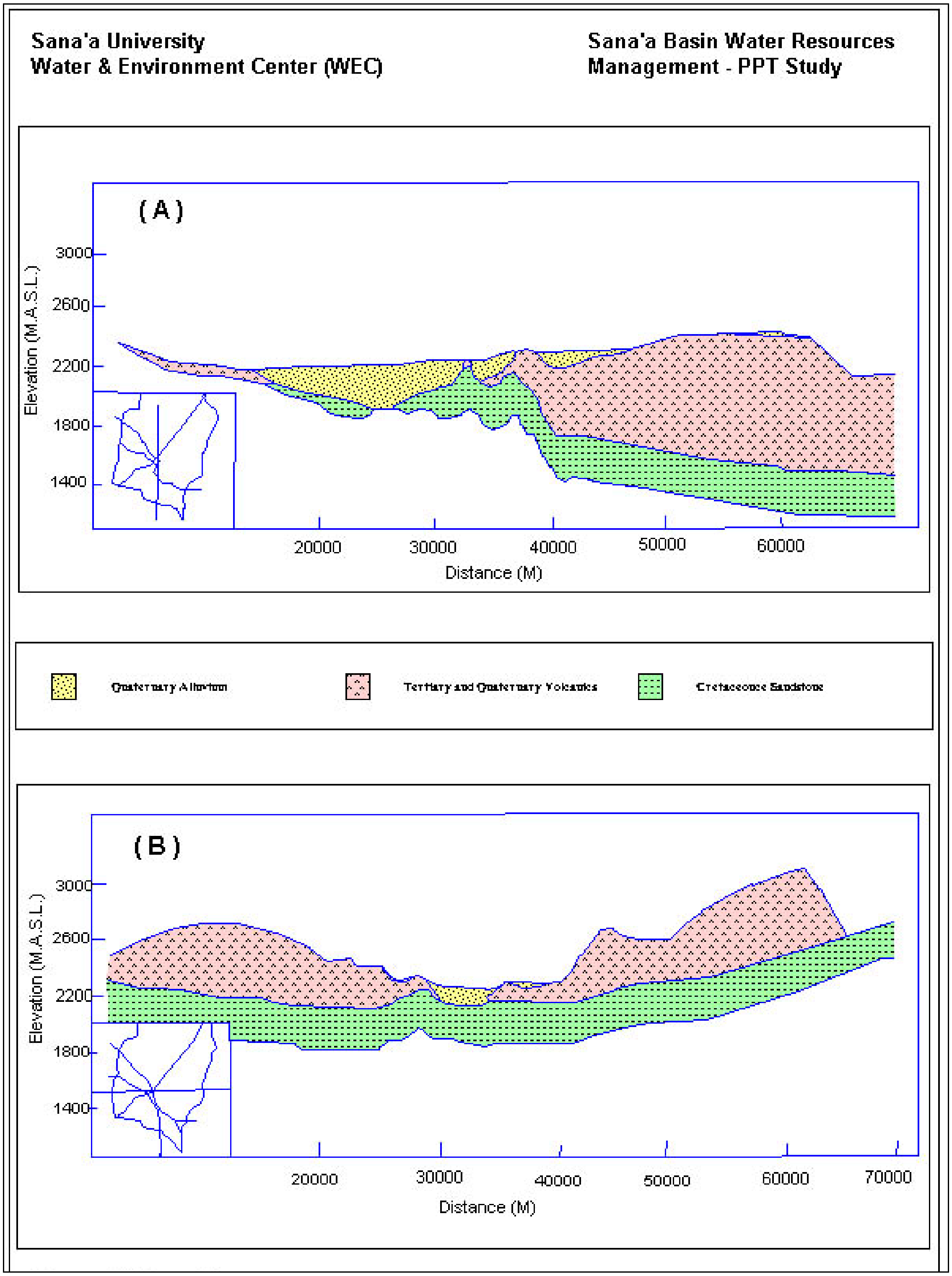

Figure 3: Cross sections through Sana'a Basin (after WEC, 2001b),

(A) N-S cross section,

(B) W-E cross section.

Table 1: The Strtigraphy of Sana'a Basin (after Italconsult, 1973)

<table>
<tr><th>System</th><th>Series</th><th colspan="2">Formation</th><th>Geohydrological Units</th><th>Description</th></tr>
<tr><td>Quaternary</td><td>PLEISTOCENE -RECENT</td><td colspan="2">Basalt / Alluvium</td><td>Basalt aquifer / Valley-Fill Aquifer</td><td>Loess.
Sandy clay with gravel and boulders.
Coarse terrace gravel.
Basalt cones and lava flows</td></tr>
<tr><td rowspan="4">Tertiary</td><td rowspan="3">EOCENE TO MIOCENE</td><td rowspan="3">Trap volcanic</td><td>Chaotic and Stratoid rock</td><td>Aquitard</td><td>Well-stratified ignimbrites and tuffs with some lava flows.
Black basalt and light coloured rhyolite.
Lava flows chaotically intermingled</td></tr>
<tr><td>Stratoid Rock</td><td>Aquitard</td><td>Well stratified tan, red and green ignimbrites and tuffs with interbedded fluvio-lacustraine layers</td></tr>
<tr><td>Basal basalt</td><td>Trap basal basalt Aquitard</td><td>Greenish black basalt with a few trachyte lenses.
Frequent quartz geodes in some horizons.</td></tr>
<tr><td>PALEOCENE</td><td colspan="2">MEDJ -ZIR</td><td rowspan="2">Cretaceous sandstone Aquifer</td><td>Tan to reddish fine-grained sandstone with interbedded siltstone, clay and weathered volcanic tuffs.
Basalt dykes.</td></tr>
<tr><td rowspan="2">Cretaceous</td><td rowspan="2">LOWER TO UPPER</td><td colspan="2">TAWILAHH</td><td>Tan to reddish fine to coarse-grained sandstone with interbedded siltstone and ironstone.
Basalt dykes.</td></tr>
<tr><td colspan="2">UNNAMED</td><td></td><td>Grey clay and shale with fine-grained sandstone beds and lignite layers and gypsum lenses.
Black pyretic shale and limestone.
Basalt dykes.</td></tr>
<tr><td rowspan="2">Jurassic</td><td>MIDDEL TO UPPER</td><td colspan="2">AMRAN</td><td>Amran Limestone Aquatard</td><td>Grey to tan fossiliferous limestone and calcareous shale.
Basalt dykes.</td></tr>
<tr><td>LIAS</td><td colspan="2">KOHLAN</td><td>Kohlan sandstone Aquifer</td><td>Sandstone and shale.</td></tr>
</table>

5. Groundwater abstraction and water use

According to a recent study (WEC, 2002), which is based on the number of wells, type, pumping hours, aquifer, and water use, the estimated the total annual abstraction of water from Sana'a Basin is 287.4 Mm^3 where the agriculture consumes about 80% of the abstracted water. This is summarized in terms of various uses in Table 2. However, it is emphasized that these results should be used as gross estimations only since the water pumped from the majority of wells in the Basin is mixed water that may not represent a particular aquifer type.

Table 2: Total annual groundwater abstraction in Sana'a basin (Mm^3/year)

<table>
<tr><th rowspan="2">Source</th><th colspan="3">Sector use in million cubic meter</th><th rowspan="2">Total</th></tr>
<tr><th>Irrigation</th><th>Municipal</th><th>Industry</th></tr>
<tr><td>Private (Urban) *</td><td>5.0</td><td>21.0</td><td rowspan="3">7.1</td><td rowspan="3"></td></tr>
<tr><td>Private (Rural)</td><td>220</td><td>12</td></tr>
<tr><td>Public (NWSA)</td><td>-</td><td>22.3</td></tr>
<tr><td>Total</td><td>225</td><td>55.3</td><td>7.1</td><td>287.4</td></tr>
</table>

* refer to Sana'a City only

6. <u>Overview of Water Resources Management Issues</u>

The prevailing water resources problems are essentially resulting from the increasing supply-demand imbalance due to the rapid expansion of the city. Further expansion is expected to aggravate the problems both directly (increasing demand in domestic water supply for the urban population) and indirectly (creating local markets for consuming more water in the agricultural and industrial sectors). The extent of such problems would to a large extent be determined by the interaction of the city with its neighboring rural areas, which results in the development of three different water uses as described above (Table 2). It is therefore convenient to assess the situation and describe the issues on the basis of these zones. A field visit was paid to the three water users (Table 2) and interviews were conducted with representatives from each group (10 from each group). The main issues that appeared to be of most concern to all stakeholder groups are summarized as follows:

Groundwater depletion scarcity: This is of most concern to all social groups who realize quite the seriousness of the water problem affecting all districts.

Inadequate infrastructure: A good number of water harvesting structures (small dams, reservoirs, ponds ….etc) have been constructed through public/private cooperative efforts and funds. However, many of them are either empty or collapsed and those that still exist are in a poor condition due to mainly the lack of financial resources and/or proper maintenance.

Dishonesty of the government: Local farmers expressed a great anxiety and mistrust in the groundwater, and in the related governmental bodies with respect to seriousness in alleviating the water-related problems that exist in their districts.

With the aid of the collected data associated with the stakeholder interviews the findings in terms of a problem matrix were summarized in Table 3. This table indicates that while drinking water shortage, the most widely publicized problem, is limited to the urban zone (i.e. Greater Sana'a city), groundwater-mining-related issues are more widespread across the entire Basin. These are the more sensitive and rapidly spreading problems that are likely to prove most challenging for attaining sustainability, if at all. Though the existence of many management measures in the National Water Strategy and Investment Plan (NWSIP, 2005), Basin co-management approach is still on the drawing board and hence concerted efforts need to be made for translating this from a management model into reality. To date only a Basin Committee in Sana'a and in Sa'adah established. Efforts are constrained by the limited number of regional branches for NWRA, limited regional and local presence and weak links of stakeholders with local authorities.

7. **Information Requirements for Integrated Water Resources Management***Nature of IWRM Information*

The complexity of water-related issues in the Sana'a Basin is a direct result of its size in terms of physical area and human population, its limited water resources, and the absence of proper institutional arrangements. The information displayed in Table 3 suggests that integrated water resources management (IWRM) in such a complex system as the Sana'a Basin involves a wide variety of information. Such information can be divided into four categories:

- Information on the supply side, or water resources information.
- Information on the demand side, i.e. socio-economic information.
- Information relevant to the facilities/arrangements through which interaction between supply and demand can proceed, i.e. water-related infrastructure.
- Information on contamination/ or potential contamination and source.

At present, limited information is being collected by either NWRA or NWSA. Preparation for the collection of more information is also underway. However it is not clear what arrangements have been made, if any, to ensure data collection continuity as well as analysis and storage of the information for future purposes. The socio-economic information is perhaps more difficult to collect for three main reasons:

- It is still difficult for many decision makers to comprehend the importance of acquiring such information, as they may perceive it as unnecessary, too subjective, and/or irrelevant to the planning and management process.
- The nature of this information requires a multi-disciplinary team with diverse backgrounds that normally cannot be found within any one organization of the local water sector.
- There is very little well-trained local staff in such institutions, including NWRA and NWSA, and MWE who can carry out the field investigations required for collecting information that reflect reasonably well on the water consumption issues.

Because of these limitations very little useful information has been collected with regards to water consumption in the Basin. Whatever collected has been obtained through senior local and/or international short-term consultants hired normally by Donors, directly or indirectly, for specific assignments not including any training. As such concerned authorities such as NWRA or NWSA still remain unable to take such a responsibility. In the context of the present study, the term infrastructure is taken in the broad sense of incorporating any facility or arrangement made to enhance water management. As such it includes not only water-related technical infrastructures but also water legislation and environmental protection measures. While the previous two categories can be classified as supply (mainly technical) or demand (mainly agro-socio-economies), this category of information involves both. Hence the local staff dealing with this information is expected to have a combination of technical and non-technical (social sciences) background. Preferably such staff should also be senior people with management perception and leadership capabilities.

All three main institutions in the water sector (MAI, NWRA and NWSA) have been active in collecting parts of this information, as deemed necessary or perceived relevant to their specific needs. As such the available information is fragmented and not necessarily utilized for common goals related to water resources management.

Table 3: Matrix of Problems of Critical Issues Related to Groundwater Mining and Water Supply Shortage (WEC, 2001)

Water -Use Zone	**Main Problem**	**Critical Issue**	**Evidence**	**Source**
Urban	Water supply and sanitation facilities shortage	Level and quality of service provision.	Proportion of population now in the future with no, or inadequate; provision of safe water; sanitation and wastewater disposal facilities; consumption per head; reliability of supplied …etc.	Shortage of investment funds; rapid growth of urban settlements; poor maintenance; inefficient services; lack of fairness in allocations; inadequate sewerage and drainage system.
Basin-wide (Urban, Urban –	Groundwater mining and groundwater contamination	Supply-demand imbalance.	By sector and/or region; future trend.	Growth in population; upgraded standard of living (i.e. increasing per capita demand); over-use of groundwater; inefficient service

rural, and Rural Zones)		Rapid depletion of major regional aquifers	Drying-up of spring and dug wells; lowering of water levels in boreholes; reduction of perennial flow in major Wadis; drop in well yield	Growth in population; expansion of a subsidized agricultural sector; introduction of modern drilling technology and pumps
		Deterioration of groundwater quality (mainly in Bani Al-Harith district)	Increased salinity in wells; soil salinization; incidences of water related diseases.	Up coning of saline water; poor irrigation practice (low irrigation efficiency); inadequate drainage systems; growth of polluting industries.
		Inefficient use	Performance measures such as system efficiency, agronomic norms, and economic value of water.	Absence of incentives to conserve water; poor system maintenance; low public awareness of water situation; limited access to imported technology.

		Growing conflicts among users	Co-existence of surpluses and deficits among regions/sectors; growing shortages in particular uses; competition for limited supplies.	Growing imbalance of water supply and demand; weak institutional arrangement; absence of water legislations; failures and/or absence of planning and forecasting.
		Costs of future abstraction	Growing environmental stress; development of water markets and transfers; rising cost of marginal water supplies. Unit costs of projected drilling; pump installation; fuel consumption compared to current and past level.	Exhaustion of easy options in the face of growing demands; absence of demand management.
Rural Zone		Inadequate water quality.	Incidences of water related diseases; change in taste; odor	Shortage of funds for construction of adequate water supply schemes; lack of proper maintenance, shortage of sources for good quality water.

Despite the existence of many scattered studies, investigations and technical cooperation projects many basic data are not available. It is often difficult to trace and collect the relevant basic information, to fill the gaps, and to fit the pieces of information together to obtain a complete and consistent picture about the water resources and hence adopting an adequate management measures. Monitoring is not conducted in a systematic way, data records are mostly not documented and most other records are only project related. Review and analysis of the available information indicate a significant gap in the information required for management of water resources in the basin toward sustainability. Immediate actions for filling some of these gaps are given in Table 4.

Table 4: Information gaps

Information Group	Missing Information
Supply	• Spatial distribution of rainfall and other meteorological data basin-wide. • Reliable and continuous data on surface water runoff. • Data on chemical composition of rain and surface water. • Spatial variation of aquifer thickness and lithology. • Degree and nature of the hydraulic continuity between aquifereous formations. • Variation in lithology and thickness of the sandstones. • Hydraulic significance of clay and paleosol layers found in between volcanic deposits or intercalated with sedimentary formations, particularly the Tawilah sandstones. • The significance of these layers also with respect to the chemical evolution of groundwaters. • Degree and nature of the hydraulic continuity between the Tawilah sandstones and the overlying volcanic and/or alluvial layers.

	• Reliability of the pumping test data and analysis in the aquifer systems, particularly the volcanics. • Accuracy of hydrogeological parameters. • Continuation of water-level measurement in wells and of ground-control (location and altitude of well) • Lack of a recent well and spring inventory, of a monitoring program and of isotopic analysis. • Characteristics of the groundwater divide, especially in the south, southwest, and northeast. • Reliable recharge estimates. • Reliable figures and time series data on abstractions/discharge rates. • Lateral and vertical flow between permeable and semi-permeable units of the aquifer system. • Reliable estimates of storability in different aquifer units. • Spatial distribution (as well as possible origin) of salinity.
Demand	• Total area of irrigated land and related water abstractions. • Reliable figures and time series data on abstractions/discharge rates.
Infrastructure	• Reliable topographical maps, aerial photographs and satellite imagery. • Location and characterization of potential pollution source (pesticides, herbicides and fertilizers used by farmers) and their impact on water quality. • Reliable chemical and bacteriological analysis.

8. Water Resources Management Programs

Examination of Table 4 shows that the nature of the identified issues ranges from strictly technical matters that should be handled by one or more Government organizations to more complex problems, which require collaborative efforts. Any remedial action to be introduced should be specified as technical, physical, policy, or institutional. The recommended measures, specific arrangements required, and the time zones within which the measures are to be introduced are summarized in two phases (Tables 5A and 5B). Table 5A describes short-term actions that are recommended to be taken within say three to four years. It is the more difficult phase because it involves a wide variety of policy actions that require strong and effective institutional arrangements. The success of the second phase (Table 5b) would practically depend on how well the first phase is handled. This phase has therefore to be monitored very closely and necessary changes have to be made all along through the program.

Table 5A: Short –Term program (year1 to year 4) for water resources measures required

(P = Policy; I = Institutional; T = Technical; Ph = Physical)

Serial number	Action Details	Code
1	Increase city water supply (MWE, NWSA)	P
2	Stop groundwater contamination (MWE , NWSA)	P
3	Establish an adequate and sustainable hydrological monitoring network (NWRA)	T
4	Initiate a basin wide public awareness program (NWRA+MAI)	I
5	Formulate and initiate the application of national water law, regulation steps, and institutional arrangements in the basin (MWE, NWRA + MAI + EPA + MPIC + Donors).	P
6	Initiate field investigations (Hydrogeology, Geo-technical, Geophysics …etc) in selected sub basins (NWRA + NWSA + MAI)	T
7	Initiate applied research (WEC in conjunction with NWRA + NWSA + MAI + EPA)	T
8	Carry out a basin-wide Socio-economic–agriculture and water use–cropping pattern survey (MAI + NWRA)	T

9	Carry out a basin-wide awareness program (MWE, NWRA + MAI)	I
10	Initiate capacity building (MWE, NWRA + MAI + NWSA).	I
11	Initiate dialogue between the main stakeholders for policy formulation (MWE, NWRA).	I
12	Formulate and promote specific water resources strategies and management plans for the basin through seminars, formal and informal meetings, brochures, media, etc. (MWE, NWRA)	P
13	Establish an accessible, public–oriented data-base and water information center (MWE, NWRA + WEC + Others)	Ph
14	Formulate a Water Resources Action Plan (MWE, NWRA)	P

Table 5B: Long–term program, for 4 -12 years.

Serial number	Action Details	Code
1	Consolidate the awareness program.	I
2	Make proper arrangement for securing a firm but socially acceptable and government – backed enforcement of the water law and supporting legislations, possibly including the establishment of a “water cost”.	I
3	Continue field investigations and expand to other areas such that the entire basin is covered by the end of this phase.	T
4	Consolidate research activities and WEC-Sector link.	I-T
5	Continue capacity building	I
6	Consolidate stakeholders’ cooperation for policy implementation and water law enforcement.	I
7	Activate water information center programs.	I-T

9. Conclusion & recommendations

Concerning the objectives of this study, the main conclusions are as follows:

1. The uncontrolled groundwater abstraction for the growing agriculture and domestic water demands caused a sharp decline in groundwater levels up to 5 m per year.
2. It was found that the three main institutions in the water sector (MAI, NWRA and NWSA) have been active in data collecting parts necessary to their specific needs and hence due to lack of coordination such data is fragmented and not necessarily utilized for common goals related to water resources management.
3. Review and analysis of the available information indicates a significant gap (Table 4) in the information required for management of water resources in the basin and hence for better estimation and management of Sana'a basin immediate action, integrated between all the related water sector bodies, is required for filling this data gabs.
4. Though the existence of the National Water Strategy and Investment Plan in Yemen (NWSIP, 2005), efforts made to translate this from of a management strategy into reality are constrained by the limited number of regional branches for NWRA, limited regional and local presence and weak links of stakeholders with local authorities.
5. For consolidate integrated water management a short and long term action plans were suggested (Table 5, a & b) defining measures to be taken and the governmental bodies involved; when applied the following important advantages will be achieved:
    - Through installing adequate hydrological monitoring network more reliable data will be obtained which subsequently lead to more accurate water resources assessment.
    - With designing and implementing adequate awareness programs, targeting all water users basin wide, the problem of water scarcity will be better realized.

- With involving all water users (representatives) in dialogue and policy formulation will certainly consolidate the cooperation for policy implementation, water law enforcement and even establishing a socially acceptable water cost.

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List of symbols

MWE	**Ministry of Water and Environment**
NWRA	**National Water Recourses Authority**
NWSA	**National Water Supply and Sanitation Authority**
MAI	**Ministry of Agriculture and Irrigation**
WEC	**Water and Environment Center**
EPA	**Environment Protection Authority**
SAWAS	**Sources for Sana'a Water Supply**
TSH-WC	**Technical Secretariat of the High Water Council**
MPIC	**Ministry of Planning and International Cooperation**

ELECTRICAL RESISTIVITY IMAGING FOR QUATERNARY AQUIFER IN WADI MURAYKHAT AND WADI SA'A, AL AIN AREA, UAE.

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ABSTRACT

Groundwater constitutes an important water resource in United Arab Emirates. Groundwater has been overexploited to meet the increasing water demands. Despite the wide expansion in the construction of desalination plants in the different Emirates, the groundwater resources still contribute the largest share in the water budget of the country. The Quaternary aquifer is the main source for groundwater in Al Ain area, where the area of study is located.

Wadi Muraykhat and Wadi Sa'a are of the main tributaries crossing east of Al Jaww Plain, Al Ain area, UAE. These wadis originate from the Oman Mountains range and form the catchment and feeding area of the water resources. From the hydrogeological point of view, subsurface investigation of these wadies is very important for better understanding of the Quaternary aquifer system, water flow, water quality and management of water pumping.

Two-Dimensional Electric Resistivity Imaging (2-D ERI) survey has been implemented. Thirteen (2-D) profiles along Wadi Muraykhat and Wadi Sa'a have been carried out. Moreover, the available borehole data have been utilized along with 2-D resistivity profiles to contribute to the Quaternary aquifer in the study area.

2-D resistivity tomograms of the thirteen profiles indicate remarkably the different hydrostratigraphic units of Quaternary aquifer along the eastern margin of Al Jaww plain. Erosional unconformities at the base of the Quaternary alluvium are traced along some of the (2-D) profiles. These unconformities represent the paleochannels in the bed rock that were formed in the geological past by the ancient wadis.

Key Words: Groundwater Exploration, Electric Resistivity Imaging, Quaternary Aquifer, Paleochannels, Al Ain, UAE.

1. INTRODUCTION

Groundwater constitutes an important water resource in United Arab Emirates. Al Ain area (Fig. 1) has experienced a rapid urbanization for the past few decades. Because of its fertile land, Al Ain area is considered to be the main focal point for agricultural activities, which in turn depend on the groundwater of the Quaternary aquifer. The Quaternary aquifer is the main source for groundwater in Al Ain area. Wadi Muraykhat, Wadi Sa'a, Wadi Muthaymimah and other wadies (Fig .2) are considered to be the main tributaries at Al Jaww Plain, East of Al Ain City. Rainfall in Oman Mountains and Jabal Hafit contributes to the recharge of the Quaternary system through these wadies.

From the hydrogeological point of view, subsurface investigation of these wadis are very important for better understanding of the aquifer system, water flow, water quality and management of water pumping etc. Moreover, the ancient wadis (paleochannels) probably followed similar system configuration as the present ones (Menges and Woodward, 1993). These paleochannels are promising targets for fresh groundwater, as they have appreciable thickness of water-bearing formations that are recharged from the surrounding mountain region.

The main purpose of this paper is to map the hydrostratigraphic units of the Quaternary aquifer at the study area using Two-Dimensional Electric Resistivity Imaging (2-D ERI) technique. Such contribution will provide the technical support for planners, decision makers, and researchers in the field of groundwater development and management especially a great project for artificial recharge of desalinated water from Fujairah plant under development and the result of study will contribute to the development of this area.

2. GEOLOGICAL SETTING

Al Ain area, where the study area, is situated in the eastern part of Abu Dhabi Emirate near the border with sultanate of Oman and at the western margin of the northern Oman Mountains (see Figs. 1&2). Al Ain is one of the largest and ancient oases of the Arabian Peninsula, due to the underground fresh water supply which is derived from the Oman Mountains to the east. Although Al Ain is located within the arid desert belt of the world and characterized by drainage net, formed as a result of the prevalence of humid climate during the Quaternary.

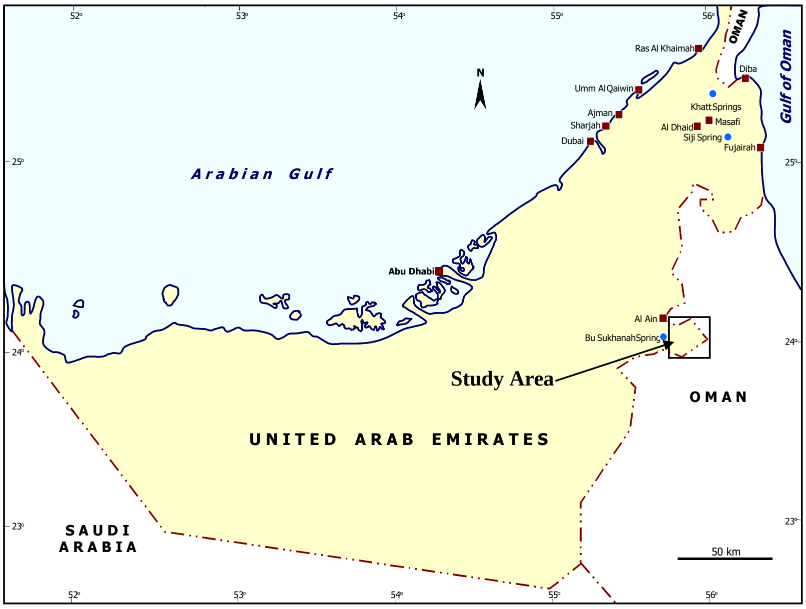


Fig. 1: Map showing locations of Al Ain area and the study area.

The geomorphology of Al Ain area was studied by many authors (e.g. Hunting, Geology and Geophysics, 1979; Abou El-Enin, 1993; Al-Shamsei, 1993; UAE National Atlas, 1993; Garamoon, 1996 and Baghdady, 1998). 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 (see Fig.3).

Jabal Hafit is considered as one of the most prominent monuments of the area, it is located to the southeast of Al-Ain. 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 Emirates (Hunting Geology and Geophysics (1979) and Abou El Enin (1993)). 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.

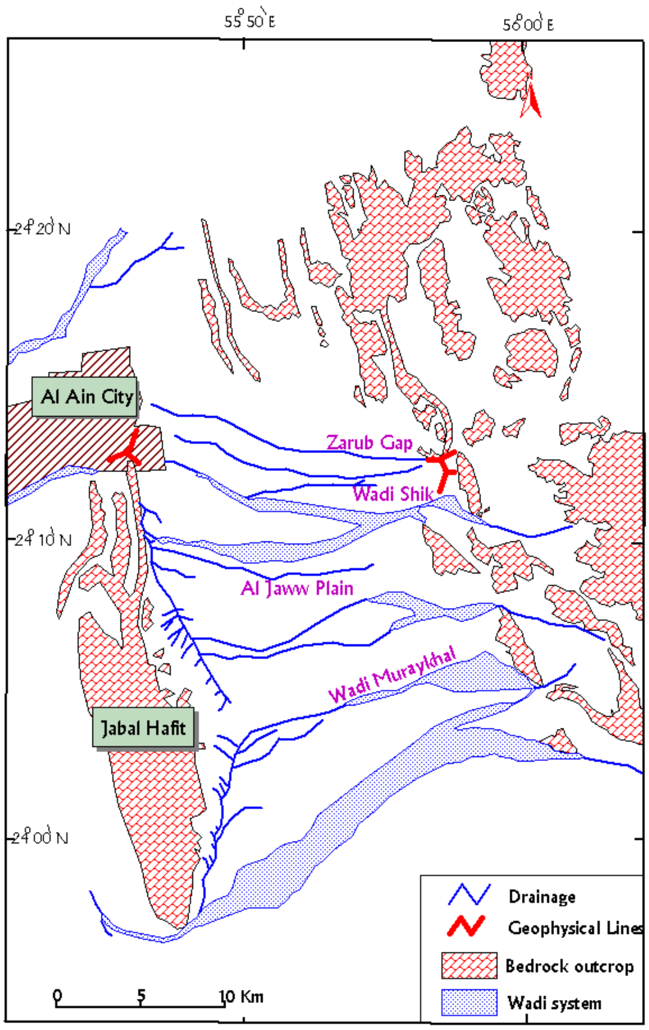


Fig. 2: Map of Al Jaww Plain and locations of Wadi Muraykhat and Wadi Sa'a (modified from Warrak, 1986).

Wadi Muraykhat and Wadi Sa'a as a part of Al Jaww Plain are mostly covered with Quaternary deposits. Hunting Geology and Geophysics Ltd. (1979) recognized five sediment types at Al Jaww Plain which are: alluvial deposits, desert plain deposits, mixed deposits, sabkha deposits and aeolian sand. Surface drainage on the piedmonts and alluvial fans subdivisions are generally canalized in wadies with variable flow patterns exhibiting complexly braided channel morphologies (Menges and Woodward, 1993).Geology of Al Ain in general, and Al Jaww Plain in particular, is elaborated in Al Nuaimi (2003).

The surface geology of Al-Ain Area (Fig. 3) is fairly well understood from the previous investigations of Gibb (1970), Terratest (1973), Holderbank (1975), Hunting (1979), Cherif and El Deeb (1984), Warrak (1986), Hamdan and El Deeb (1990), and Hamdan and Bahr (1992). At Jabal Hafit, Jabal Mundasa and Jabal Malaqat, the Cretaceous and Tertiary rocks are exposed and are strongly folded. Jabals Mundassah and Malaqet are parts of the northern Oman Mountains and located approximately 17 km east of Jabal Hafit. The rocks forming these two Jabals are composed of serpentinized predotite (in the cores), conglomerates and carbonates of Late Cretaceous age, overlain by marls and carbonates of Paleocene to Early-Middle Eocene age (Hamdan and El-Deeb, 1990). They form asymmetrical anticlinal structures (Warrak, 1986). Terratest (1973) described the Paleocene succession exposed in Jabal Malaqet, as consisting of marl layers, glauconitic limestone and marly limestone interbeded by fine-grained breccia with some chert.

Two gravel plains are terminating the eastern part of Al-Ain area; one fringes the Oman Mountains and the second fringes Jabal Hafit. The first fringe reaches its maximum development at Al Jaww plain (Hunting Geology and Geophysics, 1979). The drainage basins in Al-Ain area are of two systems; one is related to the northern Oman Mountains and the second belongs to Jabal Hafit, the first system is generally dendritic, as it is typical massive igneous rocks forming these mountains. In Al Jaww plain, the dendritic pattern usually changes to braided pattern where the slope decreases in Al Jaww plain. The main reasons for the variation in the drainage pattern are either deformation, or decrease in slope (Al-Shamsei, 1993). The second system of the drainage pattern occurs in the west of Al Jaww plain and south of Al-Ain area. The pattern ranges from dendritic to braided with some parallel or rectangular pattern especially in the structurally-controlled areas. Al Jaww plain is specially large (15 km) wide and consists of gently inclined gravelly materials transported by wadies dissecting the northern Oman Mountains. The plain is transverses by numerous wadies such as wadi Shik, Al Ain and Muraykhat (Figs 2&3). Three alluvial fans within the plain; namely: the Zarub fan in the north, the Moundassah fan in the middle and the Ajran fan in the south (Al-Shamsei, 1993).

The stratigraphy of Al Ain area (Fig. 3), comprises a sedimentary sequence ranging in age from the Cretaceous to the Quaternary (e.g. Hunting Geology and Geophysics, Ltd, 1979; Hamdan and El-Deeb, 1990; Hamdan and Anan, 1993; Whittle and 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. These units collectively form a relatively thin veneer that overlies older rocks with varying degrees of structural discordance.).

The Upper Cretaceous sequence includes (from base to top): Semail ophiolites (serpentine and serpentinized predotite), the oldest exposed rocks in Al-Ain area, Qahlah Formation (red and yellow unfossiliferous clast-supported conglomerates of serpentized predotite, derived from the Semail ophiolites, Simsima Formation (marine bioclastics limestones with rudists, corals and echinids, it is disconformably overlies the Qahlah Formation (Hamdan and Anan, 1993). The Faqa Formation consists of light grey to buff thinly-bedded pelagic marls and Cretaceous shales with creamy to orange nodular to flaggy argillaceous limestones interbeds.

The Palaeocene sequence is separated from the underlying Upper Cretaceous sequence by a regional unconformity with local conglomerate at its base. It is represented by the Muthaymimah Formation.

The Eocene sequence includes Rus Formation and Dammam Formation. The Rus Formation (Lower Eocene) is composed of fossiliferous dolomitic limestone with thin argillaceous limestone grading upward to well-bedded limestone. (Whittle and Alsharhan, 1994) The formation constitutes the core of the Jabal Hafit anticline. The Dammam Formation (Middle to Upper Eocene) unconformably overlies the Rus Formation (Hamda and Bahr, 1992). It constitutes most of the outcrops of Jabal Hafit.

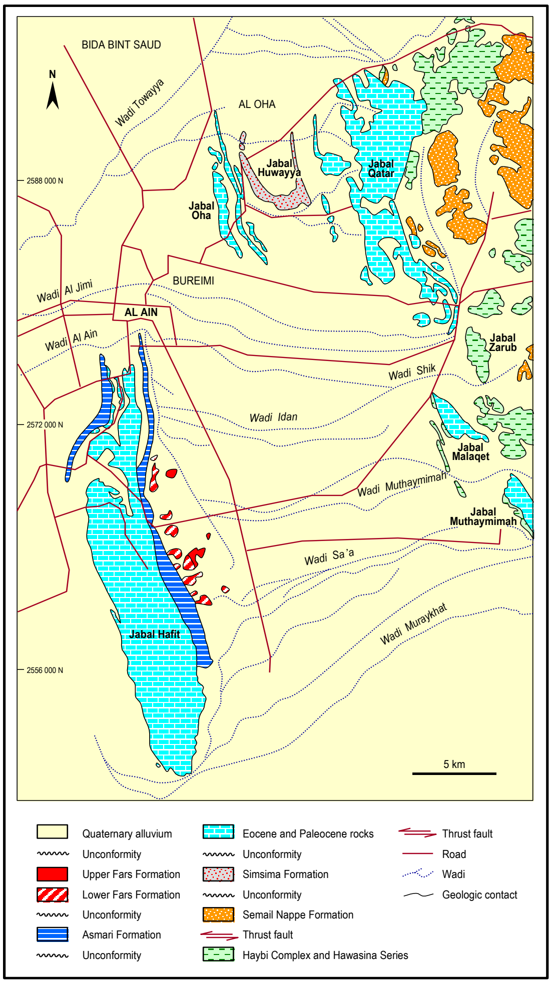


Fig. 3: Map of Geology of Al Ain area and locations of Wadi Muraykhat and Wadi Sa’a (modified from Hunting Geology and Geophysics, Ltd., 1979; Warrak, 1987).

The Oligocene Asmari Formation ranges in age from Middle to Late Oligocene (Whittle and Alsharhan, 1994). It is composed upwardly of silty marl, bioclastic nodular limestone, and interbeddd bioclastic limestone and marl.

The Miocene succession unconformably overlies the Asmari Formation (Whittle and Alsharhan, 1994). It is low-lying and located at the eastern flank of Jabal Hafit as interbeds of Gypsum and Clay and fossiliferous clay. Quaternary age deposits cover most of Al-Ain area and consist of near surface and surficial sediments of mixed alluvial, aeolian, and locally, sabkha (evaporatic origins) Quaternary alluvium constitutes the principle water-bearing litho-stratigraphic unit.

Rizk et al., 1997, reported that the main producing aquifers in the UAE are: fractured ophiolite rocks in the east, gravel aquifers flanking the eastern mountain ranges on the East and West and sand dune aquifers in the South and West. The aquifers existing in the study area are Quaternary and Jabal Hafit limestone aquifers. For more details about the different types of aquifers in UAE, references are made to Garamoon, 1996, Rizk, 1999, Alsharhan et al., 2001 and El-Saiy, 2002, Al Hamadi, 2003 and in Al Nuaimi (2003).

3 GEOPHYSICAL INVESTIGATIONS

3.1 Introduction

Surface-geophysics methods offer quick and inexpensive means to characterize subsurface hydrogeology (Elwood et al., 1994 and Powers, et al, 1999). They provide information on subsurface properties, such as thickness of layers and saturation zones, depth to bedrock, location and orientation of bedrock fractures, fracture zones and faults. Surface and borehole geophysical methods may form a part of preliminary site evaluation for groundwater investigation. The data from the geophysical surveying can guide the selection of the sites of test borings and provide data to correlate between them.

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 the natural currents and others depend on injection of artificial currents into the earth. For more details about these different techniques reference is made to Mussett and Khan, (2000), Reynolds (1997), Parasins (1997), Telford et al., (1990), Robinson and Coruh (1988) and Dobrin (1976).

The DC-resistively methods of geophysical exploration are popular and proved to be successful and have many implications in the fields of geoenvironment and hydrogeology. Electrical resistively methods were developed in the early 1900s but have become widely used since the 1970s, primarily due to the availability in the search for suitable groundwater sources. These methods have also been used to monitor types of groundwater pollution; in engineering surveys to locate sub-surface cavities, faults and fissures permafrost, mineshafts and in archaeology for mapping out the a real extent of remnants of buried foundations of ancient buildings, amongst many other applications.

One of the new developments in recent years is the use of 2-D electrical imaging/tomography surveys to map areas with moderately complex geology (Griffiths and Barker 1993). A more accurate mode of the subsurface is a two-dimensional (2-D) model where the resistivity changes in the vertical direction, as well as in the horizontal direction along the survey line.

3.2 Two-Dimensional Resistivity Data acquisition

In this study, thirteen (2-D) electrical resistivity profiles using Wenner electrode configuration along some selected profiles crossing of Wadi Muraykhat and Wadi Sa'a, Al Ain area (Figure 4). The 2-D resistivity profiles were conducted and oriented along the strike direction of the surrounding outcrops to intersect the maximum possible number of geologic features.

Due to the unavailability of a 2D dc-resistivity profiling system, a single channel Memory Earth Resistivity and IP Meter instrument manufactured by Advanced Geosciences, Inc. was used with four wheels of electric wires as a substitute for the multicore cable and amnual reading instead of the control unit. The distancces were controlled manually by marching throug the profile forward and backward. Figure (5) shows photos of the 2-D data acquisition at the study area.

Twelve Profiles extends to 600 m, length while profile 13 extends to 800 m length centered at water well no 20 (See Figure 4). For profile one and two, 10 m electrode space has been utilized, while 20 m electrode space has been used for the rest of profiles. For each profile, Wenner array was used in resistivity data acquisition.

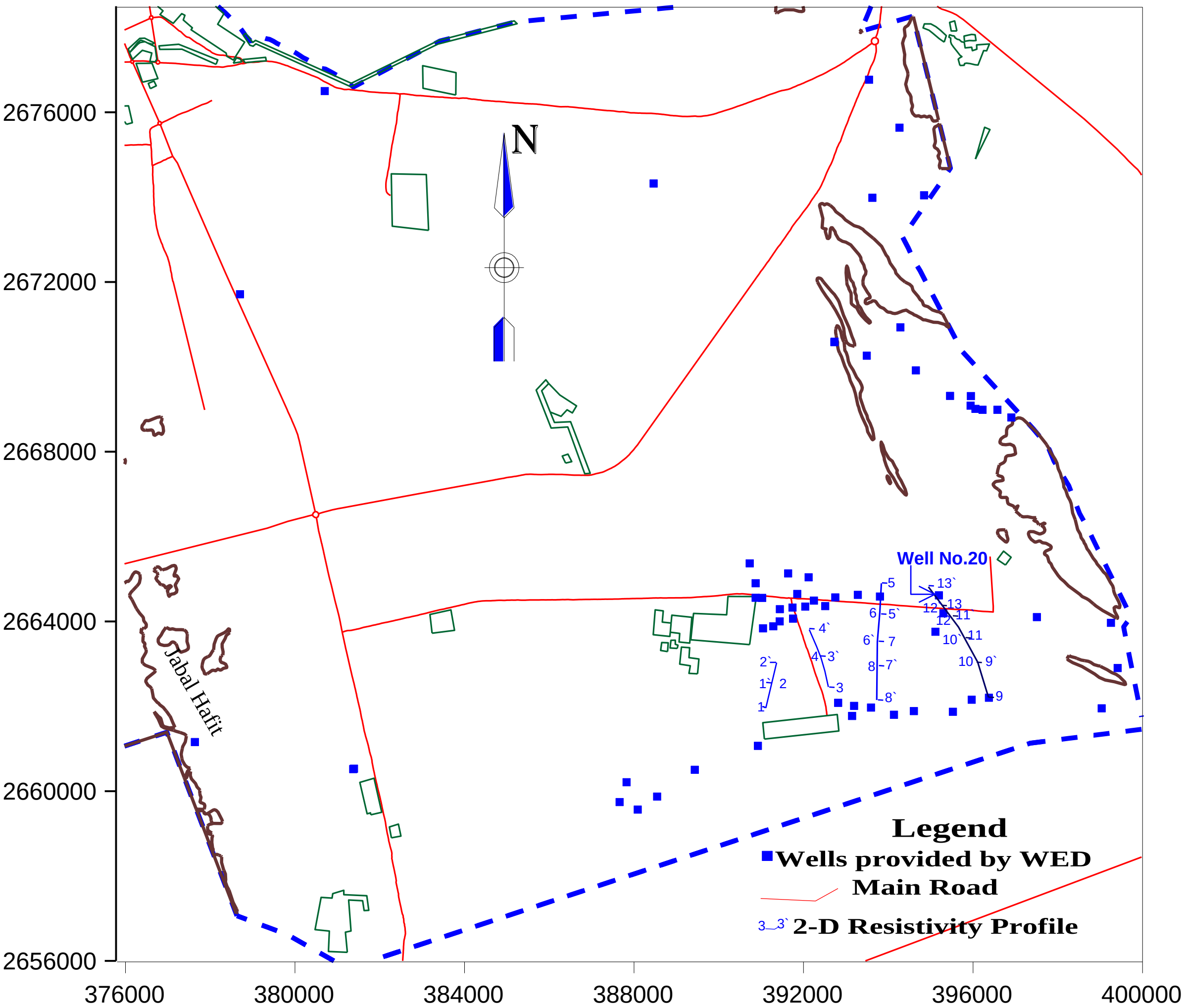


Fig.4: Base map showing the locations of the conducted thirteen (2-D profiles) and boreholes at Wadi Muraykhat and Wadi Sa'a, Al Ain area.

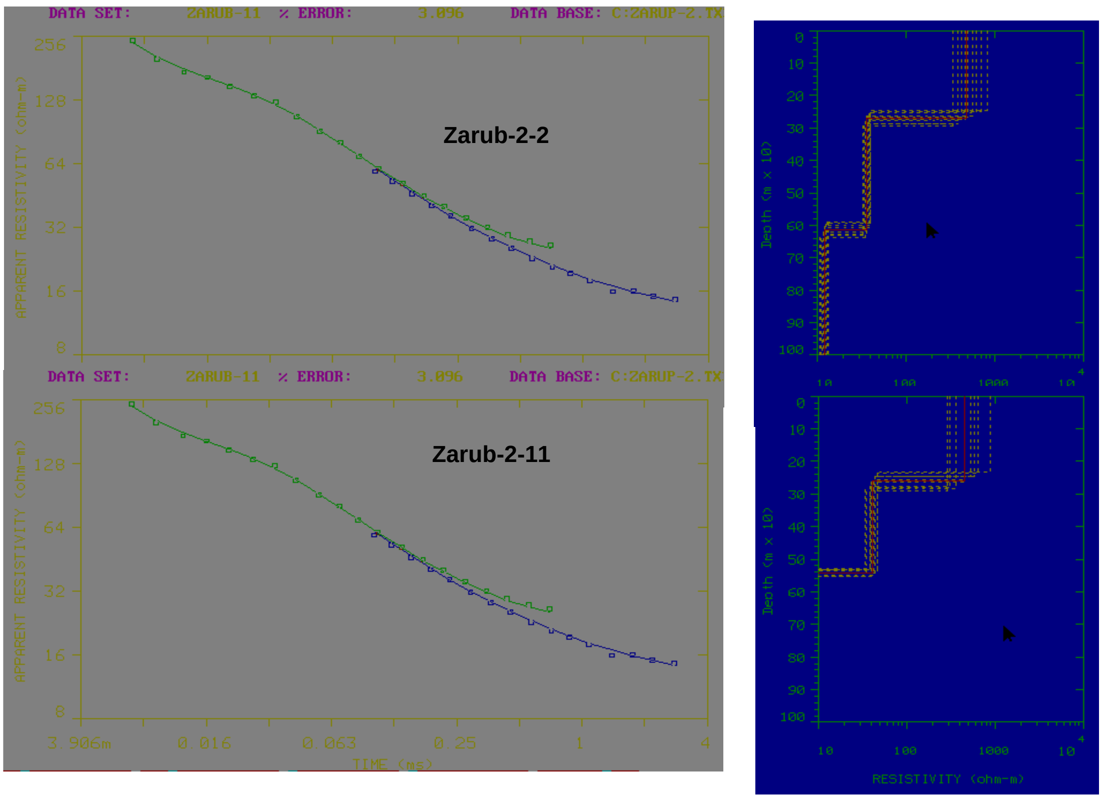
Fig 5: Photos showing the 2-D resistivity data acquisition at Wadi Muraykhat, Al Jaww Plain.

The apparent resistivity data were inverted to create a model of the resistivity of the subsurface using Res2dinv, ver. 3.54. Res2dinv uses an iterative smoothness-constrained least-squares method (deGroot-Hedlin and Constable, 1990; Loke and Barker 1996).

3.3 Resistivity model at the study area

To relate the inverted 2-D resistivity tomograms with lithology and hydrogeological conditions, previous work done by both Al Nuaimi (2003) and US Geological Survey, (1993) have been correlated with 2-D tomograms. Figure (6) shows typical TEM soundings done at Zaroub gab to the north of study area (see Fig. 2 , for location), Al Nuaimi (2003).

The model of TEM data in interdune area to the northwest of study area is reviewed and shown in Fig.(7) (US Geological Survey, 1993).



The observed data and the model response **Interpreted layer resistivity.**

Fig.6: Typical TEM soundings at Zarub gab (after Al Nuaimi, 2003)

4 Results and Discussions

Investigations of the thirteen (2-D) resistivity tomograms guided with the available borehole information (see Fig. 4) and guided with the geoelectric model given by Al Nuaimi (2003) and US Geological Survey, (1993) (Figs 7&8) leads to recognize the main hydrostratigraphic units of the Quaternary aquifer along the eastern margin of Al Jaww plain. However, the geoelectric model at Al Jaww Plain and the model in the interdune area are not similar. The interdune area does not contain an alluvial-type layered sequence (existing at Al Jaww Plain). Instead, thick resistive accumulations of variably-cemented dune sand overlying conductive bedrock (existing at the interdune area).

Investigations of the inverted resistivity tomograms (Figs 8 & 9, as typical examples), lateral and vertical variation of lithological units are recognized.

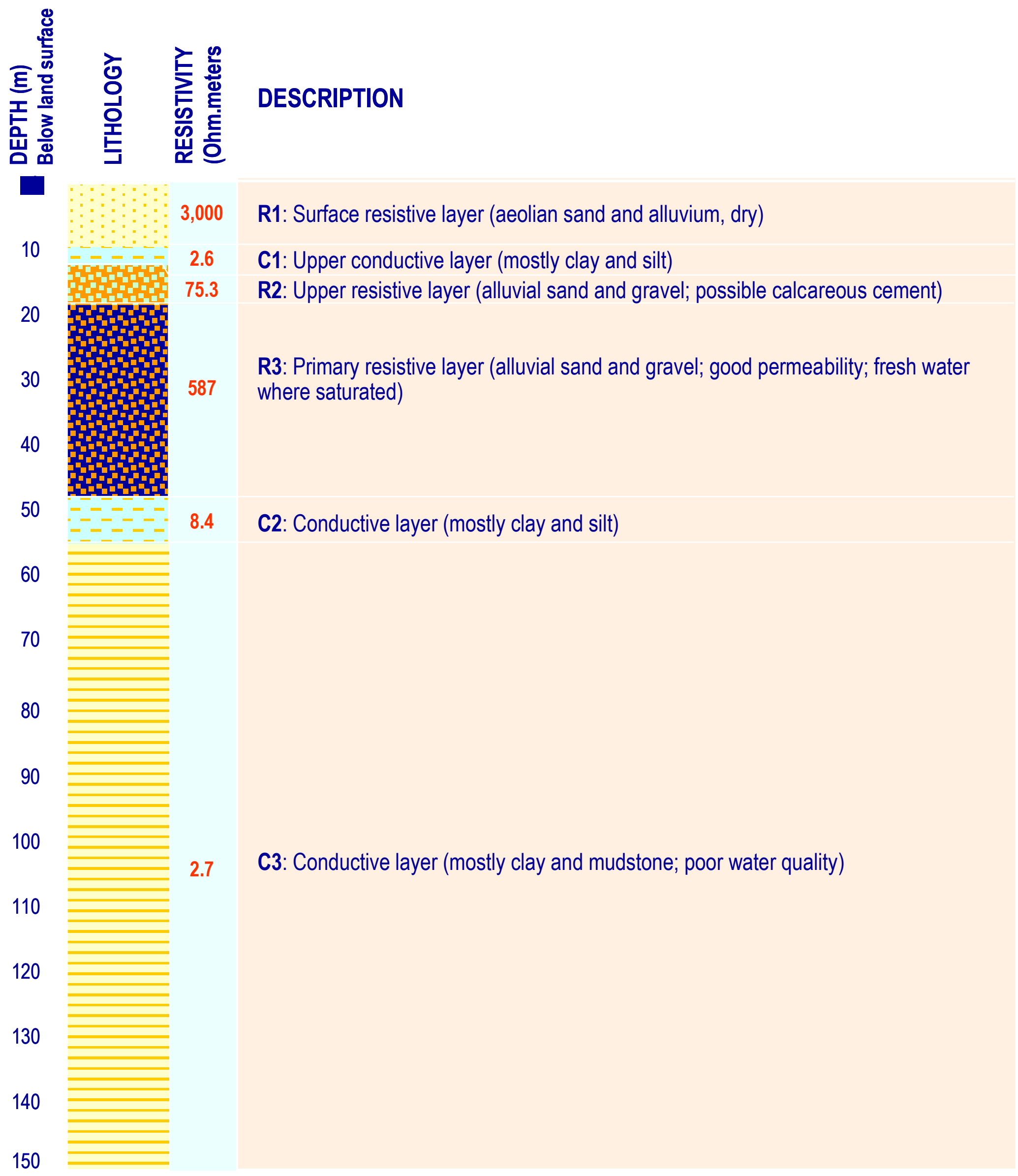


Fig. 7: Resistivity model of typical resistivities for interdune soundings at Al Qura'a, north of Al Ain (after US Geological survey, 1993).

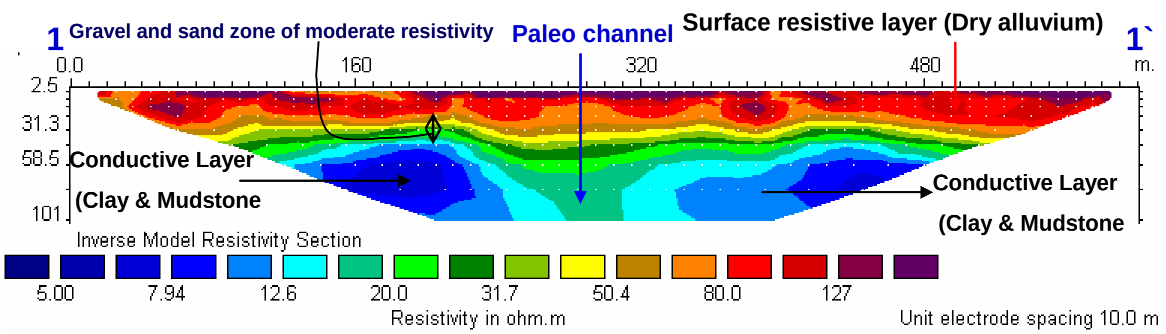


Fig. 8: Inversion results of 2-D Resistivity profile 1-1` (See Fig.4 for location).The stratigraphical succession of the resistivity values is indicated.

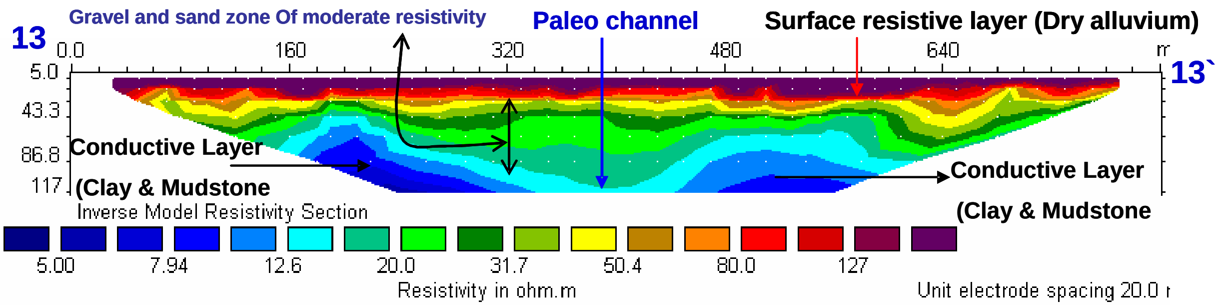


Fig.9: Inversion results of 2-D Resistivity profile 13-13` (See Fig.4 for location).The stratigraphical succession of the resistivity values is indicated.

The main three identified geoelectric-lithologic units along these tomograms (see Figs 8 & 9) are:

Layer-1 is a surficial zone of loose to weakly consolidated sand and gravel. This zone corresponds to the upper part of the very resistive (> 100 ohm-m) layer. The resistive nature of this layer is indicative of dry conditions in the upper part of the alluvium.

Layer-2 is a thick zone of gravel and sand comprising the bulk of the alluvium. The moderate to relatively small resistivity in this middle interval suggests partial saturation and/or the presence of a clay-rich matrix. However, at certain locations along these tomograms, there is a zone of coarse gravel of a varying thickness at the bottom of the alluvial section. This zone appears to represent a basal deposit of the saturated channel gravels. This feature is identified along the mid part of profile 1-1` (Fig.8) and the mid of profile 13-13` (Fig.9). Such locations are erosional unconformities at the base of the Quaternary alluvium and represent the paleochannels in the bed rock that were formed in the geological past by the ancient wadies.

The third layer has a resistivity range of less than 10 Ohm-m. This low resistivity layer is composed of bedrock consisting of marl, clay, mudstone, or shale. In some places in the deeper depth this zone would have resistivities of less than 5 Ohm-m probably due to the increase of salinity with depth. All the different hydrostratigraphic units according to their resistivity ranges are indicated along the inverted 2-D resistivity profiles as in Figs (8&9).

Conclusions

2-D resistivity tomograms of the thirteen profiles guided with borehole information and the resistivity model from TEM quite near to the area of study indicate remarkably the different hydrostratigraphic units of Quaternary aquifer at Wadi Muraykhat and Wadi Sa'a along the eastern margin of Al Jaww plain. Erosional unconformities at the base of the Quaternary alluvium are traced along some of the (2-D) profiles. These unconformities represent the paleochannels in the bed rock that were formed in the geological past by the ancient wadies. These paleochannels are promising targets for fresh groundwater, as they contain appreciable thickness of water bearing formations that are recharged from the surrounding mountain region.

Acknowledgment

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الملخص العربى:-

العنوان:-تصوير جيوكهربى لخزان العصر الرباعى فى وادى مريخات ووادي صاع بمنطقة العين بدولة الامارات العربية المتحدة.

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تشكل المياه الجوفية عنصرا هاما فى موارد المياه فى دولة الامارات العربية المتحدة. وقد تعرضت المياه الجوفية للإستغلال المفرط وذلك لتلبية الطلب المتزايد على المياه نتيجة الزيادة السكانية وتغير نمط الحياة. وبالرغم من التوسع في بناء محطات التحليه في مختلف الامارات ، إل أنه مازالت المياه الجوفية تشكل النصيب الأكبر في الميزان المائى لدولة الإمارات.ويعتبر الخزان الجوفى للعصر الرباعى هو المصدر الرئيسي للمياه الجوفية في منطقة العين ، حيث تقع منطقة الدراسه.

ويعتبر وادى مريخات ووادي صاع هي من أهم الروافد التى تقطع سهل الجاو من ناحية الشرق بمنطقة العين بدولة الامارات العربية المتحدة. و تنحدر هذه الوديان من سلسلة جبال عمان وتشكل مناطق لإستجماع المياه وتغذية الخزانات الجوفية بهذه المنطقة.. ومن وجهة النظر الهيدروجيولوجيه فإن دراسة الوضع التحت سطحى لهذه الوديان يعتبر أمر في غاية الاهميه لفهم افضل لنظام خزان عصر الرباعى ونظام سريان المياه الجوفية ، وكذلك نوعية المياه وإدارة ضخ هذا المورد المائي بهذه المنطقة.

وفى هذه الدراسة تم تطبيق تقنية التصوير الجيوكهربائى ثنائى الأبعاد ولقد تم مسح ثلاثة عشر قطاع ثنائى الأبعاد على طول ووادي وادى مريخات ووادي صاع وتم الإسترشاد ببايانات الآبار المتاحة لتحقيق أهداف هذه الدراسة.

وقد أوضحت نتائج هذه الدراسة بشكل ملحوظ الوحدات الهيدروستراتجرافية المختلفة لخزان العصر الرباعى فى شرق سهل الجاو على طول أشكال المقاومة النوعيه المفسرة للقطاعات الثلاثة عشر التى تم مسحها فى هذه الدراسة. بالإضافة إلى أمكن تصوير سطح عدم التوافق عند أسفل رواسب

العصر الرباعى والناتج عن عمليات التعرية عللى طول بعض القطااعات وتمثل هذه الأماكن مواقع المجارى المائية القديمة والتى تعتبر ذات أهمية كبيرة من الناحية الهيدروجيولوجية.

الكلمات الدالة:– المياه الجوفية– التصوير الجيوكهربائى ثنائى الأبعاد– خزان العصر الرباعى– سهل الجاو–المجارى المائية القديمة– منطقة العين– دولة الامارات العربية المتحدة

Management of Groundwater in Greater Dammam Metropolitan Area

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ABSTRACT

Greater Dammam Metropolitan has witnessed rapid growing due to comprehensive development and population growth. The water demands have increases by many folds during the last three decades. Groundwater from local aquifers namely Dammam and Umm Er Radhuma supplies more than 85% of the total water demands. The aquifers have been subjected to extensive and increasing groundwater pumping especially during the last three decades. Negative impacts such as significant decline in water levels have been experienced in the area. A new groundwater management scheme in terms of improving the long term water pumping policies is required for protection of the aquifers groundwater productivity.

A numerical simulation model of multi-aquifer system has been developed to assess the behavior of the aquifer system under long-term water stresses in Dammam Metropolitan Area. The developed numerical simulation model has been utilized to predict the responses of the aquifer system in terms of decline in water level under different pumping schemes from the multi-aquifer system the next 30 years. The model results have postulated the importance of Umm Er Radhuma (UER) aquifer as a major water supply source to Dammam Metropolitan Area. These findings have been utilized in improving the present and future groundwater management and conservation for the study area. Similar techniques can be used to improve the groundwater management in other parts of the country as well as other arid regions.

1. INTRODUCTION

Greater Dammam Metropolitan area in the Eastern province of Saudi Arabia has witnessed rapid developments in industrial, agricultural and social sectors especially during the last three decades. Groundwater from these aquifers is the major water supply source in the area. Several negative impacts such as decline of water levels have been experienced in several parts. This is due to mismanagement of aquifer systems by over pumping of groundwater from large number of wells clustered in small areas

The Greater Dammam area is located in the Eastern province of Saudi Arabia (Figure 1). It includes the cities of Dammam, Al-Khobar, Dhahran and Qatif. The groundwater resources from the local aquifers supply more than 85% of the total water demand. The rest is supplied from sea desalination plants especially for domestic purpose. A comprehensive and systematic analysis is needed to define effective plans by which aquifers can be brought into long term feasible and sound utilization. Numerical simulation techniques of the aquifer systems, especially under arid environment are important tools, which provide rational evaluation and proper management of groundwater resources. This paper describes local hydro geological settings, the history of groundwater pumping, and the resulted negative impacts on groundwater levels. The paper also describes the development of a quasi-three dimensional simulation model of an interactive multi aquifer system followed by a prediction stage to evaluate the effects of long-term pumping on groundwater conditions in the region. A better groundwater pumping scheme is suggested to improve the long-term management of the multi-aquifer system in the area.

2. HISTORY OF GROUNDWATER EXTRACTION

The major groundwater pumping activities in Dammam Metropolitan Area are from Dammam and Umm Er Radhuma (UER) Aquifers. More than 600 production wells were drilled within the area. The groundwater is mainly used for domestic, irrigation, industrial and landscape purposes. The main water users of Dammam Aquifer are in the city of Al-Khobar, Dammam, and Qatif cities; while the water users from UER are in Dhahran city. The extraction rates from Dammam aquifer have increased from 118.5 million m^3 MCM in 1967 to 199.4, 249.8, 294.0 and 263.6 MCM in 1980, 1990, 2000 and 2006 respectively (Figure 2). The total groundwater withdrawals from UER Aquifer have significantly increased from 15.9 (MCM) in 1967 to 59.4, 113.0, 141.3 and 149.2 MCM in 1980, 1990, 2000 and 2006 respectively (Figure 2). About 90 % of groundwater pumping in the area from the aquifers is for agricultural purposes.

3. HYDROGEOLOGICAL SETTING

The aquifer system in the study area lies in the Arabian Platform and can be divided into the following hydrogeologic units:

Neogene Sequence (Clayey and marl components)	Aquitard
Alat limestone	Aquifer
Alat marl	Aquitard
Khobar limestone	Aquifer

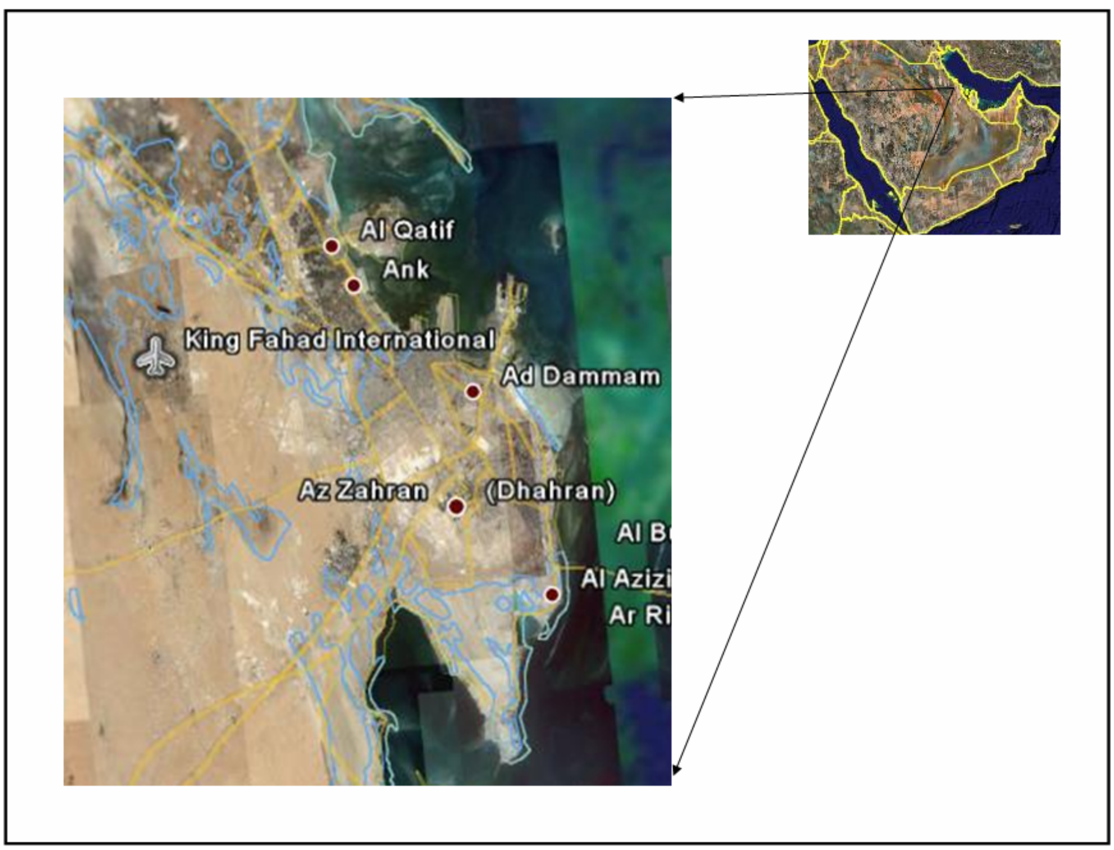


Figure 1. Location map of the study area.

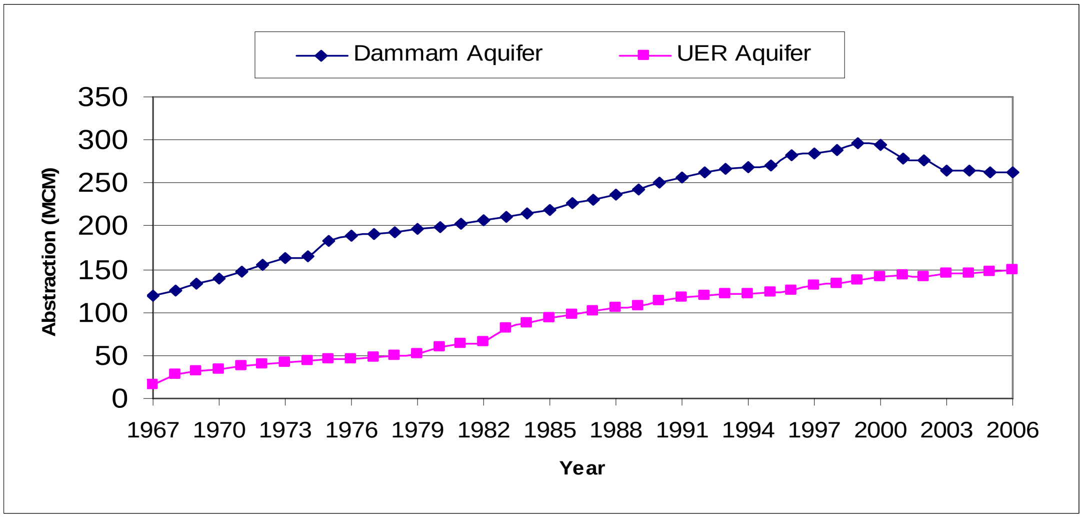


Figure 2. Average Abstraction from Dammam and UER aquifer during Transient stage (1967-2006).

Rus -Alveolina -Midra & Saila Shales	Aquitard
Umm-Er-Radhuma	Aquifer

The productive thickness of each hydrogeological unit has been determined from the regional information provided in Italconsult [1] and GDC [2], and from local well logs in the study area.

3.1. Umm-Er-Radhuma Aquifer Characteristics

Water bearing characteristics of the UER aquifer are mainly controlled by the lithology of the formation and development of secondary features, laboratory analyses and neutron porosity logs show porosity, which is around 30% [3].

Since the Umm-Er-Radhuma aquifer is the main and most important aquifer of eastern Saudi Arabia, its hydraulic properties has been studied by Italconsult [1] and GDC [2] at various locations. These values were used in the model development and calibration. The used values of T and S in UER are shown in Table 1. The T values of UER depend highly on the lithology and structural geology of the aquifer.

Table 1. Regional values of hydraulic parameters of UER.

	Transmissivity (m^2/d)	Storage Coefficient (dimensionless)
Regional values	7000-105000	$1.3x10^{-5}$ – $1.6x10^{-8}$

3.2. Dammam Aquifer *Characteristics*

The hydraulic characteristics of the Dammam aquifer are controlled by lithology and structural features such as fissures, solution voids, anticlines, and synclines. The measured values of transmissivity (T), and storage coefficient (S) from tests conducted by Italconsult, [1] and GDC [2] are shown in Table 2. These values were adopted in the model development and calibration.

Table 2. Measured and regional values of hydraulic properties of Dammam aquifer in the study area.

	Transmissivity T (m^2/d)	Storage Coefficient S
Regional values	2831,968	$5.7x10^{-4}$ – $8.3x10^{-3}$

4. DEVELOPMENT OF A REGIONAL MODEL

In this section, various steps involved in the development of a realistic conceptual model and calibration process of a multi-aquifer system for an efficient numerical groundwater flow model are explained.

4.1. Conceptual Model

The aquifer-aquitard system as defined for modeling included the following layers from top to bottom.

Layer 1: The Dammam aquifer (composite of Al-Khobar and AIat aquifers). It is a confined aquifer within the study area.

Layer 2: The Rus -lower Dammam aquitard (includes the Rus Formation, Midra-Saila shales and Alveolina limestone members of Dammam Formation).

Layer 3: The UER aquifer, which is confined throughout the study area.

Based on the geological, hydrogeological, and hydrogeochemical setting of the study area, a conceptual diagram of the simulated aquifer-aquitard system is shown in Figure 3. Vertical flows do occur between the adjacent aquifers via intervening aquitards where, the thickness of the aquitards decreases or the evaporitic complex of Rus Formation is very thin or absent.

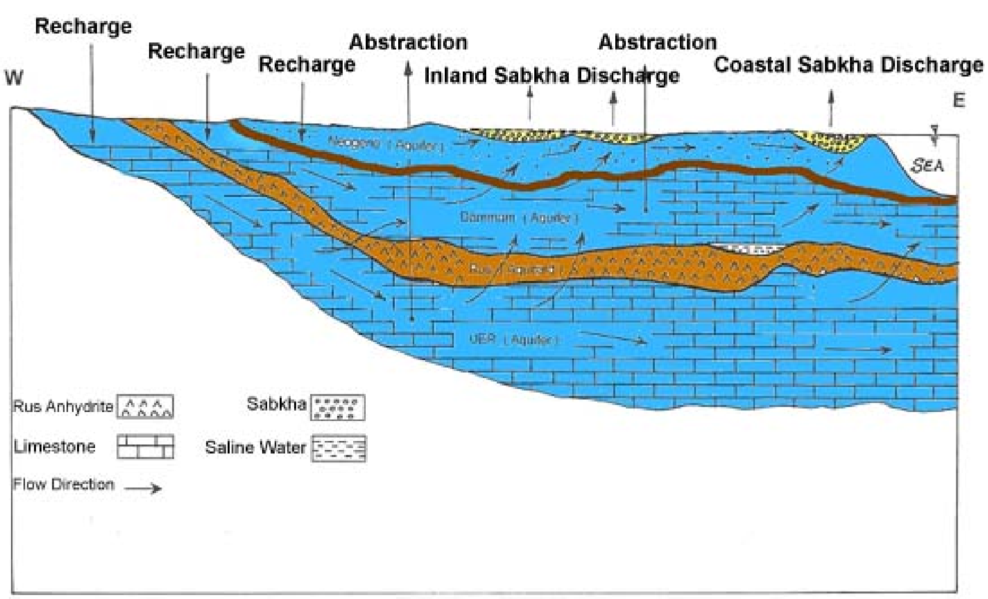


Figure 3. Conceptual model of the groundwater system in the Eastern Province,Saudi Arabia.

4.2. Modeling Technique

The present study used a "Visual MODFLOW", the MODFLOW of USGS with an efficient interface for developing three dimensional groundwater flow and contaminant transport models. Visual MODFLOW is an easy to use pre- and post- processor for the MODFLOW. The modular structure of the computer code of MODFLOW [4] consists of a main program and a series of highly independent subroutines called modules. These subroutines are grouped into "packages", each dealing with a specific feature of the hydrogeologic system to be simulated. The division of the code into modules makes the program flexible, which permits the user to examine the specific hydrogeologic feature of the model independently.

4.3. Model Calibration

4.3.1. Transient Calibration

Based on the established patterns of the aquifer and aquitard parameters obtained during steady state calibration, the model was subjected to transient calibration for a period of 38 years i.e. between the years 1967 and 2006 (inclusive of both years).

Well abstraction data were mainly extrapolated using the available information from Saudi Aramco, KFUPM/RI, Al-Khobar Municipality, Airport and recent data on well abstraction was also obtained from different branches of Ministry of Water in the study area.

Stress period duration was for one year i.e. 365 days. Therefore, the total simulation period for transient calibration was 13,870 days. The simulation period was divided into 38 stress periods. During each stress period all external stresses and boundary conditions were kept constant. Keeping in mind that, with larger time intervals, sudden changes in pumping creates oscillations in the solution of the flow equation; each stress period was sub-divided into non-uniform time steps. The length of each time step was calculated using the geometric mean [4].

Starting conditions were those obtained from the final run of the multi layer steady state calibration. Boundary conditions specified for the steady state were mostly kept unchanged. At this stage of calibration, basically, variation in storativity values (specific storage (Ss)) were of primary importance in all the three layers. Rus aquitard was assigned very low storativity values in the range of 10^{-10}- 10^{-14}. Hydraulic conductivities of aquifer and aquitard layers were also modified and readjusted locally. Assessment of reliability of the computed parameter distribution was obtained through relevant water balance checks, in terms of changes and final values.

4.3.2. Verification of the Model

The final run of the transient calibration stage has resulted in the prediction of potentiometric surface at the end of the year 2006. Hydrographs showing comparisons between simulated and observed heads are shown in Figures 4, and 5 for Dammam, and UER aquifers, respectively. There was a good match both in terms of trends and values.

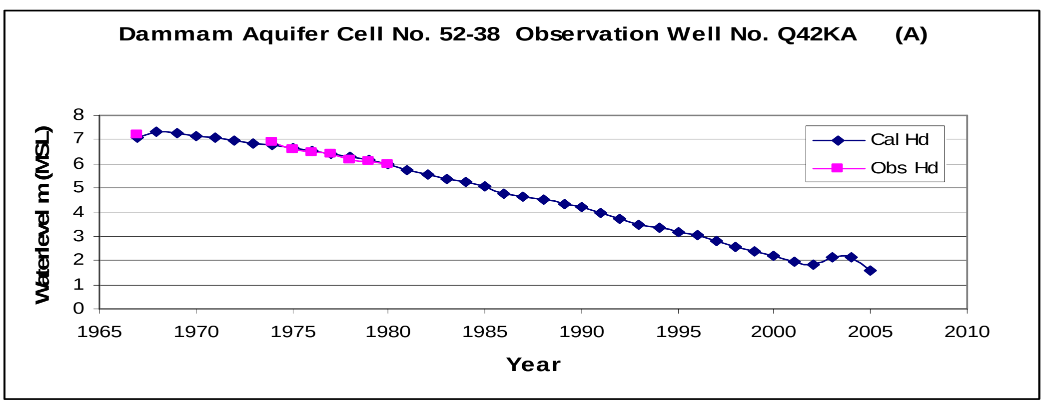


Figure 4.Hydrograph showing the comparison between simulated and observed heads in Dammam aquifer.

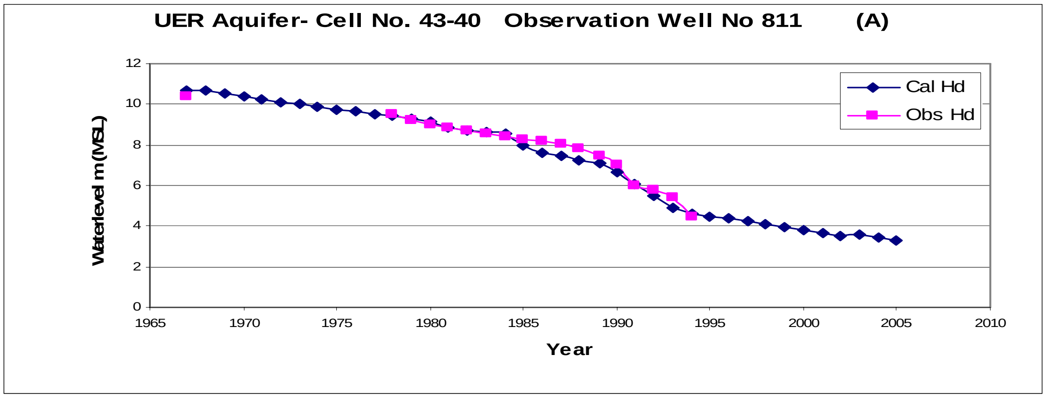


Figure 5.Hydrograph showing the comparison between simulated and observed heads in UER aquifer.

5. ALTERNATIVE DEVELOPMENT SCHEMES

A successfully calibrated and verified simulation model can be used for formulating various alternative water development schemes. The schemes can be compared in terms of their feasibility foe efficient utilization of the available groundwater resources. The selected development schemes when implemented must meet the future water demand at a minimum cost, and be commensurate with legal, organizational, political and environmental considerations.

A planning horizon of 30 years (2006-2036) was selected for the three alternative scenarios. The duration of the planning period is less than the length of the period for which the model was calibrated and validated (i.e., 39 years). Starting conditions in each case were those obtained during transient simulation at the end of 2006. Figures 4 and 5 as shown in the previous chapter illustrate the corresponding potentiometric surface of the UER and Dammam aquifers respectively, for the end of 2006. Estimation of abstraction rates for the planning period (2006-2036) was used in establishing reliable alternative schemes.

5.1. Alternative Scheme I

In this alternative, it was assumed that the groundwater abstraction trends observed during 1967-2006 period continue without modifications. Abstraction from Dammam aquifer increased from about 264 Million cubic meters (MCM) during 2006 to 393 MCM by the end of year 2036, while the abstraction from UER aquifer increased from 146 MCM during 2006 to 232.42 MCM by the end of 2036.

Figure 6 shows the drawdown contour maps at the end of the year 2036 in the Dammam aquifer. The maximum drawdown and the cone of depression were developed within the Qatif area. The drawdown contour map shows a cone of depression with a maximum drawdown of about 8.8 m at Qatif town. The drawdown decreases outwards from the Qatif agricultural area.

Figure 7 shows the drawdown contour maps at the end of the year 2036 in the UER aquifer. The maximum drawdown and the cone of depression were developed within the Dhahran area. The drawdown contour map shows a cone of depression with a maximum drawdown of about 7 m at Dhahran town. The drawdown decreases outwards from Dhahran area.

5.2. Alternative Scheme II

In this alternative, the abstractions from Dammam and UER aquifers have been assumed to increase by 25% from those of alternative I. This implies an increase in groundwater pumping from Dammam aquifer from about 264 Million cubic meters (MCM) in 2006 to 494 MCM by the end of year 2036, while the abstraction from UER aquifer will increase from 146 MCM in 2006 to 289 MCM by the end of 2036.

Figure 8 shows the drawdown contour maps at the end of the year 2036 in the Dammam aquifer. The maximum drawdown and the cone of depression were developed within the Qatif area. The drawdown contour map shows a cone of depression with a maximum drawdown of about 12 m at Qatif town. The drawdown decreases outwards from the Qatif agricultural area.

Figure 9 shows the drawdown contour maps at the end of the year 2036 in the UER aquifer. The maximum drawdown and the cone of depression were developed within the Dhahran area. The drawdown contour map shows a cone of depression with a maximum drawdown of about 9 m at Dhahran town. The drawdown decreases outwards from Dhahran area.

5.3. Alternative Scheme III

Previous studies [5] indicated that more than 50% of irrigation water use in the area is lost due to low irrigation efficiencies of the used surface irrigation, in addition to subjective irrigation scheduling in the local farms. Improvement of irrigation water management can easily lead to major reduction in agricultural water use of more than 25%.

Consequently, in this alternative, the abstractions from Dammam and UER aquifers have been assumed to be decreased by 25% from those of alternative I. The decrease in total groundwater pumping from the two aquifers can be achieved by improving the irrigation methods and adoption of proper irrigation scheduling. This implies that groundwater pumping from Dammam aquifer will increase from about 264 Million cubic meters (MCM) in 2006 to 319 MCM by the end of year 2036, while the abstraction from UER aquifer will increase from 146 MCM in 2006 to 187 MCM by the end of 2036.

Figure 10 shows the drawdown contour maps at the end of the year 2036 in the Dammam aquifer. The maximum drawdown and the cone of depression were developed within the Qatif area. The drawdown contour map shows a cone of depression with a maximum drawdown of about 5 m at Qatif town. The drawdown decreases outwards from the Qatif agricultural area.

Figure 11 shows the drawdown contour maps at the end of the year 2036 in the UER aquifer. The maximum drawdown and the cone of depression were developed within the Dhahran area. The drawdown contour map shows a cone of depression with a maximum drawdown of about 4.25 m at Dhahran town. The drawdown decreases outwards from Dhahran area indicates that the levels will not stabilize by the end of year 2036, but that they will continue to drop beyond that time.

6. CONCLUSIONS AND RECOMMENDATIONS

On the basis of the findings of the study, the following conclusions and recommendations are given for the sustainable development of the aquifer system in study area.

1. The most productive and widely used aquifers in the Eastern Province of Saudi Arabia are the Umm Er Radhuma aquifer and Dammam aquifers.
2. The total abstraction from Dammam aquifer increased from 118.5 MCM in 1967 to 264.6 MCM in 2006, which represents about 222%. Due to excessive pumping from Dammam aquifer, the average decline in water level was about 9 meters.
3. The total abstraction from UER aquifer increased from 15.98 MCM in 1967 to 147.6 MCM in 2006, which represents about 917%. Due to excessive pumping from UER, the average decline in water level was about 7 meters.
4. From the three different alternative development schemes which were formulated and analyzed to predict the future response of the aquifers under long-term water stresses, alternative three (water conservation alternative) which suggests a gradual decrease of 25% in groundwater pumping for the two aquifers especially for agricultural purposes during the coming 30 years should be adopted for protection and better management of the aquifers. The demand reduction can be achieved by utilization of advanced irrigation methods and proper irrigation scheduling for the agricultural areas during the planning period 2006-2036. Shifting the irrigation methods from surface irrigation of date palms and alfalfa to drip and sprinkler irrigation, respectively, will increase the irrigation efficiency from less than 35% to more than 70%. This will result in irrigation water saving of more than 190 MCM per year.

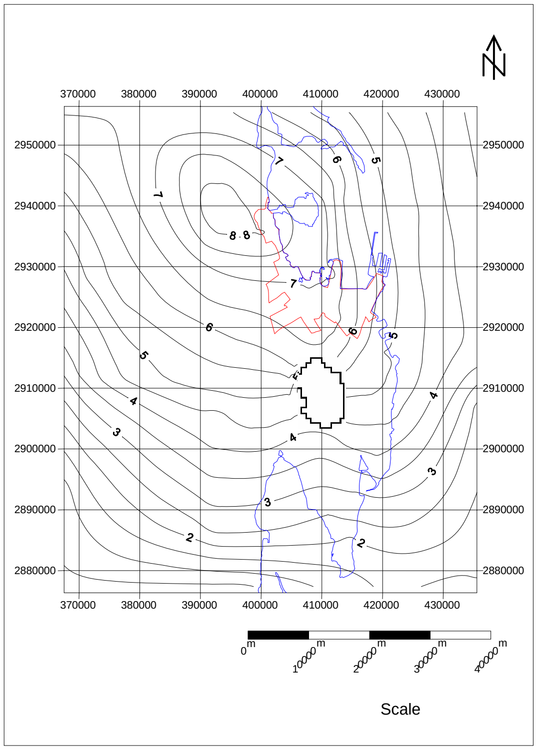
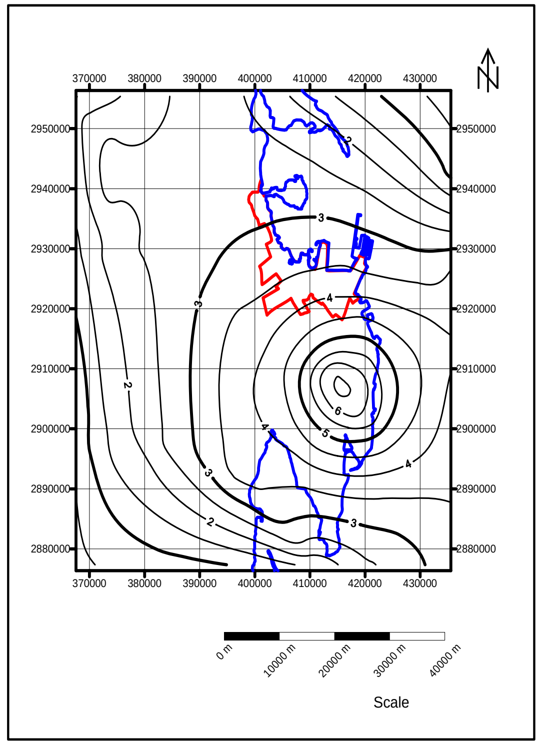


Figure 6. Drawdown contour map in Dammam aquifer at the end of the year 2036 (Alter. I).

Figure 8. Drawdown contour map in Dammam aquifer at the end of the year 2036 (Alter. II)



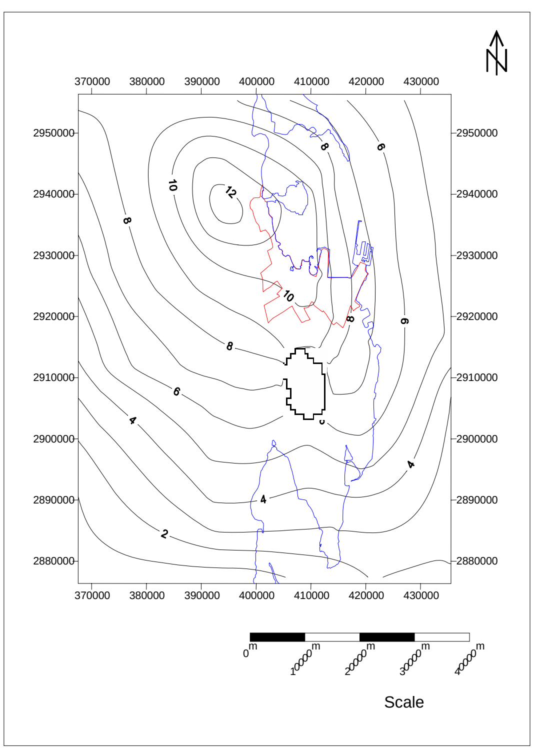


Figure 7. Drawdown contour map in UER aquifer at the end of the year 2036 (Alter. I)

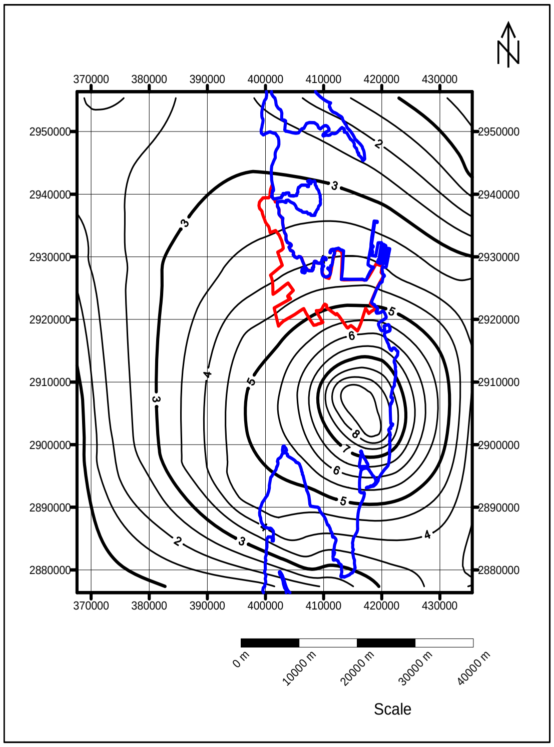


Figure 9. Drawdown contour map in UER aquifer at the end of the year 2036 (Alter. II)

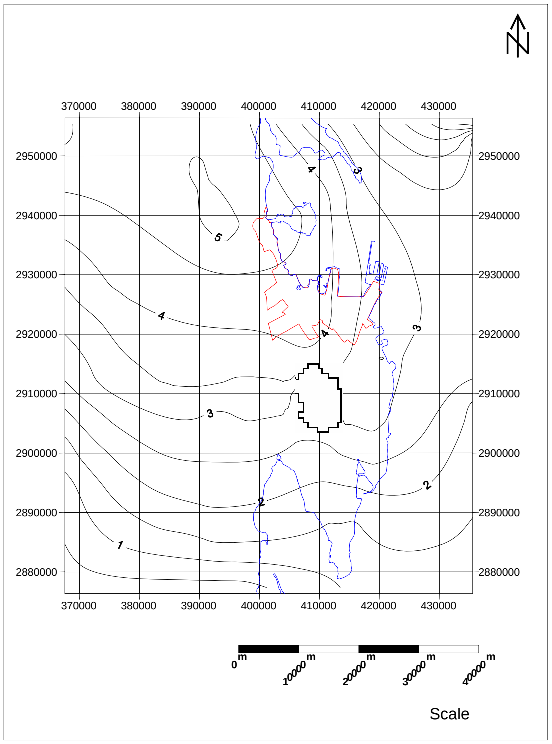


Figure 10. Drawdown contour map in Dammam aquifer at the end of the year 2036 (Alter. III)

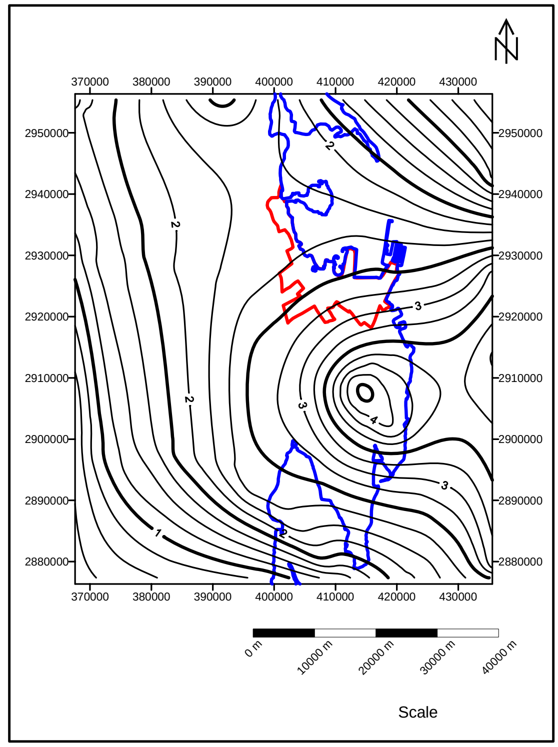


Figure 11. Drawdown contour map in UER aquifer at the end of the year 2036 (Alter. III)

Acknowledgements

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Application of Aquifer Storage and Recovery System (ASR) for Shallow aquifers in UAE

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Abstract

Groundwater sustainability has become a growing issue in many places all over the world and particularly in the Middle East because of increased usage and/or water quality degradation. With the resource decreasing, the need for active management of aquifers increases, using for instance "Aquifer Storage and Recovery" (ASR). The Aquifer Storage and Recovery (ASR) technology allows the storage of freshwater in the subsurface through the use of injection and production wells.

The hydrogeology in the United Arab Emirates (UAE) can be simplified as a two-aquifer system. The carbonate basement does not allow easy storage of water because of its fractured nature and/or because the high salinity of the groundwater in certain areas. Instead, the surficial Quaternary sand and gravel aquifer has been evaluated for ASR operations.

Presented here the specifics of ASR in the shallow aquifer environment of the UAE and describe the advantages and disadvantages as compared to usual deep confined aquifers. Indeed, if the shallow depths of the storage zone make it easier and economical to characterize and operate, it can be as well seen as more vulnerable and affected by high hydraulic gradient.

Advanced characterization and design is thus required to effectively manage ASR in this type of environment.

Keywords: ASR; Shallow aquifer management; Modeling ground water; UAE.

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Introduction

The hydrogeology of the Emirate of Sharjah is generally divided between that of the Cretaceous and Tertiary units, which mainly consist of shallow marine carbonates and mudstones, and that of the Quaternary units, which mainly consist of sand and gravel from eolian or alluvial origin ([6],[9]). The general distribution on surface is shown on Figure 1. In either case, confined and unconfined aquifers exist in the Emirate of Sharjah and they are generally over-exploited as compared to the limited natural recharge. This has been reported in particular for the area of Al-Dhaid, where the water levels have significantly decreased over the past decades ([9], [11] and [12]). Generally, most of the agricultural developments are located in the Bajada plain (or Gravel plain), which appears as 15 km-wide stripe extending between the Hajjar mountains and the Al-Fayah range (Figure 1). The surficial aquifer (Neogene and Quaternary) in that area corresponds to the piedmont deposits originated from the erosion in the mountains. It consists of river terraces, alluvial fans and flood-plain deposits over significant thicknesses (approximately 200 m according to [10] and [12]).

Population expansion and increasing demands for water in the Middle East call for an adequate and cost effective water management system in the area. This active management plan now includes the use of Aquifer Storage and Recovery (ASR). The technology is widely used in other parts of the world especially in North America ([1],[2]). It consists of the storage of freshwater in the subsurface through the use of injection and production wells ([3],[4]). The method can be used for strategic reserve or as a mean for seasonal storage to offset the supply to meet the demand. This has been described as particularly efficient when considering desalinated water: the surplus of water during winter time can be stored and recovered when needed ([5]). The ASR technology also has non-negligible advantages as compared to standard surface tanks both in terms of environmental impact (minimized visual impact) and operational costs (1/10 to 1/5 of the overall implementation costs estimated in the case our local studies).

As a result, the ASR technology is being assessed in the United Arab Emirates. The projects plan the storage of several millions of cubic meters of freshwater in the subsurface. In this framework, the selection of suitable ASR sites is of primary importance: they have to satisfy both hydro-geological, infrastructure and environmental criteria. The figures given in this paper are based on the example of studies being carried out in the Emirate of Sharjah (Northern UAE) for Sharjah Electricity and Water Authority (SEWA). Both the deep confined conditions of the Tertiary/Quaternary aquifers and the shallow unconfined conditions of the wide-spread sand and gravel aquifer ([6]) have been investigated for ASR operations. Presented here the specifics of ASR in the shallow aquifer environment of the UAE and describe in general terms the advantages and disadvantages as compared to usual deep confined aquifers. In both cases, extensive aquifer characterization is required to insure efficiency and sustainability of the ASR.

Potential for ASR application in the Emirate of Sharjah

The Emirate of Sharjah in the UAE is located in an area of arid desert climate, characterized by low rainfall and high temperatures. The high evaporation does not allow high natural recharge from precipitation (only a few percent of the rainfall) neither does it in the case of artificial recharge by dams (e.g. the low infiltration efficiency observed at the dams in the Hajjar mountains due to clogging by fines). On the contrary, no evaporative loss is associated to aquifer storage and the ASR appears as an adequate technology for the UAE type of environment.

Now, before establishing an underground storage a suitable aquifer for storage needs to be identified. A number of criteria have to be taken into account, in particular:

- The aquifer transmissivity, which will dictate the maximum recovery rate and the displacement of the freshwater bubble. Also, [7] explains that the transmissivity must lie within a range of values depending on the desired pumping rate and recoverability percentage.

- The local hydraulic gradient, which will as well impact on the groundwater velocity, as described by Darcy's law, and thus the recovery efficiency of the ASR system.
- The local hydro-geological heterogeneities, which will affect on the dispersion of the water bubble and thus on the mixing with native groundwater.
- The salinity and hydrochemistry of the native water, which will affect the impact of mixing as well as the degree of density stratification between native and injected water ([8]).
- The geochemistry of the formation, which will dictate the major water-rock interactions. Such reactions may lead to the dissolution or precipitation of minerals, flushing of contaminants, which were fixed on aquifer material and thus modify the injected water quality.
- The vulnerability of the site both in terms potential abstraction from near-by production well-fields and in terms of contamination.

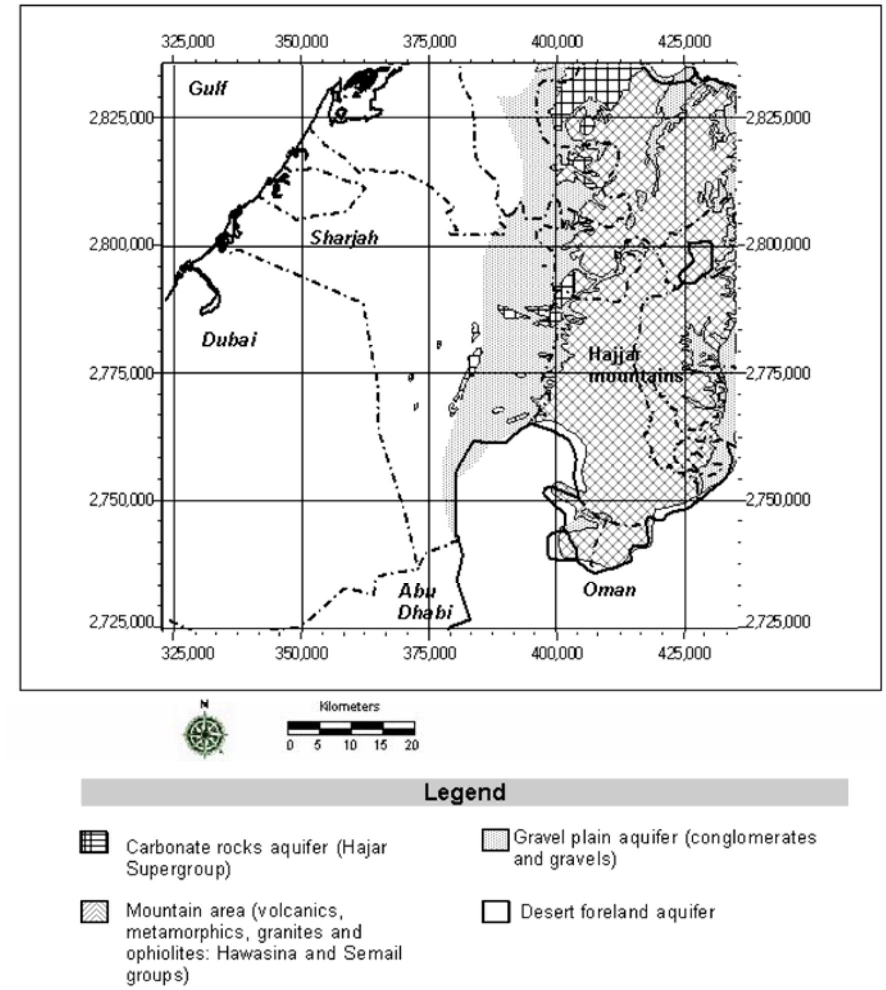

Figure 1: Hydro-geomorphic units of the Emirate of Sharjah (adapted from the UAE national Atlas [9])

In terms of ASR operations, the carbonate aquifers present a non-negligible risk because of their highly fractured nature ([11],[12]). In particular, [7] highlights the potential for preferential flow paths along larger dissolution features and fractures and thus the potential impacts on recovery efficiency. Similarly, a multi-layer paleo-alluvial aquifer, as it has been identified in Sharjah, would exhibit significant vertical and lateral heterogeneity that would be detrimental to ASR efficiency. Operating ASR in those types of environment necessitates extensive subsurface characterization and testing.

Also it is considered here the possibility of storing water in the unconfined Quaternary sand and gravel aquifer because it is the most important and widely spread aquifer in the Emirate.

It is characterized by a thin saturated thickness of 15 m on average and varying salinity conditions generally increasing from the Hajjar Mountains to the Gulf. The sediments are alternatively of eolian and alluvial origins and often present complex three dimensional heterogeneities (as illustrated on Figure 2), which can challenge both the site selection and the ASR operations. This has been for example highlighted in general terms by [13].

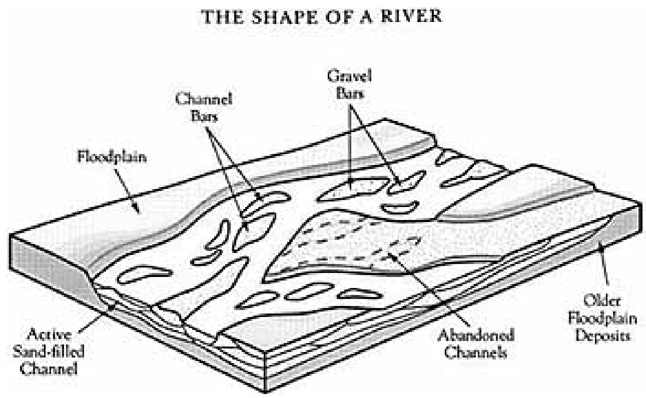

Figure 2: Paeloalluvial model (after Miall, 1985 [14])

ASR in shallow unconfined aquifer

Presented here the specifics of ASR in the shallow aquifer environment of the UAE and describe basic advantages and disadvantages as compared to usual deep confined aquifers.

a. Aquifer properties (geometry and hydrodynamic parameters):

As far as aquifer geometry and intrinsic properties are concerned, there is, in general terms, no difference between confined and unconfined settings. In many cases even, the same geological formation can present unconfined, confined or semi-confined conditions at a regional scale (Figure 3). However, one would easily report variations in physical properties that are depth-dependent (in which case, the difference is related to the increasing depth rather than to the difference in hydrogeologic condition). This is often observed for porosity and salinity for instance within the same formation. Indeed, one will see decreasing porosity with depth because of compaction and/or diagenesis and increasing salinity mainly because of density effects. This has been observed in the Emirate of Sharjah as illustrated by the downhole measurements presented on Figure 4.

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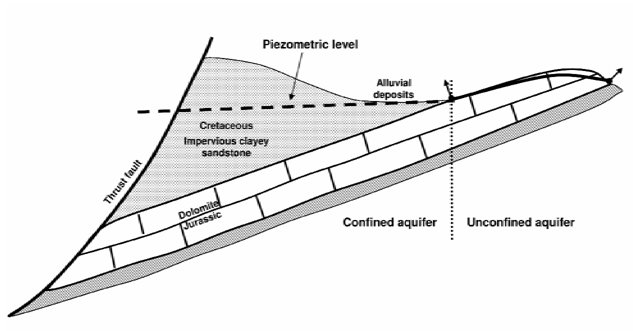
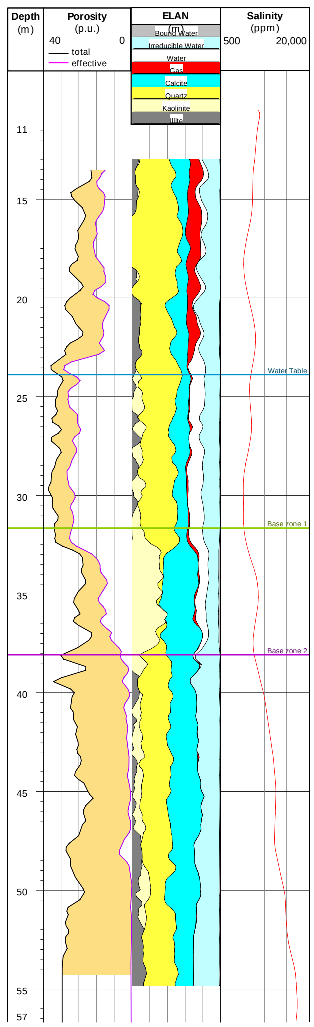


Figure 3: Unconfined aquifer getting confined (after De Marsily [15])



The left-track represents the effective and total porosity derived from downhole NMR measurements.

The center-track represents the formation components (quartz, clay, water, gas) inversed from the acquired downhole logs.

The right track displays the formation water salinity as interpreted from downhole resistivity and porosity measurements.

Figure 4: Illustration of porosity and salinity variation with depth from downhole log acquired in Sharjah.

One key difference in nature between confined and unconfined conditions is the storage coefficient: in the first case, it relates to the compressibility of the aquifer media whereas in the second case, it corresponds to the specific yield of the aquifer. This would have a direct implication during ASR operations as the behavior of the aquifer would differ.

Indeed, in the confined case, the saturated thickness remains the same and the water produced during the pumping phases comes from the decompression of the water and the aquifer formation. In the unconfined case, the saturated thickness varies (water mount during injection and cone of depression during production) and the water is produced by dewatering the pores of the aquifer. Figure 5 is an illustration of the water level mount during the injection phase based on hydrodynamic simulation results (ModFlow).

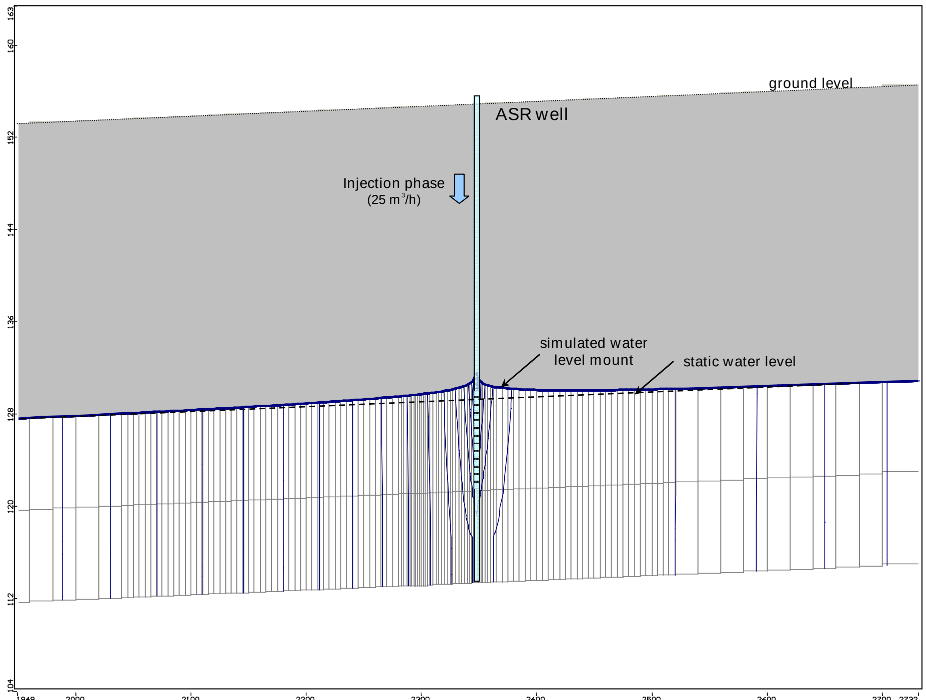


Figure 5: Simulated water level mount in an example of unconfined aquifer (Sharjah)

b. Aquifer heterogeneity:

The degree of heterogeneity of the aquifer does not depend in principle on confined or unconfined condition. In the particular case of the Emirate of Sharjah, the difference rather comes from the different nature of the aquifer formation. Indeed, the carbonate basement exhibit natural anisotropy because of the fractures and karsts system. Lying over it, the paleo-alluvial deposits have been described has very heterogeneous in particular because of the importance of paleochannels. Ideally, aquifer homogeneity is required for reduced hydrodynamic dispersion (mixing due fingering, freshwater trapping for instance…) and thus optimal recovery efficiency.

c. Aquifer characterization:

One of the key advantages related to unconfined aquifers can be seen in terms of characterization. First, the characterization of the overlying confining unit is not required. Second, more investigations are possible and at lower costs for the shallower depths, which are generally targeted.

The characterization of the aquifer system can generally be seen as simpler for unconfined conditions as only the upper layer has to be investigated. In particular, the hydrodynamic testing will be carried out for the targeted aquifer only and no assessment of vertical leakage is required. This will avoid in certain cases the need for packer testing and vertical interference tests. On the other hand however, the testing of the zone itself is certainly more complex as different hydrodynamic processes are involved (delayed yield). In particular, the pumping duration should be longer in unconfined conditions. For instance, some standard guidelines would recommend a minimum of 72h for pumping test in unconfined conditions against 24h in confined aquifers depending on the hydrodynamic parameters. The pumping test interpretation can also generally be seen as more complex in unconfined settings.

Now, if there is no confining unit to characterize in the unconfined case, the effort has to be replaced by assessing the unsaturated zone. Indeed, the fact that a water mount is created during the ASR injection phase necessitates adequate characterization of the overlying aquifers, both from a hydrodynamic and a geochemical point of view. Advanced geophysical logging can be of substantial help in this case. It would help for example determining the pore size distribution (through Nuclear Magnetic Resonance logging for instance) or the chemical composition of the rocks (through coring or elemental spectroscopy measurements for instance).

An aerial characterization of the aquifer is of primary importance in the framework of an ASR project: it will bring key information on total storage capacity of the site as well as on the hydrodynamic boundary conditions to be used in any quantitative modeling. It should then be noticed that surface geophysics will give more accurate results when targeting shallow depths. First, the resolution of any geophysical method decreases with increasing depth because of the attenuation of the geophysical signals.

Second, the area of interest could be masked in the case of confined aquifers because of the response of overlying units. This has been observed for instance with electro-magnetic methods if the confining units are clay rich, and thus very conductive.

Finally, one should admit that the investigations of shallow unconfined aquifers are more cost effective than for deeper targets. For instance in the Emirate of Sharjah, exploration wells can be drilled to a depth of about 50 m only to characterize the unconfined aquifer whereas depths to hundreds of meters would be required for deeper confined aquifers. One would easily divide by two the exploration costs.

d. ASR Implementation and ASR operations:

The advantages and disadvantages described above for shallow aquifer exploration do apply for shallow ASR implementation (reduced cost of drilling…).

However, it should be highlighted that the water levels increase during the injection phase has to be carefully monitored in the first stages of the project, both from a hydrodynamic and hydrochemical point of view. One would need to control any risk of overflow or water contamination.

In terms of well engineering and implementation, the case of Sharjah shows unconsolidated conditions in the unconfined sand and gravel aquifer. Specific drilling and sand control (adapted drilling and completion) has to be implemented.

e. ASR vulnerability:

One of the main potential risks of operating ASR close to the ground level is the vulnerability of the storage: vulnerability to potential contamination first and vulnerability to potential interference with near-by pumping.

Indeed, a shallow environment is at the same time more likely to be contaminated. The depth to water table in the Sharjah projects is about 25 m deep with an eolian sand type of cover i.e. with high permeability. The reaction time to any accidental pollution could thus be very limited. This can significantly differ from confined aquifers, in which the storage zone is generally deeper and somewhat protected by the low permeability of the confining unit(s). It is thus critical to conduct a thorough assessment of environmental vulnerability when studying the suitability of a site as well as defining adapted protection areas. In the case of desert environments, the risk is often limited as no farming, industrial or human activity is reported. The work carried out in Emirate of Sharjah corresponds to this case.

The second danger can be related to potential hydraulic interferences with near-by pumping. In the Emirate of Sharjah for instance, the surficial aquifer is heavily exploited for agricultural or potable water supply purposes. Indeed, it generally has good hydrodynamic characteristics (i.e. high yields), good water quality (at least fresher than at depth) and is relatively cheap to produce (shallow wells). The issue here is related the uncontrolled groundwater velocities that would be observed locally. Indeed, an optimal ASR field requires a design that is adapted to the local characteristics of the aquifer: variations of saturated thickness, variations of hydrodynamic properties, local hydraulic gradient… In the case of interferences with near-by pumping, the recovery efficiency can be reduced.

In order to assess and reduce those risks, as well as to define adapted protection of the storage site, a suitable hydrogeological characterization and modeling is necessary.

Advanced hydrogeological characterization

As recommended by [16], any ASR project should start by a thorough assessment phase to characterize the aquifer in an accurate manner both in terms of hydrodynamics and hydrochemistry, as well as to test the ASR feasibility.

The methodology followed in the case of the Emirate of Sharjah includes advanced hydrogeological characterization as well as an ASR pilot test. As described by [17], the 'static' model can be derived from surface imaging and mapping, surface geophysical measurements, log interpretation and well correlation, and hydrogeochemical analysis. Figure 6 illustrates 3-D data integration in an example in Sharjah. The dynamic behavior of the aquifer can then be assessed through a number pumping and injection tests. The objective of the pilot test is to further characterize the hydrogeological setting in the targeted area, to evaluate the groundwater flow movement as well as freshwater mixing through a number of monitoring wells.

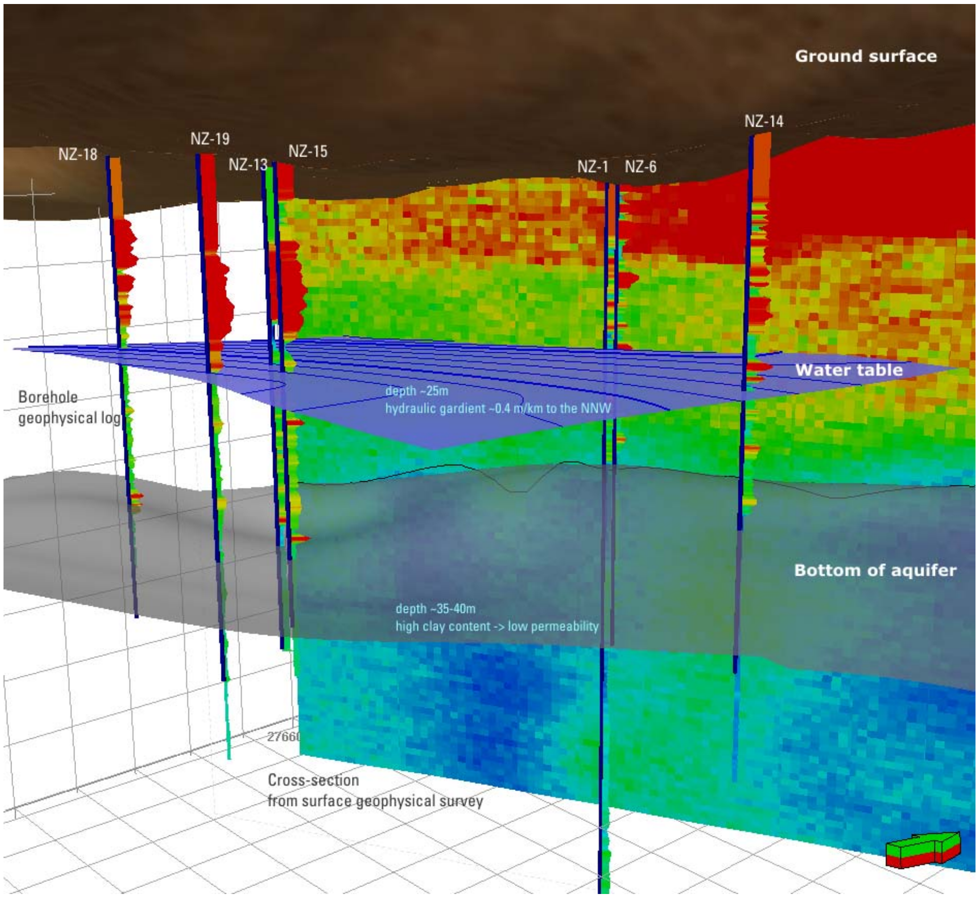


Figure 6: Illustration of 3D-data integration in the example of Sharjah ASR

The data used for the hydrogeological model here includes interpreted surface geophysics (TDEM soundings), advanced geophysical logs (resistivity, porosity, mineralogy, formation images…), and water levels measurements in the monitoring wells.

Then, an essential step in the study and design of an ASR field is quantitative hydrogeological modeling. It has to be as realistic as possible to take into account the main features of the aquifer and the main physical processes related to the ASR operations. Density dependent flow modeling may be required in most cases as freshwater is generally injected into more saline native water. The ASR schedule as well as the distances between the ASR wells also has to be optimized to take into account hydrodynamic interferences and insure coalescence of the freshwater bubbles (see [18]).

Conclusion

The work being carried out in the Emirate of Sharjah is an example of applying the ASR technology to unconfined environments. Indeed, because of the complexity of the deep confined local conditions, the shallow unconfined environment has also been assessed. It shows in particular a number of advantages in terms of exploration and operation. However, the heterogeneous setting encountered in Sharjah requires advanced hydrogeological characterization as well as quantitative simulations in order to optimize the ASR recovery efficiency.

In the on-going plans, several millions of cubic meters can be injected and subsequently recovered into and from the ASR sites. The water management strategies are thus including the ASR as a complementary source of water.

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3-D Characterization of the Complexity of Groundwater Alluvial Aquifer Systems using Geophysical Logging and Geostatistical Analysis in Arid Region

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Abstraction

The groundwater aquifers heterogeneity in arid regions makes the geologic characterization of these aquifers very challenging. In such an environment, it is difficult to determine the hydrogeologic connectivity between wells in three-dimensions using standard cross sections and geologic interpretations. However, geostatistical analysis can be used to three-dimensionally analyze the trends within the data and statistically interpolate between data values. Using geostatistics to build 3-D geologic models, the heterogeneities found within alluvial aquifer systems can be implemented in fluid flow and chemical transport modeling. Geostatistical indicators and the geophysical logging have been used for the three-dimensional characterization of a complex, alluvial aquifer system in Abu Dhabi Emirate. Seven gamma-ray logs, induction logs, and lithology determined from formation cuttings have been analyzed within an area using as pilot test for aquifer storage and recovery in Eastern Region of Abu Dhabi Emirate. The goal of the project is to explore the geological structure underlying the shallow alluvial aquifer and characterize the aquifer complexity to predict the injected fresh water plume extent and movement. The test site, approximately 4 km^2 in area, contains an aquifer 50 m below the surface which is bisected by a thrust fault running approximately north to south. The resulting 3-D geologic developed model was used to provide the framework for groundwater flow and solute transport modeling. Amongst the many properties required for aquifer characterization are total porosity, lithology, grain size and grain sorting, fracture density, aperture and directions, free and capillary bound waters, saturated and unsaturated sands, and aquifer hydraulic conductivity. In this paper, the application of lithodensity, Neutron, Array Induction, Elemental Capture Spectroscopy, Nuclear Magnetic Resonance, and Formation Micro Imager to the deduction of aquifer properties was presented. The methodology for estimating the formation Elemental Analysis through a global inversion integrating all the above mentioned measurements was also presented. Step by step analysis of the individual measurements will be presented, as well as the integration of these individual measurements into the final solution.

Keywords: Groundwater exploration, Groundwater assessment, Geophysical logging, Aquifer Characterization, Aquifer storage and recovery, Aquifer hydraulic properties.

1. General Background

Geophysical methods play an important role to minimize the cost and efforts for exploring and assessing groundwater aquifer systems through providing information about the physical and hydraulic properties of these aquifers. There are two general types of methods: Active, which measure the subsurface response to electromagnetic, electrical, and seismic energy; and passive, which measure the earth's ambient magnetic, electrical, and gravitational fields. Information provided by these tools can be applied to determine geologic and hydrogeologic conditions. Geophysical methods can also be subdivided into either surface or borehole methods. Surface geophysical methods are generally non-intrusive and can be employed quickly to collect subsurface data. Borehole geophysical methods require that wells or borings be drilled in order for geophysical tools to be lowered through them into the subsurface. This process allows for the measurement of in situ conditions of the subsurface. In the past, using borehole geophysical methods had not been cost-effective; however, in recent years, direct push (DP) technology probe rods have been fitted with geophysical sensors that can provide geophysical information rapidly. Although many geophysical methods are not available with DP technologies, the methods that are available can often provide information more cost effectively than traditional borehole geophysical methods. Data collected with geophysical tools are often difficult to interpret because a given data set may not indicate specific subsurface conditions (i.e., solutions are not unique). Instead, data provided by these tools indicate anomalies which can often be caused by numerous features. As a result, geophysical methods are most effectively used in combination with other site information (e.g., data from different geophysical methods, sampling and analytical tools, geological and historic records, anecdotal information). A combination of these sources is often necessary to resolve ambiguities in geophysical plots (i.e., the graphical representation of data produced by a specific method). Geophysical methods can be important tools through interpretation of their results with existing wells to 3-D characterize the complexity of alluvial groundwater aquifer systems geologic structure.

The three-dimensional heterogeneity of alluvial aquifers in the arid regions makes the 3-D geologic characterization of these aquifers a challenging task for the hydrogeologists. In such an environment, it is difficult to determine the hydrogeologic connectivity between wells in 3-D using standard cross sections and geologic interpretations. However, geostatistics can be used to analyze the well geophysical logging and statistically interpolate this data values in 3-D. By using this method, the heterogeneities found within alluvial aquifers in arid regions can be implemented in groundwater flow and solute transport modeling.

Geostatistics can be used to 3-D characterization of the complexity of alluvial aquifers in the arid region using the well geophysical logging. The gamma-ray logs, induction logs, and lithological description determined from cuttings during the well drilling can be used. These indicators can be used in the well columns to compute variograms and create a 3-D variogram model. The thickness of the aquifer can be simulated using sequential Gaussian simulation. The resulting 3-D geologic model provides the framework for groundwater flow and solute transport modeling. Some pervious studies used the borehole indicators and Kriging to characterize an alluvial depositional such as Johnson and Dreiss (1989). A detailed introduction to use geostatistics for interpolation of the well geophysical data was mentioned in Isaaks and Srivastava (1989), Goovaerts (1997), and Deutsch and Journel (1997). Bristow and Best (1993) and Rust (1978) studied the heterogeneities characterization of alluvial deposits.

This paper presents a case study for using geophysical logs to interpret hydraulic units and geostatistical techniques to interpolate the geology between drilled wells in an alluvial aquifer system within the eastern region of Abu Dhabi Emirate. It provides a brief introduction to the geostatistical techniques that were used during an implementation of pilot project for aquifer storage and recovery and presents the results of the application of geostatistics indicators to alluvial aquifer systems in arid region. The advanced geophysical borehole logging was utilized to assess the aquifer boundary, extent and hydraulic properties to help planning, designing and predicting the recovery efficiency and rates with reasonable confidence during the feasibility phase of an aquifer storage and recovery project. This can be done ahead of the trials by increasing our confidence in the accuracy of aquifer property values that determine those rates. Various porosity measurement techniques, together with a newly developed aquifer lithology measurement device were testes and analyzed. A combination of all these measurements was done using a global solver to calculate an accurate value for aquifer porosity. The application of lithodensity, Neutron, Array Induction, Elemental Capture Spectroscopy, Nuclear Magnetic Resonance, and Formation Micro Imager to the deduction of aquifer properties was presented. The methodology for estimating the formation Elemental Analysis through a global inversion integrating all the above mentioned measurements was also presented. Step by step analysis of the individual measurements will be presented, as well as the integration of these individual measurements into the final solution.

Due to the deterioration of non-renewable aquifers, all GCC countries rely on desalinated water as a main source of domestic water supply. It has been argued that the best long-term solution for the water crisis in the domestic sector is to build a network of large-scale desalination plants. The problem facing the GCC countries, however, is the vulnerability of desalination plants to pollution and emergency conditions. For example, the maximum stored water in the ground reservoirs and distribution network is enough only for 24 hours, except in Saudi Arabia and Kuwait, where it is three and five days respectively, as shown in Figure (1). Thus, in any crisis or emergency, the stored water will not be enough to cover the demand. Also, the production of desalination plants is constant and the demand is not constant.

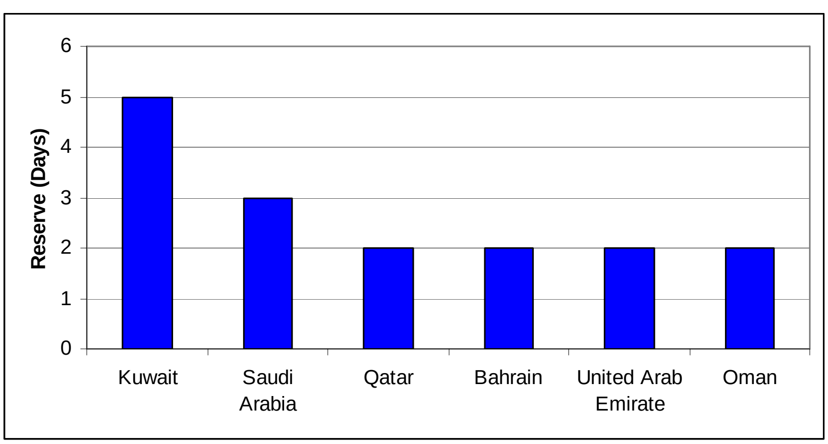

Figure 1: Storage Capacity for Emergency Water in GCC Countries

The possible alternatives for reserving fresh water sources for emergency and peak demand conditions are: 1) to increase ground reservoirs and distribution network storage capacity or 2) using a groundwater Aquifer Storage and Recovery system (ASR). It has been proved that increasing the capacity of the ground reservoirs and network is very expensive and not environment-friendly. One solution is to store this water in groundwater aquifers. Unlike groundwater aquifer storage, the fresh water cannot be reserved in surface reservoirs for more than 48 hours, otherwise it will become stagnant water and not suitable for domestic use. Aquifer systems allow for multi-year storage keeping water protected and in good quality. Usually, wells can be located where most needed and because wells require little land, the costs of
large land acquisitions are avoided. Moreover, large water volumes can be stored underground, decreasing the need for the construction of surface reservoirs.

As of 2006, over 97% of the fresh water supplied for domestic use in Abu Dhabi Emirate is produced by desalination of saline water, brackish groundwater or imported desalinated (EAD, 2006). This is due to recent massive increases in domestic demand, with declining water table levels and increasing groundwater salinity. Despite increasing production costs and poor water quality, the remaining groundwater still remains an important resource for water management, particularly for emergency back up of desalinated water sources and for water supplies in remote locations. A solution may be the use of excess production capacity of desalinated water to recharge existing shallow aquifers, through application of aquifer storage and recovery techniques demonstrated elsewhere. A key factor will be that modern desalination technology is considered a strategic option for satisfying current and future domestic water supply requirements in GCC (Gulf Cooperation Council) countries Furthermore, use of ASR will allow long-term storage of at least one year of fresh water demand, a reasonable target given the similar lead time for constructing new desalination plants (Dawoud, 2005). A pilot project was commenced to assess and evaluate the ASR as a tool for saving the emergency water requirement in the eastern region of Abu Dhabi Emirate (Brook, et al., 2006). The ASR test site of this study is located 10 km southwest of Shuwaib, east of Abu Dhabi on the western edge of the northern Oman Mountains. Figure (2) shows the general location maps of the study site and the locations of wells drilled and geophysically logged. The test site is covered by low-relief sand dunes (about 30 m high) and occupies an area of approximately 4 km^2. The majority of the groundwater in the location's surficial aquifer is draining from the Oman Mountains toward the Arabian Gulf coast, about 125 km to the West. As part from the feasibility study a comprehensive surface geophysical survey was done and fifteen wells were drilled and logged for the 3-D characterization of the alluvial shallow aquifer system which will used for the fresh water storage.

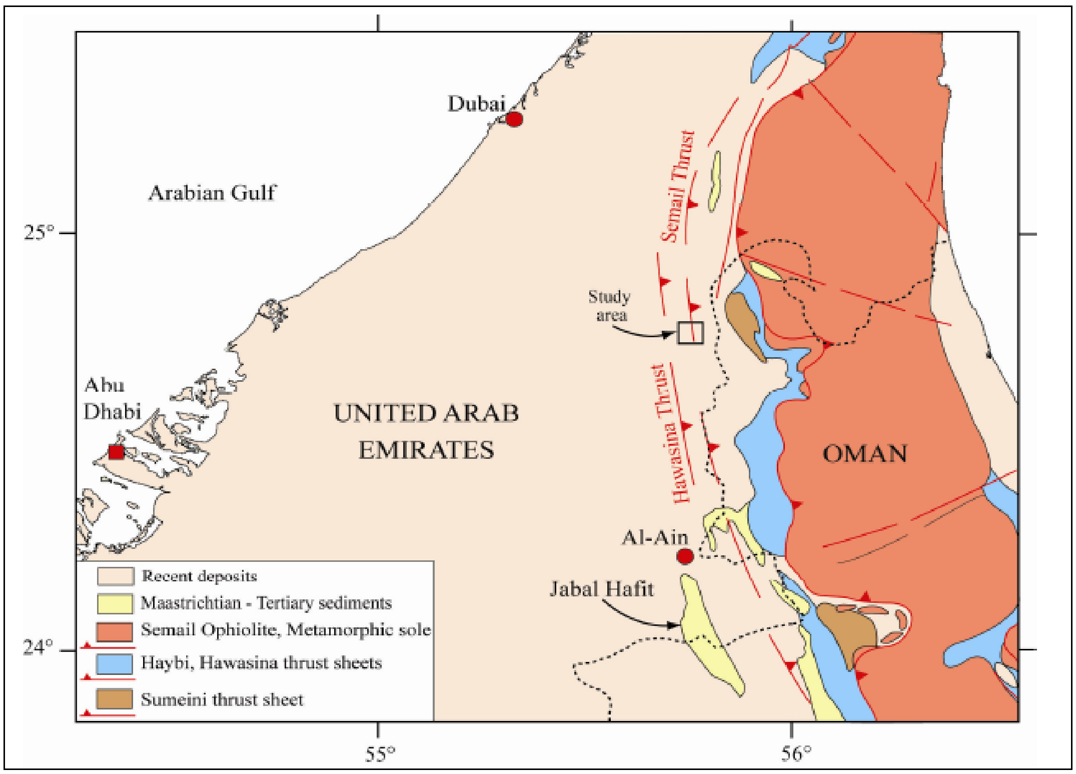

Figure 2: Location map of the study are.

2. The Geological Setting

Two major compressional tectonic events created the Oman Mountains and shaped the subsurface structures of surrounding region, including the study area. The first of these occurred during Late Cretaceous times. This event involved the emplacement of a number of thrust sheets, each of which has been emplaced from NE to SW onto the margin of the Arabian Plate. These thrust sheets consist of the Sumeini Group, comprised of shelf-edge and slope-carbonate sediments; the Hawasina Complex, comprising distal-slope and deep-sea sediments; the Haybi Complex, comprising Mesozoic exotic limestone, volcanic (Haybi volcanics), mélanges, and sub-ophiolitic metamorphic rocks; and the Semail Ophiolite complex, a massive slab of oceanic crust and mantle of Cenomanian-Turonian age, which formed above a NE-dipping intra-oceanic subduction zone.

A second compressional post-obduction event occurred in the Late Eocene-Miocene during which the Arabian Plate moved northeastward and collided with the Eurasian Plate (Searle et al., 1983). This event produced tight folds and thrust faults and the reactivation of deep-seated faults in the study area (Searle et al., 1990). Woodward (1994) documented a number of tight folds and thrust faults that trend NNW-SSE in the area, based on structural interpretation of seismic reflection profiles. One of these major thrust faults that dip steeply to the east occur at the centre

of the study area. A goal of the microgravity measurements in the current study is to investigate the impact of this thrust fault on the ASR test site. Figure (3) shows the stratigraphy of two wells drilled in the study area. Specifically, Figure 4a corresponds to well W3 and Figure 4b to well W4. The shallow sedimentary formation of the area is divided into four zones: Unsaturated Aquifer, Saturated Aquifer, Upper Fars, and Lower Fars. The surface consists of unconsolidated, quartz-rich sand dunes underlain by an aquifer. The bulk of the aquifer is composed of Quaternary unconsolidated Aeolian sands, silt clays, and calcareous material deposited in paleochannels incised into Miocene mudstones and claystones. This surficial aquifer divides into two units, the upper Unsaturated Aquifer and the lower Saturated Aquifer. It is underlain by fine-grained Miocene sedimentary rocks which are subdivided into Upper and Lower Fars units. The Upper Fars unit consists of primarily claystone with interbedded dolomitic marls, limestone and silstones. The Lower Fars unit is comprised mainly of mudstone and evaporites. As determined from these well logs and others at the site, average unit densities are approximately 1.9, 2.1, and 2.35 g/cm3 for the Unsaturated Aquifer, the Saturated Aquifer, and the Upper Fars units, respectively. Also, a single well located near W4 was logged to a maximum depth of about 300 m, showing an average density of about 2.5 g/cm3 for the Lower Fars unit.

3. Methodology

3.1 Well Log Analysis

Advanced borehole geophysical logs were acquired for 12 wells as shown in table (1). The objectives of these acquisitions were as follows:

- Delineation of the good quality aquifer layers, and their lateral and vertical extension
- Investigation and determination of the aquifer rock petrophysical and hydraulic properties
- Investigation of the aquifer water quality as far as salinity is concerned
- Calibration of log readings versus core analysis results, such that log outputs can be used directly as an input to the static and dynamic aquifer models.

The geophysical work on this well will be presented in more detail than the other wells, as extensive evaluations were completed, including:

- ***Geophysical Borehole Logging:***
  - PEX/AIT/ECS/GR/Caliper: Rock Density, Rock Neutron Porosity. Elemental Capture spectroscopy, Rock Electrical Resistance at varying distance from the borehole, Natural Gamma Ray, and bore hole caliper
  - CMR/GR: Nuclear Magnetic Resonance, Natural Gamma Ray
  - FMI/GR: Formation Micro Imager, Natural Gamma Ray

Table 1: Summary of the logged wells and the type of logs performed.

Well	Date Logged	Type of Logs*	Logged Interval (MT)	Remarks
SWS01	04 June 2004	PEX/AIT/ECS/CMR/FMI	16.80 – 323.00	
SWS05	11 Oct. 2005	PEX/AIT/ECS/CMR/FMI	18.80 – 102.20	
SWS17	14 Oct. 2005	PEX/AIT/ECS/CMR/FMI	12.20 – 145.10	
SWS15	21 Oct. 2005	PEX/AIT/ECS/CMR/FMI	11.60 – 95.10	
SWS11	23 Oct. 2005	PEX/AIT/ECS/CMR/FMI	15.00 – 119.50	Full Core
SWS16	26 Oct. 2005	PEX/AIT/CMR/FMI	13.70 – 98.20	
SWS18	03 Nov. 2005	PEX/AIT/ECS/CMR/FMI	10.70 – 101.20	
SWS08	05 Nov. 2005	CMR	10.60 – 101.20	
SWS06a	15 Nov. 2005	PEX/AIT/CMR	15.00 – 110.00	
SWS20	16 Nov. 2005	PEX/AIT/CMR	15.00 – 111.00	
SWS09	20 Nov. 2005	CMR	12.00 – 119.00	
SWS04	20 Nov. 2005	CMR	12.00 – 111.00	

* PEX: Formation Density, Neutron Porosity, and Gamma Ray
AIT: Array Induction Resistivity
CMR: Combinable Magnetic Resonance measurement

ECS: Elemental Capture Spectroscopy measurement

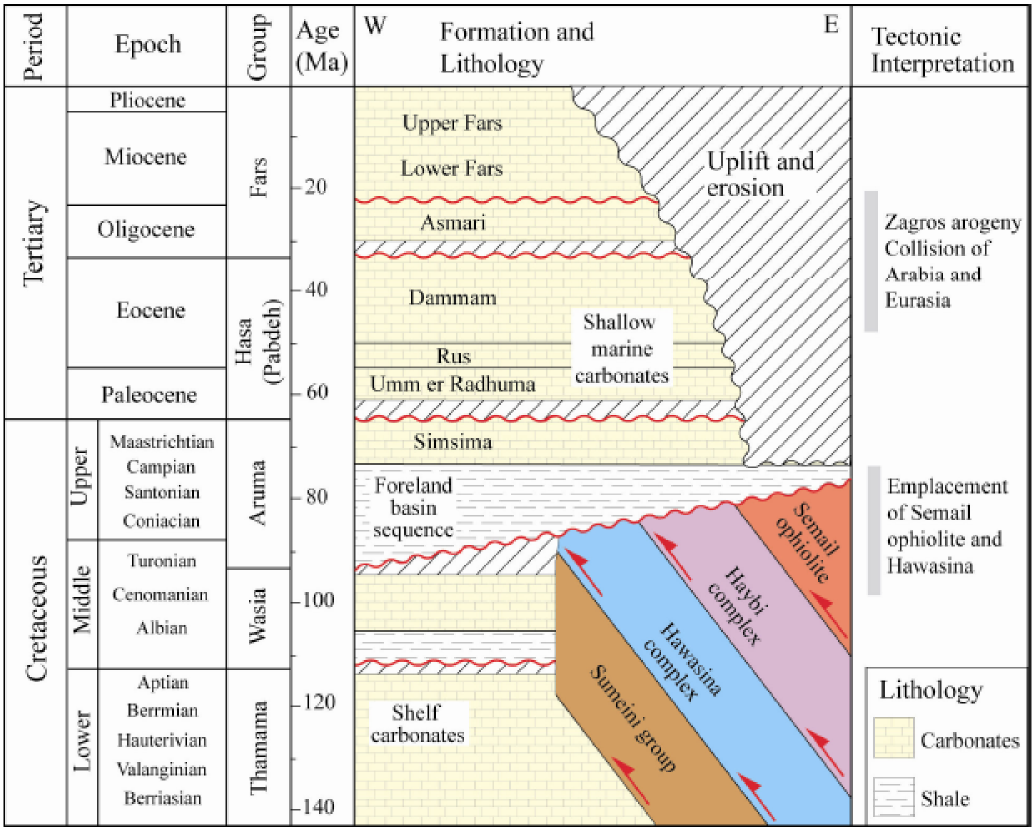

Figure 3: The Stratigraphy.

- ***Core Analysis:***
  - Conventional Core analysis: for Porosity, Permeability, and Grain Density.
  - Core Slabbing and digital imaging for selected sections.
  - Mercury Injection and Pore Throat size distribution
  - NMR Analysis and correlation to Mercury Injection.
  - Thin Section preparation and description.
  - X-Ray Diffraction (XRD)
  - Laser Particle Analysis
  - Calcimetry
  - Chromium Analysis.
- ***Hydrodynamic Testing.***

In addition to the lithology derived from aquifer formation cuttings, natural gamma-ray and rock neutron porosity data from well geophysical logging were analyzed and interpreted. Figure (2) shows the interpretation of well geophysical logging for well number SWS 11.

3.2 Geophysical Logs Interpretation

Figure (3) represents the elemental analysis (ELAN) results, which takes into account all available logs. The above measurements including formation bulk density, formation neutron porosity, nuclear magnetic resonance total, free, and capillary bound porosity, and the Elemental Capture Spectroscopy of different elemental concentrations such as silicon, calcite, iron, and aluminum are inverted to solve for the rocks including sandstone, limestone, dolomite and different types of clay, and fluids including water and air. The results are shown in the opposite processing output right hand track. Knowing the percentage of the aquifer rock occupied by aquifer native water, as well as the total aquifer electrical resisitivity, the Archie equation relating the two variables, at the aquifer temperature, is solved for the aquifer native water salinity, shown in red in the middle track. The aquifer permeability, as driven from the Nuclear Magnetic Resonance measurement is plotted in the left hand side track. From surface down to the bottom of the good quality aquifer, the capillary bound water is almost 5%, and from surface to the water table at 49.7 meters the aquifer is partially saturated with drilling fluids while the unsaturated pore volume represents some 8 to 10% of the total volume. The saturated interval of the aquifer has free water porosity (effective porosity) in the range of 27 to 28 %, with some 7 to 9 % clay minerals. The formation water salinity is 600 ppm sodium chloride equivalent, and the good saturated aquifer permeability is in the range of 4000 md. Starting from 74 meters and downward, there is a gradual increase of the capillary bound water degrading the aquifer quality down to a depth of 90 meters where all the water in the pore space is either clay bound, or capillary bound, with no free water, thus forming a lower impermeable and isolating layer. Table (2) summarizes the log interpretation results.

3.3 Core Laboratory Analysis

Over the whole cored interval of SWS11, porosity ranges from 7.5% to 42.8%, while permeability to air ranges from 0.88 mD to 11400 mD, and the porosity versus permeability cross plot shows moderately good correlation except for the samples having micro fractures. Grain density ranges from 2.65 to 3.00 gm/cc with an average value of 2.71 gm/cc. Mercury injection analysis presented in Table (3) shows that the threshold pressure of the samples range from 1.5 to 138 psi, and the distribution indicates a uni-modal pore system. The threshold pressure, where mercury injection into the pore structure begins, is identified at the pressure where the rate of mercury injection increases rapidly at nearly constant pressure. The two graphs presented in Figure (4) and Figure (5) show the pore throat size distribution for samples 5 and 13. Sample 5 at depth 63.61 meters is at the best hydraulic quality, where it is observed that a uni-model pore system with a pore throat radius in the range of 25 microns. Sample 13 at depth 85.22 meters in the impermeable aquitard below the transition zone, it is observed that a bi-model pore system with throat size ranging from 0.002 to 1.00 microns. Chromium analysis performed on rock samples indicates moderately high concentration and ranges from 40 to 194 ppm, with an average value of 92.1 ppm, as shown in Figure (6).

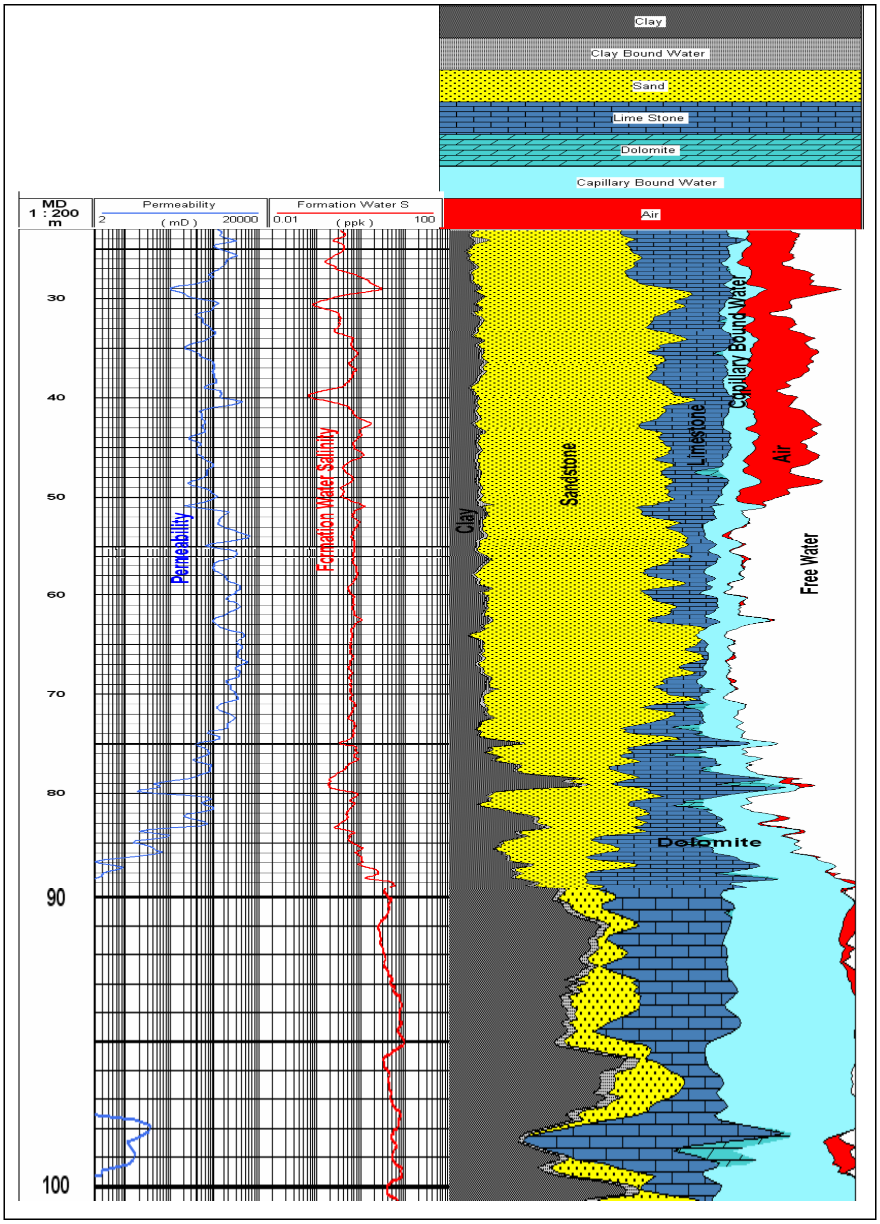

Figure 3: Elemental Analysis (ELAN) results.

Table 2: Summary of the Log Interpretation Results.

Well	Water Table mbGE	Bottom of Aquifer mbGE	Saturated thickness m	Total Porosity	Effective Porosity	Hydraulic. Conductivity m/d	Water Salinity TDS mg/l
SWS01	48.80	79.30	30.50	0.34	0.27	3.3	590
SWS08	40.80	69.60	28.80	0.35	0.28	3.6	NA
SWS04	49.50	80.5	31.00	0.32	0.25	1.6	NA
SWS06a	53.00	75.60	22.60	0.34	0.27	3.3	590
SWS15	49.40	49.40	00.00	0.30	0.24	N/A	N/A
SWS11	51.50	78.00	26.50	0.37	0.28	1.8	680
SWS16	37.50	64.02	26.52	0.36	0.29	4.5	600
SWS17	29.88	43.90	14.02	0.36	0.29	11.5	550
SWS18	29.27	48.78	19.51	0.34	0.29	3.2	550
SWS20	43.60	71.00	27.40	0.34	0.28	2.0	550

Table 3: Mercury Injection Analysis.

Sample No.	Depth (m)	Porosity (%)	Kair (mD)	Threshold Pressure, (psi)
1	51.20	35.0	3280.	6.0
2	54.88	34.9	7050.	3.5
3	59.66	36.7	3000.	6.5
4	61.23	33.6	3890.	3.5
5	63.61	37.4	11400	2.5
6	71.28	36.9	3540.	4.5
7	73.27	38.6	2540.	5.0
8	74.12	20.3	278.	6.5
9	74.67	38.1	2290.	5.5
10	77.20	25.7	457.	6.5
11	80.30	38.4	2650.	4.5
12	83.79	33.2	17.	174.0
13	85.22	32.6	2.3	215.9

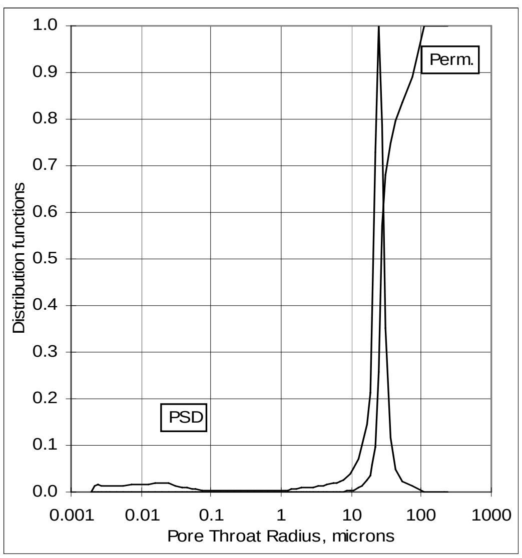

Figure 4: Pore throat size distribution (sample 5)

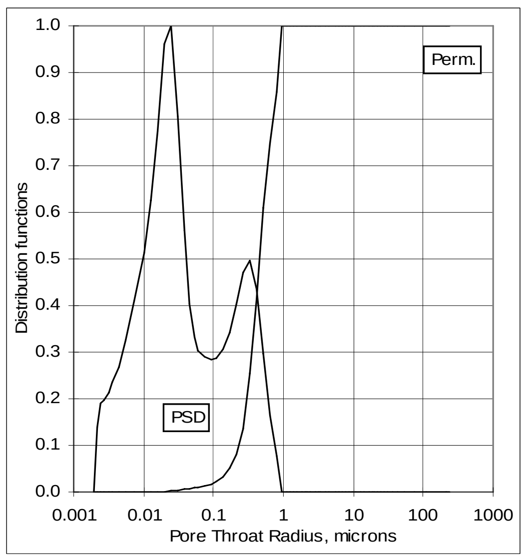

Figure 5: Pore throat size distribution (sample 13)

The native water chromium concentration is 70 ppm, while the injected water contains no chromium. It was observed on sampling well SWS12 that the sample chromium concentration was reduced to a level of 40 ppm at the end of the injection cycle, and increases to a level of 68 ppm at the end of the second recovery cycle. Presented below are comparisons between the borehole geophysical log measurements and the core laboratory analysis.

3.4 Core lab and Digital Imaging

Figure (7) shows the Formation Micro Imager on the left hand side, with the interpreted sedimentary dip angles value and direction showing northward dipping ranging around 15 deg. The core digital image on the right hand side shows layering angle as well about 10 to 15 deg, but from the core image, the orientation of the dipping planes can not be measured or predicted as the coring operation was non oriented coring.

3.5 Core Porosity/Permeability and CMR Log

Figure (8) shows the CMR log, with aquifer permeability in the left hand side track, and the different porosities in the middle track, super-imposed on them are the core measurements for the oven dried porosity and permeability to air. The comparison (Figure 12) between the log and core values are in good agreement.

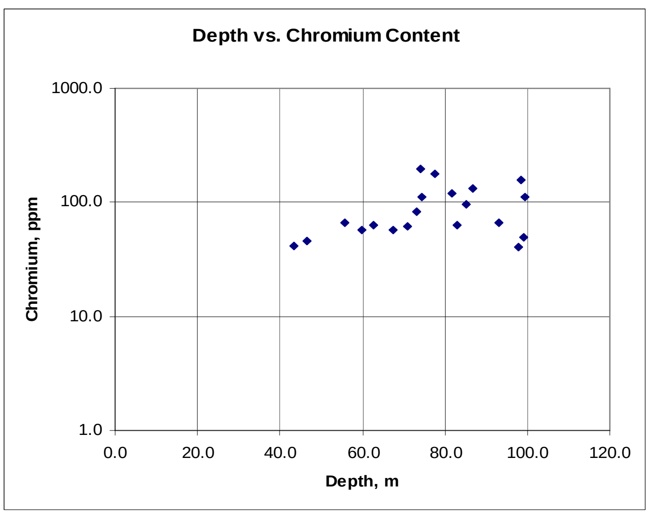

Figure 6: Depth vs. chromium content

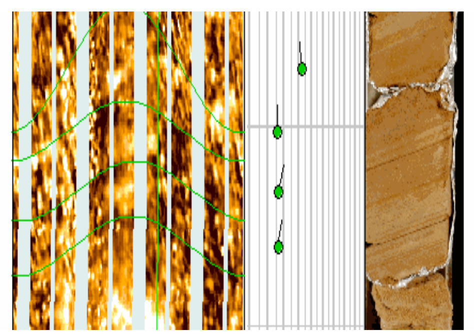

Figure 7: Core lab picture vs. digital FMI imagining.

4. Three Dimensional Geostatistical Simulation

To evaluate the heterogeneity of the aquifer system and its impact on the injected fresh water bubble and its mix with native groundwater geological modeling approach based on the geostatistical simulation was used. To date, the geological modeling work has depended on deterministic interpolation schemes to fill the volume of the model's 3-D grid structure. There is a weakness in this approach: by making the assumption that properties may be interpolated from well to well, we have overlooked important information about the way in which the data vary from well to well. An improvement would be to employ some similarity-dissimilarity analysis that quantifies correlation lengths between wells and that reproduces in the final model the statistical character of our sample data. The best way to employ this analysis is to examine lateral continuity in a single stratigraphic unit. To simulate the three existing formations, a sequential indicator simulation algorithm was used. Three categories were populated to the model: alluvial deposits lower Fars and Lower Fars. At each grid node, the category was simulated according to its conditional cumulative distribution function. For every grid node that was geostatistically simulated, the variability defined in Equation (1) (C. V. Deutsch and A. G. Journel, 1997, p. 151).

$$\Pr ob\{I(u;S_k)=1|(n)\} = p_k + \sum_{\alpha=1}^{n} \lambda_a [I(u;S_k) - p_k] \quad \text{.. Eq. (1)}$$

where:

u : location

n : index in the number of data

α : number of data

k : number of categories

p_k : global proportion of the k[th] category

λ : weight of data

$I(u;s_{k)}$: indicator random function model at u, for s_k

s_k: k^{th} category *ID*

Prob: probability of the I(u; s_k) for all n data

The well logs resistivity data was used to populate a 3D model in order to analyze the subsurface structure. The geostatistical properties of the data set were taken into account and 30 realizations of the subsurface were modeled through sequential Gaussian simulations. Figure (9) shows in 3-D model for the study area.

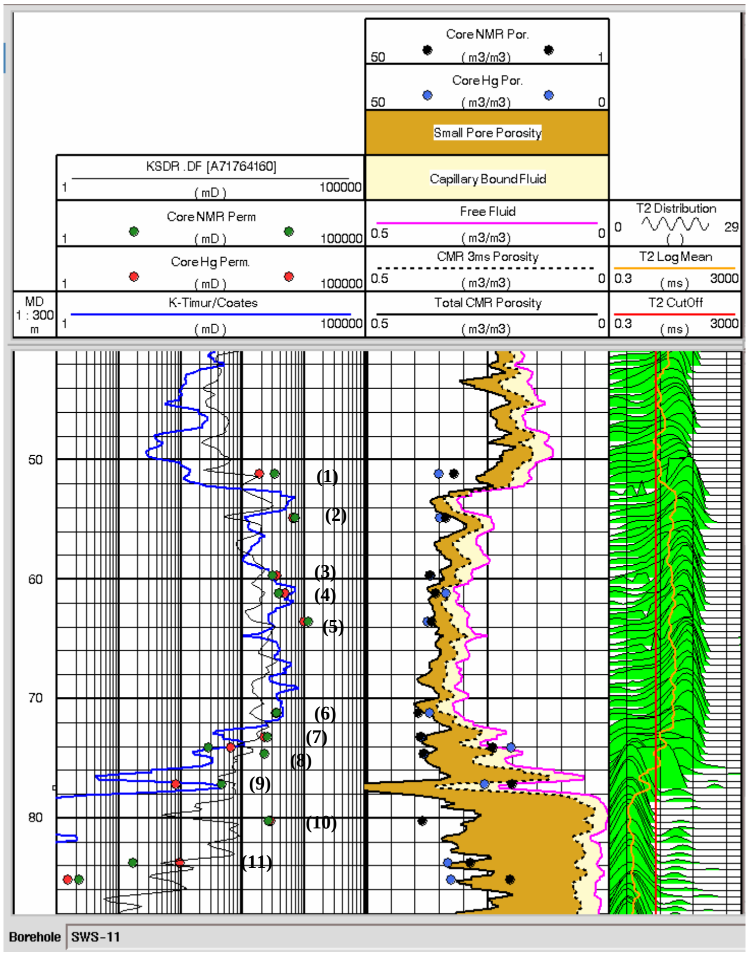

Figure 8: Core vs. log property correlation.

The analysis of the resistivity data clearly shows a discontinuity in the resistivity distribution, mostly affecting depths greater than 100 m (i.e. the clayey basement). The discontinuity appears as a resistive strip striking N245E located about 500 m to the west of the pilot test site. The resistivity in that zone averages 15-20 ohm m, whereas it is between 1 and 10 ohm m otherwise. The NNW-SSE discontinuity is easily identified. It is also of importance to notice the relative difference in resistivity between the eastern and the western compartments, the latter showing significantly higher resistivity at a given depth. The anomaly can be seen at depth in the clayey basement (from 80 m to 200 m amsl) as shown in Figures (10) and (11). This supports the assumption of a tectonic origin. Considering the regional compressional regime, the identified structure could be linked to a fold or a thrust fault.

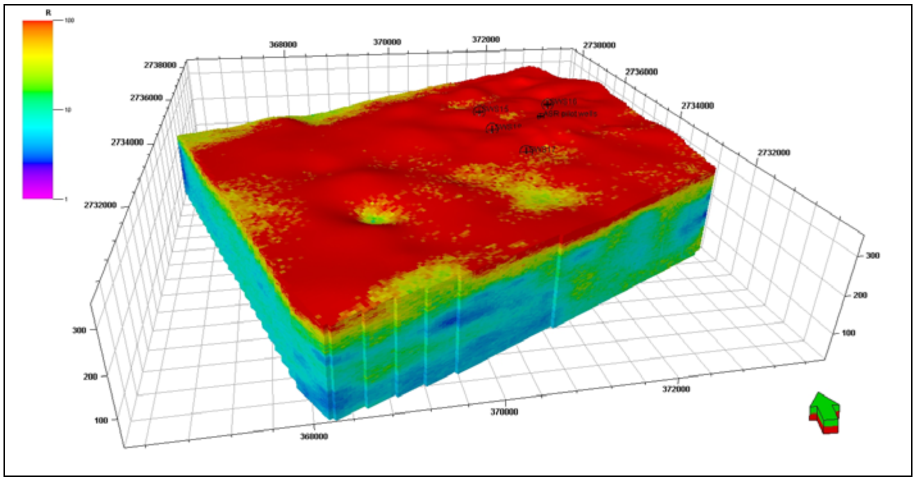

Figure 9: 3-D Model of Resistivity for the study area.

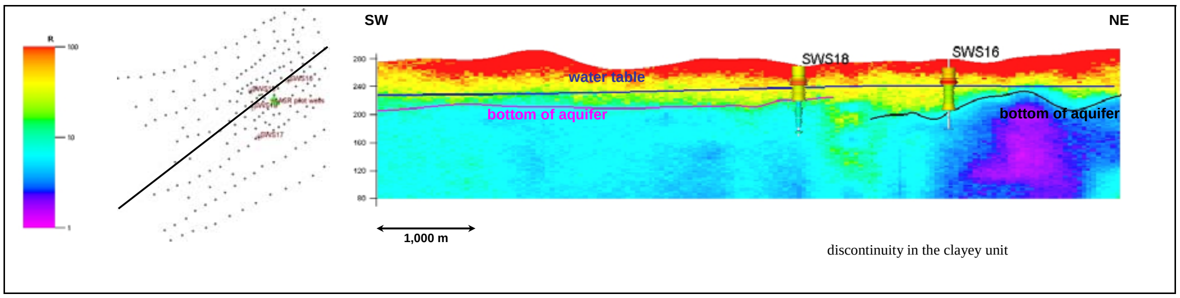

Figure10: SW-NE Resistivity Cross-section and Resistivity Log at SWS18 and SWS16.

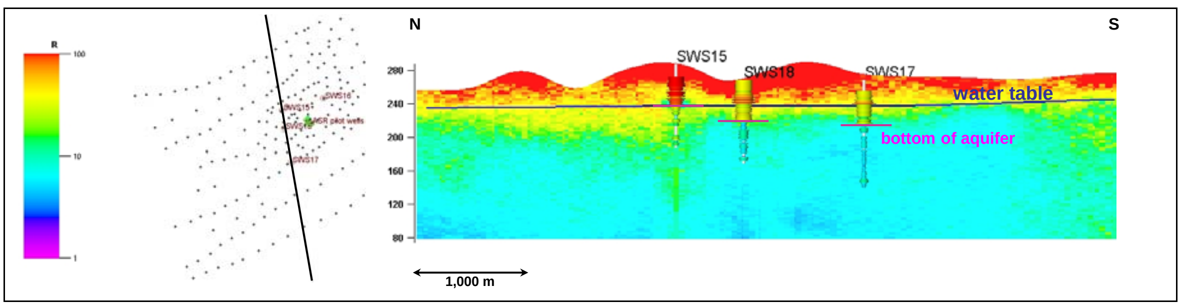

Figure11: NS Resistivity Cross-section and Resistivity Log at SWS15, SWS18 and SWS17.

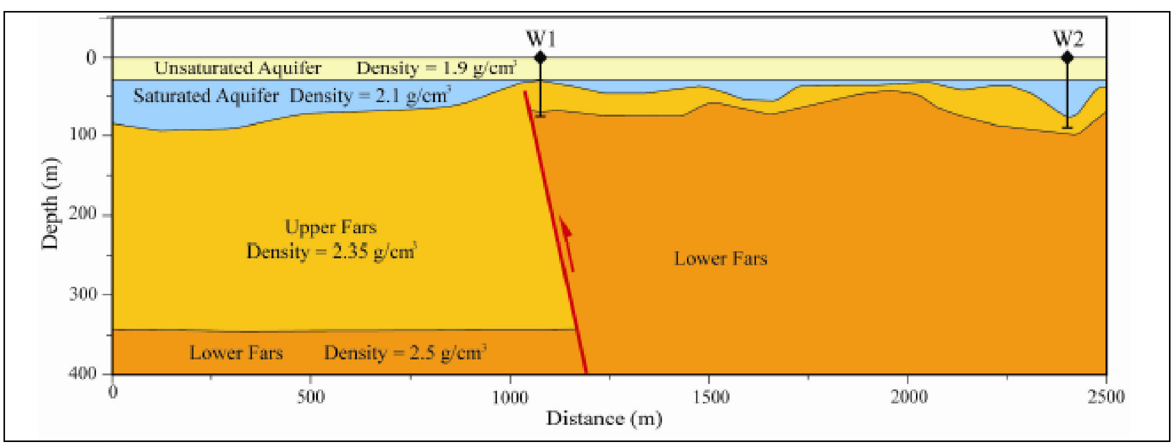

Figure12: Final Cross-section.

4. Conclusions and Recommendations

Geological modeling approach based on the geostatistical simulation can play an important role and help a lot to 3-D characterization of the shallow aquifer systems as well as evaluation of the heterogeneity of the aquifer system. The lab-measured porosity and clay content from cores can be used to calibrate the gamma-ray and conductivity logs so that porosity and clay content can be predicted. The geostatistical simulation approach needs huge information however, 2-D geophysical data can be used to better interpret the horizontal continuity of aquifer structure.

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Integrated Concept for Groundwater Evaluation and Protection -Barka Catchment (Oman) as Case Study

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ABSTRACT In this paper, we propose an innovative cyclic approach based on integrated strategy for the investigation, remediation and revitalization. The new approach does not concentrate on particular single site but considers entire city that can be heavily polluted and with different property owners and complex pollutant patterns. The proposed approach begins at Cycle I with the screening of groundwater plumes at the scale of entire city. In Cycle II, only those sites where groundwater quality is not acceptable are considered further. In Cycle III, the characteristics of the source zones are considered for remediation to control emissions, or implementation of monitored natural attenuation. The approach is currently considered and evaluated in Barka city, Oman, as a case study. For this study, 111 groundwater samples were collected from Barka and analyzed for inorganic and biological parameters. Results of this study reveal that groundwater in Barka is generally alkaline in nature and shows large variation in inorganic and biological parameters, which suggests that groundwater quality is not homogenous and regulated by distinguished processes. In Barka, groundwater in coastal region contains elevated concentrations of inorganic constituents, COD, BOD and bacteria. Barka coastal region is completely covered by distinguished land-use activities like urbanization, agricultural and industrial activities. Regional distribution maps generated by Geographical Information System suggest that highly contaminated zones are visually matching with land-use activities. Even though groundwater is influenced by saline water intrusion in the coastal region, high nitrate and bacteria population firmly argue impact of land-use activities such as irrigation activities with animal manure, septic tank leakage, domestic sewage, etc., on groundwater regime. The positive correlation between nitrate and major ions, and ionic ratios such as SO_4/Cl, alkalinity/Cl, totalcation/Cl demonstrate that highly acidic infiltrating water caused by nitrate-generating process induces dissolution of sulphate, carbonate and silica minerals and enhances solute load in groundwater. In order to evaluate the suitability of groundwater for different purposes, Oman and USEPA standards were employed. Results indicate that 52% of samples exceed anyone one of the inorganic parameters based on Oman standards while 98% of samples are unfit for domestic usage based on EPA standards. Bacteria growth is another serious problem suggesting that groundwater in the study region is not fit for domestic usage. Total coliform and fecal coliform are observed in 90% and 69% of samples, respectively, which are not appropriated for regular uses. However, almost 83% of samples are suitable for livestock based on inorganic parameters. The suitability of water for agricultural purposes was evaluated using FAO classification, suggests that 66% of samples are suitable for crops with slight to moderate restrictions. This study concludes that groundwater quality in Barka is strongly influenced by land-use activities.

KEY WORDS: Integrated concept, Groundwater, quality, monitoring, land use, dumping site, Barka, Oman

Introduction

The usage of groundwater has gradually increased due to the shortage of surface water and high water demand caused by the population growth and rapid industrialization. In Oman, groundwater is the main source of water for different purposes and groundwater supply 99% of fresh water demand (MRMEWA, 1999), and play a great role in the socio-economic development. In Oman, there are more than 128,000 wells tapping the major aquifers and around 4100 different types of Aflajes, 3095 of which originate from the groundwater. The high dependence on groundwater coupled with industrial and demographic expansion resulted in increasing pressures on available groundwater resources in terms of quantity and quality. The high withdrawal and low recharge reduced the amount of available groundwater especially in the costal areas, resulted seawater intrusion. Further, the inflow of pollutants caused by several potential sources such as land disposal of solid and liquid wastes, agricultural activities, saline water intrusion, etc., deteriorate the groundwater quality. Hence, as a consequence of limited water availability and potential issues of water quality in Oman, a proper groundwater monitoring and management plan is needed to protect and preserve valuable water resources. Further, methodologies for groundwater cleanup including excavation, backfilling, removal wells, surface capping, subsurface barriers, in situ chemical treatment, air stripping, carbonic adsorption and biological treatment are expensive and time-consuming, to remediate the contaminated aquifer and still not achieve complete remediation. Hence, the best way to retain good quality groundwater is to protect it from pollution before being contaminated. In this study, an investigation was carried out in Barka catchment to evaluate the groundwater quality and to identify the contamination process and sources through integrated approach.

Study area

Barka is located northwest of the capital city, Muscat, Oman and has an area of 1350 km2 (Fig.1).

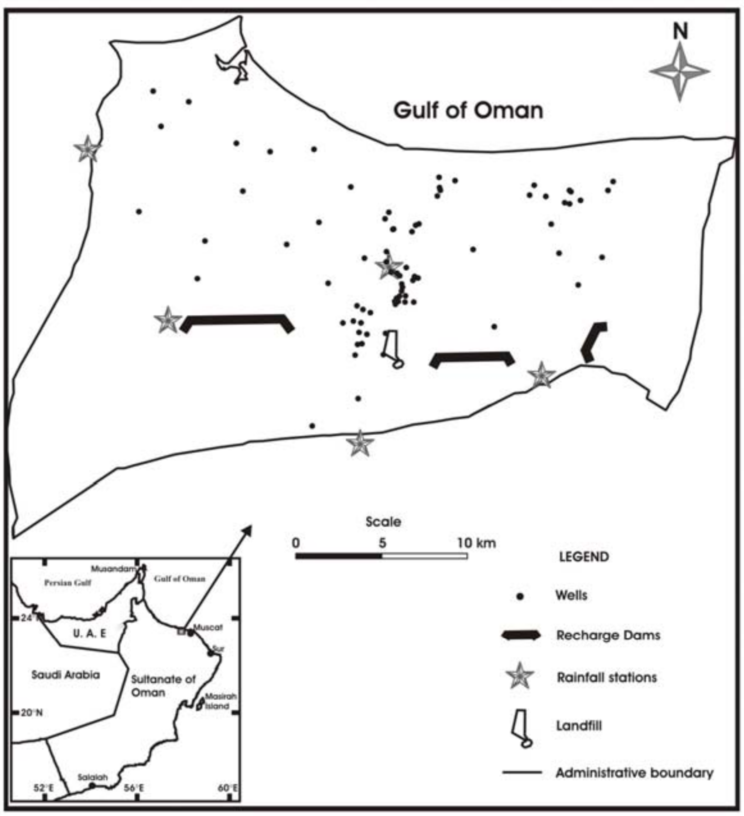

Fig. 1 – Map shows the location of monitoring wells in Barka, Sultanate of Oman.

The Gulf of Oman creates a natural border in North, while Jabal Al-Akdar and Nakhal mountains limits the South, which serves as a recharge zone of the study region. The study region sloped towards north and high elevation is observed at south. Wadis (Al-Maawil, Bani Kharus and At-Taww), ephemeral streams, existed in the study region and flow towards coast. To enhance aquifer potential through wadi flow and precipitation, three recharge dams were constructed during 1991 (Fig. 1); however, these dams are dry in most of the month. Generally, Barka experiences dry climatic condition with high rates of evapotranspiration

(Lakey et al. 1995) and the long-term annual average air temperature is 28.5°C in the coastal area and 17.8°C in the mountains (Weyhenmeyer et al. 2002). Rainfall is extremely variable with respect to space and time and the annual average rainfall based on six stations is 65 mm (from 1992 to 2003) (Fig.1, one station is located far south and not shown). However, high rainfall is recorded in the southern elevated region compared with the coastal region (Weyhenmeyer et al. 2002). Geologically, Barka lies in the Batinah coastal plain of Oman. The catchment can be divided into upper mountainous and lower alluvial plains, with Barka located in the lower catchment. The bedrock at the base of the alluvium consists of marl, limestone and dolomite and the alluvium is formed by the weathered products of limestone and ophiolite. Hydrogeologically, the alluvial sequence consists of two different hydrostratigraphic units with the total thickness of 600m (Lakey et al. 1995). The upper unconfined aquifer (Layer 1) is made up of sub-recent and recent quaternary alluvium, which consists of boulder beds, uncemented gravels and unconsolidated sands. It has low clay content and high hydraulic conductivity (20 m/day). Groundwater wells used in this study are tapping from Layer 1.

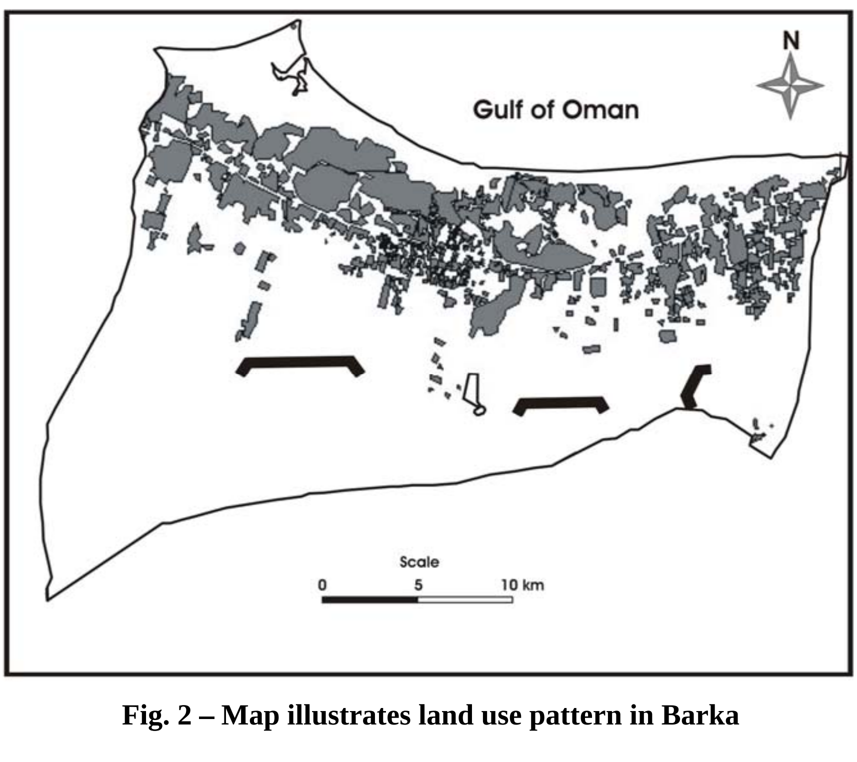

Fig. 2 – Map illustrates land use pattern in Barka

The deeper layer (Layer 2) consists of ancient alluvium, and has low hydraulic conductivity (1 m/day) and porosity. The groundwater level is mostly deeper in the southern part and shallower towards north, and becomes less than 3 m near the coast. In addition, groundwater level occurs below the mean sea level near the coast. In Barka, agricultural activities are dominant and consume large amounts of groundwater compared to domestic and industrial activities (Fig. 2). The irrigation water demands are covered by the large number of boreholes and dug wells. Agricultural production in Barka contributes significant proportion to the economy of Batinah region and the common crops such as grasses, alfalfa and vegetables, and trees like date, mango, lime, and banana are cultivated.

Methods

Groundwater sampling and analyses

Groundwater sampling was carried out in two phases to account for the different potential sources of contamination in the study region. During the first sampling trip, groundwater samples were collected from the regionally distributed wells that entirely covered the study area based on prior sampling plan. In the second sampling, groundwater samples were collected from wells existed in highly contaminated site identified by the regional water analysis results. Overall, 111 samples were collected from 79 wells and analysed for field parameters (pH, EC, DO, temperature) and inorganic and biological parameters.

Groundwater samples were taken from pre-existing supply wells and few dug wells. Field parameters such as EC, pH, DO, temperature were measured in situ using portable meters. Sampling bottles for cations and silica were soaked in 1:1 HCl solution for 24 h, washed three times with deionized water, and then washed again in the field with a few milliliters of the filtrate. Samples for laboratory analysis were filtered in the laboratory in the same day through 0.45 μm cellulose membranes prior to the analyses. The cations and silica samples were acidified to pH < 2 with several drops of ultra-pure HCl in the laboratory. All the samples taken in the field were kept on ice during transportation and then refrigerated at 4°C until analysis. For microbiological parameters, amber glass bottles were used and were thoroughly cleaned with laboratory-grade detergent followed by several rinses with deionized water. Following the cleaning, sample bottles were sterilized before use by means of autoclaving or chemical disinfection (alcohol). After the collection, amber glass bottles were wrapped by aluminum foil and immediately stored in ice and transported to the laboratory. Samples were analyzed for anions (Cl^-, SO_4^{--}, NO_3^-, NO_2^-, PO_4^-) using ion chromatography, cations (Na^+, K^+) using flame photometer and Ca^{2+}, Mg^{2+} and alkalinity (HCO_3) by the titration technique. A UV/visible spectrophotometer was used for silica analysis. Microbiological parameters such as BOD, COD, total coliform and fecal coliform were estimated as per the standard methods (APHA, 1995). Overall, measurement reproducibility and precision for each analysis were less than 2%. The analytical precision for the total measurements of ions was checked again by calculating the ionic balance errors, and was generally within ±5%.

Data analysis and GIS application

Geographical information system (GIS) is widely applied for a variety of areas such as the effective management of groundwater, agriculture, land use planning, forestry and wildlife management, municipal applications, global scale applications and resource management, etc. The general definition for GIS is an organized collection of computer hardware, software, geographic data, and personnel designed efficiently to capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (ESRI, 1994). In this study, chemical analysis results were integrated in a GIS environment in order to spatially identify the contamination zones (plume). Thematic maps for each water quality parameters were prepared by ArcGIS (v. 9.1). In the first instance, the data obtained from the first cycle groundwater samples were employed. Based on these maps, highly contaminated zones (plumes) were identified and additional wells were selected in plume area and sampled for detailed study. Finally, results of 111 samples collected from 79 wells were applied to prepare water quality maps.

Results and discussion

The water chemistry in the study region indicate that sodium and chloride behave as a predominant cation and anion, respectively, and dominated over magnesium and alkalinity, respectively in 80% of the groundwater samples. Groundwater is generally alkaline in nature (Table 1). The electrical conductivity (EC) varies from 555 to 27310 µS/cm with a mean value of 4760 µS/cm. Large standard deviation is observed in EC and major ions and suggests that groundwater quality is not homogenous and regulated by distinguished processes, which is also justified by chloride and nitrate concentrations. The nitrate ranges from below detection limit (BDL) to 191 mg/l with a mean value of 29.8mg/l. Likewise, chloride varies from 57 mg/l to 9619 mg/l with a mean value of 1360 mg/l.

Table 1. Statistical summary of groundwater quality data

	Min	Max	Mean	Med	STD	n	Domestic/Drinking water standard			No of samples exceed the limit	
							OSTD		EPA	OSTD	EPA
							Min	Max			
Temp	25.0	37.5	32.8	33.2	2.02	111					
EC (µS/cm)	555	27310	4760	1400	6540	111					
TDS	355	17478	3046	896	4185	111	800	1500	500	37	109
pH	6.90	8.95	7.45	7.42	0.28	111	6.5	9.0	8.50	0	1
Na	36.8	3520	558	114	898	111	200	400		30	
Ca	16.0	1120	142	76.0	158	111					
Mg	29.2	1416	202	55.2	309	111					
K	0.74	80.0	11.7	4.30	16.8	110					
Alk (HCO3)	154	478	275	265	64.4	111					
SO4	34.1	1989	306	126	384	110	250	400	250	26	30
Cl	57	9619	1360	235	2204	111	250	600	250	36	51
NO3	BDL	191	29.8	18.3	33.4	110		50	45	14	18
Silica	6.00	55.0	30.1	27.0	9.03	49					
NO2	BDL	42.0	2.14	0.00	8.80	70		3	3.3	4	4
PO4--	BDL	8.28	0.22	0.00	1.22	78					
TH as CaCO3	169	8074	1183	406	1625	111	200	500		43	

n = Number of samples analyzed. Unit – mg/l except pH and EC

Regional variation of EC illustrates that it increases from south to north and higher value is observed near the coast (Fig. 3). Regional variation of nitrate indicates that it is generally less than 10 mg/l in most of the study region; however, higher values were observed in north-eastern part (Fig. 3). Since Barka is located in coastal region, chloride may be originated from saline water intrusion and/or anthropogenic activities whereas high nitrate strongly suggests the influences of surface contamination sources. In Barka, urban development and agricultural activities covered most of the land in coastal strip (Fig. 2). Further, irrigation return flow, fertilizers, farm manure, domestic sewage, septic tanks and cattle farms are the major anthropogenic pollutant sources in the study region. Figure 4 firmly reflects the effect of man-made activities in the groundwater regime, especially in the north eastern part of the study region. It is understandable that saline sources enhance the ionic concentrations in groundwater in the northern region; however, high concentrations of nitrate, calcium, alkalinity and silica could not be derived from the saline sources since these ions are generally low in seawater, especially in the case of nitrate (0.67 mg/l). Moreover, high concentration of nitrate might be derived from anthropogenic activities because of low nitrate content in rainwater (5.49 mg/l).

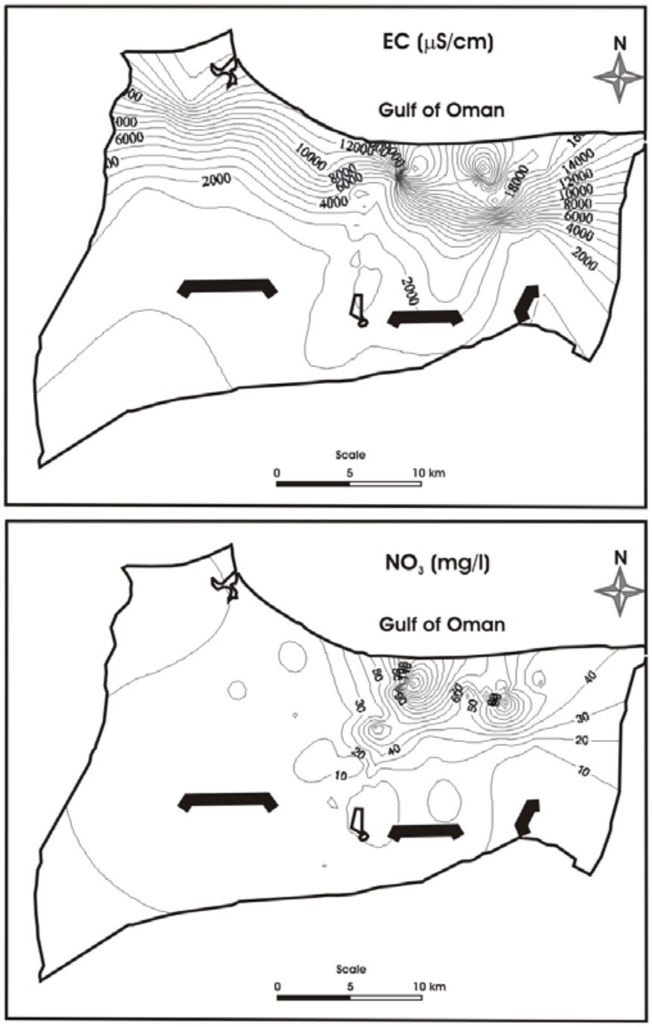

Fig. 3 – Regional variation in electrical conductivity and nitrate concentration.

Nitrate in groundwater generally originates from oxidation of ammonium (nitrification) (Nkotagu 1996; Zilberbrand et al. 2001). Nitrogen fertilizers and farm manures, which are normally used for paddy and other crops, are the major ammonium sources in agricultural areas (Min et al. 2003; Chae et al. 2004), whereas the source of ammonium in residential and urban areas is mostly septic tank effluent and sewage generated from domestic and industrial activities (Jacks et al. 1999). In addition, ammonium may also originate from landfill in Barka; however, ammonium is not analyzed in groundwater to support this argument. Under oxic conditions, ammonium is readily oxidized to nitrate by the nitrification process

$$NH_4^+ + 2O_2 \Rightarrow NO_3^- + 2H^+ + H_2O \qquad (1)$$

Nitrate also can be generated by aerobic decomposition of organic matter

$$C_{106}H_{263}O_{110}N_{16}P + 138O_2 \Rightarrow 106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ \qquad (2)$$

Relatively high DO contents (> 2 mg/l except for five samples) in the groundwater make this process possible in this aquifer (Table 2). The relation between nitrate and pH implies the nitrate-generating reactions as well. As per the equations (1 and 2), the nitrate-generating process decreases the pH and consumes equal amount of alkalinity. Figure 4 elucidates that nitrate has somewhat negative relation with pH; however, it is not apparent in alkalinity, especially at high nitrate content. These discrepancies seem to be the results of carbonate minerals and gypsum dissolution by the highly acidic infiltrating water (Collins and Jenkins 1996). Figure 4 illustrates that calcium has positive correlation with nitrate (R^2 = 0.6), and total cation (TC=Ca^{2+}+Mg^{2+}+Na^++K^+)/Chloride ratio is greater than seawater even at high nitrate concentration, and justify that some amount of calcium and/or total cation (mainly Ca^{2+}+Mg^{2+}) derived by the dissolution of minerals caused by nitrate-related process. Moreover, nitrate expresses positive relation with chloride and silica, and similar trend is also observed with sodium, magnesium and sulphate, especially at high nitrate concentration (Fig. 4). In addition, SO_4/Cl molar ratio in groundwater is generally greater than seawater ratio (0.052), even at high nitrate content. Similarly, alkalinity/Cl molar ratio varies from 0.016 to 2.141 with a mean value of 0.617, and greater than seawater ratio (0.043). Thus, ionic ratios such as TC/Cl, SO_4/Cl and alkalinity/Cl emphasize that substantial quantity of cations and anions in groundwater can be derived from nitrate-generating process; however, major source of enhanced concentrations of sodium, magnesium, chloride and sulphate observed at enriched nitrate are mainly due to saline sources in Barka since Rajmohan et al. (2007) reported that the northern and north eastern part of the Barka is affected by the saline water intrusion. In addition, the positive trend between silica and nitrate reveals the effect of infiltration as seawater contains very low silica (6.4 mg/l). Hence, these observed relationship strongly suggest that antropogenically contaminated infiltrating water is mixed with existing groundwater affected by saline water intrusion.

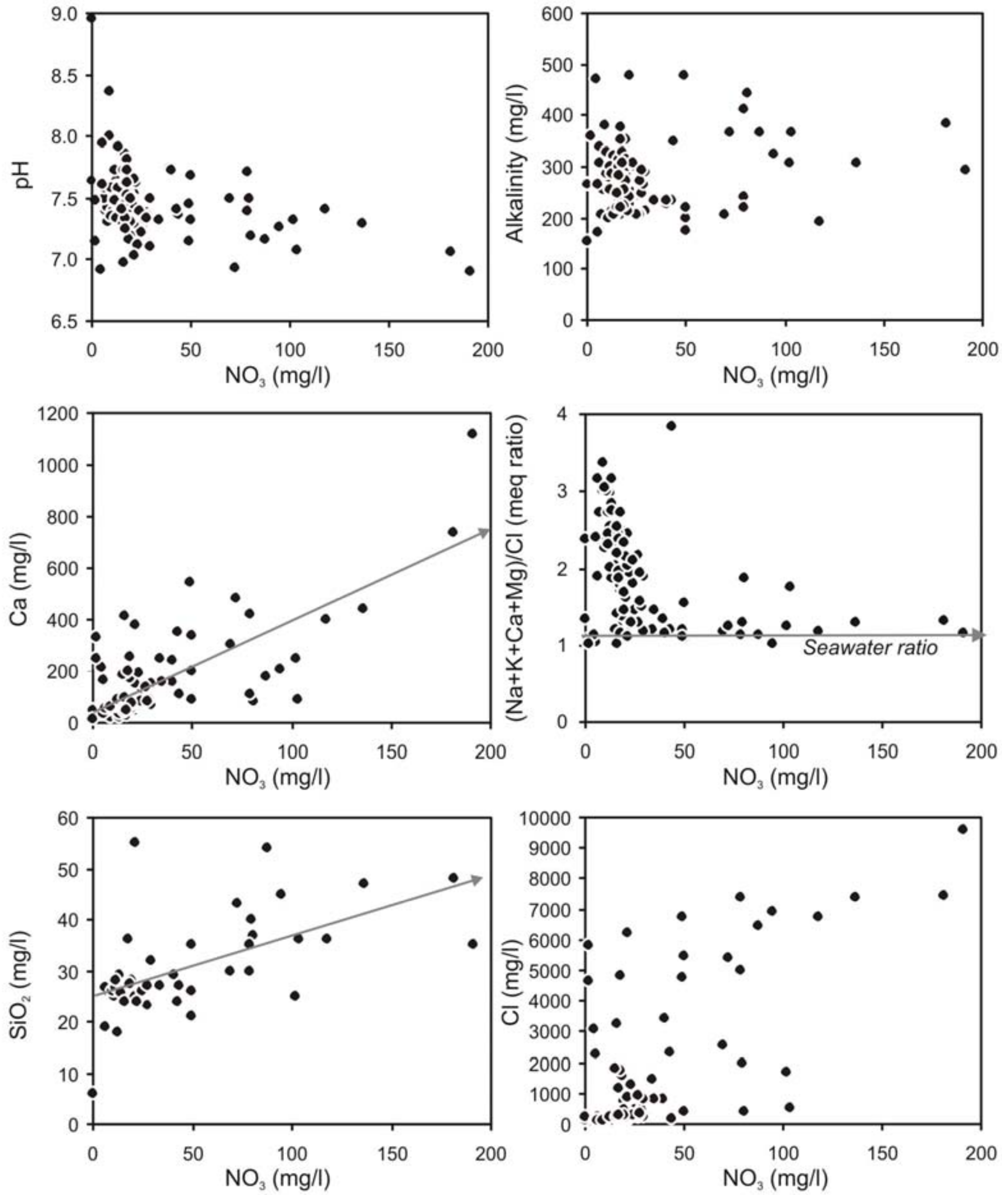

Fig. 4 – Plots of selected parameters as a function of nitrate.

The chemical oxygen demand (COD) and bacteria also justify the effect of surface contamination sources. The COD generally varies from below detection limit (BDL) to 310 mg/l except four samples and BOD ranges from BDL to 76 mg/l (Table 2). Both COD and BOD are mostly BDL in 23% and 50% of samples analyzed, respectively. Higher values of these parameters expose the severe contamination of groundwater due to decomposition of organic waste originated from different sources. Like other parameters, bacteria counting also display large variation between mean and median value. Total colifom value exhibits that it is less than 10 in 50% of samples whereas Fecal coliform denotes that it is absent in 30% of samples and less than 10 in 74% of samples (Table 2). Similarly, Fecal enterococci also behaves like Total coliform. Bacterial population is generally high near the dumping site and coastal strip (Fig. 5).

Table 2. Statistical summary of groundwater quality data – Biological parameters

	Min	Max	Mean	Med	STD	n	Domestic/Drinking water standard	No of samples exceed the limit
							EPA	EPA
DO (mg/l)	1.08	4.80	2.97	3.02	0.61	111		
BOD (mg/l)	BDL	76.0	12.6	0.0	18.6	59		
COD (mg/l)	BDL	3347	103	30.2	375	110		
T.Count (37C)	2.00	1500	233	63.7	381	59	Nil	59
T.Coli (MPN/100ml)	0.00	2420	552	7.50	927	109	Nil	99
F.Coli (MPN/100ml)	0.00	2420	84.4	0.50	387	110	Nil	77
F.Ent (MPN/100ml)	0.50	2420	151	7.50	388	59	Nil	59

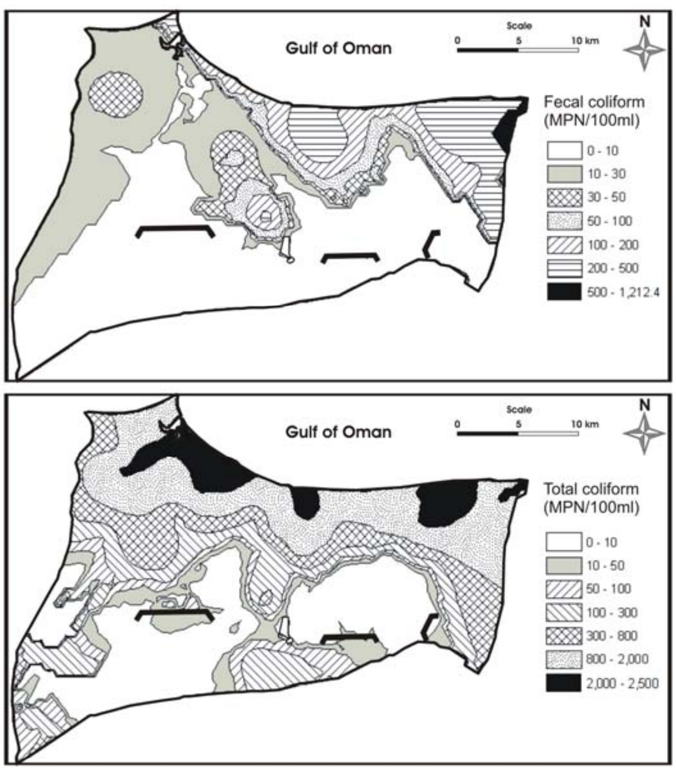

Fig. 5. Regional variation of fecal coliform and total coliform

Bacteria, COD and BOD obviously justify that groundwater is contaminated by anthropogenic activities. In the study region, agricultural activities using animal manure, septic tank leakage and dumping sites seem to be major bacterial contamination sources for groundwater. Panno et al (2006) reported that bacterial contamination of the shallow karst aquifer of southwestern Illinois sinkhole plain was attributed to private septic systems. Earlier studies reported that animal manure provides a very large source of bacteria, nitrate and other drinking water contaminants (Goss et al., 1998; Conboy and Goss, 2000).

Groundwater quality evaluation

As water scarcity is an important issue in Oman, evaluation of water quality is essential one. Quality of groundwater for domestic usage was evaluated using Oman standards for drinking water (OSTD) and USEPA standards (EPA, 2003; ODWS, 1998). Salinity highlights that 98 % and 33% of samples unfit for drinking based on EPA and Oman standards, respectively (Table 1). Besides, the concentrations of sodium, chloride, sulphate and nitrate exceed the drinking water limit in some of the samples. Hardness classification indicates that groundwater in the study region is hard to very hard (TH as CaCO3 > 120 mg/l) in nature (Table 1). In over all, 52% of samples exceed anyone one of the inorganic parameters based on Oman standards while 98% of samples are unfit for domestic usage based on EPA standards. Similarly, bacteria population also evident that most of the groundwater in the study region is not fit for domestic usage (Table 2). Total coliform and fecal coliform are observed in 90% and 69% of samples, respectively, which are not appropriated for regular uses. Groundwater is an important source for livestock especially for poultry and cattle activities in Barka.

Table 3. Groundwater quality classification for livestock and poultry uses– Based on salinity (FAO method)

Water Salinity (EC) (μS/m)	Rating	No. of samples within the limit
<1500	Excellent	64
1500 – 5000	Very Satisfactory	19
5000 – 8000	Satisfactory for Livestock	6
	Unfit for Poultry	
8000 – 11000	Limited Use for Livestock	5
	Unfit for Poultry	
11000 – 16000	Very Limited Use	4
>16000	Not Recommended	13

Table 3 describes the groundwater classification for livestock and poultry application using salinity based on Food and Agricultural Organization (FAO) method

(Ayers and Westcot, 1994). Almost 83% of samples come under excellent to very satisfactory category while 12% of samples are unfit (Table 3). For livestock, high salinity water is generally not recommendable which cause physiological upset, depression of appetite or even death (Ayers and Westcot, 1994). The suitability of water for agricultural purposes is also evaluated using FAO classification (Table 4). In this classification, EC, sodium adsorption ratio (SAR), sodium, chloride, nitrate and bicarbonate were employed. Based on EC, 66% of samples come under slight to moderate restrictions to use of these waters for agricultural activities whereas 32% have severe salinity restrictions. Generally, 85% of samples in the study region are low sodium water (SAR < 10), and are applicable for all crops and soil condition. In the FAO system, SAR and EC are used together to understand the effect on water infiltration rate, which will be increased with increasing EC at a given SAR.

Table 4. Classification of groundwater quality for irrigation - Based on FAO method

Potential Irrigation Problem			Units	Degree of restriction on use			No. of samples		
				None	Slight to Moderate	Severe	None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*									
Electrical conductivity (EC)			µS/cm	< 700	700 – 3000	> 3000	2 (2%)	73 (66%)	36 (32%)
Infiltration *(affects infiltration rate of water into the soil. Evaluate using EC and SAR together)*									
SAR	0 – 3	EC	µS/cm	> 700	700 – 200	< 200	66 (60%)	2 (2%)	0
	3 – 6			> 1200	1200 – 300	< 300	14 (13%)	1	0
	6 – 12			> 1900	1900 – 500	< 500	13 (12%)	0	0
	12 – 20			> 2900	2900 – 1300	< 1300	13 (12%)	0	0
	20 – 40			> 5000	5000 – 2900	< 2900	2 (2%)	0	0
Specific Ion Toxicity *(affects sensitive crops)*									
Sodium									
surface irrigation		SAR	meq/l	< 3	3 – 9	> 9	68 (61%)	24 (22%)	19 (17%)
sprinkler irrigation				< 3	> 3		68 (61%)	43 (39%)	
Chloride			meq/l						
surface irrigation				< 4	4 – 10	> 10	19 (17%)	48 (43%)	44 (40%)
sprinkler irrigation				< 3	> 3		4 (4%)	107 (96%)	
Miscellaneous Effects *(affects susceptible crops)*									
Nitrogen (NO_3 - N)			mg/l	< 5	5 – 30	> 30	73 (66%)	34 (31%)	3 (3%)
Bicarbonate (HCO_3) *(overhead sprinkling only)*			meq/l	< 1.5	1.5 – 8.5	> 8.5	0	111 (100%)	0

As per the chloride toxicity, 96% of samples have slight to moderate restrictions to apply in sprinkler irrigation whereas 60% of samples have none and slight to moderate restrictions to use for surface irrigation. In Barka, date-palms are very common and dominating crop over other fruits or vegetable. Date-palms are tolerable for high salinity water; however, yield will be reduced if the EC exceed certain limit (EC-2700 μS/cm, 100%; EC-12000 μS/cm, 50%; 21000 μS/cm, 0%) (Ayers and Westcot, 1994). High salinity water increases soil as well as soil water salinity by evaporation, which will greatly reduce plant water uptake through osmotic effect and causes dehydration and low yield.

Conclusions

An investigation was carried to evaluate groundwater quality in Barka catchment, Sultanate of Oman through an innovative cyclic sampling approach. Geochemical characteristic and regional distribution pattern of chemical constituents of groundwater samples, collected from regionally distributed wells during first sampling campaign, were applied to identify contamination zones, which are more concentrated during second sampling campaign. On the whole, 111 samples collected from 79 wells were analyzed for chemical and biological parameters. Results of this study suggest that the groundwater of this region shows wide range of electrical conductivity (EC) and chemical constituents. Enhanced nitrate and chloride concentrations obviously suggest the impact of anthropogenic as well as saline sources. Even though groundwater is influenced by saline water intrusion in the coastal region, high nitrate and bacteria population firmly argue impact of land-use activities such as irrigation activities with animal manure, septic tank leakage, domestic sewage, etc., on groundwater regime. Further, regional distribution maps generated by Geographical Information System also suggest that highly contaminated zones are visually matching with land-use activities. In Barka, groundwater in coastal region contains elevated concentrations of inorganic constituents, COD, BOD and bacteria. Barka coastal region is completely covered by distinguished land-use activities like urbanization, agricultural and industrial activities. The positive correlation between nitrate, chloride and silica reveals that the anthropogenically contaminated infiltrating water seems to be interacted with carbonate and silica minerals, and finally mixing with existing groundwater contaminated by saline sources. This observation is well supported by the regional distribution pattern of nitrate, chloride, total coliform and fecal coliform. In order to evaluate the suitability of groundwater for different purposes, Oman and USEPA standards were employed. Results indicate that 52% of samples exceed anyone one of the inorganic parameters based on Oman standards while 98% of samples are unfit for domestic usage based on EPA standards. Bacteria growth is another serious problem suggesting that groundwater in the study region is not fit for domestic usage. Total coliform and fecal coliform are observed in 90% and 69% of samples, respectively, which are not appropriated for regular uses. However, almost 83% of samples are suitable for livestock based on inorganic parameters. The suitability of water for agricultural purposes was evaluated using FAO classification, suggests that 66% of samples are suitable for crops with slight to moderate restrictions. In overall, this study concludes that groundwater quality in and around Barka dumping site is degrading due to distinguished land-use activities.

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The expected effects of climatic changes on water resources of the Arabian Peninsula.

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Abstract

The paper gives an overview of the current climate and the status of water resources on the Arabian Peninsula and identifies climatic forcings that shape the current climate and the variables that are most prone to the change of existing atmospheric conditions. Annual and monthly climatic and streamflow records at a number of locations are examined in light of the possible effects of the global circulation patterns that include El Niño – La Niña, North Atlantic Oscillation (NAO), Indian Ocean Oscillation (IOA) and other phenomena that affect weather. A short overview is given of the status of scientific thinking and forecasts in relation to global warming and climate change, with special attention to the expected effects of changes of weather patterns and resulting climatic changes on the Arabian Peninsula. Conclusions are drawn the expected variations of meteorological and hydrological variables and their effects on rainfall, evaporation and streamflow. Expected effects of these changes and anticipated challenges in water resources management are outlined and discussed.

Keywords

Arabian Peninsula, climate change, global warming, water resources

Introduction

There is scientific consensus that the changes of prevailing atmospheric conditions that we observe over the last century, and especially during the last several decades, point out to widespread climatic changes, termed also as the global warming. As IPCC (2007) declares, water resources are among systems and sectors that are particularly vulnerable and strongly impacted by climate change. While precipitation on average is expected to change only slightly, its variability is expected to increase. Extreme weather events both in temperature and precipitation are likely to occur more often, leading to both more floods and droughts. Climate change will influence the global hydrological cycle, and can have major impacts on water resources.

IPCC (2007) states that warming observed over the past several decades is consistently associated with changes in the hydrological cycle such as: increasing atmospheric water vapour; changing precipitation patterns, intensity and extremes; widespread melting of snow and ice; and changes in soil moisture and runoff. Precipitation has generally increased over land north of 30°N, but decreases have dominated from 10°S to 30°N since the 1970s. Globally, very dry areas have more than doubled since the 1970s.

Both weather and climate are very important from the point of view of water resources and their management, especially in a hyper-arid region like the Arabian Peninsula. While the chaotic nature of weather makes it largely unpredictable beyond a few days, projecting changes in climate (i.e., long-term average weather) due to changes in atmospheric composition or other factors is a very different and much more manageable issue.

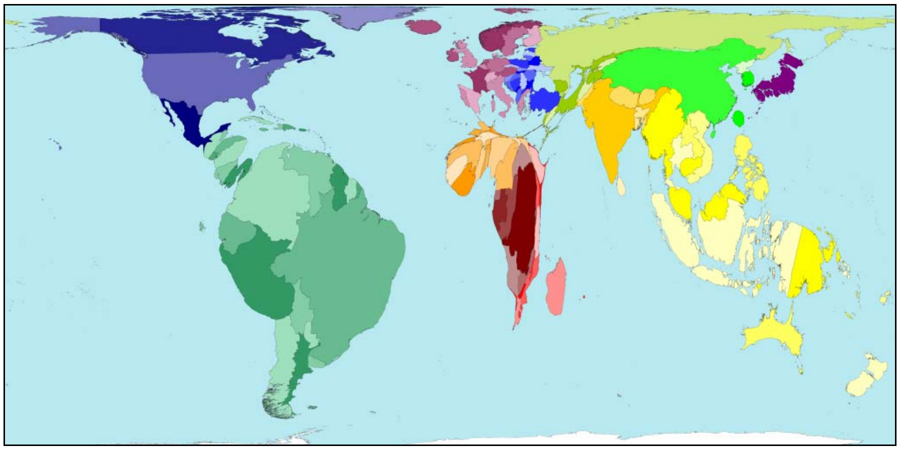

Figure 1. The Arabian Peninsula ranks very low on the map of global water resources.

The Arabian Peninsula is one of the most waterless places on Earth (Figure 1), yet it has one of the highest population growth and water consumption *per capita* figures. As WB (2005) observes, given the specific economic, social and climatic conditions, the GCC countries face water challenges and possible solutions that are quite unique in comparison to the rest of the World. While they are generally well endowed with substantial financial and human resources, their water challenges are far more pressing than what other regions may have encountered. These challenges require important actions in order to stimulate investment and enhance efficiency in the water sector so as to avoid future crises. Therefore, it is important to identify the key issues and challenges which an expected climate change will bring in water resources management and provide recommendations for the future, keeping in mind the unique circumstances in this part of the World.

<u>Historical and present climate of the Arabian Peninsula</u>

Palaeclimates of the Arabian Peninsula were often very different from the present climate (Bray and Stokes, 2004, Jorgensen and Al-Tikiriti, 2003) and were at times characterized by lower temperatures, flowing rivers, and abundant vegetation. Presently, the Arabian Peninsula is in one of its dried periods, and is covered mostly by a hyper-arid desert, with the process of desertification additionally augmented by human activities over the past millennia (Abahussaina *et al.,* 2004).

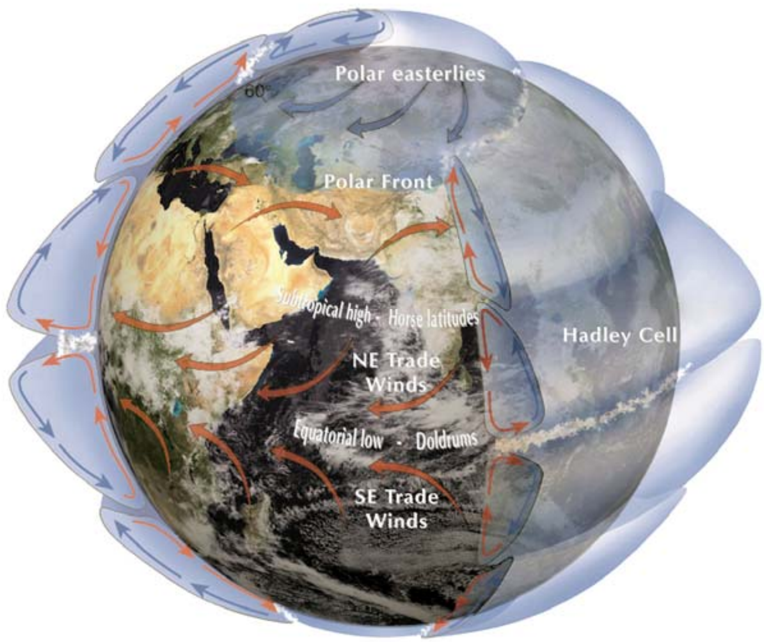

Figure 2. Hadley cells govern the climate of subtropical highs

The Arabian Peninsula in the northern belt of the Horse Latitudes and the present weather patterns of the region are dictated foremost by the Hadley cell circulation (Figure 2) which result in low rainfalls, generally confined to a 100 mm annual isohyet, and only locally modified by orography, or monsoon in its south-eastern outskirts. The weather patterns are seasonally affected by competing air masses from Africa, the Mediterranean, the Indian Ocean and Siberia (Barth and Steinkohl, 2004), which in turn are modulated by major global circulation patterns that include El Niño - Southern Oscillation (ENSO), Indian Ocean Oscillation (IOO), North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO) and a number of their subsets. Monsoon is driven by ocean temperature and winds, but the influences over those two factors are complex (Zhang *et al.*, 2004), and sometimes difficult to decipher. For example, both El Niño and La Niña demonstrate an influence, but not systematically: other oscillations and coupled ocean-atmosphere phenomena, like the Equatorial Indian Oscillation (EQUINOO), are also important, and at times may be dominant over the ENSO cycles.

Ali Khan *et al.* (2004) state that increasing trend of SST is observed throughout all the seasons in the northern Arabian Sea extending from Oman to Karachi and Mumbai and furthersouth to Salala and Colombo. Riegl (2003) shows that Arabian Gulf (Abu Dhabi, Dubai, Sharjah) corals have already been measurably affected by climate change and further negative impacts are expected. Nasrallah and Balling (1996) found that rainfall records for the region show a slight, statistically insignificant decrease over the past 40 years. Nasralah *et al.* (2004 found that the most significant heat wave events, as far as both their duration and intensity are concerned occurred in the last decade of the 20th century. The Arabian Peninsula is a significant heat source for the surrounding areas, and for example affects the Mediterranean summer storms (Solomon *et al.,* 2006).

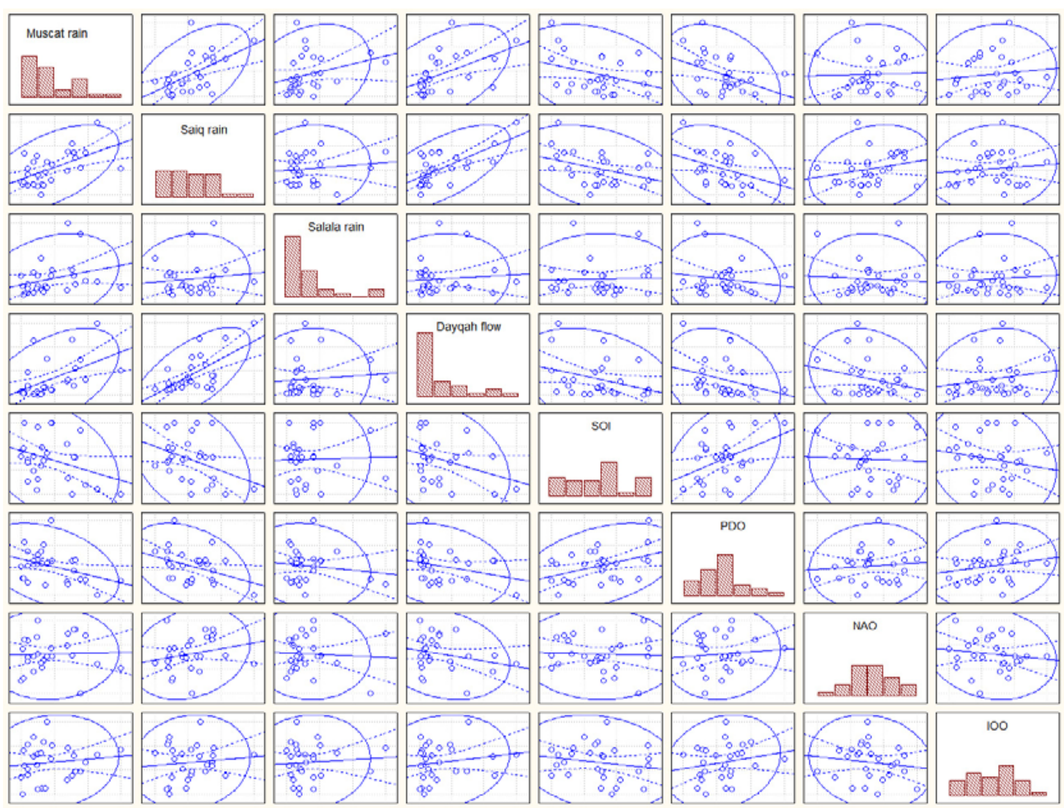

Figure 3. A matrix plot of rainfall in Muscat, Saiq Plateau, and Salala, Wadi Dayqah flow, SOI, PDO, NAO and IOO for 1979-2006, annual figures (Kotwicki *et al.,* 2007).

Matrix plots presented in Figure 3 show the responsiveness of rainfall and runoff to several major global circulation patterns in several key location of The Sultanate of Oman on the eastern rim of the Arabian

Peninsula, which include the coastal city of Muscat, mountainous region of Saiq Plateau and monsoon affected areas of Salala.

The Figure demonstrates that natural water resources of Oman are responsive to global-scale weather forcings, especially SOI and IOO combinations.

Status and predictions of climate change

As IPCC (2007) declares, due to human activities, the concentration of carbon dioxide in the atmosphere is increasing, and is expected to double in the next 100 years. The scientific consensus exists that this process will change the thermal gradient of the atmosphere with an overall warming of its lowest part. The rising temperature will affect most weather and climate parameters of the planet. However, we do not know whether carbon dioxide may be trapped in oceans or in biosphere, how cloud cover will affect the changing climate, and a number of other feedback mechanisms. At times, major volcanic activity may trigger cooling, thus off-setting the warming. But, foremost, we do not know: are we entering the next Ice Age? Theoretically, we could enter it anytime within the next thousand years.

IPCC (2007) predicts that by 2050, annual average river runoff and water availability will increase by 10-40% at high latitudes and in some wet tropical areas, and decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics. Globally by the 2090s, the proportion of the land surface in extreme drought at any one time is predicted to increase by a factor of 10 to 30, the frequency of extreme drought events to double, and the mean drought duration to increase 2- to 6-fold. The predictions which specifically address the Arabian Peninsula presented in IPCC (2007) can be summarized as follows:

Rainfall

As multi-model ensembles show, globally averaged mean water vapor, evaporation and precipitation are projected to increase. The models provide that precipitation generally increases in the areas of regional tropical precipitation maxima (such as the monsoon regimes, and the tropical Pacific in particular), with general decreases in the sub-tropics. The models also show increases at high latitudes as a consequence of a general intensification of the global hydrological cycle. Regarding prospects for the future, in high latitudes and parts of the tropics, climate models are consistent in projecting precipitation increases, while in some subtropical and lower mid-latitude regions they are consistent in projecting precipitation decrease. The Arabian Peninsula belongs to the regions for which precipitation predictions are not unequivocal, but some models predict that the summer rainfall will increase by 40%, while the winter rainfall will decrease by 30%.

Humidity

Tropospheric water vapour is increasing. Total column water vapour has increased over the World Ocean by 1.2 ± 0.3% per decade from 1988 to 2004, consistent in pattern and amount with changes in sea surface temperature (SST) and a fairly constant relative humidity. Strong correlations with SST suggest that total column water vapour has increased by 4% since 1970. Similar upward trends in upper tropospheric specific humidity, which considerably enhances the greenhouse effect, have also been detected from 1982 to 2004.

Evaporation

Global land evapotranspiration closely follows variations in land precipitation. Evaporative demand is likely to increase almost everywhere because both the water-holding capacity of the atmosphere and the evaporation rate increase with higher temperatures.

Soil moisture

Annual mean soil moisture content commonly decreases in the sub-tropics and the Mediterranean region.

Groundwater

Climate change will affect groundwater recharge rates (i.e., the renewable groundwater resources) and groundwater levels. However, even knowledge of current recharge and levels in both developed and developing countries is poor; and there has been very little research on the impact of climate change on groundwater. The variability of precipitation may increase it in semi-arid and arid areas where heavy rainfalls and floods are the major sources of groundwater recharge. Flood events of higher magnitude will result in more runoff finding its way to the sea rather than recharging aquifers.

Streamflow

The discharges from high latitude rivers is likely to increase, while those from rivers in the Middle East, Europe and Central America is likely to decrease.

Droughts

Globally, the proportion of the land surface in extreme drought at any one time is predicted to increase 10 to 30 fold by the 2090s. In addition, the number of extreme drought events per 100 years is expected to double and mean drought duration to increase six fold - by the 2090s.

Water quality

Higher water temperatures, increased precipitation intensity and longer periods of low flows will exacerbate many forms of water pollution, including sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt and thermal pollution. In semi-arid and arid areas, climate change is likely to increase salinization of shallow groundwater due to increased evapotranspiration.

As streamflow is likely to decrease in many semi-arid areas, salinity of rivers and estuaries will increase.

Floods

The frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) will also very likely increase over most areas; and the intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas. Even in areas where mean precipitation decreases (most sub-tropical and mid-latitude regions), precipitation intensity is likely to increase - but with longer periods between rainfall events. This would affect the risk of flash flooding and urban flooding.

The effects of climate change on the Arabian Peninsula

There is a plethora of predictions of the effects of climatic change on water resources, and they often differ considerably. For example, Tao *et al* (2003) state that water shortage is expected to worsen in western Asia and the Arabian Peninsula, while Dai *et al.* (2001) reckon that large precipitation increases, up to 50%, are to be expected over northern mid- and high latitudes and over India and the Arabian Peninsula.

Monsoon and El Niño Southeastern Oscillation (ENSO) patterns might change, but climate models are not conclusive. The previously noted intensification of El Niño tropical precipitation anomalies in a warmer mean base state that applied when there was no appreciable change in El Niño amplitude does not hold in the present study of Meehl *et al.* (2005) where the El Niño events decrease in magnitude in a future warmer climate. The predicted sea-level rise by up to 0.88 m by 2090 is expected to be a problem in some low-lying areas, like the southern Arabian Gulf. Fischer *et al.* (2006) and Arnell *et al.* (2004) also project increases in water stress—the ratio of irrigation withdrawals to renewable water resources—in the Middle East.

Groundwater recharge is a major and often the sole source of natural water supply in the Arabian Peninsula. Döll and Flörke (2005) present a global map that depicts impact of climate change on long-term average annual diffuse groundwater recharge. Percent changes of 30-year averages groundwater recharge between 1961-1990 and the 2041-2070, as computed by WGHM applying four different climate change scenarios (climate scenarios computed by the climate models ECHAM4 and HadCM3, each interpreting the two IPCC greenhouse gas emissions scenarios A2 and B2).

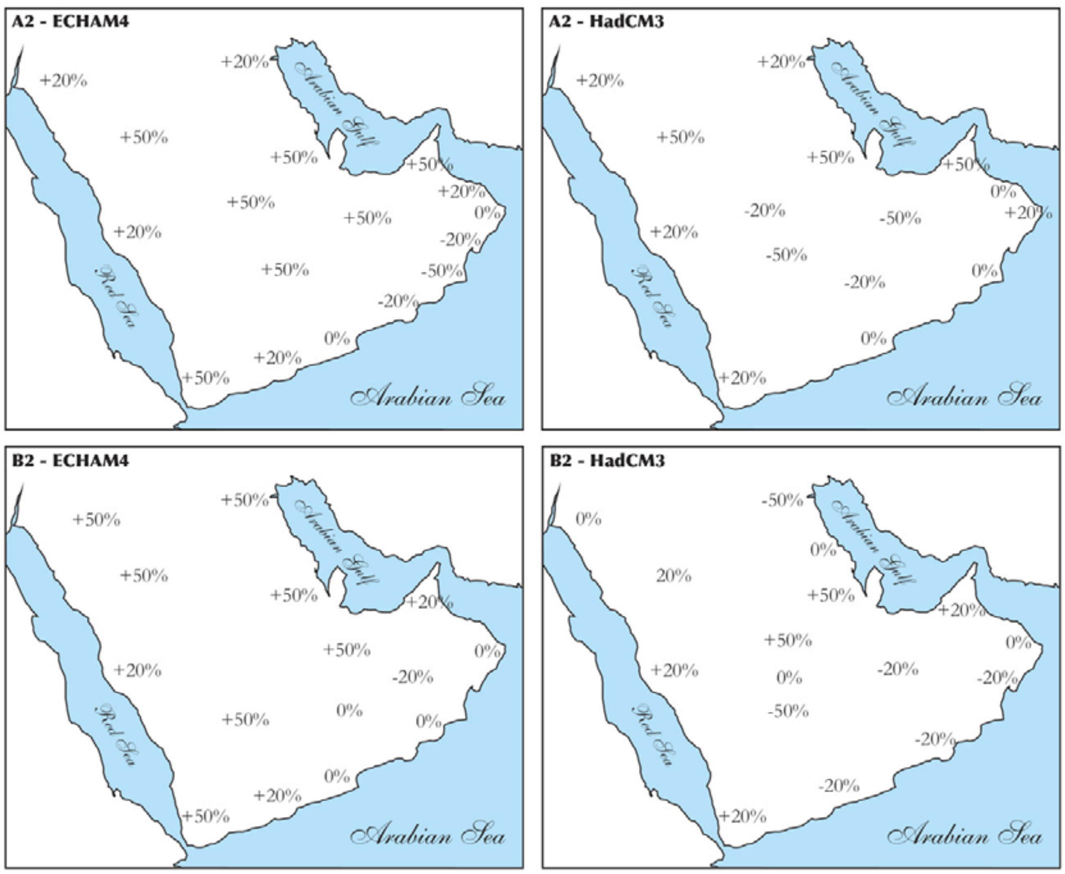

Figure 4. Change of groundwater recharge in 2050 in relation to a base period of 1960-1990 (based on Döll and Flörke, 2005).

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Chauvin and Denvil (2007) state that extremes of precipitation also experience a change toward more intense precipitation events in winter and longer dry events in summer.

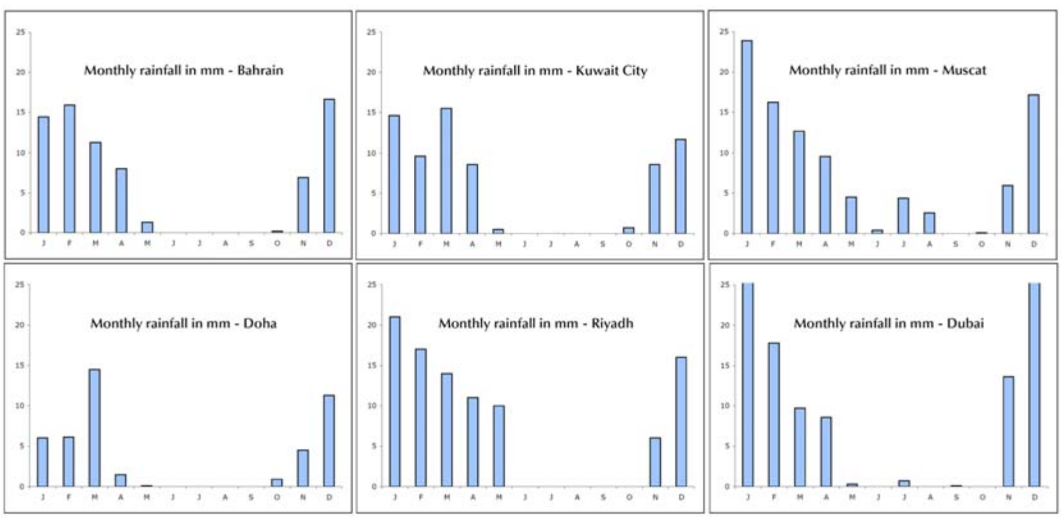

Figure 5. Mean monthly rainfall in capitals of GCC countries

As can be seen from Figure 5, rainfall events in most locations of the Arabian Peninsula are confined to winter, with minor exceptions of annual monsoonal and occasional cyclones along its east-southern rim (Muscat). Considering higher summer/lower winter rainfall scenarios, summer rainfall increases will not contribute to much runoff, however, winter rainfall decreases will significantly reduce the amount of runoff at all locations depicted in Figure 5.

Hydrological considerations indicate that increased rain intensity combined with a reduction in of annual rainfall is likely to reduce vegetation cover and increase surface runoff, leading to increased desertification. The resulting soil erosion, salinization, and loss of vegetation will further increase surface runoff. Agricultural fields will become more saline from increased evapotranspiration.

Increased surface runoff from major rainfall events will increase flash floods peak flows which will lead to destruction of property and crops. Possible adaptations include water-sensitive urban planning to reduce surface runoff, promotion of structures that increase water infiltration into the soil, and conservation and rehabilitation of natural vegetation in rural areas.

Conclusions

There is a very high probability (>99%) that a significant climate change will affect most areas of Earth in the foreseeable future. Present arid and hyper-arid areas will generally become even drier. Even if the annual amount of rainfall changes little in these areas, rainfall intensity will increase due to overall acceleration of the hydrological cycle. Extreme weather events both in temperature and precipitation are likely to occur more often, leading to both more floods and droughts. In the Arabian Peninsula, we could expect more violent floods, and more severe and long-lasting dry conditions.

However, the overall futuristic picture for the Arabian Peninsula is underdeveloped and sketchy, with many models in disagreement on the magnitude, and even the sign of change. Given the importance of water in this one of the driest places on Earth, the GCC countries should give consideration to the development of their own advanced forecasting tools, to be followed by the development of suitable water resources management measures. There is a need for effective adaptive measures against increased uncertainties and frequency of extreme climatic events. For example, a cursory examination of flood mitigation and protection facilities in many countries of the region shows that they are seriously under-designed by an indiscriminate application of flood calculations that are mindlessly transposed from countries with totally different rainfall and runoff patterns.

The climatological effects of greening effect over the desert (Hozumi and Ueda, 2005) warrants further research. Measures for combating desertification, such as afforestation, and methods for rehabilitating and regenerating natural vegetation are also adaptations for climate change.

The projected widening of the gap between supply and demand caused by climate change will exacerbate water scarcity. This will require an elastic adaptation to the change, by improved management of water demand, increased conservation efforts, and development of additional water sources that may include treating and recycling wastewater, desalination, dual distribution systems, and an extensive range of other water resources development options, which may sound impractical at present, but will become feasible in future.

Country	Water availability million m^3/year			Water use million m^3/year				Water deficit million m3/year
	Rene-wable	Desali-nation	Total	Muni-cipal	Industry	Agricul-ture	Total	
Bahrain	110	76	**186**	107	19	161	**287**	**-101**
Kuwait	160	418	**578**	520	13	140	**673**	**-95**
Oman	900	55	**955**	85	6	1150	**1241**	**-286**
Qatar	50	132	**182**	85	17	337	**439**	**-257**
Saudi Arabia	3850	1022	**4872**	2387	193	18575	**21155**	**-16283**
UAE	190	674	**864**	600	73	1539	**2212**	**-1348**

Table 1. Water deficit of GCC countries, based on figures from WB (2005).

However, it should be remembered that many scenarios and graphs which attempt to portray the future are predictions, not facts, and generally, much more research is needed to improve our current status of understanding of weather and climatic phenomena. As they say, arid zone hydrology is one of the highest forms of art and science, so it stands to reason that there is no substitute to the development of local expertise. As ESCWA (2003) postulates, Arab countries should be made aware of and provide more inputs to the IPCC deliberations, and the IPCC should give more attention to guidelines on vulnerability and adaptation issues. Capacity building efforts should include national and/or regional expertise to collect, process and analyze data for enhancing the preparation of national communications and planning for sustainable development.

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Crossing the Threshold of a Higher Order Urban Groundwater Level Forecast

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Abstract:

This study investigates the periodic pattern of groundwater level for monitoring wells located in residential areas in Kuwait. Monthly water-level measurements obtained by the Ministry of Energy during a period of 10 years were employed to examine the relationship with monthly-averaged temperature and –totaled rainfall. The periodograms of the subsurface water-level, rainfall, and temperature data were also determined. The results reveal that the water-level periodogram has significant periodicities of 12-month, coincident with that observed in the last two climatological data, and of 27-month, in the rainfall. A time series model that triggers the influence of the two detected periodicities was developed as an attempt for providing a higher order forecast of monthly water-level changes.

Keywords: Annual periodicity; Groundwater level rise; Periodogram; QBO; Seasonality.

Introduction

Groundwater level increase constitutes a common problem in some residential areas of Kuwait City and the suburbs. For example, at some residential locations, the water table became at a level of 2 m or less below the ground surface. One problem is attempting to explain the pattern of subsurface water table variation and thus forecasting the future sequential records. The varied water level pattern among different seasons and years drives to investigate in an objective manner the main parameter responsible for this behavior. It is believed that the human-induced recharge activities have high impact on groundwater level changes in the residential areas of Kuwait, of desert environment, mostly from the excessive irrigation of private gardens and public parks (Senay, 1991). However, it is impractical to assess directly this source of groundwater recharge, because the prevailing factors that influence the mode of people for watering activities are highly interrelated and difficult to measure. Rather, different climatological parameters such as temperature and rainfall are available and can possibly be considered to find, in an indirect manner, any causative relationship with groundwater level fluctuations. This can also be performed for a relatively short period of time (say ≤ 10 years), during which the growth of population in an occupied residential location can be assumed, to some extent, ineffective on water level fluctuations.

This study investigates the variation pattern for groundwater level measurements available from monitoring wells located in residential areas in Kuwait. Initially, the variation of water level records is compared with that of temperature and rainfall so that to examine the correlation and to draw general conclusions regarding the relationship with groundwater table changes. Then, the cyclic structure of the three data sets of water level, temperature, and rainfall is examined in the frequency domain by using the periodogram technique. Moreover, a sinusoidal model that exploits the nature of the periodic pattern for the water level data is developed and verified.

Components of Water Level Series

Monthly water-level measurements collected during a period of 10 years (1993-2002) from a monitoring well of HL-1A, located in a residential area southeast of Kuwait City (Figure 1), can be used to examine the correlation with climatological parameters such as temperature and rainfall. As seen in Figure (2), two main components of time series can be identified: long term trend, and short term seasonality. The trend of water level increases with the time and has an obvious shift in the mean starting from the beginning of 1997 until the middle of 1999. The shift in the runoff series observed for this data set is mainly due to human-induced factors, dewatering activities related to construction works. To examine more closely this component of time series, the water level data of HL-1A can be divided into three ranges, before, after, and within the shift. Then simple linear regression technique can be used to fit separately a trend for each data range, and the corresponding slope of the fitted trend can then be determined. This formulation yielded the overall regression relation for HL-1A

$$y(t) = \begin{cases} 0.0158t - 5.3091, & \text{if } t < 48 \\ 0.0122t - 5.7302, & \text{if } 48 \le t < 80 \\ 0.0045t - 4.4914, & \text{if } 80 \le t \le 120 \end{cases} \qquad (1)$$

where y = trend component of water level; and t = time elapsed since January 1993 in months. From Equation (1), the trend before the beginning of 1997 has a relatively steep slope equal to 0.0158. The slope decreases to 0.0122 during the shift period and then approaches 0.0045 after that. These changes in slope may be attributed to urban development that tends to increase the impervious surface area at the study location, thereby reducing the amount of water infiltrated into the subsurface. Although the slope declines during the time specified, the overall trend suggests that the water level approaches the ground surface in a continuous manner.

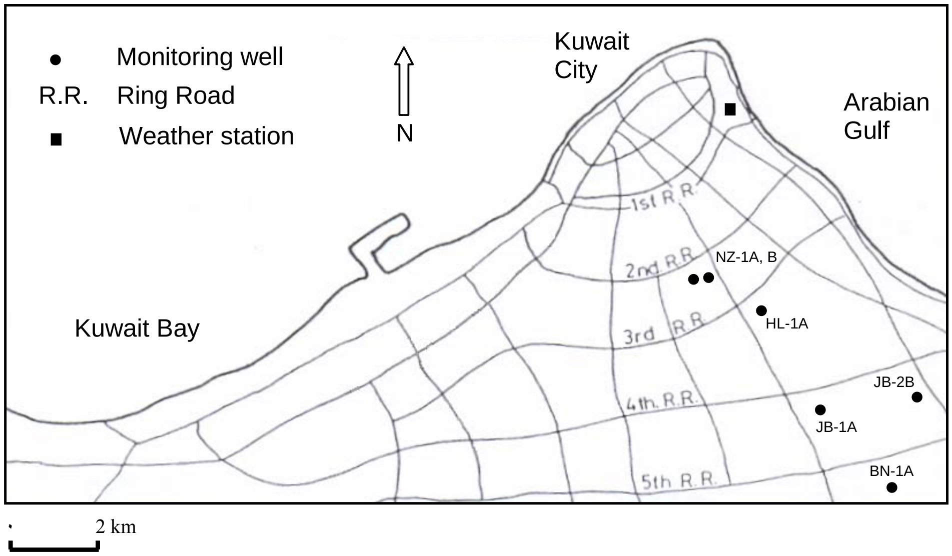

Figure 1. Map showing the location of the monitoring wells.

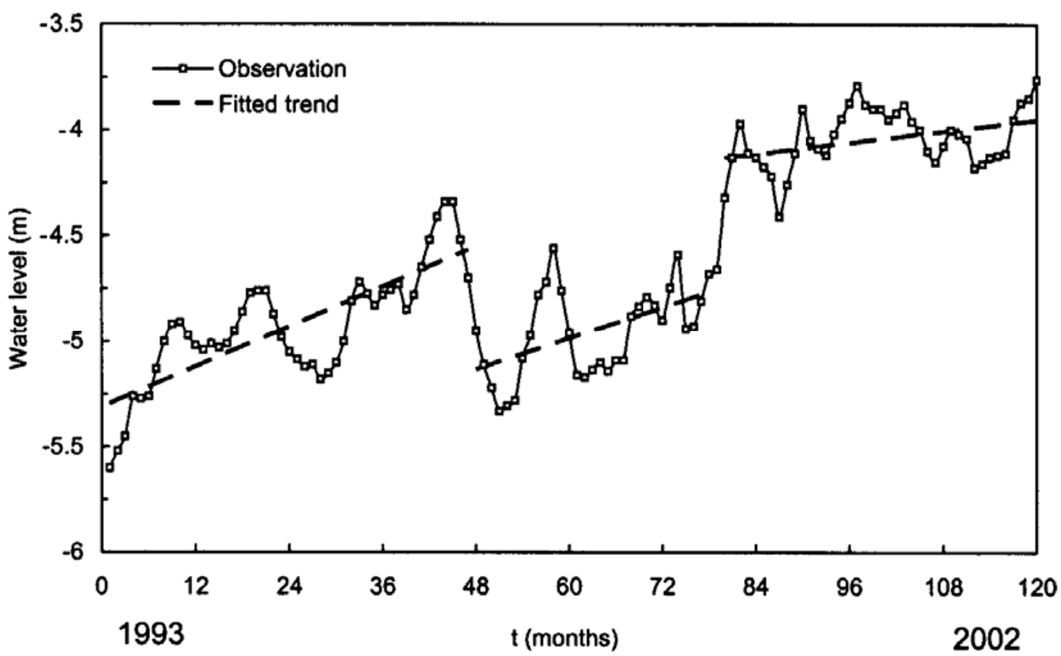

Figure 2. Groundwater level data for HL-1A during the period 1993-2002.

The second component of time series is a short-term periodic pattern. This component observed in the water level data seems to have a more complicated behavior than that of the trend. It is important to remove the trend component from the data in order to study the periodic behavior more clearly. This can be achieved by subtracting Equation (1) from the water level data. By this way, the detrended water level data will have a mean value equal to zero.

Figure (3) shows the variation of the detrended water level data of HL-1A together with the monthly-averaged temperature and -totaled rainfall series, both of which were obtained for the same time duration and for a location sufficiently close to that of the monitoring well.

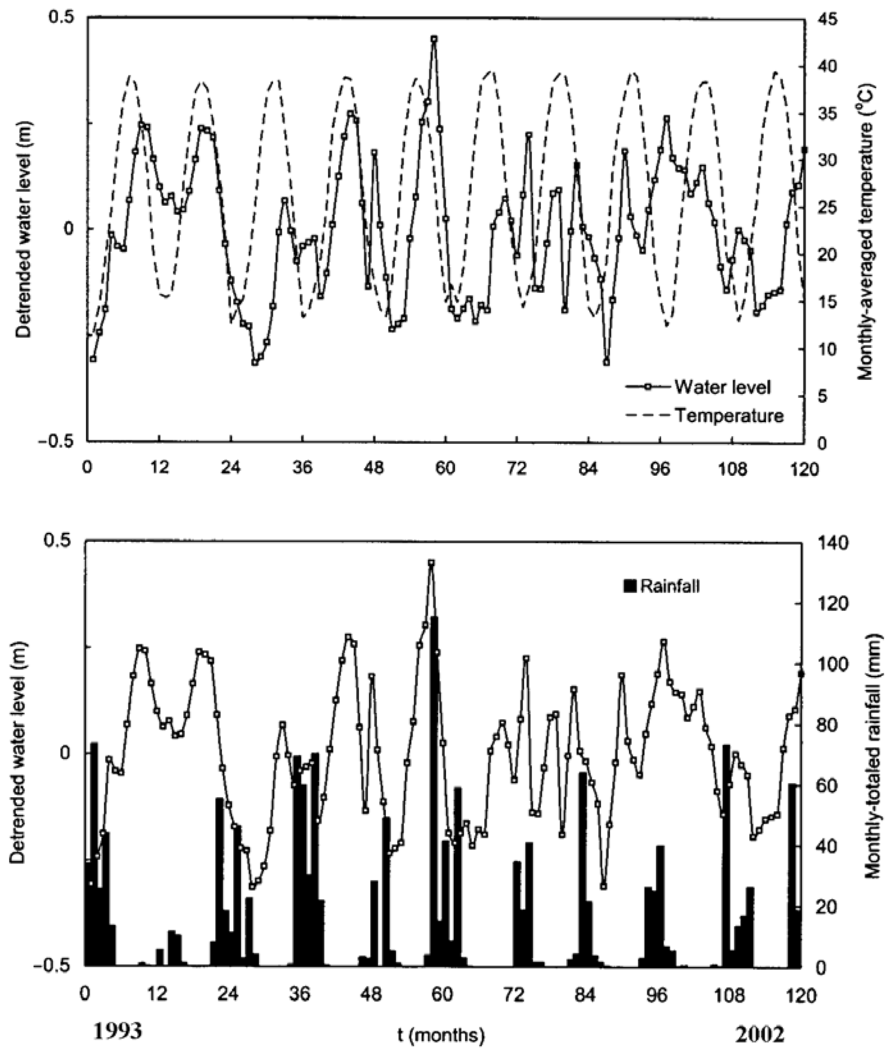

Figure 3. Detrended water level for HL-1A versus temperature and rainfall during the period 1993-2002.

While the plotted data exhibit a complicated behavior during the time period, an apparent correlation can be observed such that the variation of the water level is directly and inversely proportional to that of temperature and rainfall, respectively. This correlation can better be described by considering statistics on a seasonal basis. The seasonal mean for the three data sets, of water level, temperature and rainfall, is obtained by using the expression

$$\bar{j} = \frac{1}{N}\sum_{\nu=1}^{N} j_{\nu,\tau} \qquad \tau = 1,\ldots,12 \tag{2}$$

where j = seasonal time series; $\bar{j}$ = seasonal mean; and N = total number of years. The results are shown in Figure (4). The correlation coefficient of the seasonally-averaged water level with temperature data, r_T, has a value equal to 0.37 and that with the rainfall, r_R, is -0.44. From Figure (4), the subsurface water level rises from March through October and declines during the winter season. The reason for this observed seasonality is highly related to human-induced recharge activities such as irrigation and gardening. The decline in water levels normally occurs during winter, because watering activities are relatively less. This proportionality with temperature and rainfall can also be found in water level data collected from other monitoring wells, as shown in Table (1). The wells presented in this table were randomly selected from others available exhibiting the problem of subsurface water-level rise.

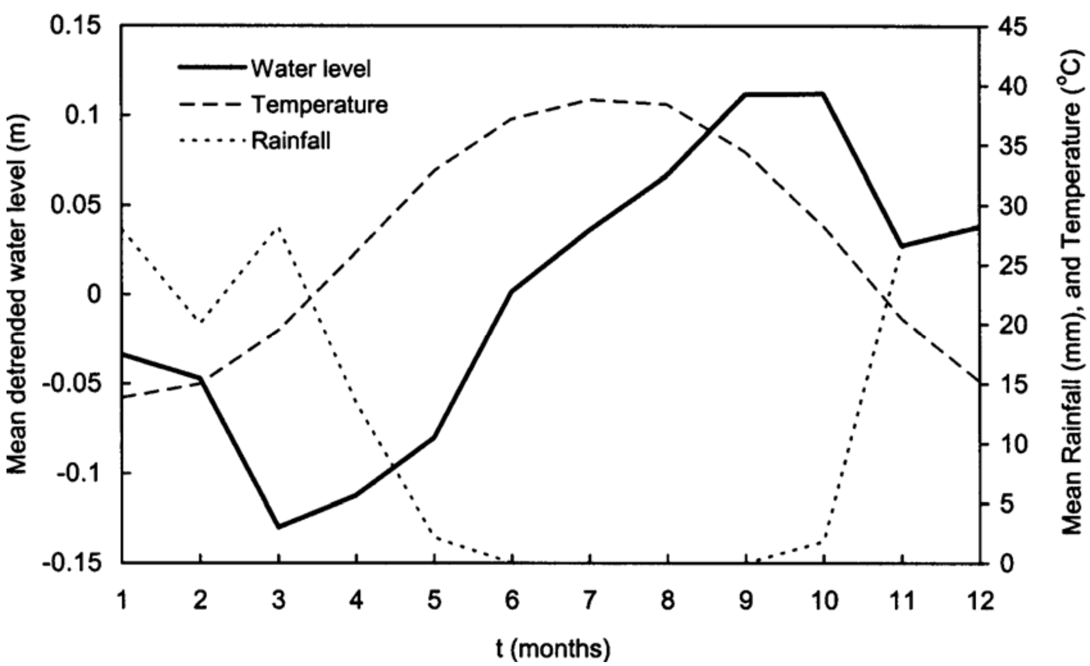

Figure 4. Seasonal mean variation for the monthly series of detrended water level (HL-1A), temperature and rainfall calculated by using Equation (2) for the time duration from January 1993 to December 2002.

Table 1. Groundwater level data condition for the examined wells.

Well No.	[a]Ground Level (m)	Duration (year)	[b]Water Level (m)	r_T	r_R	Periodicity (months)
BN-1A	27.74	1992-2001	8.42-12.23	0.35	-0.29	12, 20, 30
JB-1A	23.00	1993-2002	4.52-6.08	0.26	-0.37	12, 17
JB-2B	14.23	1993-2002	1.92-2.56	0.43	-0.58	12
HL-1A	20.06	1993-2002	3.76-5.60	0.37	-0.44	12, 27
NZ-1A	16.45	1992-2000	2.68-4.07	0.36	-0.43	12, 18
NZ-1B	16.45	1993-2000	2.68-4.07	0.34	-0.43	12, 19

[a]Above MSL (Mean Sea Level).

[b]Below ground surface.

Periodic Behavior

The periodic behavior of the monthly water-level data of HL-1A is investigated in Figure (5) by using the periodogram technique, which is an unsmoothed spectral plot for examining the cyclic structure in frequency domain (Brockwell and Davis, 2002). As seen in the figure, there are two dominant periodicities in the water level data of 12 and 27 months. Apparently, the 12-month period is related to the annual variation of temperature and rainfall events typically observed in climatological data.

This is evident, given that the same 12-month period exists in the examined periodograms of temperature and rainfall. It is interesting to examine the second periodicity of the 27 months. This period exists in the periodogram of rainfall, which has a more complicated cyclic structure than that of both temperature and water level.

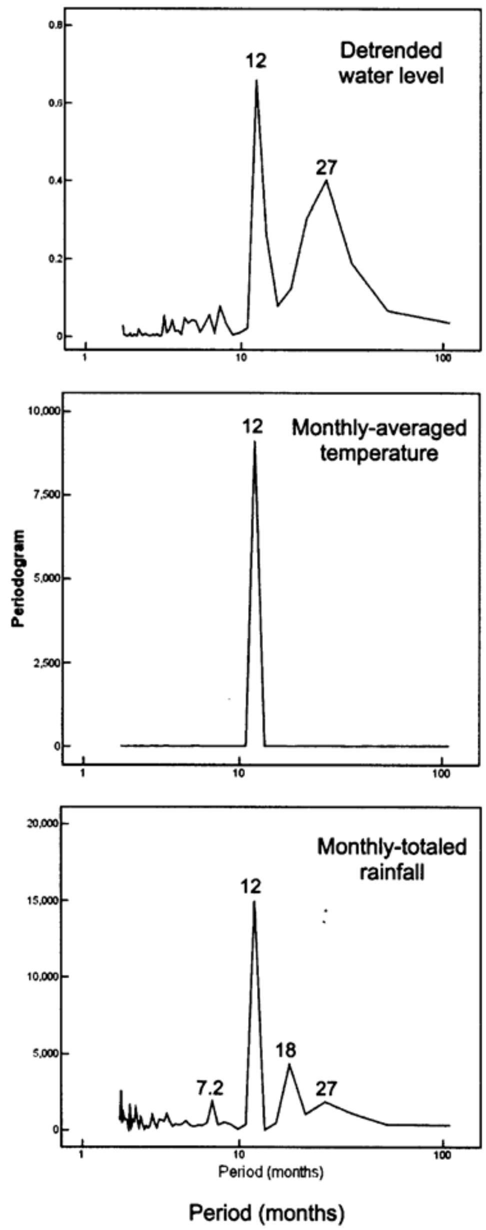

Figure 5. Periodograms of detrended water level (HL-1A), temperature and rainfall
for the time duration from January 1993 to December 2002.

It is worth mentioned that the 27th periodicity has been observed in rainfall data for areas located near the equator such as India (e.g., Naidu *et al.*, 1999) and Indonesia (e.g., Shimizu and Tsuda, 2001). For example, India is located between latitudes 8° and 36° north. This can also be the case for Kuwait, which is located between latitudes 28° and 30° north. Most likely for locations close to the equator the 27-month period of rainfall is attributed to the well-known Quasi-Biennial Oscillation (QBO) in zonal wind, a dominant natural oscillation in the equatorial lower stratosphere (e.g., Ebdon and Veryard, 1961). The QBO is described as the phenomenon of reversal of wind directions; that is, for about one year the prevailing wind direction is easterly, while during the following year it is westerly (Angell and Korshover, 1964).

Though other periodicities are present in the periodogram of rainfall, they are not significant in the plot of water level data. This is not a surprising result because of the presence of other prevailing factors that may have a direct influence on human-induced recharge activities, which play an important role in the variation of groundwater level. One obvious periodicity not present in the water level data is that of the 18 months. The existence of this period in rainfall data may be attributed to climate variability and need further investigation to establish any relationship. Although the 18-month period of rainfall is not present in the water level data of HL-1A, it can be found in another series obtained for a different residential location as NZ-1A (see Table 1). Periodicities close enough to this one are also found in BN-1A, JB-1A and NZ-1B, having 20-, 17- and 19-month periods, respectively. Moreover, it can be expected that the 27th period of rainfall present in the water level data of HL-1A can rarely take place in another series from a different well location. This can be related to the same reason mentioned earlier in this paragraph, regarding the influence of other factors on artificial recharge activities. Nevertheless, a periodicity that is sufficiently close to this one is available in the data of BN-1A.

Model Formulation and Forecast

A possible application for examining the behavior of water level data is to employ the detected periodicities for forecasting groundwater table variation. An example is provided here using the HL-1A data with the periodicities of 12 and 27-month. A time series containing a periodic sinusoidal component with a known wave length can be modeled using

$$s(t) = \sum_{i=1}^{k} R_i \cos\left(2\pi f_i t + \theta_i\right) \qquad (3)$$

where s = periodic sinusoidal component of water level; R_i = amplitude of variation; f_i = frequency, equal to the inverse of period; θ_i = phase angle; and k = total number of periodicities. The term $(2\pi f_i t+\theta_i)$ is measured in radians. Apparently the k value is equal to two, and the values of f may be set by the periodic nature of water level variation, *i.e.*, f_1 = 1/12 and f_2 = 1/27 cycles per month. The phase angle, θ, is necessary to adjust the model so that the cosine function crosses the mean, which is equal to zero for the detrended data, at the appropriate time t. The values of θ_i and R_i can be determined by means of numerical optimization method. The range of detrended water-level data until December 2001, having 108 of monthly measurements, can be used to fit the model, while the remaining range of 12 measurements may be employed to perform the model verification. The fitted periodic sinusoidal model for HL-1A is found to be

$$s(t) = 0.11067 \cos\left(\frac{2\pi}{12} t + 1.526\right) - 0.086376 \cos\left(\frac{2\pi}{27} t - 0.64181\right) \qquad (4)$$

The overall model including the trend of Equation (1) can then be expressed by

$$h(t) = y(t) + s(t) + \varepsilon(t) \qquad (5)$$

where h = overall water level; and ε = error term. The error term, ε, represents the remaining stochastic component of time series free from the non-stationary trend and periodicity, and it is usually taken to be sufficiently stationary in simple time series models. To evaluate specifically the two systematic components, the trend and the periodic, □ is also assumed to be uncorrelated random variable with zero mean. Based on this, the performance of the model can be tested.

The overall observed and calculated water level data of HL-1A (by Equation 5) are presented in Figure (6). As seen, the model fits the data with some variation that could relatively be considered as random. It is also seen that the range of data from the beginning of 1997 to the middle of 1999, with the shift due to dewatering activities, has a higher variation from the remainder. This is expected when active construction works occur within the effective area. Figure (6) also presents three years ahead forecast for the period from 2003 to 2005, with 36 data points. As can be seen, the water level will increase continuously until approaching 3.6 m below the ground surface. The implication is that the model can be used to set a time plan for starting a continuous dewatering process for the examined residential location to avoid problems related to groundwater level rise.

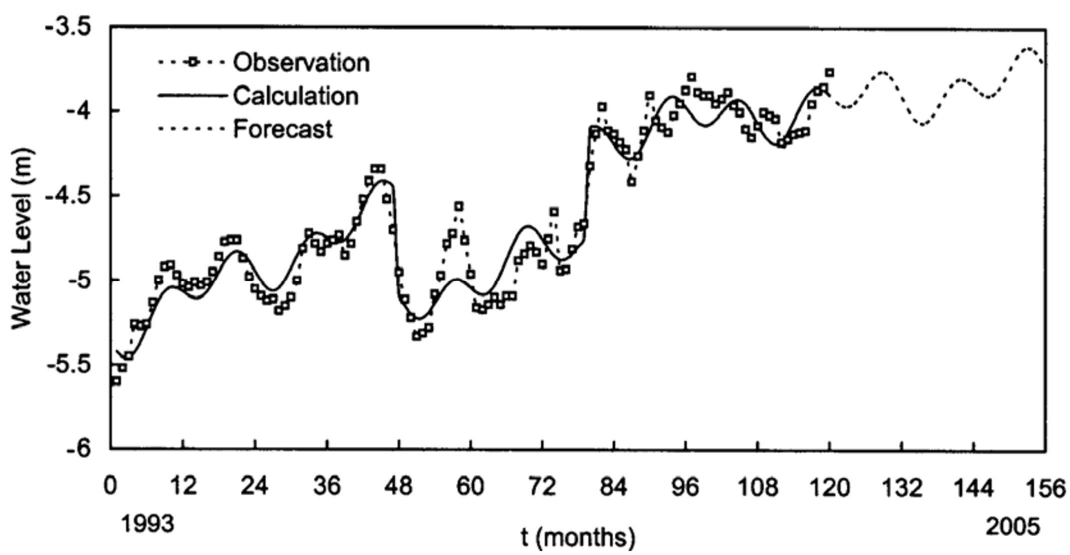

Figure 6. Observed, calculated and forecasted groundwater levels for HL-1A.

Conclusions

This study has revealed that the water level variation in the examined residential locations in Kuwait experiences a seasonal behavior during the year with positive and negative correlations of temperature and rainfall, respectively. The seasonality suggests, in turn, that the water level variation is highly pertinent to human-induced recharge activities such as irrigation and gardening.

The present study has also shown that, examining the periodogram of the monthly water-level series indicates causative relationship with climatological parameters and can provide means for modeling and forecasting groundwater table fluctuations. This has been supported by applying a sinusoidal model exploiting the nature of the periodic pattern of water level fluctuations for HL-1A to help with the assessment of future groundwater table changes in the residential location.

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Towards Sustainable Management of Jerash Watershed- The SMAP Project

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Abstract

With limited resources and rapidly increasing demands, sustainability is becoming an increasingly important, yet difficult goal to achieve in wadis (Salih and Ghanem, 2003). Sustainability of wadi systems is more complicated due to the conflicts and interactions among the different resource utilizations. It is a fact that sustainability of any natural entity can only be achieved through an integrated approach for its management.

In this paper, an attempt is made to summarize the challenges facing sustainable development of wadi Jerash and to propose some solutions towards achieving that goal. The challenges considered in this paper include technical, socio-economic, environmental, institutional, political and legal aspects. Wadi Jerash project area is defined as the surface catchment of the Zerqa River in Jordan, is taken as an example due to its characteristics as a natural environmental set-up that need to be managed in a comprehensive, sustainable manner.

The proposed methodologies are based on the outcome of wadi al Far'a and Jerash integrated watershed management project. The overall aim of the project is to create sustainable development conditions for the study area through which water resources, natural resources and human resources are protected and conserved. The project is conducted by the Jordanian ministry of Environment (MoEN) and United Nation University-International Network on Water, Environment and Health (UNU-INWUH) with financial support from the European Union (EU); Short and Medium term environmental Action Program (SMAP) and the Dutch Ministry of Environment (VROM).

Key words: sustainability, wadis, hydrology, Jordan, Jerash Watershed

1. Background

Sustainable development may be defined as the ability to meet the needs of the present without compromising the ability to meet future needs (Serageldin, 1995). This can be projected on wadi development from different perspectives. While one might visualize sustainability as a physical concept for the preservation of a single resource (e.g. water), another might consider a larger, but still purely physical scope, of conservation of a group of resources or an ecosystem (e.g. within a wadi watershed or basin). A third could apply the concept through a wider vision encompassing physical-social-economic-ecological aspects (Dixon and Fallon, 1989).

The first definition of sustainability with regard to a single resource is too narrow regardless the importance of that resource. The interrelationships between the different forms of water, from rain to surface and groundwater, and the complex processes involved of rainfall, runoff, erosion, deposition, seepage … etc. will logically introduce other aspects such as surface and underground geology, morphology, biology, … etc. Further, it is not merely the quantity of freshwater that is relevant, but also its quality and distribution in time and space in relation to other elements of the ecosystem as defined, for example, by a watershed (Salih and Ghanem, 2003).

However, even this second definition of sustainability as a physical concept for an ecosystem is also too narrow. This because interest is not only in the preservation of the physical entities of the ecosystem, but also in the sustainability of potential services provided by the ecosystem's resources, and the impact of human activities and behavior on the system. This leads to the adoption of the third global view, encompassing all physical, social, economic and ecological aspects of wadi development. Thus, sustainable management of wadi systems should satisfy present objectives of society, without compromising the ability of the system to satisfy the objectives of future generations (Hufschmidt, 1993). Services provided by the system to society include support to activities such as domestic, agricultural, industrial, and recreational uses, as well as the maintenance of the ecosystem. The value to society, in the form of economic productivity, human health, biodiversity and social equity needs to be maintained.

Based on the above and due to the existence of a multitude of interacting and interdependent systems in wadis, a truly integrated wadi management approach is essential, which incorporate the subsystems into a larger encompassing system.

The approach of Integrated Watershed Management has brought about a drastic change in how to resolve environmental problems, moving from a supply-oriented, engineering bias towards the demand-oriented, multi-sectoral approach and preferable, decision making at the lowest appropriate level (Loucks and Gladwell, 1999).

Integrated Watershed Management adopted in this study, is about more than simply matching demand with resources. It entails a series of crosscutting policy issues that are an integral part of the decision-making process. These issues relate to two core elements:

A: Sustainability:

The following aspects of sustainability are distinguished:

- Technical sustainability (balanced demand and supply, no mining)
- Financial sustainability (cost recovery)
- Social sustainability (stability of population, stability of demand, willingness to "pay")
- Economic sustainability (sustaining economic development or welfare and production)
- Institutional sustainability (capacity to plan, manage and operate the system)
- Environmental sustainability (no long-term negative or irreversible effects)

Sustainable development is a key concept in watershed management.

B: Stakeholder involvement: taking account of public interest and sharing ownership:

Integrated Watershed Management takes account of:

- all natural aspects of the natural resources
- all sectoral interest of stakeholders (inter-sectoral approach)

- the spatial variation of resources and demands (upstream-downstream interaction, basin-wide analysis, inter-basin transfer).
- relevant policy frameworks (national objectives and constraints (social, legal, institutional, financial, environmental))
- all institutional levels (institutional framework and stakeholders (national, provincial, local))

Four activities were distinguished:

Resources Development: actions, mostly physical, that lead to the beneficial use of land and water resources for single or multiple purposes.

Resources Planning: planning of the development, conservation and allocation of a scarce resource (sectoral and inter-sectoral), matching availability and demand, taking into account the full set of national objectives and constraints and the interests of stakeholders.

Planning is only effective if all interested parties during the planning and implementation stage (stakeholders) are – in one way or another – involved in the process of decision making and feel committed. *If not the project or programme is likely to fail.*

Resources Management: the whole set of technical, institutional, managerial, legal and operational activities required to plan, develop, operate and manage resources for sustainable use.

Demand Management: the development and implementation of strategies aimed at influencing demand, so as to achieve efficient and sustainable use of a scarce resource. Demand management should be considered as one of the most important components of Integrated Watershed Management strategies (next to institutional arrangements and physical measures). It entails a set of actions to be taken by the manager to reduce demand, which include:

- Awareness and promotion;
- Education and training;

- The formulation and application of incentives to influence the demand for water. Implementation incentives for demand management can be grouped in two main categories:
- Economic instruments, which include: charges, subsidies, taxes, and regulations which create markets where water rights and emission rights can be traded;
- Legal instruments, including for example general quota or individual licenses for extraction or discharges and ambient water quality standards. Such regulations are often combined with financial enforcement incentives such as fines and penalties.

2. Description of the Study Area

The proposed Jerash watershed project area is defined as the surface catchment of the Zerqa River (Figure 1). It covers about 117 hectares. The catchment area consists of a main river valley with various springs fed tributaries. The Baga'a basin, a relatively flat depression, within the catchments, is the main groundwater infiltration zone. The Baqa'a basin accommodates a large settlement. The main economic activity here is groundwater irrigation. The lower regions of the Zerqa region, as well as the Jordan valley itself, are subject to structural water shortages. Especially the agricultural sector here is suffering from these shortages.

The King Talal Dam, is the main physical intervention in the area. Its objective is to optimize and regulate water supply for the downstream agricultural activities in the Zerqa region and the Jordan valley, as well as generation of hydropower. To reach this objective, substantial amount of the upstream surface water runoff needs to be intercepted and stored in the reservoir. However, an already significant part of this water is currently applied for agricultural purposes upstream of the reservoir, and is lost for downstream users as result of evapotranspiration. During dry periods, the dependence on the scarce groundwater resources increases, causing higher abstraction rates and increasingly lowering groundwater tables.

Locally, this causes increasing salinity rates. A large portion of the rural wastewater is discharged without treatment in the wadi systems. This causes increasing nitrate and coliform concentration in groundwater and springs.

Still, population growth and overgrazing are important driving forces for the erosion problems. Also water scarcity and abandoned agricultural lands are important causes for land degradation, desertification and erosion.

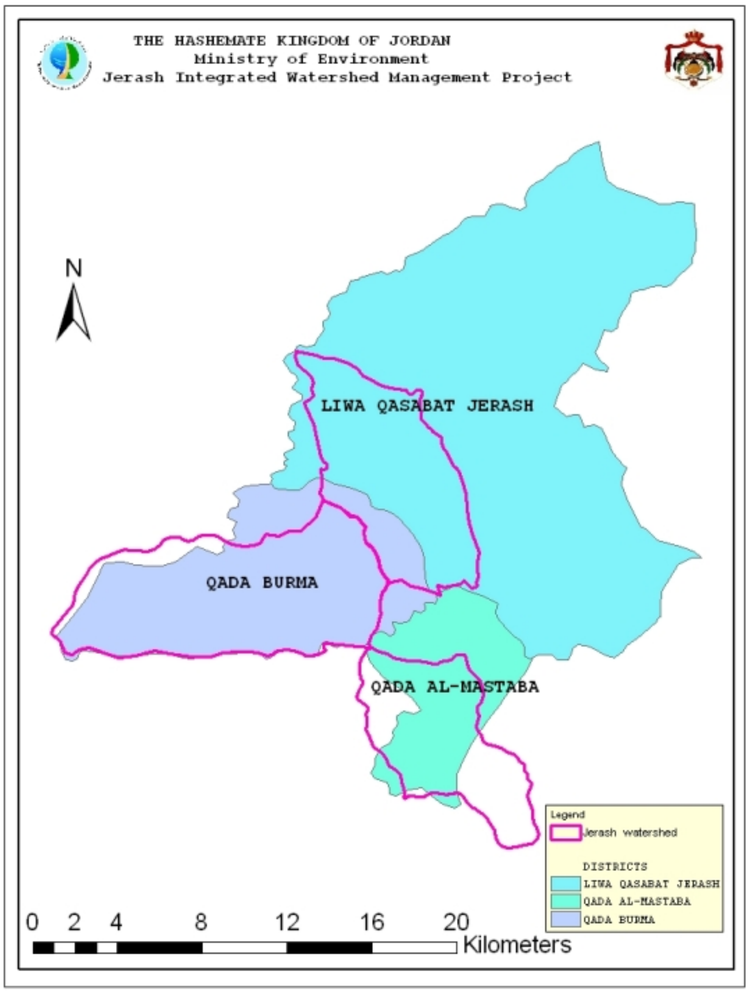

Figure 1: Location of Wadi Jerash catchment

A series of environmental themes, relate to the watershed related problems that are addressed in this study. A practical watershed management plan is urgently needed. Such a plan should be based on realistic options and alternatives, and should therefore ideally be based on experiences of a series of already implemented pilot actions. The relevance of this proposed SMAP Integrated Watershed Management Project is therefore very high.

The anticipated project results are urgently needed to reverse the deterioration of Jerash watersheds.

The study takes furthermore into account the measures and actions that have already been initiated through other channels, such as the numerous small-scale rural developments projects that have been realized by the other projects in the area. The project is fully in line with other programmes and initiatives in the region, such as the Initiative for Collaboration to Control Natural Resources Degradation of Arid Lands in the Middle East, under leadership of the World Bank and administrated by ICARDA (International Centre for Agricultural Research in the Middle East).

3. Project Design

Policies and strategies, developed by ministries are often theoretical, without input from those for whom the strategies are developed. Therefore, implementation of interventions, developed at national level, does not always lead to guaranteed success. Two-way interaction should take place and interests and decisions at lower levels need to be carried upward to be taken into consideration at higher levels, particularly to the national level. An important element in this process is the *participation of stakeholders in decisions processes at all levels*; this requires a *demand driven* approach instead of supply driven.

Action plans should be in line with the general strategies at national level, but backed up by practical experiences from local level. To include experiences from local level, our project approach will therefore be *bottom up* instead of top down.

The project teams will learn from information and knowledge from farmers and other stakeholders at local level. The project will use this information to develop methods to select and implement sustainable interventions, which will improve the living conditions of the rural population. The experiences will be transformed into action plans, using methodologies, which can be replicated in other areas. The methodologies will be tested in two watersheds (in two different countries), and exchange of experiences will improve our learning process.

3.1Technical Aspects

Several problems have occurred in the past due to a fragmented view of a wadi system. This is mainly because decision-makers and planners did not consider or were not aware of the nature of such systems (Wheater, 1997). Many projects are planned and executed without any consideration to the boundaries of the watershed and its physical features. Maintaining the integrity of the hydrologic whole of the wadi system in any management plan to secure sustainability (Salih and Ghanem, 2003). To achieve this, a scientific understanding of the system is an essential component. Physical phenomena of precipitation, runoff, evapotranspiration, stream flow, seepage, sediment transport and deposition, and flooding should be carefully observed, measured and analyzed.

Unfortunately, our scientific understanding of these phenomena in wadi Jerash is still inadequate. Several difficulties underlie wadi exploration, including climatic conditions, difficulty to conduct measurements, and complexity and interdependency of the different processes. Further, there has been a noticeable lack of coordination of data collection activities and dissemination of information and techniques. The data collected under the Jerash project included information regarding the different elements of the natural environmental system and the socio-economic system in the region. The Jordanian Ministry of Water & Irrigation, and the Ministry of Environment were the main source for water resources data. Collected water resources data included the historical data for the wells, springs, and precipitation data related to the basin. The ministry of Agriculture was the main source for agricultural data related to the irrigated lands, existing cropping patterns, agricultural practices and socio-economics of different agricultural practices.

The Jordanian Department of Statistics was the main source for data on demography, the infrastructure and the socio-economics of the watershed. It was clear that the data collected can be classified as fragmented, incomplete and in-continuous. This data issue forms a main challenge to better understand the physical characteristics and processes of the Jerash catchment.

3.2 Socio-Economic Aspects

Sustainable water resources management should be based upon the social and economic circumstances existing within the boundaries of any water project. Although the importance of this statement is stressed in many reports, few specific cases can be found where the socioeconomic dimension has been given its proper share during the planning, design, implementation and management of such projects. It is true that in many water projects insufficient attention is given to social and economic aspects, such as land tenure, unemployment and involvement of beneficiaries. This has turned out to be a major constraint in water related projects in wadi Jerash.

In the Jerash project, special attention was given to this issue. Stakeholder's analysis for wadi Jerash was conducted. This involves the identification of a project's key stakeholders, an assessment of their interests, and the ways in which these interests affect project viability. It is linked to both institutional appraisal and social analysis, drawing on the information deriving from these approaches, but also contributing to the combining of such data into a single framework. Stakeholder analysis contributes to project design through the logical framework, and helps to identify appropriate forms of stakeholders' participation.

In wadi Jerash, the list of stakeholders includes:

Local level, including two general main groups:

- Local partners who support the project activities in the issues related to maintenance and sustainability.
- Agencies and NGO's actively working in the project area, which support the project in research and technical experience.

National level, including two general main groups:

- Governmental ministries and authorities that support the project in reporting, monitoring and other related activities.
- International consulting agencies that support the project in technical assistance and other related activities.

The conducting of the above mentioned stakeholder analysis allow the study team to better understand the socio-economic challenges within the Jerash watershed.

3.3 Environmental Aspects

Environmental aspects consideration is the key to success of any managerial plan in wadis. The importance of the environmental dimension has now been well recognized as of great influence on all elements of the hydrological cycle. In turn, terms like environmental hydrology are increasingly receiving global recognition. The effects of quality aspects -chemical, biological and physical-of the components of the hydrological cycle, can not at all be neglected. Real examples from wadi Jerash and based on the outcome of the projects are:

Deterioration of groundwater and surface water quality.
Low productivity of rain fed agriculture
Reduction of irrigated agriculture productivity
Improper management of natural resources
Deterioration of Public health
Land Degradation
Improper solid waste management practices

All the above mentioned issues form a challenge to any integrated management plan within the Jerash catchment. These challenges will have to be considered in an appropriate manner in developing any future plan for the area.

3.4 Political Aspects (Political Well)

So often political instability play as the major constrain in the sustainable development of wadi systems. Many wadis in the Middle East cross political boarders which, according to the international laws and principles, make them international water courses. In these cases, international water law principles should naturally apply but due to disagreements between parties, the international laws are often replaced by Caesar's Law (Al-Masri, 2005).

Historically, political aspects concerning water rights in wadis and watercourses have received great attention and different international water laws and principles have been proposed and applied to different wadi systems. In general, the weakness in these laws lie behind its general nature and the absence of some specific issues related to specific wadis.

3.5 Institutional and Legal Issues

The institutional and legal aspects represent an important component of any sustainable management plan for wadis (Abdulrazzak,1998). Institutional framework and the question of ownership are complex and diverse issues in many catchments including Wadi Jerash. Historically, legal aspects concerning the use of water in wadis have received great attention and the management of wadis' water resources has been well accepted ever since. Different legislations throughout history were enforced in wadi Jerash. These legislations, however, mainly addresses the legal aspects of the wadi water resources. It was always felt that there is a need for a national initiative to develop a legal framework that addresses the specific problems of wadis and groundwater. If these institutional and legal aspects are not resolved, they will form a major threat to any integrated management plan.

4. Wadi Jerash Management Plan

The ministry of Environment in Jordan is a governmental authority engaged in planning and development of all environmental aspects in a rational manner. As mentioned earlier and among the excellent tasks performed by this authority, its current involvement with the preparation of a comprehensive and sustainable management and developmental plan for wadi Jerash with great focuses on environmental protection of the natural resources and ecosystems.

The main concern was on how to address the above mentioned challenges within wadi Jerash. For that, the project has divided its involvement into two main phases: the first one has included pilot projects program with different environmental and planning themes to remove or halt environmental deterioration in the wadi, while the second task concentrated on elements related to the development of the comprehensive management plan components.

In selecting the possible interventions, the team transferred the challenges mentioned above into problem trees and then into objective trees and the causes transferred into means. Then a list of possible interventions for each core objective tree was developed through transferring the means of the core objectives into possible interventions. Later on, all the possible interventions derived from the different objective trees were combined together into one list.

A list of thirty-six interventions was developed. Based on selection criteria, Cost Benefit Analyses and Risks identification, the priority list of interventions was developed and will be implemented to develop better understanding before the development of the integrated management plan. In addition to the priority list, a set of Performance Indicators and a monitoring system were prepared to make use of the pilot outcomes.

The pilot projects consist of water harvesting; Establishing a factory to treat goat, sheep and cows manure and turn it to a fertilizer; Developing , maintaining, and protecting water springs in the three watershed areas of Jerash. Conducting an environmental assessment study to olive mills in Jerash, Establishing local environmental community awareness center; Conducting an environmental degradation study in the targeted area . The pilot projects, together with the socio-economic aspects, will be integrated in a comprehensive sustainable developmental plan for the management of the wadi.

5. Conclusions

Integrated wadi resources management that will lead to better use of the available resources to meet current and future demands, is seen as the answer to sustainable development of wadi systems. To make the management system work, a thorough understanding of the natural resource system and detailed knowledge of its interactions with human activities, are vital prerequisites. To achieve that, one must assure the existence of some pre-requisites. They include:

The full understanding of the state of the physical resources in a wadi system;

Integration and coordination of meteorological and hydrologic data collection and interpretation activities; Socio-economic analysis of different water users and the evaluation of the different socio-economic factors impact.; Conducting Environmental Impact Assessment (EIA) studies as part and parcel of all processes related to the planning, implementation and operation of water projects.

Political well is definitely a key factor towards sustainable development and management of wadi systems. Institutional reform and legislative efforts are needed to enact laws and regulations, and to address the integration of all interrelated aspects of wadi management.

The Jordanian Ministry of Environment attempt to develop an integrated management plan for wadi Jerash is a promising initiative that considers all aspects that needs to be addressed within an integrated management plan. The analysis within the project shows that different technical, environmental, socio-economic and institutional exist in the Jerash catchment and for that, they need to be addressed in the plan.

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Submarine Groundwater Discharge: The Phenomenon, its Implications and Initial Assessments at Kuwait Bay

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Abstract

The flow of groundwater into the sea, which is known as submarine groundwater discharge (SGD), is an important phenomenon that takes place at the interface between the inland groundwater resources and the marine environment. The importance of this phenomenon arises from its proven quality and management implications on the two concerned resources. Though the global estimates of the volume of this flux are considerably lower than 10% of the rivers input, because the chemical and biological composition of the groundwater is inherently different from the receiving resource, the impact on the chemistry of the coastal waters is often profound. Furthermore, in those areas where groundwater contamination has occurred, SGD provides a significant pathway for these contaminants to enter the near shore marine environment. From water resources view point; this phenomenon can result in freshwater springs in the coastal waters that might be of great benefit for countries with little or no naturally occurring freshwater resources such as the GCC countries. The SGD, its associated processes and the approaches for its quantification are discussed here. This paper also overviews, in general as well as specifically for the Kuwaiti conditions, the potential implications of SGD on the ecosystem of coastal waters as well as the water resources. In addition, this paper introduces the plans and the initial efforts conducted by the Water Resources Division of the Kuwait Institute for Scientific Research to study this phenomenon at the Kuwait Bay.

Key words: Submarine groundwater discharge, Kuwait Bay, Submarine groundwater springs

Introduction

With the increasing realization of the interdependence of natural resources, planning and management approaches are steadily moving towards integration. This integration is possible only when the interrelationship between the different resources is fairly understood, which requires, among other things, assessing the mass exchange and its implications at the resources interface.

One of the most significant interfaces of the natural resources is the zone where the groundwater resources meet the marine environment. As groundwater flow downgradient, it flows directly into the sea wherever a coastal aquifer is connected to the sea. Furthermore, artesian aquifers can extend for considerable distances from shore, underneath the continental shelf, with discharge to the ocean at their points of outcrop. In some cases, these deep aquifers may have fractures or other breaches in the overlying confining layers, allowing groundwater to flow into the sea (Figure 1). This phenomenon is known as submarine groundwater discharge (SGD). Simultaneously, and looking from the other side of the interface, seawater often invades the inland aquifers as a result of salinity gradients and hydraulic pressure differences, creating the phenomenon known as seawater intrusion. Both phenomena occur simultaneously.

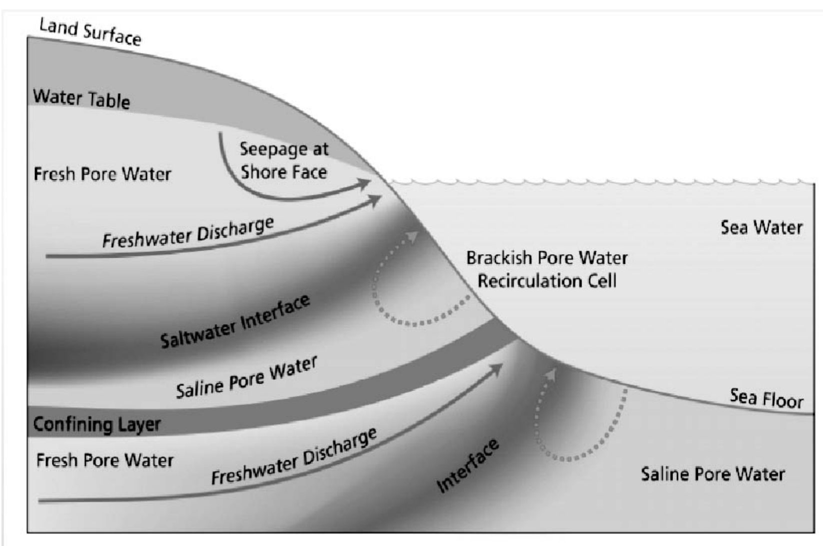

Figure 1: Schematic of pathways of SGD

During the last ten years, significant attention was given to this phenomenon with numerous field studies carried out to quantify the SGD in various parts of the world (Buddemeier, 1996; Moore, 1996; Cable et al., 1996; Charette et al., 2000; Burnett et al., 1996; Kontar and Burnett, 1999; Corbett et al., 1999; Krest et al., 2000; Kelly and Moran, 2002 and Charette and Buessler, 2003). Nonetheless, these studies are confined to the western hemisphere and Australia. Accordingly, providing an additional experience, which has the uniqueness of being from this region will add to the scientific knowledge of this phenomenon. This paper gives a background on the phenomenon, associated processes, quantification, implications and introduces the initial efforts carried out by KISR to quantify the SGD to the Kuwait Bay.

Processes and Definitions of SGD

The relation between the coastal groundwater aquifers and their neighboring sea is complex. In which, a number of phenomena are typically taken place simultaneously (Figure 1). Due to pressure head differences, groundwater typically flows into the sea (i.e. if geological conditions allow). Simultaneously, the two water-bodies exchange salts extensively through advective and diffusive forces until pseudo-equilibrium is reached creating an inland the interface zone between the fresh and saline waters. The location of this interface depends, in the long term, on the salinity and pressure differences between the two waters. In the short term, interface intrudes further inland and recedes beyond its equilibrium location on daily bases due to tidal fluctuations. This continuous interaction has serious consequences on both resources due to the extensive mass exchange that takes place as a result of mixing, diffusion, and desorption of nutrients from inland solid phases due to tides driven intrusions/recedes (recirculation).

Submarine groundwater discharge has two main definitions, mainly in accordance with the discipline (i.e. water resources versus oceanography). The water resources definition is; the fllux of water that enters the coastal ocean/sea from a hydraulically connected aquifer. The oceanography definition is; the advective flow of mixtures of ground and recycled sea waters into the coastal zone. The main difference is that the oceanography definition takes into account the seawater that flows in and out of the aquifer due to tides. This discrepancy is due to the difference in interests as the water resources discipline is interested in the volume/flow rate of the groundwater into the sea, while oceanographers are interested in the load of nutrients input to the coastal water due the contact with the aquifers (both solid and liquid phases).

Approaches for quantifying SGD

Effectively, SGD can be measured through flow equations, i.e., analytical or numerical solutions, direct physical measurement or tracer techniques. The flow equations calculations suffer many limitations in accurate quantification of limited scale fluxes. For example, the assumption of homogeneity, usage of spatially idealized or lumped parameters, usage of extrapolated rather than measured parameters, and even usage of calibrated parameters that are based on extrapolated parameters (Burnett et al., 2000). Additionally, the margin of error in the field measurements of the major hydraulic parameters such as aquifer's conductivity is considerable. Accordingly, though flow equations solutions are powerful tools for predicting groundwater systems response, they would lead to erroneous results in precision measurement of mass balance.

On the other hand, the only direct measurement instrument is the seepage meter (Figure 2). Apart from its drawbacks related to the measurement technique, the crucial problem with the seepage meters is related to the nature of the phenomenon. That is, the high heterogeneity of the SGD making representative measurements for a long sea front, virtually impossible (Charette et al., 2000).

Figure 2: Seepage Meters

Currently, the most promising approach is the employment of natural isotopic indicators to assess the groundwater inputs to the sea (Moore, 1996; Cable et al., 1996; Burnett et al., 1996; Kontar and Burnett, 1999; Corbett et al., 1999; and others). The isotopic tracers/indicators are employed to assess SGD in two ways; conducting a mass balance of the indicator over a specified section of the coastal waters, or constructing a seaward gradient of the indicator activities at the coastal waters perpendicular to the shoreline. The literature (Moore, 1996; Cable et al., 1996; Burnett et al., 1996; Kontar and Burnett, 1999; Corbett et al., 1999) indicates that radium has shown to be a useful chemical indicator of SGD and proven to be successful to estimate rates of SGD on a wide range of time-scale.

Significance and Implications

While the magnitude of SGD may be relatively minor, i.e. compared to the volume of the receiving water body, recent studies have indicated its significance (Valiela and D'Elia, 1990; Buddemeier, 1996; Moore, 1996; Charette et al., 2000; Krest et al., 2000; Charette and Buessler, 2003; and Kelly and Moran, 2002). Because the chemical and biological composition of the groundwater is inherently different from the receiving resource, the impact on the chemistry of the coastal waters is often profound. Furthermore, in those areas where groundwater contamination has occurred, SGD is being recognized as a significant pathway for these contaminants to enter the near shore marine environment. Accordingly, the vulnerable marine environment is likely to suffer from nutritional surges where SGD occur (Charette et al., 2000). Nutritional eutrophication is one of the documented reasons for fish kill. On the other hand, SGD can create, given the suitable geological conditions, what is known as submarine freshwater springs. These are essentially common freshwater springs as those found inland, however, existing at the bottom of seas and oceans. Some of these springs are of significance as a water resource, especially in arid zones (there are reports on 5,000 L/S spring off the shores of Syria).

Relevance to the Kuwaiti case manifests itself in the knowledge that naturally enriched groundwater in H_2S, lithium, aluminum, nitrate and fluoride has been proven on many occasions at the costal aquifer (Kuwait Group) (Al-Senafy et al., 2002). Additionally, anthropogenic pollution such as nitrogen, TPH, TCB, etc. was also detected in a number of studies (Al-Senafy et al., 2003; Mossaad et al., 1997; Hamdan, 1987). Accordingly, the groundwater discharge into the coastal water has the potential to significantly impact the nutritional balance of the bay. The ecosystem for the Kuwait Bay, which is one of the most important Kuwaiti marine nurseries, is already suffering considerable deterioration due to extraneous nutritional input to the system (Khan et al., 1999). In fact, the fish-kill occurred at the Kuwait Bay in 1999 was attributed, among other reasons, to coastal nutrient eutrophication (Heil et al., 2001; Al-Yamani et al., 2001). Submarine groundwater discharge can be one of the contributors to this deterioration.

Assessment of SGD to Kuwait Bay

Kuwait Bay is essentially the most important feature of the Kuwaiti sea front. It has profound presence in the Kuwaiti social life, economics and environmental heritage. At the same time the Kuwait Bay is a fragile and vulnerable environmental pollution. In realization of the vitality and vulnerability of Kuwait Bay as well as the significance of SGD, the Hydrology Department at KISR, with the partnership of Kuwait Foundation for Scientific Research (KFAS), has initiated a research project to evaluate the SGD and its associated nutritional and pollutants load to Kuwait Bay. The study is based on utilizing the naturally occurring isotopes to achieve its goals. Accordingly, the basic principle of the study is to estimate the SGD to the bay through radium mass balance for the Kuwait Bay. The following simple mass balance equation would be used (input – accumulated mass = output). This equation may be rewritten in terms of rates as; input flux – output flux = accumulated mass/accumulation time. Typically, the probable inputs to the system, apart from the groundwater, are desorption from sediments and the Ra in waste discharge points. Desorption is only considered in the presence of recently deposited river-borne sedimentation (Hancock et al., 2000), which is not the case for the Kuwait Bay. The inputs from the groundwater and the waste disposal would be quantified through sampling and laboratory analysis. Whereas biological uptake and precipitation were deemed insignificant due to various reasons (Krest et al., 2003; Charette and Buessler, 2003; and Kelly and Moran, 2002), the output from the bay is essentially the tidal removal flux of Ra. This flux (dpm m^{-2} d^{-1}) would be calculated using the tidal prism method as described in (Krest et al., 2000; and Kelly and Moran, 2002).

$$J_{Ra} = \frac{exRa \times \forall \times \tau \times 10}{A_B} \qquad (1)$$

where *ex* is indicating the excess Ra in dpm 100 L^{-1} (Ra in the bay minus Ra in the open water), $\forall$ represents the tidal prism of the bay (m^3), τ represents the tidal period (d^{-1}), and A_B represents the area of the bay (m^2) and the factor of 10 is a correction for units conversion.

The accumulated mass would be based on the Ra mass in the bay water minus the background Ra in the seawater. Accumulation time would be calculated using the ratio of a short life Ra (^{223}Ra or ^{224}Ra with 11 and 4 days half-life respectively) to a long life Ra (^{228}Ra or ^{226}Ra with 5.75 and 1600 years half-life respectively) as described in Charette et al., 2001; and Kelly and Moran 2002.

$$\left[\frac{^{223}Ra}{ex^{228}Ra}\right]_{obs} = \left[\frac{^{223}Ra}{^{228}Ra}\right]_i e^{-\lambda_{223}\tau} \qquad (2)$$

where i is symbolizing the initial ratio as the groundwater enters the bay, obs is the ratio as observed in the bay's water, λ is the decay factor for the ^{223}Ra and t is the residence time (or accumulation time).

A total of 13 bay water samples and 17 groundwater samples were collected in October-November 2007. The distribution of the bay samples (Figure 3) is based on providing a spatially unbiased average of the radium content in the bay water. Groundwater samples (Figure 3) were allocated to ensure encountering the groundwater as it approaches the bay and provide background quality. Bay samples (100 L) were collected and slowly filtered through MnO fiber filters (Figure 4) according to the procedures described in

Charette and Buesseler (2004). Groundwater samples (20 L) were collected from various depths wells and also slowly filtered through MnO fiber filters where 20 liters of groundwater were passed through MnO filters. As field measurements showed that groundwater is in reduced condition, two MnO filters in series were used to ensure that all the radium is captured on the filters.

Upon returning to the laboratory, the filters were partially dried and shipped to the laboratories of Duke University for ^{223}Ra, ^{224}Ra, ^{228}Ra, and ^{226}Ra analyses. The short-lived isotopes (^{223}Ra and ^{224}Ra) are measured immediately using delayed coincidence counter. Samples are measured after three weeks to correct for supported ^{224}Ra (via ^{228}Th). This is followed by measuring the long-lived Ra (^{228}Ra and ^{226}Ra) using gamma spectrometer.

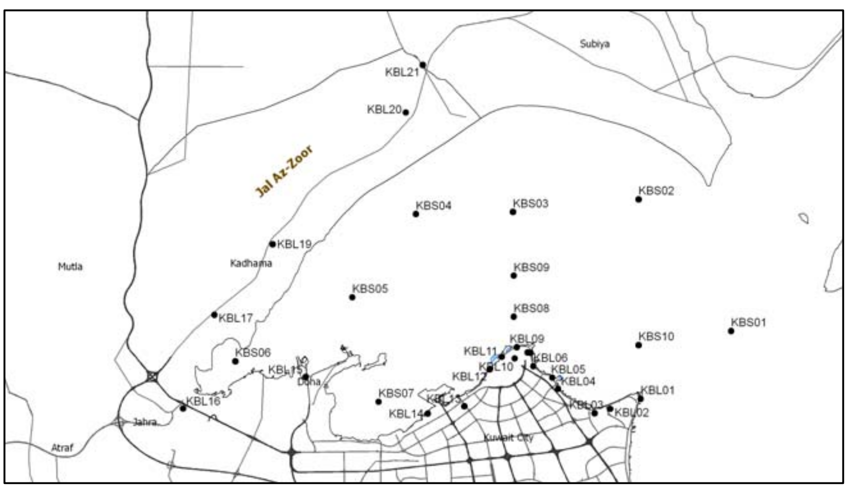

Figure 3: Locations of Ground and Bay water samples

The preliminary results show that all the samples yielded good and readable signals for the short-lived radium. This initial result is very important to support the validity of the study approach. Groundwater, however, did not show as strong signals (compared to bay samples) as expected. This was attributed to the high salinity of the groundwater. Typically, the recirculation of the high salinity seawater into the aquifer increases the radium content in the solution due to enhanced desorption from the solid phase. However, in this case, the continuous exposure of the solid phase to the high salinity groundwater (TDS reaches 60,000 mg/l in some locations) is probably depleting the radium from the aquifer.

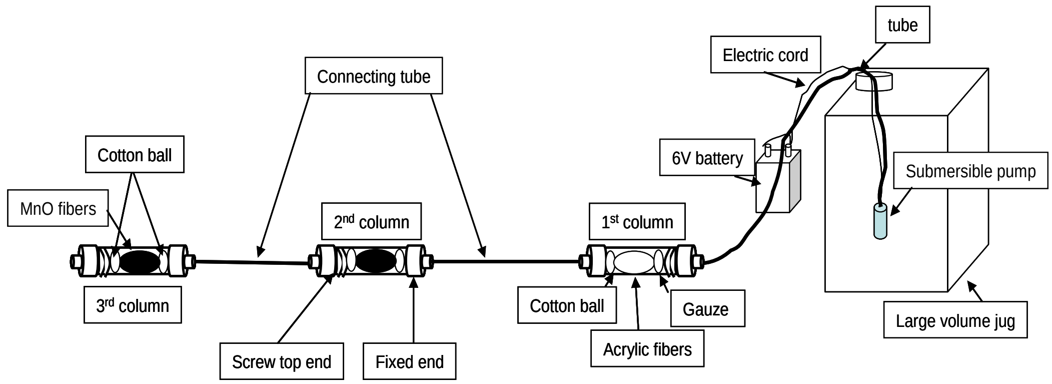

Figure 4: Schematic presentation of Radium sampling setup

Concluding remarks

Submarine groundwater discharge is a significant phenomenon that takes place as the groundwater flow encounters the sea/ocean. While it represents a threat to the healthiness of the marine environment, it presents, in some cases, an opportunity for unaccounted-for freshwater resource. In both cases, the understanding and quantifying of this phenomenon is important. Approaches for quantifying this phenomenon are direct physical measurements, application of various solutions for the groundwater flow equations, and utilization of natural isotopic tracers. Experiences show that the most reliable is the later.

In recognition of the importance of this phenomenon and its potential impacts on the Kuwait Bay marine life, KISR is conducting a study to estimate the groundwater flux to Kuwait Bay along with the associated pollutant/nutritional load. The study is adapting a radium mass balance approach that would enable estimating the groundwater flux as the end-member of the balance. The first sampling round resulted in 30 water samples (13 from the bay and 17 from the groundwater). The initial results of the analysis shows that MnO fiber filters are yielding strong signals for all samples, which should enable proper application of the radium mass balance approach.

Acknowledgment

The authors express their appreciation to the Kuwait Foundation for the Advancement of Sciences (KFAS) for funding the study. Funding, facilities and resources provided by the Kuwait Institute for Scientific Research (KISR) as well as the management's support are gratefully acknowledged.

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Enhancing the Part Load Operational Performance of MSF Desalination Plants.

By

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ABSTRACT.

This paper proposes a scenario that enhances the performance of Multi Stage Flash (MSF) desalination plants at part loads. More emphases are given to large capacity plants, and those connected to electric power generation plants. The motivation for the present study arises from the fact that in many part load periods of power plants forces the desalination plants to reduce its production loads or shutdowns (due to product water full tanks). These conditions cause a thermal stresses to the MSF system and a deterioration of its overall performance. These problems could be mitigated and the performance could be maintained through the present proposed scenario.

The proposed operational scenario includes the simultaneous increase in both make-up flow rate and blow down rate. Under this operational scenario, the performance of MSF system could be maintained with improved operational parameters that have a direct effect in controlling the scale potential during part load periods. These parameters include; reduction in brine Total Dissolved Solids (TDS), Concentration Factor (C.F.) and the frequency of the acid cleaning interval.

The proposed operational scenario realizes the balance between the costs of additional rejected heat and chemicals in blow down against the positive gain results from decreasing input heat, increasing distillate and maintaining the plant normal operational performance. Economical and technical assessment and comparisons between the present and proposed operational scenarios are high lighted. Sidi krir 2*5000 m^3/day desalination plant supplies make-up treated boiler feed water to 2*325 MW power plants, is taken as the case study.

Introduction

Multi Stage Flash (MSF) is the used widely used distillation process for seawater desalination. Distillated water produced by MSF may represents about 50% of the water produced in the world. In Egypt, the only two MSF plants, Sidi krir and Auon Mosa (2*5000 m^3/day each) are connected to 2*325 MW power plants. Each MSF unit serves only one power plant unit.

These and similar MSF desalination plants, particularly those connected to power generation plants, are usually exposed to multi-shut downs or part load operation, due to the un-availability of distillate storage tank (storage tanks are full, connecting header maintenance, …etc) or other operational scenarios for the power or desalination plants. Plants multi- shut downs or part load operation, exposes them to several thermal stresses. If such condition are considered as a prevailing operation mode for a long term, all operation parameters, especially the performance ratio (PR), would be deteriorated giving rise a degrading in efficiency of the system.

An operational scenario is proposed in order to optimize several parameters includes; performance ratio (PR), concentration factor $x_{\mathbf{c}}$, flash range and Gain output ratio (GOR). The proposal assumes an increase in a make up feed water to the MSF system using up the useless rejected water in the rejection loop. Make up heat balances the equal increasing of heat rejection in the additional blow down flow (due to the make up increasing in order to maintain the level of brine water at last stage). Such proposed process decreases the total dissolved salts (TDS) in recovery loop and minimizes, therefore, the tendency for tubes scaling process in the system. Sidi krir Desalination Plant (MSF) 2 * 5000 m^3/day was the case study in this paper. Specification and details were demonstrated in table (1).

Distillation Process & Scale Deposits:

Distillation is the process in which a portion of the saline liquid is evaporated and subsequently condensed to form the product. In the particular case of distillation of sea water, it is assumed that the dissolved salts in solution are completely nonvolatile, in the operation range of temperatures and pressures. Thus, in principle pure H_2O is evaporated alone as a vapor and by condensing this, get pure H_2O liquid (distillate) as an end product. So, the concentration of salts increases in brine water due to evaporation of part of the pure water. Concentration increase must be controlled, in order to avoid the scale formation, through controlling a factor termed as concentration factor x_c (defined as the factor by which the initial sea water salts (feed water) concentration is multiplied to give the concentration of salts in the rejection stream (brine)).

In MSF system feed sea water supplied at rate M_f and the produced distillate at rate M_d , a rate of (M_f –M_d) is rejected from that system as rejected brine. If the original concentration of all salts in the sea water is represented by C_f , the original rate of total salts fed to the system is C_f M_f , the reject brine will have a concentration equal C_f M_f / (M_f-M_d) by a quantity equal (M_f -M_d), denoted as M_b. The concentration factor x_c = M_f/M_b . So, the x_c has a inverse relation with M_b, i.e., the x_c decreases as M_b increases, consequently the liquid being processed in that system may vary in concentration at different location in the plant between C_f -----> x_c C_f .

This last conclusion is considerable to get the main concept of the proposed scenario, where the variation in M_f (+ve value) may improve the level of x_c during the process. This factor has a direct effect in the tendency of scale deposit in the system. So, the operation modification scenario proposes an increasing in make-up flow rate as it is available during all operation periods of part loads to improve the x_c value, reduce the TDS in the recovery loop, and consequently minimize the advance of scale formation.

Three simultaneous factors are required in the initial crystallization from solution (Brine Water) at the of scale formation sites. These are; (i) super-saturation of the solution locally, (ii) nucleation sites, and (iii) adequate contact time of the solution and nucleus. All three factors must be present for scale to form initially and prevention of scaling requires elimination of any one or more of three factors. The first factor as it is mentioned above should be eliminated by reducing the x_c value through increasing the make up flow rate (M_f).
Scaling, as well known, is a function of a number of initial crystal sites resulting from the nucleation step, adequate contact time and degree of super-saturation of solution. Decreasing of flowing brine TDS gets the deposition of scale fails and diminishes the probability of super-saturation occurrence. In addition the input heat which is required to heat the brine water in brine heater, will decreases too to reach the same temperatures at the same different loads (lower fouling factor value and higher overall coefficient of heat transfer). A considerable value of heating steam and distillate may be saved by this modification, and could balance the costs of the excess chemical injection rate to both of the additional make up sea water to the system and the rejected heat in blow down stream. Further positive effect is the decrease in an acid cleaning frequency.

Technical Assessment:

The performance ratio PR of the plant is defined precisely as the number of pounds of distillate produced per 1000 Btu of heat input. Therefore;

PR = 1000Md/heat input
PR = 1000Md/H
H = 1000Md/ PR

The total heat input H to the plant is calculated as follows, Figure (1),

$$H = (M_c - M_f)\, C_p\, (t_{fj} - t_{fo}) + M_d\, C_p\, (t_d - t_{fo}) + M_b\, C_p\, (t_b - t_{fo}) \quad (1)$$

or

$$H = M_r\, C_p\, (t_{bo} - t_r) \quad (1^*)$$

The total heat which is rejected through blow down stream is,

$$H_b = M_b\, C_p\, (t_b - t_{fo}), \quad (2)$$

After application the t_r decreases and logically the input heating steam must increases as in Eq.(1`). From the relation between TDS and Input heat, Figure (2), physically, the input heat which is required to maintain the optimum value of TBT should decrease.

If the additional blow down rate after application equal "x", then the total rejected heat in blow down stream will be:

$$H_{b'} = M_{b+x}\, C_p\, (t_b - t_{fo}), \quad (3)$$

The net additional latent heat blow down stream is found to be,

$$H_n = H_b - H_{b'}, \quad (4)$$

If the additional make up water flow rate after application equal "y", then the total latent heat in feed water stream will be:

$$H_{f'} = M_{f+y}\, Cp\, (t_{fj}) \quad (5)$$

Then the additional latent heat intruded to the system as feed water is:

$$H_{n'} = H_f - H_{f'} \quad (6)$$

Then the actual amount of heat which is loosed after application equal,

$$\Delta H = H_n - H_{n'} \quad (7)$$

Practically the difference in temperatures between the rejection loop and the blow down stream, Eq. (7), is usually about two degrees centigrade. Eventually, this small amount of lost heat could be restored depending on the decreasing of the input heat to be the system at the same loads. Further, the excess of distillate gained in the test could be restored in the additional chemicals costs in feed water to the system.

All variables, operation parameters readings and chemicals cost estimation in the MSF system of Sidi Krir Desalination plant (2*5000 m^3/h) were recorded in Tables (2), (3), (4) and (5). Comparison between the two operational cases, before and after proposal modification, resulting observations ate described as following:-

1- Decreasing of bottom temperature could be considered as a positive effect to increase the efficiency of recovery loop as a cooling element.

2- Due to the decreasing in TDS value in recovery loop, as the increasing of make up flow rate (M_f); the input heating steam to the system decreased, as shown in figure (2).

3- The decreasing in TDS leads to increasing in flashing rate which gave rise an increase in distillate water production, as shown in figure (3).

4- The blow down flow rate M_b progressively increases to maintain the level at the last stage due to the additional make up water into the system. So, this additional rejected water leads to a more loses in chemicals and latent heat. Consequently such changes mathematically affects directly in performance ratio PR, of the system. However, the gained excess in production rate and the saved input heating steam those are obtained after the application could equalize this loses and maintain the performance ratio PR, which may increases too. Figure (4).

Concluding Remarks

- A proposed a scenario that enhances the performance of Multi Stage Flash (MSF) desalination plants at part loads has been presented. The proposed operational scenario includes the simultaneous increase in both make-up flow rate and blow down rate.

- Under this operational scenario, the performance of MSF system could be maintained with improved operational parameters that have a direct effect in controlling the scale potential during part load periods.

- The proposed operational scenario realizes the balance between the costs of additional rejected heat and chemicals in blow down against the positive gain results from decreasing input heat, increasing distillate and maintaining the plant normal operational performance.

- Economical and technical assessment and comparisons between the present and proposed operational scenarios are high lighted. Sidi krir 2*5000 m^3/day desalination plant supplies make-up treated boiler feed water to 2*325 MW power plants, is taken as the case study.

- The proposal will, therefore, have the following advantages:

1-Decrease the possibility of scaling deposit process.
2-maitaining the performance ratio (PR) of the system and the target values of operation parameters.
3-Decrease the frequency of acid cleaning, and save, therefore, the costs of maintenance and chemicals of chemical cleaning processes.
4-Preventing the un-scheduled shut down of the system.

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Table (1) Technical Specifications of Sidi Krir

2 x 5000 m3/day MSF Desalination Plant

Parameter	Valur (Remark)
No. of Units	**2**
Unit Capacity	**5000 m3/day**
No. of Stages	**20 (17 + 3)**
Designed PR	**8 kg (PW) / kg (steam)**
TBT	**110 C**
Seawater Temp.	**27 C**
Heating Steam Temp.	**117 C**
Cooling Water Flow Rate	**1570 m3/hr**
Brine Recirculation Flow Rate	**1850 m3/hr**
Seawater Concentration	**43900 ppm**
Brine Concentration	**63000 ppm**
PW Quality	**25 ppm**
Method of Scale Control	**High Temp. Additives (Belgard EV)**
Tube Sheet Material (BH + Condensers)	**90 / 10 Cooper Nickel**
Condensers Tubes	**90 / 10 Cooper Nickel**
Brine Heater Tubes	**70 / 30 Cooper Nickel**
Water Box (BH + Condensers)	**90 / 10 Cooper Nickel**

Table (2) Readings recording before proposal application.

Item Load%	Steam Flow Tons/h	Inlet BH. Temp C`	Outlet BH Temp. C`	Conc. Factor	Brine Recirc. Temp. C`	Make up Flow Tons/h	Blow Down Temp. C`	Make up Temp. C`	Distillate Outlet Flow Tons/h	Blow Down Flow Tons/h	Sea Water Temp. C`
60%	**16.4**	**87.4**	**93.6**	**1.59**	**31.9**	**360**	**33.2**	**31.9**	**142**	**218**	**24.2**
70%	**18.0**	**92.1**	**98.3**	**1.60**	**32.5**	**400**	**34.0**	**32.7**	**155**	**245**	**24.2**
80%	**20.6**	**95.2**	**101.9**	**1.61**	**34.6**	**450**	**36.2**	**34.4**	**170**	**280**	**24.2**

Table (3) Readings recording after proposal application

Item Load%	Steam Flow Tons/h	Inlet BH. Temp C\`	Outlet BH Temp. C\`	Conc. Factor	Brine Recirc. Temp. C\`	Make up Flow Tons/h	Blow Down Flow C\`	Make up Temp. C\`	Distillate Outlet Flow Tons/h	Blow Down Flow Tons/h	Sea Water Temp. C\`
60%	**15.0**	**86.8**	**93.4**	**1.42**	**30.8**	**470**	**33.2**	**31.9**	**144.5**	**325.5**	**24.2**
٧٠%	**16.6**	**91.3**	**98.3**	**1.42**	**31.5**	**520**	**34.0**	**32.7**	**١٥8.0**	**٢٤4.5**	**24.2**
٨٠%	**19.0**	**94.0**	**101.7**	**1.44**	**33.7**	**585**	**٣٦.2**	**34.4**	**173.5**	**411.5**	**24.2**

Table (4) Chemical Injection System.

Item Chemicals	Injection point	Dosing Rate	Chemical Consumption rate		The Excess Dosing Rate	Additional Cost
			Before Application	**After Application**		
Anti-Scale **(20000LE/ Ton)**	**Recirculating Discharge pump**	**4.0ppm**	**45.6 kg/day**	**55.2 kg/day**	**0.96 kg/day**	**192LE**
Na_2SO_3 **(2350LE /Ton)**	**Recirculating Discharge pump**	**1.0ppm**	**13.2 kg/day**	**15.6 kg/day**	**2.4 kg/day**	**5.64 LE**
Anti-Foam **(23000LE/ Ton)**	**Make up Sea water**	**0.1ppm**	**0.24 kg/day**	**1.56 kg/day**	**0.24 kg/day**	**5.65 LE**
Total Cost						**203.3LE/day 74204.5/year**

Table (5) The Positive income costs after proposal application.

Item	Distillate production Tons/day	Heating Steam Tons/day	Chemical Cleaning Per year	Total Income Costs
Income	**72**	**36**	**Once/year**	
Cost(L.E)	**720**	**1080**	**18000**	**676440/year**

Key Wards

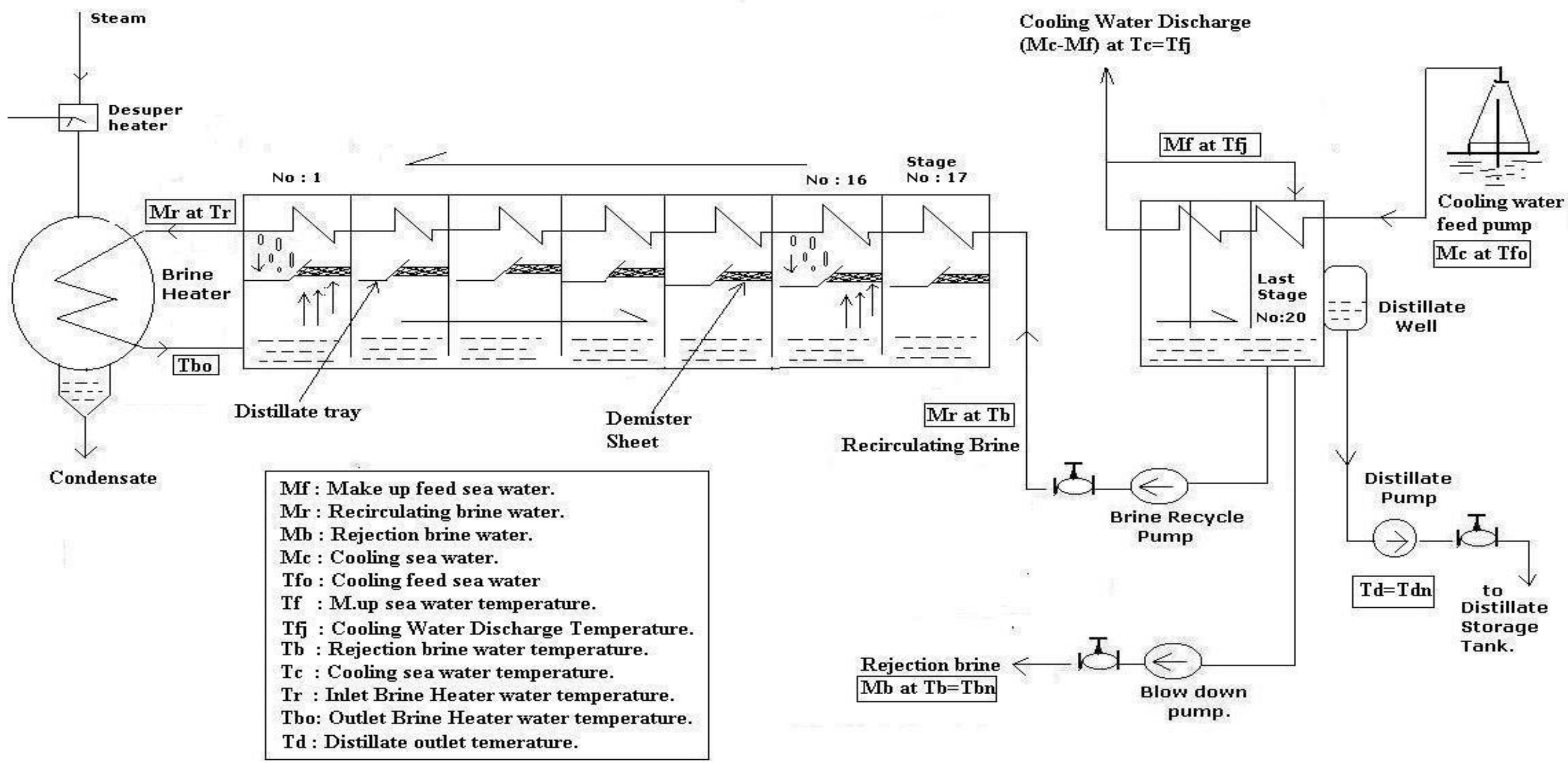
The following symbols are used in this paper

M_f: Mass flow rate of Make up feed sea water.
M_r: Mass flow rate of Recirculating brine water.
M_b: Mass flow rate of Rejection brine water.
M_c: Mass flow rate of cooling sea water.
M_d: Mass flow rate of Outlet Distillate water
T_{fo}: Cooling Feed sea water temperature.
T_f: Make up sea water temperature.
T_{fj}: Cooling water discharge temperature.
T_b: Rejection brine water temperature.
T_c: Cooling sea water temperature.
T_r: Inlet brine heater water temperature.
T_{bo}: Outlet brine heater water temperature.
T_d: Distillate outlet temperature.
R: Performance ration of plant, weight/energy.
Btu: British Thermal Unit.

Note. While the British units defined above have been used by the author, it will be observed that in general the equations given are not dependent on the system of units used. It will be recalled, however, that R was defined as the number of pounds of distillates produced per 1000 Btu of heat input ,i.e.,

$$R = \frac{1000M_d}{\text{Heat input}}$$

Hence if another system is adopted, the value of the constant 1000 must be suitably where it occurs, so that the design parameter R will be invariant in the different systems of units.


Steam
Desuper heater
Brine Heater
Mr at Tr
Tbo
Condensate
No : 1
No : 16
Stage No : 17
Distillate tray
Demister Sheet
Mr at Tb
Recirculating Brine
Cooling Water Discharge
(Mc-Mf) at Tc=Tfj
Mf at Tfj
Cooling water feed pump
Mc at Tfo
Last Stage No:20
Distillate Well
Distillate Pump
Td=Tdn
to Distillate Storage Tank.
Brine Recycle Pump
Blow down pump.
Rejection brine
Mb at Tb=Tbn
Mf : Make up feed sea water.
Mr : Recirculating brine water.
Mb : Rejection brine water.
Mc : Cooling sea water.
Tfo : Cooling feed sea water
Tf : M.up sea water temperature.
Tfj : Cooling Water Discharge Temperature.
Tb : Rejection brine water temperature.
Tc : Cooling sea water temperature.
Tr : Inlet Brine Heater water temperature.
Tbo: Outlet Brine Heater water temperature.
Td : Distillate outlet temerature.

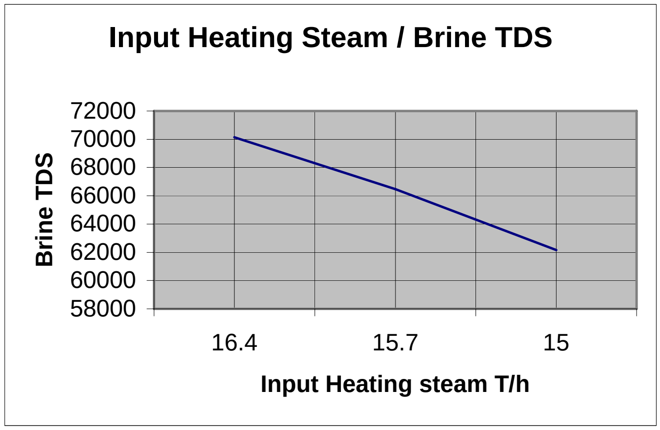


Figure (2) Input Heat/TDS

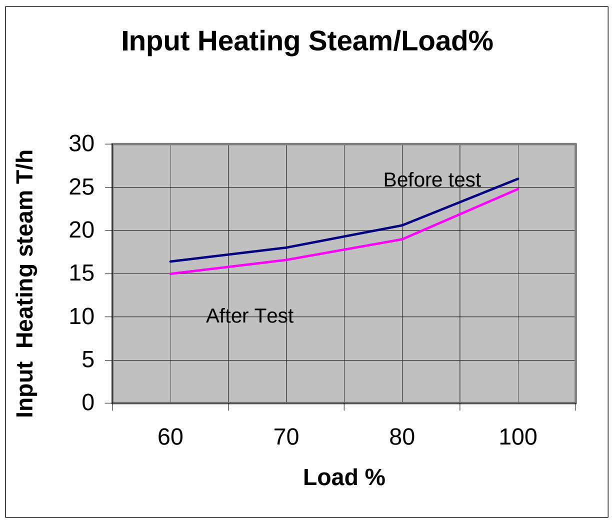


Figure (3) Input Heat/Load %

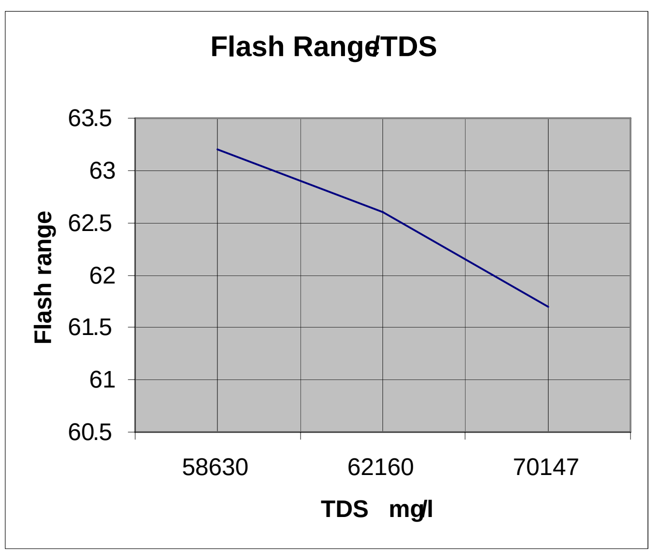


Figure (4) Flash Range/TDS Relation Ship.

Title: Policy guidelines, regulations and standards of wastewater treatment and reuse in Jordan

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Abstract:

Jordan has very limited renewable water resources of only 143 cubic meter per capita per year which is basically at the survival level. As a result, reclaimed water as a non-conventional water resource is one of the most important measures that have been considered to meet the increasing water demand of the growing population and industrialization. Over 60% of the Jordanian population is connected to sewerage system and raw wastewater is discharged to 22 wastewater treatment plants to be treated for minimum discharge standards and reuse requirements stated in the JS 893/2006. With the current emphasis on environmental health and water pollution issues, there is an increasing awareness of the need to dispose wastewater safely and beneficially. In Jordan, appropriate standards and guidelines for water reuse are an important requirement to rely on reclaimed water as a resource, therefore; the previous water reuse standards JS 893/2002 were reviewed, and issued in 2006. The revised standards allow for a wide range of water reuse activities including, where economic conditions allow, highly treated reclaimed water for landscapes, cut flowers and high-value crops, and for lower cost smaller-scale treatment and reuse activities with restricted cropping patterns. Reclaimed water use in Jordan will result in the conservation of higher quality water and its use for purposes other than irrigation. Properly planned use of municipal wastewater alleviates ground and surface water pollution problems and not only conserves valuable water resources but also takes advantage of the nutrients contained in sewage to grow crops.

Key Words: Reclaimed water, reuse, Domestic wastewater, sustainable, Standard

Introduction:

In Jordan water is becoming an increasingly scarce resource and planners are forced to consider any source of water which might be used economically and effectively to promote further development. 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 as stated in the Jordan's water Strategy, formally adopted by the Council of Ministers in May 1997 (Wastewater shall not be managed as waste; it shall be collected and treated to standards that allow its use in unrestricted agriculture and other non domestic purposes, including ground water recharge.){2}.Since the early 1980s the general approach has been to treat the wastewater and either discharges it to the environment where it mixes with fresh water flows and directly or indirectly reused. Jordan is in the process of rehabilitating and expanding its wastewater treatment plants and reclaimed water, appropriately managed, is viewed as a major component of the water resources supply to meet the needs of growing economy. Appropriate standards and guidelines have been set to allow for a wide range of wastewater reuse activities including, highly treated reclaimed water for landscapes and high value crops and treatment plant discharge requirements. Reclaimed wastewater discharged from domestic wastewater treatment plants is an important component of Jordan water budget. About (94.0) MCM in the year 2003, 101.7 MCM in the year 2004 , 107.4 MCM in the year2005 and 112 MCM in the year 2006{8} were treated and discharged into various watercourses or used directly or indirectly for irrigation and other intended uses and it is expected to increase up to262 MCM in the year 2020{6}.

Greater efforts have been made to conserve water by providing non-conventional water supplies to deal with the demands of agriculture. However, several challenges have still to be over come in terms of wastewater treatment and reuse such as scientific, public acceptance, institutional and legal aspects.

The monitoring of reclaimed wastewater quality involves many distinct activities to give reliable and usable data. A monitoring program for domestic wastewater is designed according to standard number 893/2006 to collect representative samples and analyze them through quality assurance and laboratories accreditation process complying with ISO 17025. The generated water quality data from these monitoring programs provide information about the reclaimed water quality and ensure its safety for irrigation, other intended uses, protection of public health and the environment. Decisions for improvements and reuse permission are taken depending on the quality of reclaimed water for each treatment plant.

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. Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries connected to the sewer systems. Moreover, table 1 shows the universal levels of the major constituents of strong, medium and weak domestic wastewaters. Since water use in Jordan is often fairly low, raw wastewater tends to be very strong as stated in table number 2 comparing it with the universal concentration tabulated in table 1.

Table 1: Major Constituents of Typical Domestic Wastewater

Constituent	Concentration, mg/l		
	Strong	Medium	Weak
Total solids	1200	700	350
Dissolved solids (TDS)	850	500	250
Suspended solids	350	200	100
Nitrogen (as N)	85	40	20
Phosphorus (as P)	20	10	6
Chloride[1]	100	50	30
Alkalinity (as $CaCO_3$)	200	100	50
Grease	150	100	50
BOD_5	300	200	100

Source: UN Department of Technical Cooperation for Development (1985)

Table 2: Major Constituents of Typical Domestic Wastewater in Jordan {4}

Constituent	Concentration mg/l
Dissolved solids (TDS)	800 – 1300
Suspended solids	600 – 1500
Nitrogen (as N)	30-150
Phosphorus (as P)	20 - 80
FOG	48-206
Sulphate (as SO_4)	200 - 400
BOD_5	600 - 1500
COD	1000 – 2500

Municipal wastewater also contains a variety of inorganic substances from domestic, hospitals and industrial sources, including a number of potentially toxic elements such as arsenic, cadmium, chromium, copper, lead, mercury, zinc,… etc. However, from the point of view of health, a very important consideration in agricultural use of wastewater, the contaminants of greatest concern are the pathogenic micro- and macro-organisms. Pathogenic viruses, bacteria, protozoa and helminthes may be present in raw municipal wastewater and will survive in the environment for long periods. Pathogenic bacteria will be present in wastewater at much lower levels than the coliform group of bacteria. In addition, certain synthetic organics are highly toxic. Pesticides, Benzene, toluene and herbicides are toxic to humans, fish, and aquatic plants and often are disposed of improperly in drains or carried in storm water. They also can damage processes in treatment plants and complicate treatment efforts.

Wastewater Treatment plants in Jordan:

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 as a minimum requirements. The existing public–sector wastewater treatment plants in Jordan are 22 using different type of treatment systems. The systems are divided into activated sludge, trickling filters, and waste stabilization ponds shown in table 3.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 replace most of the treatment plants working with Stabilization ponds to activated sludge processes. For example, Samra wastewater treatment plant, the largest treatment plant in Jordan, serves the greater Amman area, Russeifa and Zarka where 60%of the population of Jordan lives. The collected wastewater will be treated using activated sludge process.

The new project is a public private partnership (PPP) for financing the construction and operation based on a Build Operate Transfer approach over a period of 25 years It is the first BOT project in Jordan and expected to operate by the end of the year 2007 replacing an overloaded waste stabilization pond treatment system established in 1985.The existing wastewater treatment plants are summarized into table 3.

Table-3 Wastewater Treatment Plants in Jordan{9}

Plant	**Method Of Treatment**	Hydraulic Load (m3/day)	Efficiency	Treatment Cost (fils/m3)*
As-Samra	Stabilization Ponds	221510	75%	3.4
Irbid	Activated Sludge+ Trickling Filter	6696	97%	100.3
Aqaba new	Activated Sludge	6962	98.8%	112.1
Aqaba	Stabilization Ponds	7041	90.7%	71.5
Salt	Extended AERATION	4569.4	97.9%	126.6
Jerash	Extended AERATION	3598.3	95%	114.2
Mafraq	Stabilization Ponds	1958	58%	80.3
Baqa'a	Trickling Filter	10615	96.1%	79.2
Karak	Trickling Filter	1679.3	89%	115.9
Abu-Nusir	Activated Sludge	2240.3	96%	133.1
Tafila	Trickling Filter	1116	95%	214.9
Ramtha	Stabilization Ponds	3674.7	88%	107.4
Ma'an	Stabilization Ponds	2352	65%	59.1
Madaba	Stabilization Ponds	4660.5	99.4%	160.7
Kufranja	Trickling Filter	2794.6	95.6%	115.4

Wadi Al Seer	Aerated Lagoon	2762	95%	48.6
Fuhis	Activated Sludge	1606.3	98%	158.4
Wadi Arab	Activated Sludge	8316	98.8%	120.7
Wadi Hassan	Activated Sludge	1140.7	99.5%	454.8
Wadi Mousa	Activated Sludge	1820.4	97.8%	369.7
Jor. Valley	Activated Sludge+ Trickling Filter	271.5		461.6
AL- Ekeder	Stabilization Ponds	3156		14.5
Alljoon	Stabilization Ponds	634.8		61.6

*:1 JD=1000 fils, 1 US$=710 fils.

Source: WAJ Wastewater Sector Annual Report 2005

Existing water reuse standard in Jordan:

The Institution for Standards and Metrology is the national entity responsible for issuing standards in Jordan. Standards are set by technical committees formulated by the Institution for Standards and Metrology from members representing main parties concerned with the subject. All concerned parties have the right to express their opinion and comments on the final draft of the subject standard during the notification period in order to make the Jordanian standards in harmony with international standards, to alleviate any technical boundaries facing trade and to facilitate flow of commodities between countries. Based on this, the permanent technical committee for water and wastewater No.17 has set the Jordanian Standard 893/2002 dealing with "Water-Reclaimed Domestic Wastewater" and recommended its approval as a Jordanian Technical base No. 893/2006 in accordance with article (11) paragraph (b) of the Standards and Metrology Law No. 22 for the year 2000. Jordan standard number 893\2006 of reclaimed water determine the standard ,regulations and guidelines that are required for water reuse in the present and for the future.

In fact, the higher the standards, the higher is the level of treatment leading to a better quality of reclaimed water intended for reuse. Jordan controls water reuse activities through country wide standards and signed official agreement with the users. The legal basis governing use of reclaimed water is encoded in the Jordanian standard. This Jordanian standard is purposely set to specify the conditions that the reclaimed domestic wastewater discharged from wastewater treatment plants should meet in order to be discharged or used in the various fields mentioned in this standard .The standard consists of several items discussed below and also a summary of selected water reuse guidelines, criteria and standard are presented in table number 4.

Jordan standard 893/2006{1}:

This standard identifies several Requirements and it has two primary components:

a) Reclaimed water discharged to streams, wadis or water bodies.

b) Reclaimed water for reuse.

1.0General Requirements:

The main general conditions are summarized into:

- Reclaimed water must comply with the conditions stated in this standard for each of its planned end uses.
- It is not permitted to dilute by mixing reclaimed water before being discharged from wastewater treatment plants with pure water intentionally to comply with the requirement set in this standard.
- Should reclaimed water be used for purposes other than those mentioned in this standard (such as for cooling or for fire distinguishing), special standards or guidelines are to be applied in each case after conducting the necessary studies taking into consideration the health and environmental dimension.

- Official and specialized concerned parties overseeing the operation and development of wastewater treatment plants must always work towards improving the effluent quality to levels, maybe, exceeding those presented in this standard to ideally use the reclaimed water and protect the environment and public health.

2.0 Standard Requirements:

Reclaimed Water to be discharged to streams, wadis or water bodies:

- It is allowed to discharge reclaimed wastewater to streams or wadis or water bodies or reuse it when its quality complies with the properties and criteria mentioned in table (4) and measures must be taken to prevent the leakage of the reclaimed water to ground waters.
- It is prohibited to discharge it into wadis draining to the Gulf of Aqaba.

3.0 Reclaimed Water for reuse:

A) Artificial recharge of groundwater aquifers:

This part of the standard consists of reusing reclaimed water for artificial recharge of groundwater aquifers used for irrigation purposes if its quality complies with the criteria mentioned in Table 4 and technical studies must be performed to verify that there is no effect from artificial recharge activities on groundwater aquifers used for drinking purposes.

B) Reuse for irrigation purposes:

.The part of the standard is concerned with reclaimed water reuse for irrigation purposes and it consists of two main groups; standards group and guidelines.

- Standards group: is the group of properties and standards that are presented in Table 4 part A and where operating parties must produce water complying to it and according to the usages mentioned in this standard.

- Guidelines group: The guidelines group shown in Table 4 part B is considered for guidance only and in case of exceeding its values the end user must carry out scientific studies to verify the effect of that water on public health and the environment and suggest ways and means to prevent damage to either.
- It is prohibited to use reclaimed water for irrigating vegetables that are eaten uncooked (raw).
- It is prohibited to use sprinkler irrigation except for irrigating golf courses and in that case irrigation should practiced at night and the sprinklers must be of the movable type and not accessible for day use.
- When using reclaimed water for irrigating fruit trees, irrigation must be stopped two weeks prior to fruits harvesting and any falling fruits in contact with the soil must be removed.
- Allowable limit for properties and criteria for reuse in irrigation is tabulated in table number 4.

4.0 Quality Monitoring:

The Wastewater Treatment Plant Owner Party and the Regulatory body must ensure that the reclaimed water quality complies to the standards and according to its end use. Operating and Monitoring parties must carry out the required laboratory tests according to the frequency of sampling mentioned in JS893/2006.

5.0 Evaluation Mechanism:

For the purpose of evaluating the quality of reclaimed water as per the different uses allowed in this standard the periods mentioned in the standard are followed and when any value violate the standards set for discharge of reclaimed water to streams, wadis or water bodies an extra-confirmatory sample must be taken. If the two samples exceeded the allowable standard limits the concerned party will be notified in order to conduct the necessary correction measures in the shortest possible time.

Discharge to water bodies and wadis		Artificial Recharge		Irrigation			
Group A		Group A		Cut flowers	C	B	A
BOD_5	60	BOD_5	15	30	300	200	30
COD	150ب	COD	50	100	500	500	100
DO	>١	DO	>2	>2	-	-	<2
TSS	60	TSS	50	15	300	200	50
PH	(6-9)	pH	(6-9)	(6-9)	(6-9)	(6-9)	(6-9)
NO_3	70	NO_3	30	45	-	-	10
T-N	70	T-N	30	70	70	45	30
E. coli	1000	E. coli	<1.1	<1.1	100	70	45
Intestinal Helminthes Eggs	≤1	Intestinal Helminthes Eggs	≤1	≤1	-	1000	100
FOG	8.0	FOG	<1.1	8..0	≤1	≤1	≤1
Group B				Cut flowers	A	B	C
Phenol	<0.002	Phenol	<0.002	Phenol	<0.002		
MBAS	25	MBAS	25	MBAS	١٠٠(15) Cut flowers		
TDS	1500	TDS	1500	TDS	1500		
$T-PO_4$	15	$T- PO_4$	15	$T-PO_4$	30		
Cl	350	Cl	350	Cl	400		
SO_4	300	SO_4	300	SO_4	500		
HCO_3	400	HCO_3	400	HCO_3	400		
Na	200	Na	200	Na	230		
Mg	100	Mg	100	Mg	100		
Ca	200	Ca	200	Ca	230		
SAR	6.0	SAR	6.0	SAR	9.0		
Al	2.0	Al	2.0	Al	5.0		
As	0.05	As	0.05	As	0.1		
Be	0.1	Be	0.1	Be	0.1		
Cu	0.2	Cu	0.2	Cu	0.2		
F	1.5	F	1.5	F	1.5		
Fe	5.0	Fe	5.0	Fe	5..0		
Li	2.5	Li	2.5	Li	2.5)0.075)		
Mn	0.2	Mn	0.2	Mn	0.2		
Mo	0.01	Mo	0.01	Mo	0.01		
Ni	0.2	Ni	0.2	Ni	0.2		
Pb	0.2	Pb	0.2	Pb	5.0		
Se	0.05	Se	0.05	Se	0.05		
Cd	0.01	Cd	0.01	Cd	0.01		
Zn	5.0	Zn	5.0	Zn	5.0		
Cr	0.02	Cr	0.02	Cr	0.1		
Hg	0.002	Hg	0.002	Hg	0.002		
V	0.1	V	0.1	V	0.1		

Table-4 Water – Reclaimed domestic wastewater Standard 893/2006{1} **WHO water reuse Guidelines and JS 893/2006:**

The current water quality laws, regulations and application standards for discharge of wastewater into rivers,Wadis, lakes and reuse in irrigation systems in some countries such as Sudia Arabia, Egypt, Jordan and the Palestinian Authority follow the rules developed by the World Health Organization (WHO, 1989,2004) or they follow more stringent rules developed in the United States by the State of California. The basis for these standards is essentially the protection of public health against risk of exposure to microorganisms and chemicals that are typically found in raw wastewater. None of the standards are strictly based on the level of risk associated with the limits in those standards (Risk Management Assessment). The standards of reclaimed water were developed to protect health of the agricultural workers, those who might enter a field in which wastewater is used as irrigation water, and the general public. The standards specify chemical, physical and a microbiological quality guideline values or a method of wastewater treatment that will achieve the required quality by trained operators who carefully operate and monitor the wastewater treatment plants. The long-term goal of Jordan is to treat wastewater used in agriculture to minimum WHO guidelines and it has a unique system of rules and regulations to protect the quality of water resources and to regulate wastewater use and applications. The World Health Organization (Table 5) set the guidelines for wastewater use in agriculture. In fact, in 1989, the World Health Organization published the Guidelines for the safe use of wastewater and excreta in agriculture and aquaculture (WHO, 1989) focusing on microbiological parameters, to protect public health as well as the new edition issued in 2004. These guidelines identify necessary treatment levels depending upon whether the irrigation will be restricted (cereal, industrial, fodder crops or pastures and trees), or unrestricted (irrigation of crops likely to eaten uncooked, sports fields, public parks). Even the most stringent treatment levels in the WHO guidelines can be met by a series of wastewater stabilization ponds.

In addition to identifying a combination of treatment and crop restrictions, the WHO guidelines as well as JS 893/2006 also outline safe waste application methods and control of human exposure, to protect public health. In summary, the technical committee depends on WHO guidelines while revising and updating the new edition of JS\893/2006.

Table 5. The WHO criteria for effluent application for irrigation agricultural crops {7}.

Constituents (Mg/1)	Group A Irrigation of crops to be eaten uncooked	Group B Cereal crops, industrial crops, fodder crops, pasture and trees	Group C Localized irrigation of crops in Category B if exposure of workers and the public does not occur
Effluent quality			
Intestinal nematodes (arithmetic mean no. of eggs per liter)	<1	<1	N/A
Coliform Counts/100 ml	<1000	No Standard	N/A
Mandatory treatment			
Stabilization pond	Required	Required 8-10 days retention time	N/R
Equivalent water treatment plant	Required	N/R	N/R Pretreatment needed by irrigation technology or primary sedimentation

*N/R means not recommended

Monitoring and reporting for reclaimed water:

Effluent quality and quantity may change with time as a result of available water quantity, the seasonal nature of some industries connected to sewerage system or operational problems in treatment processes. The regulatory body and operational party have to monitor reclaimed water regularly to maintain compliance with the approved JS 893\2006. In general, monitoring programs are implemented by environmental monitoring division at WAJ through collecting samples from the point of entry to the treatment plant, the effluent point from treatment plant and selected samples from sails,wadis and dams receiving reclaimed water. This Jordan standard illustrates the reclaimed water monitoring programs which have to be implemented by the regulatory body such as Ministry of Health and Ministry of Environment and the operational party responsible for managing and treating wastewater in Jordan.

Wastewater Analysis Carried at WAJ Central Laboratories:

Various types of pollutants are present in domestic wastewater that can be measured by many different parameters. Wastewater chemistry analysis which are carried at WAJ laboratories including (Iron, Manganese, Copper, Chromium, Cadmium, Nickel, Lead, Zinc, Vanadium, Cobalt, Aluminum, Silver, Tin, Lithium, Molybdenum, Barium, Beryllium Arsenic, Selenium and Mercury), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD) , pH ,Turbidity, Total Suspended Solids, Total Dissolved Solids ,Phosphate Ammonium, Nitrate, Total Nitrogen, Boron, Sodium, Potassium, Calcium, Magnesium, Chloride, Sulfate FOG, MBAS, Cyanide and Phenol. The second class of wastewater analysis is Total Coliforms, Escherishia coli and Helminthes Eggs Count & Identification.

Wastewater Evaluation:

The generated water quality data analyzed at WAJ central laboratories shown in tables (6, 7, 8) prepared and evaluated by the staff of Environmental monitoring Division according to the reclaimed wastewater standard number 893/2006.

It is clear from these tables that some water quality parameters in some treatment plants such as ammonia, total nitrogen are exceeding the allowable limits because these treatment plants are not designed to deal with nitrogen compounds. After the evaluation process the directorate of Laboratories & quality issues monthly, quarterly, biannual, annual reports that show treatment plants violating the standard. The objective of issuing these reports is to address the problems and asking for correction to protect and minimize their effects on water resources, reuse activities and the environment. More over, the water quality differs from treatment to another depending on the operation conditions, water quantity, and the type of treatment system. A number of elements of heavy metals and trace elements are normally present in relatively low concentrations, usually less than the allowable standard limits, and they tend to concentrate in the sludge (biosolids).Heavy metals and trace elements are rarely a proper concern of any of the uses of reclaimed water in Jordan and they are normally monitored on quarterly basis for regular irrigation water and other uses, but more attention is given to them when using sewage effluents, particularly if contamination with industrial wastewater discharges is suspected**.** The E. coli count and Intestinal Nematodes are the most satisfactory indicators for wastewater use in agriculture and public health. They comply with the current standard according to intended uses taken in consideration that reclaimed water is chlorinated before being discharged to receiving bodies. The total dissolved solid is one of the most important agricultural water quality parameters and it ranges from 702 mg\l for Aqaba treatment plant to 2029 mg\l for Lajjoun treatment plant. In conclusion, most of the reclaimed water produced in Jordan is suitable for restricted irrigation.

Table-6Reclaimed water quality in Jordan for the year 2006{5}

WWTP	Treat. Sys	End Use	(BOD)	(COD)	T.P	TDS	T.N	TSS	pH
Abu Nusseir	A.S	Wadis	11.93	49.86		1071.60	19.02	34.85	7.06
Akaider	S.P	Irr	189.75	488.90		1452.00	107.69	308.00	8.10
Alsamra	S.P	Wadis	167.13	357.00	4.20	1220.92	102.66	141.00	8.00
Aqaba Mechanical	A.S	Reuse	11.18	29.00	3.60	702.44	12.58	29.40	7.61
Aqaba S.P	S.P	Irr	72.81	213.07	4.80	906.10	29.71	138.00	7.89
Baqaa	Tri	Wadis	20.50	113.00		1154.22	48.35	49.64	7.75
Fuheis	A.S	Wadis	19.50	96.08		878.11	54.19	50.83	7.92
Irbed	A.S	Wadis	30.63	131.38		1019.50	83.84	55.50	8.01
Jarash	A.S	Wadis	171.33	442.64		1230.67	127.67	249.78	7.57
Karak	Tri	Wadis	87.90	263.15		1014.75	75.57	95.08	7.85
Kufranja	Tri	Wadis	117.38	293.60		934.33	114.94	95.89	7.85
Lajjoun	S.P	Wadis	215.36	528.86		2029.75	132.53	317.71	8.09
Maan	S.P	Irr	190.00	391.50	4.40	1047.00	89.65	215.80	7.91
Madaba	A.S	Irr	25.06	106.87	2.30	1256.27	49.45	57.81	7.95
Mafraq	S.P	Irr	344.00	624.31		1197.11	132.82	194.38	7.80
Ramtha	A.S	Irr	14.57	42.25		1314.30	25.11	44.08	7.96
Salt	A.S	Wadis	17.33	63.80		903.25	43.82	127.83	7.96
Tafeileh	Tri	Wadis	38.05	136.14		790.07	48.87	76.60	7.82
Tal Mantah	A.S	Irr	35.50	155.60		1488.29	115.34	108.80	7.65
Wadi Arab	A.S	Wadis	16.10	69.36		939.63	35.15	45.17	7.92
Wadi Aseir	S.P	Wadis	33.91	115.17		854.56	93.97	68.83	7.98
Wadi Hassan	A.S	Irr	50.75	109.00		1245.00	11.60	75.31	7.96
Wadi Mousa e	A.S	Irr	11.08	39.13		896.50	13.38	119.40	7.96

Table-7**Reclaimed water quality in Jordan for the year 2006{5}**

WWTP	NH4 mg/l as N	(ABS)	Chloride	Nitrate	Oil and Grease	Phosphate
Abu Nusseir	5.18		375.85	9.36	5.50	10.79
Akaider e	81.34	1.20		1.00	20.00	9.31
Alsamra	88.88	18.84	396.31	0.97	32.50	15.00
Aqaba Mechanical	2.62		152.33	1.77	22.00	5.09
Aqaba S.P	26.63		236.18	5.11	24.00	7.16
Baqaa	38.61			7.49	8.50	9.17

Table-8Reclaimed water quality in Jordan for the year 2006{5}

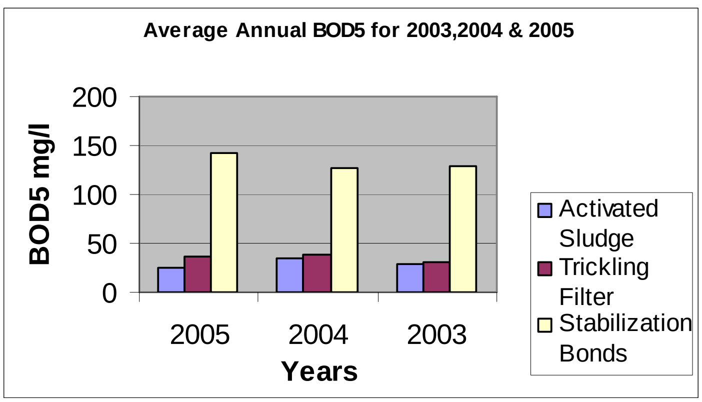
WWTP	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead
Abu Nusseir	0.02	1.16	0.01	0.05	0.02	0.06	2.42	0.12
Akaider		1.16	0.01	0.01		0.03	0.64	0.10
Alsamra	0.02	1.28	0.01	0.26	0.02	0.04	0.61	0.10
Aqaba Mechanical	0.02	0.59	0.01	0.03	0.02	0.05	0.66	0.46

Treatment plants efficiency:

The efficiency of 22 treatment plants is shown in Table -8 measured by BOD_5 as an indicator of removing dissolved organic matter from treated sewage, it ranges from 69% for Mafraq T.P to 99.4% for Wadi Hassan T.P. The average annual BOD5 for the wastewater treatment plants & the operation systems used in Jordan is shown in Figure No (1). This figure clarifies 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 followed by wastewater stabilization ponds.

Treatment Plant Efficiency- Table#8{5}

T.P	Efficiency %	T.P	Efficiency %
Madaba	98	As-samra	76.6
Jerash	94	Tafila	94
Kufranja	93.7	Karak	88.6
Irbid	97.2	Maan	76
Baqaa	96.8	Fuhis	96
Salt	97	Wadi Alseer	94
Wadi Hassan	99.4	Wadi Mousa	97.4
Mafraq	69	Abu-Nusir	96.6
Wadi Arab	98.5	Aqaba WSP	93.9
Ramtha	98	Aqaba Mechanical	98.74
AL- Ekeder	88	Alljoon	84
Tall-Almantah	98		



Annual BOD5 for wastewater treatment systems-Fig. 1 – {4}

Treated wastewater quantity:

The wastewater quantity flows to treatment plants is about 112 MCM for the year 2006 and 107 MCM for the year 2005. It was increased by (5%) from the year 2005. More over, about 72.5% of wastewater quantity was treated at Sammra T.P. The discharged and used quantity of reclaimed water from all treatment plants is about (86.2) MCM for the year 2006, in addition to 20 MCM used locally at Samra treatment plant.

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. WAJ has a goal of attaining total water reuse by having highly treated effluent to be used in the intended aspects.

Wadi Mousa Water Reuse Pilot Project:

This pilot project is located near the historic Petra funded by the United States Agency for International Development(USAID) and was initiated in 2003 and included a 69-duunum demonstration site and 300 dunums of farm plots divided among 14 farmers, who used reclaimed water to cultivate fruit trees, alfalfa and other fodder crops. Building on the project's success, 6 women farmers were incorporated the following year. By the mid of 2006 ,an additional 450 dunums of irrigated plots have been added to the site, allowing 20 additional farming families to benefit from the project, rendering a total cultivable area of around 800 dunums and 40 men and women farmers allowing them to earn JD 1000-2000/year from their plots. The demonstration site receives regular visits from professionals, school children, journalists and residents of nearby towns who come to enjoy the lush greenery. Olive trees, ornamental trees, fodder crops, geraniums and spruce are just a few of the crops on display at the site.

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, 22 treatment plants exist all over the country working 24 hours a day and the number of carried out connections is (187760) at the end of the year 2006, 68.8% of these connections flow to Samra T.P{9}. Water reuse is now a part of Jordan's overall water resources balance and also it is a tool 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 uses.

Conclusions:

Jordan experience in quality aspects of reclaimed water and standards gives an excellent example of how developing countries can proceed forward and take full advantage of reclaimed wastewater as a valuable resource depending on numerical standards for intensive monitoring, control and legal enforcement. The first step toward capturing this important resource is implementing and enforcement reclaimed water standard 893 for the year 2006.This standard varies with the type of application and the overall risk perception and there will be different water quality requirements and criteria for each aspect. Generated reclaimed water quality from most of the treatment plants in Jordan is suitable for restricted irrigation

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Virus Removal from Tertiary Treated Wastewater Using Dune Soil Columns, Kuwait

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Abstract

A laboratory experiments were carried out in order to assess the removal of coliphage viruses from tertiary treated wastewater by filtration through natural soils collected from Sulaibiya area, Kuwait. Tertiary treated wastewater was passed through soil columns filled with natural dune soil. All columns were subjected to short flooding and drying cycles of one day each alternatively. Water samples were collected from the inlet and outlet of soil columns and analyzed for the concentration of coliphage virus. The concentration of coliphage viruses in the tertiary treated wastewater ranged between 300 and 62800 pfu/100 ml. The coliphage removal efficiency for the dune soil ranged between 23-100% with an average value of 81.5%. The high removal efficiency of the dune soil could be attributed to its higher content of fine sediments and organics.

Key words

Coliphage viruses, soil columns, removal efficiency, dune soil, tertiary treated wastewater

Introduction

Kuwait is a modern industrialized nation that meets most of its domestic, commercial and industrial water needs by desalination of seawater. However, while desalination technologies demonstrated a remarkable progress in recent years, they still do not present a viable economical option for wide agricultural use. Therefore, countries with limited water resources carry on research effort into agricultural use of wastewater since recycling of renovated wastewater generates a valuable water resource.

As Al-Otaibi (2005) points out, Kuwait produces 135 million m^3 of tertiary treated wastewater per year, of which only 40% is used for irrigation, while the rest is being discharged to the Arabian Gulf. The volume of tertiary treated wastewater is set to increase in line with growing population and escalating water needs. In this context, the methods that can restore the wastewater quality to usable levels will be gaining and ever increasing importance.

Water for agriculture needs to meet stringent quality requirements, which include absence of pathogens like virus and bacteria, and low nitrogen levels (Bouwer and Idelovitch, 1987). These parameters are difficult to achieve within economic realms of existing purification technologies. Therefore, researchers concentrate on efficient ways of improving the quality of wastewater using natural environments, for example soil.

Soil Aquifer Treatment (SAT) technique is an economically attractive method for the treatment of wastewater for restricted and unrestricted irrigation. These systems are operated to use underground formations as a treatment facility, and thus are called soil aquifer treatment or geo-purification systems. While significant research effort has been applied to SAT throughout the world, there is an evident need to test this technique with local Kuwaiti soils, wastewater, and climatic conditions. A laboratory study concentrated on the tertiary treated wastewater from the Sulaibiya Wastewater Treatment Plant, treated by sandy soils from Kuwait.

The objective of the study was to assess the removal of viruses from tertiary treated wastewater by the Soil Aquifer Treatment (SAT) system in Kuwait.

Methodology

Dune soils from Sulaibiya area were used in column experiments. A number of soil samples were tested to determine the properties of the soil. These properties included grain size distribution, specific surface area (SSA), total organic carbon content (TOC %), total carbonate content (CO_3 %), cation exchange capacity (CEC), density, specific gravity (SG), porosity (P) and clay content of the soil.

Total of two soil columns were constructed to study removal of viruses from tertiary treated wastewater using natural dune soil. The removal of coliphage in two columns was tested on 0.1 m soil depth. The columns for the tests of virus were constructed using polyvinyl chloride (PVC) pipes 0.4 m in length and 0.12 m in diameter. The PVC pipes were selected to reduce contamination and interaction between coliphage and the column walls. The total length contained 0.05 m of gravel, 0.1 m of natural soil, 0.1 m of constant wastewater head, and a margin of safety is shown in Fig.1. The gravel in this study was used as a filter zone to prevent the passing of fine materials through the outlet.

The tertiary wastewater was pumped daily from the Sulaibiya DMC to a high level 2.3 m^3 tank through a PVC line. The tertiary wastewater was fed to the soil columns simultaneously. Constant heads of wastewater 0.1 m was used in measuring the removal of coliphage from the wastewater. These constant heads were maintained for the soil columns by overflow outlets above the soil surface. To verify the results, the experiment was carried out on two columns with the same condition. The coliphage tests were studied only under alternating flooding and drying conditions. The columns were subjected to short flooding and drying cycles of 1 d of flooding alternating with 1 d of drying for 4 months. During the drying periods and at the end of each month, the maintenance of the soil columns was carried out by scratching and removing organic layer on top of soil surface using long plastic forks to increase the infiltration rate. The tertiary treated wastewater tank, and all the feeding PVC lines were flushed and cleaned regularly during drying and maintenance periods of column operation.

Samples of influent and effluent were collected directly after the flooding periods. Each sample was separated into two sub-samples, and measurements of the coliphage content of each sub-sample were carried out to ensure the accuracy of the analyses. Influent and effluent coliphage samples were collected following 2 and 3 cycles of flooding periods for the first and second months of flooding, respectively. Samples were collected using sterile 100 ml glass bottles with glass stoppers, and they were analyzed within 4 h of collection. Any samples kept for 4 to 24 h were cooled to at least 10°C. Virus samples were analyzed by the Hydrology Department of the Water Resources Division at KISR using the standard methods for the examination of water and wastewater (APHA, 1998). Fresh coliphage media were prepared at the end of each month.

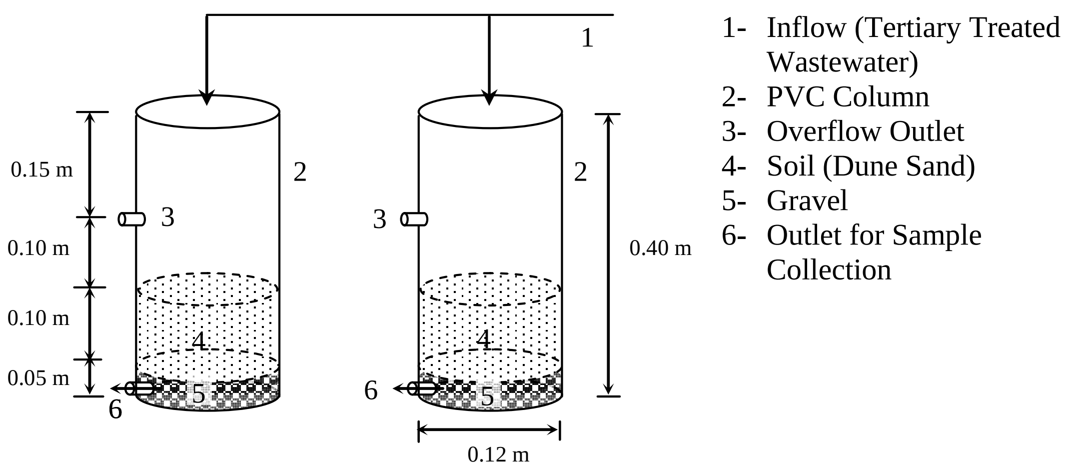

Fig. 1. Layout of the experimental soil column tests.

Results and Discussion

The result of grain size distribution for Dune soil is plotted in Fig. 2. The S-shaped grain size graph indicates rather poorly sorted distributions spanning the gravel, sand, and fine classes. The soils tested consisted of fine sandy soils with different percentages of fines (i.e., silt and clay). The mean value of fines for tested soil samples was found 0.1%. The amount of fines was found to be an important factor for the removal of virus by adsorption within the soil particles. Soils with high contents of fines are expected to adsorb more viruses. The density, specific gravity and porosity of the tested soil are 1.77 g/cm^3, 2.67 and 0.33, respectively. The mean values of specific surface area and cation exchange capacity was found to be 3.49 m^2/g and 1.13 meq/100 g for Dune soil. On other hand, the mean values of total organic carbon and carbonate percentage was found to be 812.03 mg/kg and 7.0%l. The soil analysis results indicated that the Dune soil showed high values of TOC, CO_3, porosity and relatively high SSA and CEC values, and therefore expected to remove high levels of viruses from the tertiary treated wastewater.

The soil columns were recharged with treated wastewater during period August to November 2004. The concentrations of coliphage viruses in the tertiary treated wastewater ranged from 300 to 62800 pfu/100 ml, with mean value of 7320 pfu/100 ml. The results of using Dune soil on the reduction of effluent coliphage virus from the treated wastewater are shown in Fig. 3. The virus removal efficiency for the tested soils ranged from 23 to100%, with mean value of 81.5%. The high coliphage removal efficiency of the Dune soil could be attributed to its higher content of organics, carbonate and fine materials for adsorption. The same conclusions were also arrived by other researchers studying soil with carbonates (Lance et al., 1976 and Gerba and Lance, 1978). Moreover, the fluctuation in the values of virus removal efficiency probability related to the fluctuation in the values of the infiltration rates (0.4-10.9 m/d). In general, the low infiltration rates produced longer contact time for virus adsorption with the soil particles and increasing the removal efficiency.

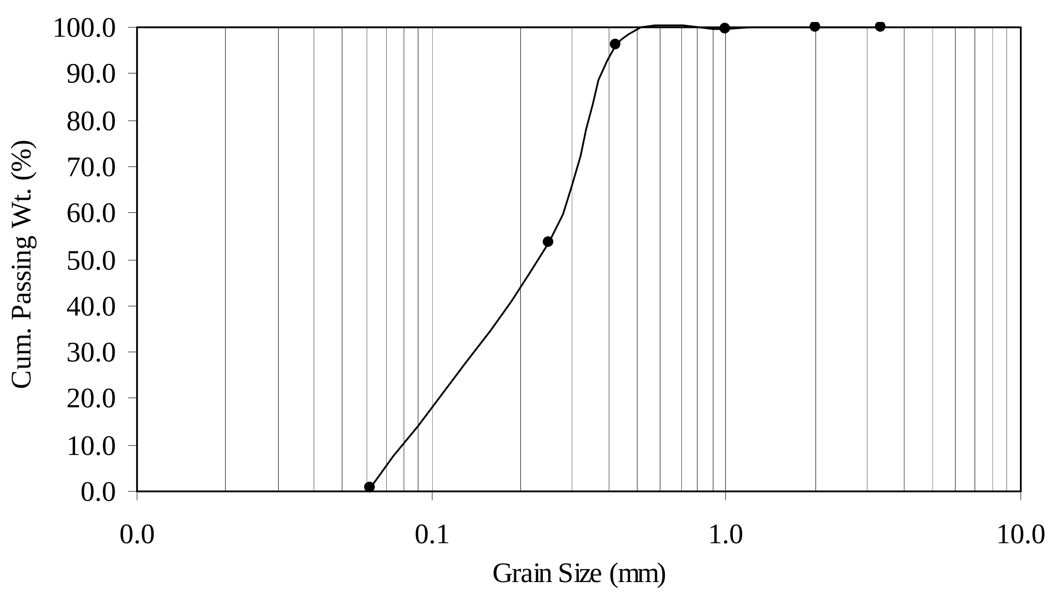

Fig. 2. Grain size distribution for Dune soil.

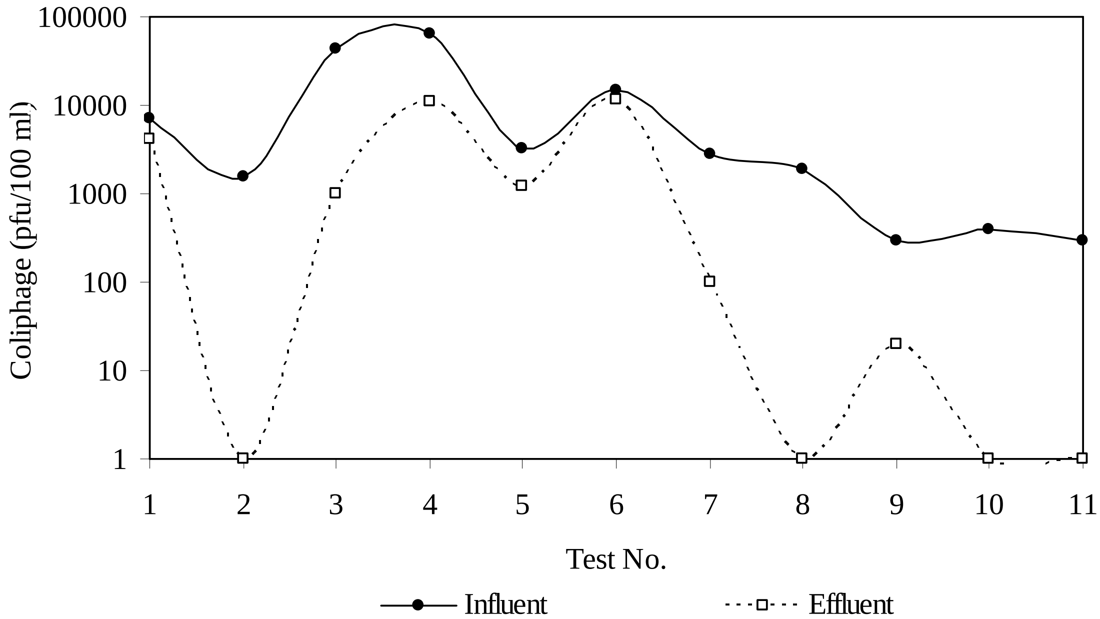

Fig. 3. Results of coliphage content before and after soil treatment.

Conclusions

Soil column experiments were carried out to determine the removal of coliphage viruses from the tertiary treated wastewater using sandy Dune soil collected from Sulaibiya area. The laboratory results indicated that the main soil properties that affect virus adsorption to the soil particles are total organic carbon, total carbonate and fine materials, and the highest coliphage removal efficiency (23%-100%) with mean value of 81.5% was obtained with Dune soil. Based on the laboratory experiments, the following recommendations are suggested including, the removal efficiency of viruses from the wastewater using the SAT system in the field should be evaluated. Also, in agricultural areas the tertiary treated wastewater should be passed through the sand dune filters before this water is used for irrigating the agricultural areas. Moreover, the quality of the groundwater regarding parameters such as viruses and bacteria should be monitored for long period in the agricultural farm areas.

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EVALUATING DIFFERENT TYPES OF IRRIGATION WATER AND ITS EFFECT ON LEVEL OF HEAVY METALS IN SOIL AND PLANT IN AL- HASSA OASIS, KSA

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ABSTRACT

The present study is conducted to investigate the effect of irrigation water quality on heavy metals content in soil and plant grown in the Al- Hassa Oasis. The investigated irrigation water included groundwater (GW), mixture of groundwater and drainage water (GW+DW), mixture of groundwater and tertiary treated wastewater (GW+TTWW) and mixture of groundwater, drainage water and tertiary treated wastewater (GW+DW+TTWW). The results of this study indicate that the water types used in the present study may cause one problem or another according to the water type. By applying the criteria used for interpreting water quality for irrigation, the most domain problems are salinity hazard, potential salinity and soluble sodium percentage. Therefore, it is expected that continuous irrigation without good water management (leaching requirements) can led to severe problems from the salinity point of view. (GW+DW +TTWW) have the highest effect on elemental composition of plants and soil followed by (GW+TTWW), (GW+DW) and then (GW). Generally a significant difference in the heavy metals concentrations for both treated soil and plants was found. The contents of the heavy metals in both soil samples and plants are compared with the worldwide standards. Based on these comparisons some recommendations are raised.

Keywords: - Al Hassa Oasis, Water Quality, Heavy metals, Water Resources, Environmental hazards.

INTRODUCTION

Water insufficiency is one of the most critical problems that confront the world particularly in the arid and semi arid regions. The water policy of any country is to use all water resources. The sources of irrigation water in Al-Hassa Oasis, Saudi Arabia are drainage water, tertiary treated wastewater and groundwater individually or mixed. The agriculture production of the country does not supply enough for the people demands. Most of the principal foods, such as wheat, oil, corn, soybeans, etc. are imported. The agriculture policy is planned to produce enough for local consumption. This policy will succeed by adding more arable land and increasing production per unit area.

The limiting factor for reclaiming and increasing the arable land is the available good quality water. Before using any source of water that mentioned before, it should be tested to find out its effect on soil chemical, physical, nutritional, fertility and toxicity properties. The effects on plant growth, yield and elemental analysis must be calibrated. Also, the hygienic and pathogenic effect on animal and human must be studied. The irrigation regime, the amount of applied water, the method of irrigation and, soil texture are some of the most important factors governing soil salinization.

Heavy metals are components of the biosphere, occurring naturally in soils and plants, but, as a consequence of industrialization. Heavy metals from various sources such as fossil fuel combustion, sewage sludge, industrial waste and fertilizer, contaminate the environment. Plants growing on polluted soils may contain elevated levels of heavy metals (Gallego et al., 2002; Zornoza et al., 2002). Heavy metal ions such as zinc, manganese and nickel are essential micronutrients for plants, but when present in excess, these, and also non-essential heavy metals such as cadmium, can accumulate in plant parts used for human or animal nutrition to undesirably high contents. At even higher levels, they can become toxic to the plant (Williams et al., 2000). The growing urbanization increases domestic water use while supplying wastewater that can be used for non-potable purposes, such as agricultural irrigation.

The wastewater is becoming a preferred marginal water source, since its supply is reliable and uniform, and is increasing due to population growth an increased awareness of environmental quality. In principle, the costs associated to this water source are low compared with those of other water sources (Bahri, 1999). In developed countries the predominant trend in agricultural wastewater reuse is to irrigate treated wastewater (Smith, 1996; Haruvy, 1997; Bahri, 1999,; Nicholson et al., 2003). In contrast, most developing countries such as Mexico, Peru, Chile and Argentina rely on raw wastewater for agricultural irrigation (Siebe and Cifuentes, 1995; Peasey et al., 2000).

The present study is conducted to investigate the effect of using different irrigation water qualities on some heavy metals content in soil and plant grown in the Al- Hassa Oasis, Saudi Arabia.

MATERIALS AND METHODS

Al-Hassa Oasis is one of the important agricultural regions in the Kingdom of Saudi Arabia. In the past, the ground water was the main source of irrigation water. Nowadays, other water resources are used to meet agriculture expansion due to the limited ground water resource. Drainage water (DW), tertiary treated wastewater (TTWW) and groundwater (GW) individually or mixed were used for long term to irrigate the soil of Al-Hassa Oasis.

The investigated irrigation waters include groundwater (GW), mixture of groundwater and drainage water (GW+DW), mixture of groundwater and tertiary treated wastewater (GW+TTWW) and mixture of groundwater, drainage water and tertiary treated wastewater (GW+DW+TTWW). Average characteristics of irrigation water quality used for irrigating the investigated soil are illustrated in (Table, 1).

Quality of irrigation water was determined according to the following parameters (Wilcox, 1958 and FAO, 1973& 1976).

1. The salt concentration of water, which can be expressed in terms of electrical conductivity (EC_{iw}, dS/m).

2. The chemical composition of water, by determining the concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, CO_3^{2-}, HCO_3^{-}, Cl^{-} and SO_4^{2-} ions. The quality parameters were calculated from as follows:

a. Sodium Hazard:

Can be expressed in terms of Sodium Adsorption Ratio (SAR) or Soluble Sodium Percentage (SSP, %).

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

$$SSP = \frac{Na^{+}}{\sum Cations} \times 100$$

(The concentration of cations was expressed in me/L).

b. Magnesium hazard (SMgP):

It can be expressed by the value of Soluble Magnesium Percentage (SMgP, %),

$$SMgP = \frac{[Mg2+]}{[Ca^{2+} + Mg^{+2}]} \times 100$$

c. Bicarbonate hazard:

It can be expressed by the value of Residual Sodium Carbonate (RSC, me/L):

$$(RSC) = [CO_3^{2-} + HCO^{-}_3] – [Ca^{2+} + Mg^{2+}]$$

(The concentration of ions was expressed in me/L.)

3-The concentration of toxic compounds, can be expressed by the values of:

a. Potential Salinity (PS) PS (me/L) = $Cl^{-} + 0.5 * SO_4^{2-}$

b. The boron concentration (B, mg/L)

c. The nitrate concentration (NO_3^{-} , mg/L).

Table (1) Average characteristics of irrigation water quality used for irrigation in the present study.

Characteristics	Irrigation Water			
	GW	GW+DW	GW+TTWW	GW+DW+TTWW
pH	7.37	7.41	7.44	7.55
EC (dS/m)	2.24	2.85	3.84	4.24
TDS (mg/L)	1433.6	1824.0	2457.6	2713.6
Soluble Cations, me/L				
Ca^{2+}	6.29	7.37	12.09	9.21
Mg^{2+}	4.56	4.58	5.63	6.12
Na^{+}	10.31	15.21	19.85	25.14
K^{+}	0.96	0.53	0.42	0.89
Soluble Anions, me/L				
CO_3^{2-}	-	-	-	-
HCO_3^{-}	3.38	4.59	3	5.57
Cl^{-}	8.12	11.61	25	21.11
SO_4^{2-}	10.42	11	9.16	14.58
NO^{-}_3 , mg/L	3.43	6.9	13.13	11.21
Micronutrients, mg/L				
Fe	2.29	3.05	2.31	4.43
Mn	0.34	0.43	0.38	0.39
Cu	0.11	0.09	0.08	0.17
Zn	0.18	2.12	2.34	3.31

B	**0.23**	**0.42**	**0.33**	**0.41**
Heavy metals, mg/L				
Cd	**0.040**	**0.050**	**0.090**	**0.130**
Co	**0.012**	**0.015**	**0.017**	**0.021**
Ni	**0.010**	**0.014**	**0.020**	**0.026**

Forty sites (10 sites for each irrigation type) were selected to represent the irrigated soil with the above mentioned water types. From each site, three soil samples (0 – 30 cm) were collected and mixed to represent a composite sample. The sample position was recorded using Global Position System (GPS). All the collected soil samples were air dried, grounded and sieved through a 2mm sieve and kept for analysis. Mechanical analysis was carried out according to the international hydrometer method using sodium hexametaphosphate as a dispersing agent (Richards, 1972). Organic matter content was determined according to Walkley-Black rapid titration method (Jackson, 1967). pH and total soluble salts were measured in the soil paste extract (Jackson, 1967). Fe, Mn, Cu, Zn, Cd, Co and Ni in the soil were determined by inductively coupled plasma optical emission spectrometer (Carter, 1993) after extraction with DTPA extracting solution. Some physical and chemical properties of the soil are presented in (Table, 2). Figure (1) illustrates the locations of plant and soil used in this study.

For each soil site, three date palms were chosen randomly to collect a composite leaf sample from each date palm using five pinnate from the middle of the third leaf (from top) in all directions, i.e. 20 pinnate per date palm. Also, for each site, fifteen plants of squash crop as another crop, 10 leaves from each plant were taken to represent a composite leaf sample. Leaf samples were washed with tap water, distilled water, air-dried, oven dried at 65C° for 72 hrs, and then ground in a stainless steel mill and the powder stored for elemental analysis. The ground material (plant powder) was digested with concentrated Sulphuric acid + 30% hydrogen peroxide according to the method of Wolf (1982). In the digest, Fe, Mn, Cu, Zn, Cd, Co and Ni were determined by inductively coupled plasma optical emission spectrometer (Carter, 1993).

The data were arranged in randomized complete block design with 10 replicates (one site represent a replicate) for each irrigation type. All collected data were subjected to statistical analysis of variance using SAS Software (SAS Institute Inc., 1996).

RESULTS AND DISCUSSION

1. Soil characteristics:

To make sure, that water type is the main factor in the heavy metals accumulation in soil and plants, the relationship between all characterization of the investigated soil and all heavy metals determined in soil and plants were statistically analyzed (Table, 3).The statistical analysis indicated that the correlation coefficient between all characterizations of the investigated soil and all heavy metals determined in soil and plants were insignificant. This means that, accumulation of heavy metals in the soil and plants are attributed to the water type not to soil properties.

2. Quality of irrigation water:

The water quality parameters for the all investigated water types are presented in Table (4). From these data, it appears that for all types of water, the EC_{iw} ranged from 2.24 to 4.24 dS/m. The critical level of EC_{iw} to cause severe salinity problems is 3 dS/m as reported by FAO (1976). The values of EC_{iw} for (GW) and (GW+DW) are less than the critical limit and no problems of using these types of irrigation water. (GW+ TTWW) and (GW+ DW+TTWW) have EC_{iw} values more than the critical level. It could be considered as high salinity and may cause severe salinity problems. Therefore, it is expected that continuous irrigation without good water management (leaching requirements) can led to severe problems from the salinity point of view.

The data presented in Table (4) also revealed that the SAR value of all water sources is relatively low in comparing with the critical level of sodium hazard (less than 10) as reported by Richards (1972).

With respect to the SSP as indicator for sodium hazard, the values of SSP for all types of water were ranged from 46.61 to 60.78%. The data revealed that all values of SSP were less than the critical limit (< 60%) as reported by Wilcox (1958); accept SSP for (GW+DW+TTWW) were more than the critical limit (> 60%) as reported by Wilcox (1958).

Magnesium hazard is one of the criteria for suitability of water for irrigation. In this respect, the values of SMgP tabulated in Table (4) indicated that all types of water have a values ranged from 32 to 42%. The values are below the harmful level (> 50%). This means no problem of Magnesium hazard. The magnesium salts have toxic effects on the plant and the toxicity of Mg ion is higher than the toxicity of Na ion having the same concentrations.

Table (2) Some physical and chemical characteristics of the experimental soil used in the present study.

NO.	clay,%	Silt,%	Sand,%	Texture	ECe (dS/m)	pH	OM,%	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3-	Cl^{-}	SO_4^{2-}
GW														
1	10.1	8.1	81.8	LS	1.68	7.66	0.25	8.83	6.51	1.24	0.15	1.59	1.86	12.74
2	8.1	6.1	85.8	LS	1.09	7.67	0.36	5.65	3.71	1.38	0.14	2.05	1.86	6.90
3	9.1	10.1	80.8	LS	1.50	7.70	0.24	5.39	4.00	5.00	0.46	2.77	3.75	8.38
4	4.5	4.0	91.5	S	2.56	7.60	0.37	12.27	10.37	2.45	0.22	1.88	1.93	21.31
5	12.1	8.1	79.8	SL	1.52	7.56	0.31	5.34	4.80	4.49	0.55	2.04	3.68	9.28
6	10.1	6.1	83.8	LS	1.26	7.41	0.58	6.40	4.53	1.26	0.17	1.81	1.76	9.00
7	10.1	10.1	79.8	SL	2.09	7.58	0.38	6.16	5.17	8.16	0.88	2.16	5.16	13.00
8	12.1	6.1	81.8	SL	1.39	7.48	0.36	4.52	3.61	5.39	0.34	1.28	3.43	8.99
9	12.1	8.1	79.8	SL	1.63	7.51	0.27	6.76	5.00	4.00	0.46	1.88	2.46	11.73
10	10.1	6.1	83.8	LS	2.58	7.62	0.23	13.14	6.33	5.18	0.88	1.55	3.49	20.53
GW+DW														
11	12.1	8.1	79.8	SL	1.54	7.77	0.49	6.55	5.44	2.58	0.69	2.90	3.59	8.85
12	10.1	8.1	81.8	LS	2.62	7.68	0.38	11.00	9.18	5.11	0.79	2.29	3.21	20.60
13	8.1	6.1	85.8	LS	2.04	7.75	0.60	9.43	7.38	3.07	0.47	1.72	2.26	16.35
14	10.1	8.1	81.8	LS	3.83	7.62	0.36	14.00	12.67	10.93	0.30	1.57	7.01	29.00
15	5.7	6.0	88.3	S	2.26	7.61	0.47	9.42	8.89	3.15	0.61	2.46	3.57	16.07
16	10.1	6.1	83.8	LS	2.02	7.66	0.36	8.43	7.00	4.07	0.47	1.68	2.30	16.00
17	6.1	8.1	85.8	LS	3.42	7.34	0.41	12.80	10.47	9.86	0.88	1.44	6.59	26.02
18	8.1	8.1	83.8	LS	1.89	7.25	0.57	6.86	4.77	6.86	0.20	1.31	5.47	11.69
19	10.1	10.1	79.8	SL	2.40	7.51	0.49	12.03	7.50	3.63	0.75	2.06	3.33	18.25
20	9.1	10.1	80.8	LS	2.56	7.50	0.31	12.44	10.24	2.54	0.22	1.93	2.02	21.44
GW+TTWW														
21	11.1	10.1	78.8	SL	1.59	7.46	0.38	7.08	5.00	3.21	0.58	2.75	3.67	9.45
22	8.1	6.1	85.8	LS	1.88	7.35	0.36	8.11	5.65	3.95	0.63	2.69	3.49	12.13
23	10.1	6.1	83.8	LS	1.38	7.41	0.34	6.31	3.74	3.39	0.34	2.28	3.43	7.99
24	10.1	8.1	81.8	LS	1.98	7.48	0.27	7.93	4.35	7.25	0.23	1.51	6.47	11.80
25	12.1	10.1	77.8	SL	2.17	7.74	0.36	9.91	3.51	7.92	0.32	1.49	8.31	11.65

26	12.1	6.1	81.8	SL	2.10	7.70	0.34	9.10	4.05	7.49	0.29	1.36	7.98	10.93
27	8.1	10.1	81.8	LS	2.24	7.66	0.31	10.70	8.28	3.11	0.27	1.58	2.16	18.44
28	9.1	6.1	84.8	LS	2.57	7.56	0.25	12.05	9.69	3.59	0.26	1.88	2.06	21.70
29	10.1	6.1	83.8	LS	1.83	7.47	0.34	8.85	5.91	2.87	0.58	2.67	3.58	11.91
30	12.1	10.1	77.8	SL	2.19	7.69	0.30	10.00	3.68	7.91	0.27	1.55	6.73	13.21
GW+DW+TTWW														
31	11.1	10.1	78.8	SL	3.26	7.53	0.40	13.53	9.16	9.38	0.22	1.31	6.33	24.45
32	16.2	8.1	75.7	SL	2.32	7.47	0.38	12.21	7.59	2.60	0.70	1.72	2.38	18.90
33	10.1	8.1	81.8	LS	2.43	7.58	0.28	11.96	7.88	3.72	0.72	2.04	3.28	18.80
34	11.1	12.1	76.8	SL	2.62	7.28	0.34	12.37	8.50	4.39	0.79	2.29	3.21	20.50
35	12.1	10.1	77.8	SL	3.70	7.54	0.32	14.00	12.49	10.00	0.35	1.57	6.01	28.81
36	6.5	4.0	89.5	S	3.48	7.42	0.40	13.80	10.67	9.86	0.31	1.44	6.63	26.45
37	10.1	6.1	83.8	LS	2.87	7.37	0.41	14.34	9.00	4.29	0.88	1.67	3.99	22.76
38	8.1	6.1	85.8	LS	2.25	7.35	0.40	11.27	7.49	3.07	0.58	2.42	1.11	18.70
39	10.1	8.1	81.8	LS	2.39	7.50	0.41	11.00	8.58	3.57	0.67	1.98	3.17	18.59
40	8.1	6.1	85.8	LS	2.65	7.56	0.37	12.21	9.00	4.32	0.80	2.43	3.32	20.31

SL = sandy loam LS = loamy sand S = sand

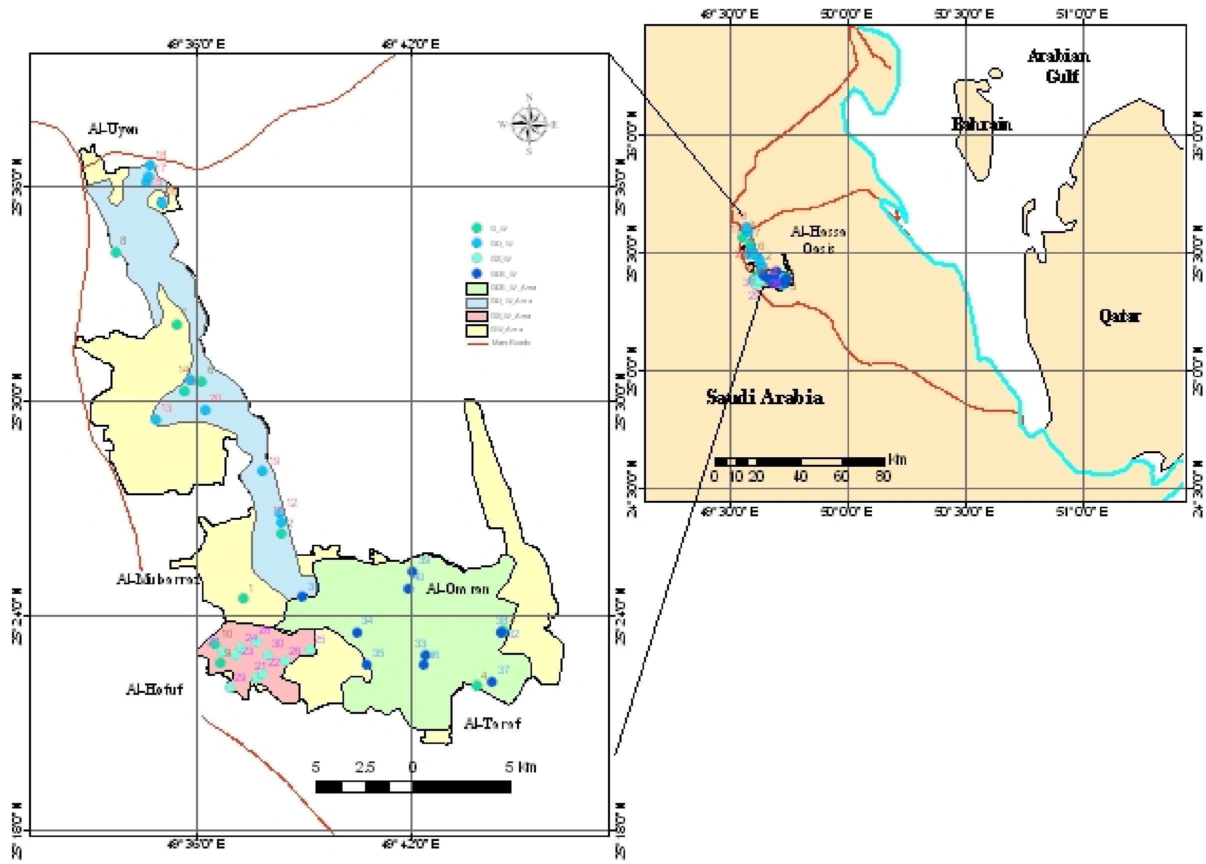

Fig. (1) The locations of plant and soil irrigated by different irrigation water types, Al-Hassa Oasis, KSA.

The RSC value evaluates the tendency of irrigation water to form carbonates and to dissolve or to precipitate the calcium and to a less degree the magnesium carbonates. The precipitation of poorly soluble carbonates increases the sodium hazard of irrigation water and as a result increases the sodicity of irrigated soils. The present values of RSC have a negative values, this means that Ca^{2+} + Mg^{2+} is more than the CO_3^{2-} + HCO^-_3 resulted in no problem of sodium hazard.

Potential salinity (PS) for all water types used was ranged from 13.33 to 29.58 me/L. The high values of PS over the critical level (5 me/L) as reported by Richards (1972) may be due to high chloride and sulphate content in the irrigation water.

Chloride ion (Cl^-) is extremely high and ranged from 8.12 to 25 me/L. According to the guidelines for interpreting water quality (FAO, 1976) this may also cause severe problems concerning Cl^- toxicity to plants.

The concentration of B for all the water types in the present study is < 1 mg/L. The palm trees are considered as semi-tolerant to Boron, which the limit of boron in irrigation water is from 1 to 2 mg/L (Wilcox, 1958). This would put these waters in the range of no problem of toxicity with respect to palm trees.

Table (3) Correlation coefficient between soil characteristics and heavy metals in the investigated soil and plants.

Soil parameters	Fe	Mn	Cu	Zn	Cd	Co	Ni
Date Palm							
Clay (%)	0.01	0.12	0.16	0.07	0.10	0.18	0.14
Silt (%)	0.01	0.14	0.01	0.03	0.12	0.10	0.12
Sand (%)	-0.01	-0.15	-0.11	-0.06	-0.13	-0.17	-0.16
ECe (dS/m)	0.35	0.49	0.35	0.49	0.51	0.40	0.40
pH	-0.34	-0.27	-0.21	-0.20	-0.29	-0.31	-0.27
OM (%)	-0.07	0.02	-0.12	-0.02	0.09	-0.08	-0.03
Ca^{++} (me/L)	0.37	0.58	0.46	0.52	0.58	0.51	0.49
Mg^{++} (me/L)	0.30	0.41	0.19	0.40	0.40	0.27	0.26
Na^+ (me/L)	0.19	0.17	0.20	0.25	0.23	0.20	0.21
K^+ (me/L)	0.04	0.19	0.14	0.14	0.19	0.13	0.11
HCO_3^- (me/L)	0.09	0.02	-0.05	0.00	0.01	0.00	0.02
Cl^- (me/L)	0.19	0.16	0.26	0.26	0.26	0.24	0.29
SO_4^{2-} (me/L)	0.32	0.47	0.30	0.44	0.47	0.36	0.34
Squash							
Clay (%)	-0.08	0.14	0.08	0.06	0.09	0.10	0.13
Silt (%)	0.00	0.05	0.12	0.16	0.13	0.12	0.11
Sand (%)	0.05	-0.11	-0.12	-0.13	-0.13	-0.13	-0.15
ECe (dS/m)	0.44	0.42	0.33	0.39	0.48	0.52	0.48
pH	-0.32	-0.37	-0.38	-0.26	-0.26	-0.30	-0.31
OM (%)	-0.09	-0.03	0.01	-0.03	0.10	0.09	0.03

Ca^{++} (me/L)	0.56	0.53	0.38	0.43	0.55	0.60	0.57
Mg^{++} (me/L)	0.46	0.38	0.30	0.30	0.37	0.42	0.36
Na^{+} (me/L)	0.04	0.07	0.08	0.20	0.23	0.23	0.22
K^{+} (me/L)	0.18	0.30	0.41	0.11	0.16	0.20	0.17
HCO_3^- (me/L)	0.08	0.01	0.17	-0.02	0.02	0.00	0.00
Cl^- (me/L)	-0.01	0.02	0.02	0.20	0.28	0.25	0.25
SO_4^{2-} (me/L)	0.48	0.44	0.34	0.36	0.43	0.49	0.44
Soil							
Clay (%)	0.10	0.22	0.04	0.08	0.16	0.14	0.15
Silt (%)	0.11	0.20	0.02	0.09	0.10	0.11	0.10
Sand (%)	-0.12	-0.25	-0.04	-0.10	-0.16	-0.15	-0.15
ECe (dS/m)	0.41	0.22	0.26	0.32	0.46	0.48	0.51
pH	-0.16	0.01	-0.09	-0.03	-0.33	-0.31	-0.34
OM (%)	-0.11	0.02	-0.14	-0.08	-0.04	0.01	0.01
Ca^{++} (me/L)	0.46	0.31	0.32	0.30	0.56	0.57	0.60
Mg^{++} (me/L)	0.31	0.10	0.22	0.19	0.34	0.36	0.40
Na^{+} (me/L)	0.23	0.11	0.08	0.30	0.20	0.22	0.20
K^{+} (me/L)	0.09	0.04	0.14	-0.08	0.17	0.17	0.21
HCO_3^- (me/L)	-0.04	-0.03	0.02	-0.08	0.00	0.00	-0.01
Cl^- (me/L)	0.23	0.16	0.08	0.35	0.22	0.24	0.19
SO_4^{2-} (me/L)	0.38	0.19	0.25	0.24	0.42	0.44	0.49

Table (4) Water quality parameters used as irrigation water in the present study.

Irrigation water	EC_W dS/m	SAR	SSP %	Mg Hazard %	RSC me/L	Potential salinity me/L	Cl^- me/L	B mg/L	NO^-_3 mg/L
GW	2.24	4.43	46.61	42	-7.47	13.33	8.12	0.23	3.43
GW+DW	2.85	6.22	54.93	38	-7.36	17.11	11.61	0.42	6.90
GW+TTWW	3.84	6.67	52.25	32	-14.72	29.58	25.00	0.33	13.13
GW+DW+TTWW	4.24	9.08	60.78	40	-9.77	28.40	21.11	0.41	11.21

The nitrate contents (NO_3^-) in this water varied from type to another, but it not exceed the critical limit (45 mg/L) that cause nitrate poisoning (Wilcox, 1958).

Generally, from the data previously presented, it appears that the water types used in the present study may cause one problem or another according to the water type. By applying the criteria used for interpreting water quality for irrigation, the most domain problems are salinity hazard, potential salinity and soluble sodium percentage.

3. Leaf mineral composition:

Crops can be characterized by typical chemical composition of growing or developed tissues. Chemical analysis of plant parts is often used for diagnostic purpose in determining fertilizer needs. Poor fertility level, excessive concentration of available nutrients, or high salinity in the root zone is reflected in lower or higher concentrations of certain elements in plant tissues in comparison with the optimum range (Feigin, 1985).

Table (5) shows the leaf mineral composition of palm and squash irrigated by the different types of irrigation water. The results revealed that (GW+DW), (GW+TTWW) and (GW, DW+TTWW) significantly increased Fe, Mn, Cu, Zn, Cd, Co and Ni in palm and squash plants as compared with ground water. It is observed that (GW+DW+TTWW) have the highest effect on elemental composition of plants followed by (GW+TTWW), (GW+DW) and then (GW). Similar results were obtained by Campbell et al (1983); they showed that Fe, Cu, Zn, Pb, Ni and Cd in alfalfa, sweet corn and wheat crops were below hazardous levels.

Samia et al (1989) reported that the application of different treated wastewater effluents to three soils in Egypt (sandy, calcareous and clay) increased the concentration of heavy metals (Cd, Cu, Fe, Mn, Ni and Zn) in leaves of corn and wheat. Hussein (1991) reported that drainage and sewage water significantly increased Fe, Mn, Cu and Zn in corn, sugar beet and cotton plants. Shahin and Hussein (2005) reported that the effect of different types of irrigation water on Cd content in cucumber, lettuce and tomato plants in the following order (GW+DW+TTWW) > (GW+TTWW) >(GW+DW) >(GW). These results are in contrast with the results obtained by Abdel-Nasser et al (2000), they found that the leaf micronutrient contents (Fe, Mn, Cu, Zn and B) in olive plants significantly decreased as increasing the salinity of irrigation water.

Referring to the nutrient criteria, the concentration of Mn in palm and squash plants are within the normal range (15-100ppm) (Hausenbuiller, 1985). The levels of Zn in the plants are much less than the general toxic limit for plants given by Leeber (1972) of 500 mg/Kg. The values of Cu concentration in the plants of palm and squash were within the normal range found in plants (5-15ppm) (Hausenbuiller, 1985), except Cu concentrations in squash plants irrigated with (GW,DW&TTWW) were higher than this range, but these value less than the toxic level (30 ppm) according to Leeber (1972). The concentration of Fe in the plants of palm and squash were more than the normal range found in plants (30-150 ppm), but generally these excesses concentrations are not toxic to plants (Hausenbuiller, 1985).

Table (5) The leaf mineral composition (mg/kg) of Palm and Squash irrigated by different irrigation water types in the present study.

Irrigation water	Fe	Mn	Cu	Zn	Cd	Co	Ni
	Date Palm						
GW	146.78	13.98	5.16	10.73	0.24	0.28	4.40
GW+DW	178.22	20.01	6.62	12.00	0.30	0.35	5.94
GW+TTWW	239.01	28.32	9.63	13.23	0.32	0.49	7.61
GW+DW+TTWW	298.77	43.67	10.77	15.35	0.35	0.56	7.96
LSD (0.05)	40.41**	5.02**	0.77**	0.91**	0.02**	0.02**	0.20**
	Squash						
GW	174.45	20.52	11.06	30.19	0.12	0.26	2.37
GW+DW	231.15	21.97	12.29	36.27	0.30	0.45	4.12
GW+TTWW	264.34	26.34	13.94	42.93	0.36	0.51	5.31
GW+DW+TTWW	331.35	43.44	20.77	44.60	0.41	0.63	6.52
LSD (0.05)	39.03**	3.63**	2.27**	3.38**	0.06**	0.06**	0.09**

** Significant at 1% probability level

4. Soil chemical analysis:

Table (6) illustrates the effect of different types of irrigation water quality on the chemical properties of soil cultivated with palm and squash. The results indicated that (GW+DW), (GW+TTWW) and (GW+ DW+TTWW) significantly increased available micronutrients Fe, Mn, Cu, Zn, Cd, Co and Ni of the soil as compared with ground water. It is noticed that the effect of different types of irrigation water quality on the chemical properties of soil are in the following order (GW+ DW+TTWW) > (GW+TTWW) > (GW+DW) > (GW). Also, the data showed that there were a positive significant correlation between soil micronutrients content (Fe, Mn, Cu, Zn, Cd, Co and Ni) and plants content (Fe, Mn, Cu, Zn, Cd, Co and Ni). The correlation coefficients were 0.96, 0.90, 0.92, 0.98, 0.96, 0.99 and 0.92, respectively for palm plants. The corresponding values for squash plant were 0.96, 0.77, 0.99, 0.97, 0.93, 0.99 and 0.97, respectively.

These results are in agreement with those obtained by Abdel-Nasser et al (2000), they found that available soil micronutrients (Fe, Mn, Cu and Zn) significantly increased as increasing the salinity of irrigation water. Also, these results are in agreement with those obtained by Hussein (1991), who found that sewage and drainage water significantly increased Fe, Mn, Cu and Zn in sandy clay loam soil, sandy soil and calcareous soil. These results are in harmony with those obtained by Shahin and Hussein (2005), they reported that (GW, DW &TTWW) have the highest effect on Cd content of soil followed by (GW&TTWW), (GW&DW) and then (GW).

Table (6) The chemical analysis of soil irrigated by different irrigation water types in the present study.

Irrigation water	Fe	Mn	Cu	Zn	Cd	Co	Ni
	mg/kg						
GW	2.13	2.94	0.37	1.18	0.10	0.26	0.28
GW+DW	2.95	6.02	0.56	2.31	0.13	0.41	0.39
GW+TTWW	3.95	9.06	0.84	4.48	0.17	0.53	0.48
GW+DW+TTWW	7.40	9.86	1.48	6.00	0.21	0.65	0.67
LSD (0.05)	1.14**	2.36**	0.41**	1.85**	0.01**	0.03**	0.05**

** Significant at 1% probability level

According to Follet and Lindsay (1970) the concentrations of Mn, Cu and Zn in the soil were adequate. Also, the concentration of Fe in soil irrigated with (GW, DW &TTWW) was adequate. The concentration of Fe in soil irrigated with (GW&TTWW) and (GW&DW) was marginal while, the concentration of Fe in soil irrigated with (GW) was deficient.

A positive significant correlation between some available micronutrient in soil and some microelements in palm and squash plant were fitted and presented in Fig. (2).

CONCLUSION:

It can be concluded that the water types used in the present study may cause one problem or another according to the water type. By applying the criteria used for interpreting water quality for irrigation, the most domain problems are salinity hazard, potential salinity and soluble sodium percentage. Therefore, it is expected that continuous irrigation without good water management (leaching requirements) can led to severe problems from the salinity point of view.(GW+DW +TTWW) have the highest effect on elemental composition of plants and soil followed by (GW+TTWW), (GW+DW) and then (GW). Heavy metals in the studied soil and plants were in the range of the uncontaminated area.

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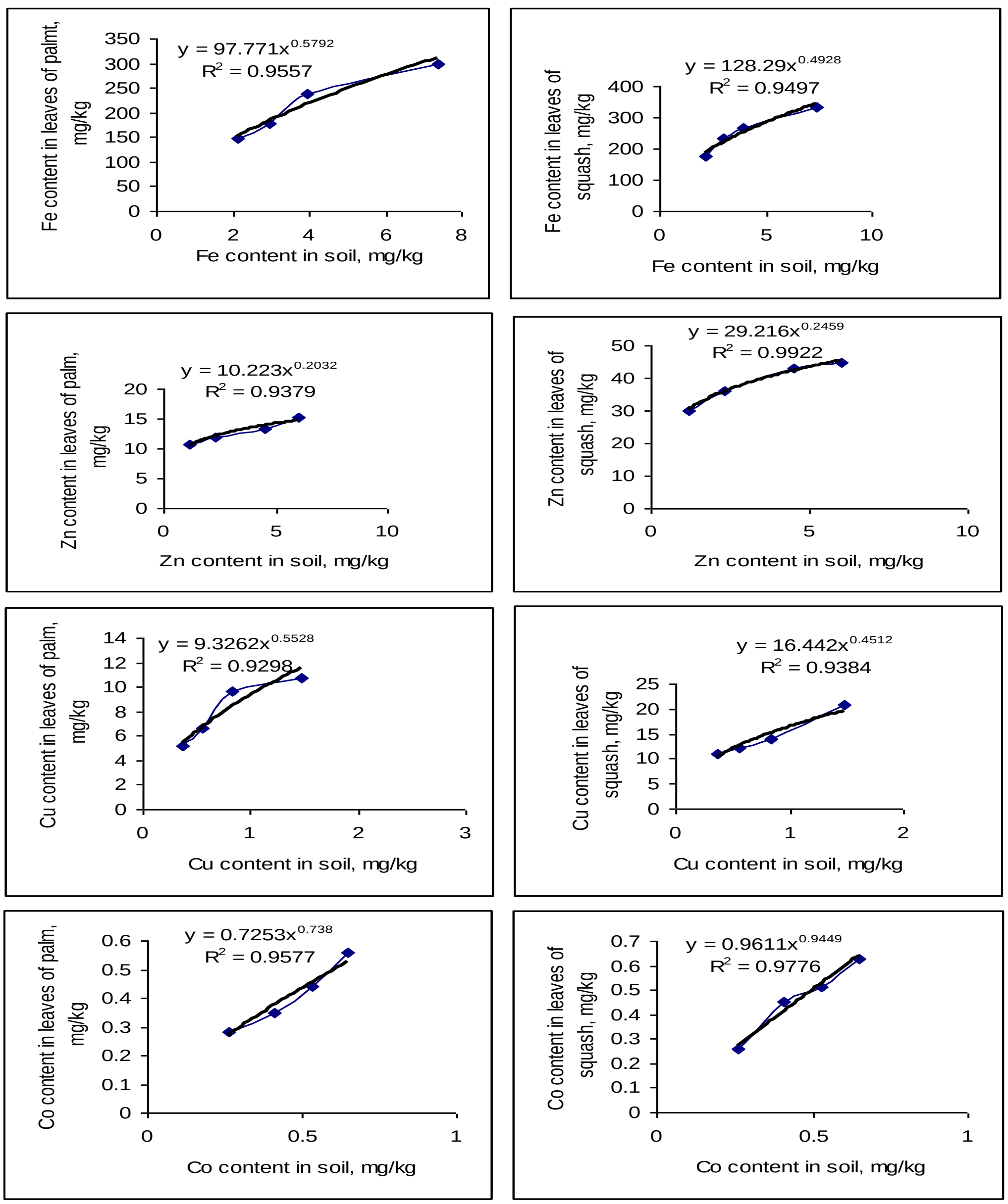

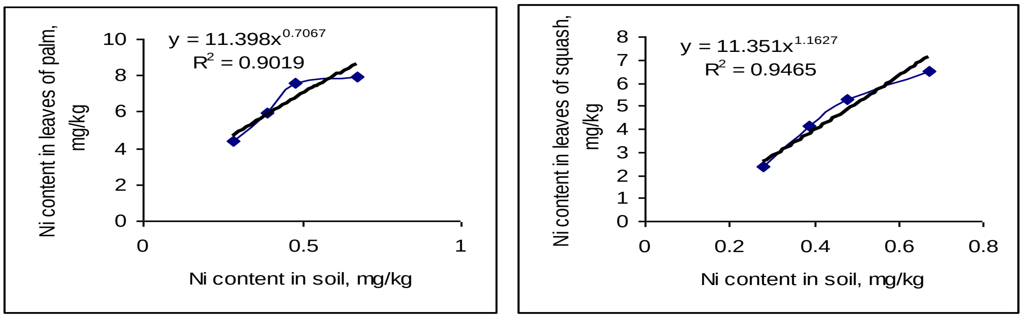

Fig. (2) Correlation between some available micronutrient in soil and some microelements in palm and squash plant.

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اثر مخلفات مياه المحطات الكهروحرارية في تلوث نهر دجلة بمدينة بغداد الكبرى

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الخلاصة :

تمثل مدينة بغداد الكبرى الثقل السكاني الاكبر لسكان الحضر في القطر، فقد تضاعف عدد سكانها خمسة مرات ونصف تقريباً للمدة من 1947-2007 ,حيث بلغ عدد السكان فيها عام 1947 نحو 540 الف نسمة قفز العدد بعد نصف قرن إلى 4.3 مليون نسمة حسب تعداد عام 1997 , ويتوقع في عام 2007 ان يصل عدد السكان الى 5.8مليون نسمة, فقد كان معدل نمو سكان المدينة مرتفعاً قبل السبعينات عما وصل إليه الآن ,بلغ عام 1965 (6.5%) انخفض المعدل الى (3.1%) عام 1987، وهذا يعود إلى نمط التركز السكاني في تلك الفترة والذي دفع إلى اعتماد سياسات اقتصادية في نشر التنمية والخدمات إلى عموم محافظات القطر وعدم تركزها في مدينة بغداد.

لقد ادى النمو السكاني السريع لمدينة يغداد الكبرى خلال نصف القرن الماضي ,خاصة في عقوده الاخيرة الى زيادة الطلب على المياه في المدة من (1980-2000) والمخصصة للاستخدامات الصناعية والزراعية والمنزلية تراوحت من 39,5 - 59,6 مليار متر مكعب سنوياً, بلغ تدفق العائد بعد الاستخدام في عام 2000 نحو 22,3 مليار متر مكعب سنوياً, شكل نصفها تقريباً تصريف محطات الطاقة الكهروحرارية, بالإضافة إلى 41 % من عائد الري و9 % من المصادر الصناعية والمنزلية. ....

كما إن الثقل الصناعى الموجودة في بغداد, – متجسدا بمنشات محطات الكهرباء الحرارية و التصفية النفطية ومصانع الدباغة ومنتجات الألبان والنسيج والمجازر ومعامل الصوف وتجهيز الدواجن وزيت الطعام والمشروبات واللدائن– ,,,كل هذه المنشات تقوم بتصريف المطلقات الصناعية السائلة الى نهر دجلة , وهنا يتحمل نهر دجلة الوزر الاكبر ,كونه احد موارد المياه السطحية الرئيسة في القطر مع نهر الفرات,اذ يعد مصدراً مهماً من مصادر الثروة التي من الممكن اتخاذها اساس في تنمية اقتصاد القطر على المدى الطويل,لذلك دفع هذا الامر الكثير من المصانع الى معالجة الفضلات الكيميائية المعقدة باستخدام طرق التنقية العادية مثل الترسيب والمعالجة البيولوجية, إلا انه ثبت عدم فاعلية مثل هذه المعالجات في إزالة المواد السامة في كثير من الأحيان .

,....تضمنت الدراسة الحالية تفاصيل الطرح غير الأمثل للمنشات الحر ارية التى تستخدم المياه بكميات كبيرة , وتأثيرها على نوعية المياه إضافة إلى الحلول التي وضعت لمعالجة بعض المصادر الملوثة متخذة من مدينة بغداد الكبرى حالة تطبيقية لتركز مثل تلك الصناعات ذات التأثير المباشر في نهر دجلة , الذي يعد عصب الحياة في المدينة

المقدمة :

نظراً لما يلقيه التطور الصناعي والتكنولوجي من آثار إيجابية على حياة الإنسان, بنفس الوقت يلقى بثقله سلبياً على البيئة, من هنا بادر الباحثون في العراق باهتمامات علمية مكثفة بتقييم الآثار البيئية واقتراح تدابير ملائمة لحماية الرصيد المائي المهم في الأنهار العراقية . من حيث توجيه النمو الصناعي وحث الصناعات الجديدة على استخدام تكنولوجيا متطورة وتشريع القوانين الصارمة..

إن الأضرار البيئية الناجمة عن المطلقات الصناعية متعددة وخاصة المرتبطة بالمياه , نتيجة لطرح المواد السامة والجراثيم الملوثة التي تغير من خواص المياه الطبيعية. ويمكن تعريف المطلقات الصناعية السائلة (أي مياه المخلفات الصناعية (Industrial Waste Water "بأنها تلك المياه التي تنتج من الاستعمالات الصناعية المختلفة والتي تحوي حسب المصدر على مواد كيماوية ضارة لا يسمح لها بان تعالج مع المياه البلدية لاحتوائها على مواد سامة[1].

اشكالية وفرضية البحث :

ان بناء منهج عملى يخدم المخططين في اتجاه السيطرة على تلك المطلقات السامة لحماية البيئة المائية ,والمعالجة اينما وجدت من مثل هذه المشكلات,, يعد المنطلق الاساس لصياغة مشكلة بحثنا الحالية والتى يمكن طرحها بالسؤال الاتى :

س_ هل يمكن تحديد الخصائص والمواد للمياه الصناعية الملوثة المطروحة في نهر دجلة ضمن مدينة بغداد الكبرى ,والناتجة من المحطات الكهروحرارية والمصافي القائمة عليه لتحديد مستوياتها وفق المنظور الجغرافي لبيئة النهر وامكانية الحفاظ على الثروة المائية .؟

لذلك تدفع الاتجاهات الحديثة في المنهج العملى للجغرافيا _ان يجمع الباحث بين النظرية والتطبيق في معالجة المشكلات المكانية التى تؤثر على حياة الانسان_ ..من هنا تنطلق فرضيتنا العلمية من شعور الباحث بان نهر دجلة اصبح يعانى الكثير من المشكلات البيئية ,احد اسبابها دخول الكثير من المطلقات الصناعية المختلفة الى النهر ,مصدرها المنشات الصناعية التى تستخدم المياه بكميات كبيرة في الانتاج , الامر الذى غير من الخواص الكيماوية والفيزياوية للماء النهر , وهي ناجمة عن مطلقات صناعية معقدة وسامة (سائلة, صلبة، غازية) دون مرورها بمعالجات فعالة قبل الطرح, مما يهدد حياة النهر وديمومته.!! ان هذا الامر يستدعي وضع النقاط على الحروف لتحديد الملوث والمسبب المباشر وسبل المعالجة العملية والمخططة للحفاظ على بيئة النهر .

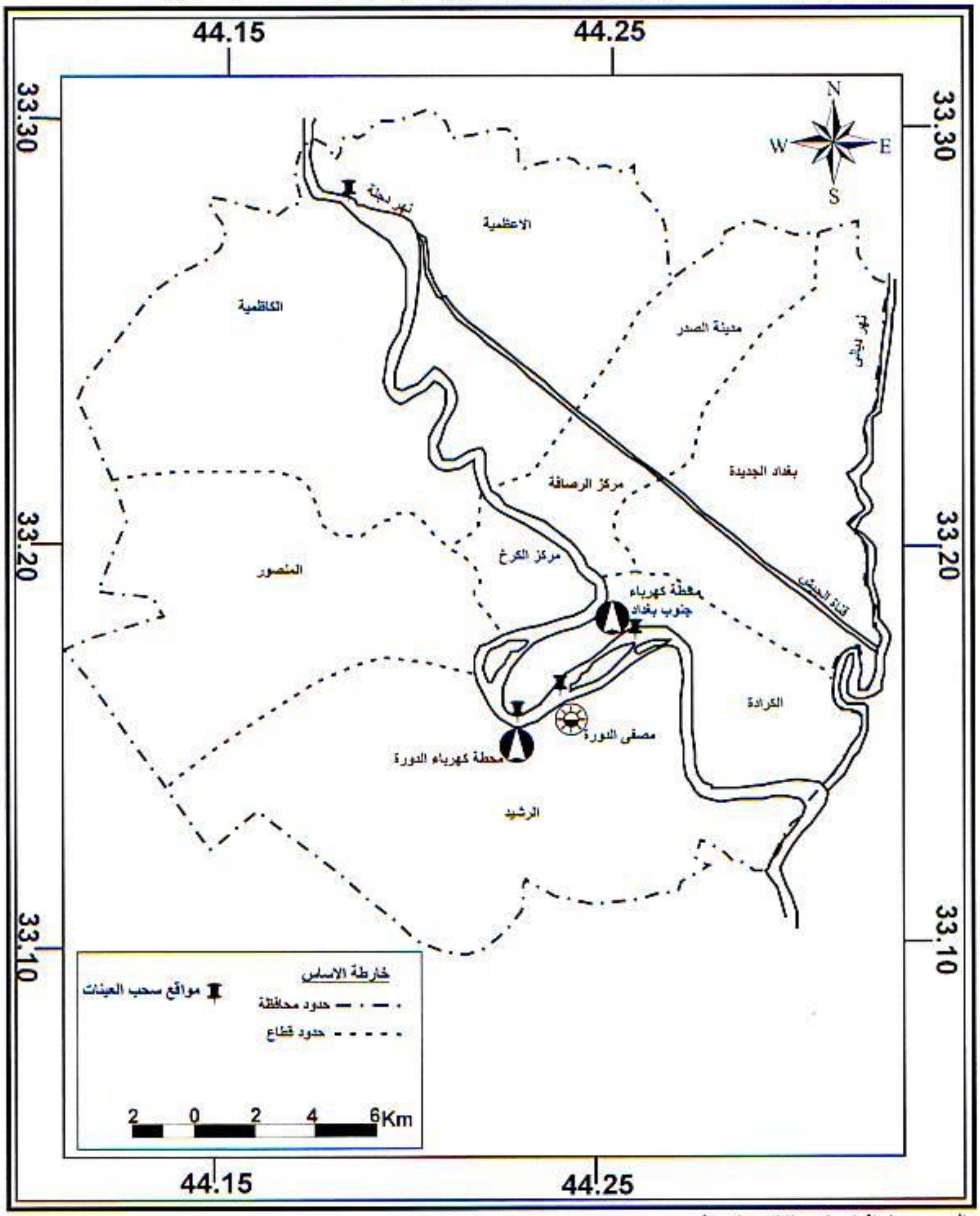
حدود البحث وادوات التحليل :

تم اختيار محطتين كهروحرارية لانتاج الطاقة الكهربائية و مصفى الدورة لانتاج المشتقات النفطيةكمنشأت صناعية تنموية مهمة تستخدم المياه بكميات كبيرة تقع على نهر دجلة.. ضمن مدينة بغداد الكبرى والتى هى عاصمة العراق – انظر خارطة (1) مستعيناً بنتائج الفحوصات التي قام بها الباحث لقياس نسبة التلوث المسجل ومقارنتها بالمعاملات والمعايير المسموح بها لمياه المطلقات الصناعية الخاصة بحماية البيئة العراقية,حيث تم اخذ العينات في منتصف شهري تموز وكانون اول خلال عام 2005 , لتمثل فصلين من السنة الصيف والشتاء ,كى تعطى الموشرات معدلات فصلية دقيقة عن مياه النهر .كما تم سحب عينة من مياه النهر شمال جزيرة بغداد السياحية للتعرف على خصائص مياه نهر دجلة قبل ان يمر من المنشات قيد الدراسة . حيث كان الباحث يسعى لاخذ عينات اكثر من شهرين لكن الظروف الداخلية التى تمر بها مدينة بغداد ؟ حالت دون ذلك !.

لقد استخدم الباحث أدوات متعددة لحل المشكلة واثبات الفرضية ,منها نظرية ومنها عملية جاءت من المشاهدة الميدانية لطبيعة النهر ,والمقابلات, وتحليل مجموعة من العينات اخذت من مناطق التصريف للمياه المعدمة بالطرائق المختبرية , اذ كان لهذه الأدوات أهمية في تحديد خصائص المطلقات والمسبب لها, حيث جاءت الدراسة بمبحثين مترابطين ,كان الاول منها يتعلق بالجانب النظري , اما الثاني فيتعلق بالجانب التطبيقي , نسعى منها تحقيق اهداف البحث العلمى وحماية مياهنا في المستقبل ..

خارطة (١)

التوزيع الجغرافي للمحطات الكهروحرارية ومصفى الدورة في مدينة بغداد وتحديد مواقع اخذ العينات



المصدر / الباحث بالاعتماد على

- امانة بغداد ، قسم التصاميم ، التصميم الانمائي الشامل لمدينة بغداد لعام ٢٠٠٠
- تم تثبيت موقع المحطات من مرئية فضائية للقمر الصناعي لاندسات 7 - 2002 - gogel Eareh

المبحث الأول(الجانب النظري)

استهلاك المياه في الصناعة وانتاج الطاقة :

يعد الماء ضرورة في قيام بعض الصناعات, إذ يزداد استخدام المياه في المدن التي تمتاز بالنمو السريع للسكان وارتفاع درجة توسيع الصناعة فيها, فتحتاج الصناعات الكيماوية والبتروكيمياوية وتكرير النفط والورق والحديد والصناعات الغذائية إلى كمية كبيرة من المياه لذا ترتفع درجة استخدام هذه الصناعات للمياه بشكل كبير, إذ يمكن استخدامه كمادة أولية أو عامل مساعد في بعض العمليات الصناعية . أما بالنسبة للعراق كان معدل استهلاك المنشآت الصناعية للماء في عقد الستينات حوالي 250 مليون م^3 سنوياً[2], اما الان فقد ازداد هذا الرقم عما كان عليه في السابق نتيجة لحركة النهضة الصناعية التي قامت في القطر. وقد أشار تقرير مستقبلى لمشروع التنمية الحضرية لمدينة بغداد حتى عام 2025 – تناول فيه معدلات الاستهلاك اليومي للماء لكافة الاستعمالات المختلفة , وجد فيه إن القطاع الصناعي يستهلك حوالي 8% من مجموع الاستعمالات[3] وهذا يتضح في الجدول (1-ملحق).

لقد اشارت إحدى الدراسات الشمولية التي أجريت عام 1996 على المخلفات المطروحة في الأنهر العراقية من المنشأت الصناعية, إن الكمية الفعلية بلغت بمقدار 62813 م^3/ ساعة. وتمتلك هذه المنشأت الصناعية وحدات لمعالجة مطروحاتها بحدود 61 وحدة عاملة من اصل 93 وحدة موجودة بعضها عاطل عن العمل وهذا يتضح في الجدول (2-ملحق) . وهنا يمكن القول بأن كمية استهلاك وتصريف الصناعات للمياه تعتمد على عوامل عدة منها:[4]

أ- نوع الصناعة وحجم المنشأت الصناعية : إن المياه المطلقة من هذه الصناعات تختلف في نوعيتها على أساس (نوع وحجم الصناعات). اذا كانت صغيرة ,متوسطة ,كبيرة في الحجم . استهلاكية ام انتاجية ..تستخدم الماء بكثرة في العمليات الانتاجية .

ب- كمية الإنتاج الصناعي : إذ ترتفع كمية استهلاك الماء ودرجة تصريف المياه الملوثة الذي تحدثه العمليات الصناعية وذلك بارتفاع كمية وحجم الإنتاج الصناعي مما يدل على وجود علاقة طردية تجمع فيما بينهما.

ج- اساليب الإنتاج : إذ تتفاوت كمية المياه المستعملة والمصرفة تبعاً لاختلاف مراحل التصنيع ضمن الصناعة الواحدة.

د- أسعار صرف المياه وشدة القوانين البيئية : إذ كلما زادت شدة القوانين البيئية وارتفعت أسعار صرف المياه حاولت المنشأة الصناعية تقليل كمية المياه المستخدمة وذلك عن طريق إعادة الاستفادة من المياه المستخدمة قدر الامكان, وهو بدوره يعمل على تقليل كمية المياه الملوثة المصروفة إلى المصدر المائي .

مخاطر المطلقات الصناعية من مياه الصرف على الانسان

تسبب مياه الصرف للمطلقات الصناعية سواء كانت معالجة جزئياً أو غير معالجة عدة أضرار على البيئة المائية. يمكن حصرها بماياتى :[5]

1. ترسب أو تأكسد المواد الملوثة غير المذابة في الحياة .
2. المواد المترسبة تعمل على تكوين غازات تعفنية بعد التخمر تؤدي إلى استهلاك الأوكسجين .
3. وجود الزيوت والدهون في المياه تشكل طبقة فوق الماء وتمنع التهوية.
4. وجود المواد الملونة والدابغة والقطرات في الماء يؤدي إلى استهلاك الأوكسجين .
5. تخضع المواد اللاعضوية الذائبة إلى تفاعلات كيماوية مما تزيد من ملوحة المصدر المائي .
6. وجود المادة السامة يؤدي إلى موت الأحياء وخاصة الأسماك (كالزئبق والرصاص) .
7. وجود العصيات الجرثومية في مياه الصرف الصناعي له الأثر في انتشار الأمراض والتي تؤثر على صحة الإنسان والحيوان .

ويمكن ملاحظة الجدول(3-ملحق) الذى يكشف بعض الملوثات التي تحويها مطلقات المياه الصناعية المعدمة. حسب نوع الصناعة القائمة اذا كانت كيمياوية او بتروكيمياوية ,انتاجية او استهلاكية والتى لها علاقة بحاجتها للماء بشكل كبير .

مراحل التخطيط للسيطرة على المطلقات الصناعية من مياه الصرف

ان التخطيط للسيطرة على المطروحات الصناعية السائلة لايرتبط فقط بكمية ونوعية هذه المطروحات , بل بامكانية طرحها، والمجال المتوفر لهذا الغرض. ومن الامثلة التي تثار في هذا المجال هو هل هناك مورد مائي قريب ومناسب كماً ونوعاً لاستقبال الملوثات الصناعية وتخفيفها لدرجة تجعلها ضمن الحدود المسموح بها ؟ وان لم يتوفر مثل هذا المورد المناسب، ما هي امكانية المدينة لاستقبال المطروحات الصناعية وما هي شروطها لتقبل مثل هذا الطرح ؟ وعلى العموم فالصناعة ملزمة بتعديل خصائص فضلاتها بما يتناسب مع متطلبات الجهات المعنية بموضوع الطرح سواء كان ذلك الادارة المحلية للمجاري او الاجهزة المعنية بحماية الموارد المائية. وفي جميع الاحوال تبقى القرارات الخاصة بالتخطيط لحلول مشاكل المطروحات الصناعية السائلة مرتبط بموقف هذه الجهات وتشريعاتها.

بعد حصول القناعة بوجود المشكلة وضروة حلها، على الجغرافي ان يسأل الاسئلة التالية:

1. ما هي الامكانية الذاتية للصناعة في تخفيف او في حل مشكلة المطلقات الصناعية السائلة؟
2. من اين يجب ان تاتي المساعدة في حل هذه المشكلة؟
3. هل ستكون الحلول بمستوى القدرة الفنية المتوفرة , ام انها ستكون قفزة لا يؤمل مواكبتها من قبل المستوى الفني المتوفرة .؟

و للاجابة عن هذه الاسئلة يمكن الاستفادة من الستراتيجية المرتبطة بمراحل السيطرة على مخلفات المطلقات الصناعية والتي اشارت اليها توصيات ندوة متخصصة في مجال انسب المعايير في حماية المياه الملوثة من المطلقات الصناعية في الدول العربية خلصت بها لماياتى , [6]:

المرحلة الاولى:

لهذه المرحلة وجهان الاول مرتبط بمصير المطروحات واين ستنتهي ومواصفات الطرح المطلوبة التي تعتمد على اسلوب الطرح، وتخضع المطروحات الى مواصفات وتحديدات الجهات البيئية اذا كان الطرح الى(المورد المائي مباشرة),فهنا يستدعى الامر دراسة خصائص الوسط المائى الذي تنتهي اليه المطلقات من الناحية الطبيعية (المورفولوجية والهيدرلوجية) , والى تحديد الجهات البلدية اذا كان الطرح الى شبكة مجاري المدينة. اما الوجه الثاني فيشمل التحديد الدقيق لكافة مصادر المطروحات مع التحليل النوعي والكمي لها وذلك من خلال برنامج كامل لاخذ العينات وتحليلها. ثم تحليل نتائج عملية المسح الصناعي للمطلقات مع تدارس امكانية عزل الفضلات او اعادة استعمال الماء او تقليل كمية المياه المستعملة او تحسين الصيانة والتشغيل وغيرهما من الامور التي تحدد كمية ونوعية المطلقات المطروحة.

المرحلة الثانية:

هناتدرس قابلية المطروحات للتحليل والمعاملة لمعرفة الاساليب الممكن اتباعها للمعالجة وطبيعة وسعة الوحدات اللازمة لهذا الغرض. والى جانب الدراسة المختبرية لقابلية المعاملة تدرس الخبرات السابقة وتجدول كافة الوسائط الممكنة والمتبعة لمعاملة المطروحات المماثلة والموجودة في الدوريات العلمية. كما ويتم اختيار التركيب الامثل لمحطة التصفية اي ان الوحدات المختارة تجمع بطريقة مثلى لتعطي احسن نتيجة نهائية في المعاملة. ويصار الى دراسة اقتصادية اكثر تفصيلاً وعلى ضوء هذه الامور تقرر الصيغة النهائية للمحطة . **المرحلة الثالثة:**

تشمل هذه المرحلة التصميم التفصيلي للوحدات واسلوب ربطها ويشمل كافة الجوانب التصميمية و الميكانيكية والانشائية فضلاعن الحياتية.

إذن كان من الضروري بان يتم التخطيط المرحلي لكل مشروع و نأخذ الأبعاد المكانية بالحسبان لإقامة أي منشاة صناعية واقعة بالقرب من مصادر المياه العذبة ,وذلك للتأثيرات البيئية التي تسببها هذه المنشات . وهذا ما سنلاحظه في إحدى المناطق الصناعية المهمة في القطر, وهي مدينة بغداد. ذات الثقل السكاني و الصناعي الكبير مقارنة ببقية المدن العراقية الاخرى, والذي باتت الصناعات القائمة على نهر دجلة تشكل خطراً مباشراً على صلاحية المياه التي تجري في النهر وهذا ما سوف نستعرضه في المبحث اللاحق.

الخصائص الطبيعية والهيدرولوجية لنهر دجلة :

ينبع نهر دجلة من المرتفعات الواقعة في جنوب شرق تركيا, وتشترك في حوض دجلة اربع دول هي تركيا وسوريا والعراق وايران, وتبلغ المساحة الكلية للحوض 340500 كم^2 ومن ضمنها حوض شط العرب. يبلغ طول نهر دجلة 1718 كم منها 1290 كم داخل الأراضي العراقية[7]. كما يمثل نهر دجلة احد موارد المياه السطحية الرئيسية في القطر مع نهر الفرات, كما يعد مصدراً مهماً من مصادر الثروة, التي من الممكن اتخاذها أساس في تنمية اقتصاد القطر على المدى الطويل, ونظراً لهذه الأهمية فلابد من دراسة الخصائص الطبيعية المؤثرة في النهر ضمن منطقة الدراسة. إذ يضم نهر دجلة روافد خمس , اولها من الشمال رافد الخابور يبلغ طوله 160 كم ,يليه الزاب الكبير,, ويلتقي بنهر دجلة 70 كم جنوب مدينة الموصل.. اما الرافد الثالث فهو الزاب الصغير ويكون التقائه مع نهر دجلة على بعد 30 كم شمال موقع الفتحة. ويعد الزابان (الكبير والصغير) أهم روافد نهر دجلة حيث يمدان النهر بما يتراوح بين 43%- 63% من مجموع مياه النهر.,اما نهر العظيم الرافد الرابع , وهو رافد صغير من روافد نهر دجلة يقع حوضه بالكامل في العراق . واخيرا نهر ديالى وهو الرافد الخامس ,حيث يصب في جنوب مدينة بغداد. [8]

هذا ويتحرك نهر دجلة بشكل ملتوي داخل مدينة بغداد ,مما أعطاه مسافة طولية بحدود 58.5 كم مقاسة من مقدم جزيرة بغداد السياحية وحتى 3 كم بعد التقاء نهر ديالى به, وضمن هذا الجزء من النهر يوجد 34 انحناءة مميزة بأنصاف أقطار مختلفة..ويكون عرض النهر داخل مدينة بغداد ما بين 190م و 500م، وتبلغ سرعة ماء النهر 1.42م/ثا في حالة التصاريف العالية و 0.45 م/ثا في حالة التصاريف الواطئة، ويصل معدل انحدار سطح الماء في النهر داخل المدينة 6.9 سم/كم، اما مكونات قعر النهر فهي الرمل الناعم والغرين والطين[9]. وترتفع نسبة الترسبات كلما اتجهنا إلى جنوب مدينة بغداد وتقل باتجاه حافات النهر إلى الوسط، حيث تزداد سرعة التيار عما عليه في الجرف وخاصة إذا لم توجد جزر وسطية تمنع حركة انسياب جريان المياه بشكل طبيعي.

اما مايتعلق بالنظام المائي Hydrologic regime ، ويقصد به الفترات التي يكون فيها نسبه التصريف والمناسب عالية فيه وتسمى (فترة الفيضان) وايضا الفترات التي تقل نسبة التصريف والمناسيب وتسمى (فترة الصيهود),,ولغرض معرفة نوع النظام المائى لنهر دجلة ,,,تصنف انظمة الانهر الى ثلاثة اصناف : النظام البسيط, النظام المزدوج و النظام المركب . إذ يتألف النظام المائي من مؤشرات تصريف الماء ومنسوبه وسرعته، لذا فأن النظام المائي لانهار العراق تتوزع على ثلاث فترات واضحة تمثل فترة الفيضان الشتوي وفترة الفيضان الربيعي وفترة الصيهود. وتقسم مواسم فيضان دجلة إلى مرحلتين : [10]

- المرحلة الأولى تمثل المطرية من شهر تشرين الأول ولغاية شباط.
- المرحلة الثانية تمثل فترة ذوبان الثلوج وسقوط الأمطار وتمثلها من شهر شباط ولغاية شهر مايس، أما الفترة من حزيران والى أيلول فتمثل فترة الصيهود. إذن فالنظام المائي لنهر دجلة يتمثل بوجود قمتين للتصريف مع زيادة منسوب الماء يعقبها فترة صيهود مع انخفاض منسوب الماء، لذا فهو يقع ضمن النظام المائي المزدوج.

. يتأثر تصريف نهر دجلة في مدينة بغداد بعدة عوامل منها الأمطار ومعدلات فترات سقوطها، فضلاً عن السدود التي تعترض جريان مياه النهر وتتحكم في تصاريفه ومناسيبه، لذا فأن تصريف النهر يتعرض إلى تغيرات كثيرة خلال اشهر السنة ومن سنة الى اخرى. وتزداد معدلات التصريف زيادة ملحوظة في فترة الخريف والشتاء وذلك لسقوط الأمطار بمعدلات عالية، وتقل كمية التصريف في فترة الصيف لكونه يمثل فترة انخفاض تصاريف النهر (فترة الصيهود)، كما إن لمشروع الثرثار و ما له من أهمية على تصاريف النهر من خلال استخدامه لخزن كميات كبيرة من المياه والتي تصل سعة الخزن 88كم^3، ويتم خزن المياه في موسم الفيضان وإعادته إلى النهر خلال موسم الصيهود.[11] .

المبحث الثاني (الجانب التطبيقي)

التوزيع الجغرافي والتوصيف الوظيفي للمنشات الحرارية في مدينة بغداد الكبرى :

لوحظ في الخارطة السابقة رقم (1) إن نهر دجلة يشطر مدينة بغداد إلى قسمين يسمى الجانب الشرقي الرصافة، والجانب الغربي الكرخ. وقد اعتمدت الدراسة على محطتين لتوليد الطاقة الكهروحرارية ,اما المنشاة الثالثة فهو مصفى الدورة, الذي يقع في جانب الكرخ مع محطة كهرباء الدورة ,اما محطة كهرباء جنوب بغداد فتقع في جانب الرصافة من مدينة بغداد ,وتجدر الاشارة ان هذه المنشات الكبيرة قد تاسست بعد منتصف القرن الماضي ويمكن ان نعطى تصور لعملها ومنتجاتها واسباب توطنها لاهميته في بناء البحث :

1. محطة توليد كهرباء جنوب بغداد وتاسست سنة 1959.

تقع المحطة على الجانب الشرقى لنهر دجلة ,وهى محطة تعمل بقوة البخار فهي تحتاج الى كميات كبيرة من الماء والوقود وذلك من اجل توليد البخار في المراجل التى تنقل القوة الناتجة في تدوير المولدات التى تقوم بدورها بتوليد تيار كهربائي ,فوجودها ضمن مناطق تجهيز المحروقات من (مصفى الدورة)ومن مورد مائى دائم (نهر دجلة) حقق وفورات اقتصادية استغلت جميعا كوسط للمدخلات والمخرجات ، شكل هذا الامر عامل جذب وتوطن للمحطة في ذلك الموقع . هذا وتتالف المحطة من ستت وحدات حرارية واخرى غازية ,تبلغ الطاقة الانتاجية التصميمية للوحدات الاربعة الاولى بمقدار 55ميكاواط-ساعة ,اما الوحدتين الاخريتين فتبلغ الطاقة التصميمية لهما 67.7 ميكاواط –ساعة .وقدسجل اعلى معدل لانتاج الطاقة للمحطة عام 1992 بلغ 169.8 ميكاواط –ساعة -وهي الان تنتج 93.4 ميكا واط- ساعة عام بسسبب توقف البعض من وحداتها الحرارية وقلة المحروقات التى تجهز من المصفى 2005.[12].

2. محطة توليد كهرباء الدورة وتاسست سنة 1964.

تقع المحطة في منطقة الدورة محاذية للجانب الغربي لنهر دجاة ,ولكون المحطة تعمل بقوة البخار فهي تحتاج للماء والوقود بكثرة ,الامر الذى انعكس على ان تنجذب المحطة الى مصفى الدورة يسبب الروابط الصناعية بين المنشاتين ,حيث يجهز المصفى المحطة بزيت الوقود وزيت الخام وزيت الغاز والغاز الطبيعى .حيث تستعمل من اجل توليد البخار في المراجل لانتاج البخار لتدوير المولدات لانتاج الكهرباء . تتالف المحطة من اربع وحدات حرارية ,السعة التصميمية لكل منها 160ميكاواط –ساعة كما توجد اربع وحدات غازية اخرى ،سعة كل منها 37ميكاواط-ساعة فاذن القدرة التصميمية لجميع وحدات المحطة 788 ميكاواط-ساعة (الحرارية والغازية) حققت اعلى انتاج لها عام 2000 وصل الى 368ميكاواط –ساعة امالان فيبلغ 275 ميكا واط –ساعة وهي اقل من القدرة التصميمية لانخفاض تجهيز المحروقات للمحطة من المصفى كذلك [13].

3. مصفى الدورة-نفط المنطة الوسطى وتاسس سنة 1958.

يقع المصفى على الجانب الغربي من نهر دجلة ضمن منطقة الدورة .وينتج البنزين والنفط وزيت الغاز ووقود الديزل والدهون الجاهزة والشحوم (علما بان المصفى كان ينتج وقود الطائرات والبنزين الممتاز والاسفلت والشمع)لكن اغلب هذه المنتجات متوقفة حاليا ,ان هذا المصفى يستخدم مواد اولية تدخل في الانتاج منها النفط الخام وبعض المذيبات العضوية , ومواد كيمياوية ,كالفوسفات والصوديوم الثلاثى وحامض الكبريتيك ,والصودا الكاوية ومانع التاكل وقاتل الاشنات وكلوريد الصوديوم ..ان المصفى يضم عدة وحدات,يمكن تحديدها (التكرير وتضم اربعة خطوط) ,و(البنزين) و(معاملة النفط الابيض بالهيدروجين)و(المراجل البخارية) و(انتاج حامض الكبريتيك) و(الحرق والنفايات)و (معالجة المياه

الصناعية)و (خدمات الطاقة والتبريدوالسلامة) [14] اما الانتاج فلم تتوفر بيانات دقيقة عن الانتاج حاليا ,فهي محدودة التداول .

إن اغلب هذه المنشات الصناعية قد تأسست في الخمسينات والستينات. كما يلاحظ، وهي تستخدم المياه بكميات كبيرة، إذ أنشأت هذه الصناعات الانتاجية والتحويلية, ولم يؤخذ بنظر الاعتبار عند التصميم اقامة محطات فعالة لتصفية المياه الملوثة ومعالجتها قيل الطرح .فضلاً عن ذلك أن هذه المنشات تستخدم المياه بغزارة بعمليات التبريد وخاصة في المصافي والمحطات الحرارية.فالتقادم والاندثار كان ولازال ملازما لوحداتها الخاصة بمعالجة المطلقات الصناعية ,فقد مضى على تشييدها اكثر من نصف قرن ,لازالت الى الان تلقى بمخلفاتها في مجرى نهر دجلة.!

إن هذه المنشات تستخدم مواد كيماوية وبتر وكيماوية لها خصائص سامة بعد الاستخدام وحتى بعد المعالجة ولو بسب ضئيلة ، مضرة بصحة الكائنات الحية البشرية والحياتية. مما يؤثر على البيئة المائية , ويكمن الخطر إذا زادت عن حدها ,فإذا لم يكن المجرى المائي مستعد وفيه كفاية مائية من تخفيض الأثر والتركيز، فهذا يبلغ الأمر بحصول كارثة بيئية في الوسط المائي وبالتالي تكون النتيجة وخيمة. وهذا ما سوف نلاحظه. من خلال المتطلبات المائية للمنشات الصناعية والتلوث المائي الذي يمكن أن يحصل من المطلقات .

وحدات معالجة المياه المطروحة من المنشآت الحرارية :

من اجل إدراك واستيعاب عملية تلوث المياه بالمطلقات الصناعية، لابد أن نبحث في عملية استهلاك المياه في تلك المنشات وطريقة تلويثه للبيئة المائية ويمكن ان يكشف جدول (4-ملحق) كميات المياه المستهلكة والمصروفة في المنشات الصناعية في بغداد والتي تعكس ان الماء عنصر مهم و فعال في العملية الإنتاجية، ويتباين دوره من صناعة لأخرى حسب طبيعة العمليات الإنتاجية، لذا يمكن استعراض هذه المنشات بالشكل الاتي :

1- محطة توليد كهرباء جنوب بغداد :

تقوم محطة كهرباء جنوب بغداد باستهلاك مقدار من المياه الخام المسحوبة من نهر دجلة تبلغ كميته بحدود 37000 م^3/ساعة، إذ يتم استخدامها من اجل التبريد لذا يتم هنا تغذية الوحدات الحرارية للمحطة، أما الكمية الأخرى 120م^3/ س , فتستخدم لاغراض استخدامات الوحدة. وتتمثل طبيعة المياه المتخلفة المصرفة من المحطة بارتفاع الملوثات العضوية واللاعضوية والشوائب، حيث منشأها من مياه غسل المرشحات والمياه المتسربة من خطوط توليد البخار في وحدات المحطة بالإضافة إلى مياه الاستعمال البشري. أما النوعية الأخرى من المياه المصرفة فتكون عبارة عن مياه ساخنة تتصرف من الوحدات الحرارية نتيجة لمرور كمية كبيرة من المياه عبر المكثفات لاجل تخفيض درجة حرارتها العالية، لذا ترتفع درجة حرارة مياه التبريد مسببة بذلك تلوث حراري للبيئة المائية. ويمكن أن تصل الدلتا الحرارية(والمقصود بها كمية ارتفاع درجة حرارة المياه المسحوبة من النهر نتيجة لقيام هذه المياه بتبريد الوحدات الحرارية في المحطة الكهربائية).في فصل الشتاء للمياه الداخلة إلى المحطة بحدود 14مْ كمعدل، أما درجة الحرارة المياه الخارجة في الفصل البارد بحدود 24مْ , أما بالنسبة لدرجة حرارة المياه الداخلة في فصل الصيف تكون 32 مْ , اما الخارجة والمصرفة من المحطة فتكون بحدود 43 - 46 مْ، ولا تحوي هذه المياه على ملوثات كيمياوية أو بايولوجية، وهي تدخل لاجل تبريد المكثفات وتخرج بنفس الكمية لكن مع ارتفاع في درجة حرارتها.[15]

أما طريقة معالجة المياه المتخلفة فتمتلك المحطة وحدة بطاقة تصميمية 35م^3/ساعة، وتمتاز المياه المصرفة بارتفاع في درجة حرارتها فضلا عن احتوائها على ملوثات عضوية واملاح, والناتجة من تصريف مياه المحطة ذات طبيعة صناعية وصرف صحي الذي يجمع في حوض المعالجة. ويتم تصريفها منه والى النهر وذلك بعد أن تجري عليها معالجة كيمياوية بإزالة المواد العضوية والعالقة، وتبلغ كمية المياه المصرفة إلى نهر دجلة بحدود 37000 م^3/س والتي تمثل مياه التبريد، و 120م^3/س مياه مصرفة من الوحدات الأخرى، إذ تبلغ الكمية الكلية للمياه المصرفة بحدود 37120م^3/س[16].

2- محطة توليد كهرباء الدورة:

تستهلك محطة توليد الدورة كمية من المياه التي تسحب من نهر دجلة، وتقدر الكمية المسحوبة بحدود 60000 م^3/س والتي تستخدم من اجل تبريد المكثفات والتي لا تشترط بان تكون مياه نقية، حيث تدخل الكمية نفسها الى المحطة وتخرج بنفس الكمية مع نسبة ضياع 2% من الكمية الداخلة. وتستخدم المياه لاغراض الاستخدام البشري وللشرب ايضاً.وتتمثل طبيعة المياه المصرفة باحتواء كل منها على مصدر ملوث سواء أكان صناعيا وصرف صحي ام شبكة امطار , ثم تتجه بعدها لشبكة تصريف خاصة بها حيث يتم معالجتها وتصريفها الى النهر , وتقدر كمية المياه الثقيلة المصرفة 5 م^3/س ، اما مياه الامطار فتبلغ 300 م^3/س بالاعتماد على نسبة ارتفاع مستوى الماء في الحوض الرئيسي[17].

وتتميز طبيعة المياه المصرفة اولا بارتفاع المواد العضوية مع نسبة من الاملاح المذابة , نشات من مياه غسل المرشحات والمياه التي تتسرب من خطوط توليد البخار في وحدات المحطة مضافا لها مياه الصرف الصحي. وتتمثل النوعية الثانية في مياه ساخنة تتصرف من الوحدات الحرارية لمرورها عبر مكثفات لاجل تخفيض درجة حرارتها العالية لذا تسبب تلوث حراري للبيئة المائية.

3– مصفى الدورة:

يتم استخدام مياه نهر دجلة للاستخدامات داخل المصفى، اذ تسحب الى وحدة الاسالة وتجري عليها عملية معالجة قبل استخدامها، وتقدر كمية المياه المسحوبة من النهر بحدود 1650 م^3/س وتسحب بصورة مستمرة 24 ساعة، وتستخدم المياه حسب نوع الاستخدام، فمثلاً تستخدم في المراجل البخارية لانتاج البخار، كما يستخدم في عملية التبريد وفي غسل الارضيات ولانتاج مياه صالحة للشرب. وبعد ان تسلك المياه داخل الاقسام التابعة للمصفى يتم تصريفها الى وحدة المعالجة وتحوي المياه الداخلة الى الوحدة على نسبة من المواد النفطية وعلى العناصر السامة كالفينول، وتصرف هذه المياه بواسطة مجاري مبطنة اذ يبلغ طول المجرى من وحدة المعالجة الى نهر دجلة بحدود 500 م تقريباً .اما عملية معالجة مياه المطلقات الصناعية , فتتجه المياه المتخلفة في داخل الاقسام الانتاجية والاقسام الاخرى التابعة للمصفى لتتجمع المياه في حوض المعالجة , اذ تجري عليها معالجة ميكانيكية أي فيزياوية باستخدام قاشطات خاصة لعزل طبقة النفط الطافية على سطح الحوض وتعزل وتعاد الى قسم انتاج الزيوت الخفيفة ليتم اعادة استخدامها. وتذهب المياه بعدها الى حوض المعالجة الكيمياوية، اذ يتم اضافة حامض الفسفوريك ومادة اليوريا والبولي الكترولايت من اجل التخلص من المواد الكيمياوية الموجودة فيها وبعدها تذهب المياه الى حوض المعالجة البايولوجية حيث تزرع بكتريا خاصة ويوفر لها الاوكسجين والغذاء ليتم بواسطتها التخلص من العناصر السامة وخاصة الفينول، وتبلغ الطاقة التصميمية لوحدة المعالجة بحدود 750 م^3/س وبدون وجود مشاكل في الوحدة، وبعد ذلك تصرف المياه الى نهر دجلة وتبلغ الكمية المصرفة الفعلية بحدود 550 م^3/س. [18].

من خلال هذا الوصف الميداني للمنشأت الصناعية، ومعرفة كميات المياه المستخدمة والمصرفة اثناء عمليات التبريد و المعالجة ، بات من الضروري تحديد مستويات التلوث المائي في نهر دجلة باستخدام عينات من مياه النهر وفحصها بالطرق المختبرية ، لبيان صلاحية النهر للاستخدام وتحديد سبل معالجة المشكلة قبل ان تستفحل المشكلة وتأخذ ابعادها البيئية في الافق القريب .

خصائص ومكونات المطلقات الصناعية السائلة في نهر دجلة

يعالج هذا المبحث خصائص ومكونات المطلقات الصناعية للمشاريع ا المعتمدة في البحث في ضوء مقاييس اعتمدت فيها الحدود القصوى لنوعية المياه الصالحة للبيئة المائية، حيث اصدرت التشريعات البيئية المعايير الدولية المسموح بها في نظام صيانة الانهار من التلوث، والتابعة الى دائرة حماية وتحسين البيئة في العراق.

حيث هناك بحدود 26 معيار لقياس نوعية المياه منها درجة الحرارة T.M ، والعكورة Turbidity (NTU) والتوصيلة الكهربائية E.C. اضافة الى المتطلب الحيوي للاوكسجين BOD والمتطلب الكيمياوي للاوكسجين COD فضلاً عن تحديد جميع المركبات العضوية والمعدنية الموجودة في الطبيعة.

وقد اعتمد الباحث لضرورات الدراسة التي تركز على المنشات الحرارية باختيار خمسة معايير مهمة تشترك فيها جميع الصناعات القائمة لتحديد مستويات المطلقات وهي المواد الكلية الصلبة الذائبة TDS والتى تبلغ فيه الحدود القصوى المسموح لها لنوعية المياه الصالحة كاقصى تركيز هو 1500 ملغم/لتر. اما المواد الكلية الصلبة العالقة TSS حيث تبلغ فيه الحدود القصوى لنوعية المياه الصالحة كاقصى تركيز مسموح لها هو اقل من 60 ملغم/لتر ..اما درجة الحرارة المئوية C فالحدود القصوى المسموح بها دوليا هو اقل من 35مْ . اما المتطلب الحيوي للاوكسجين (BOD)، فالمعيار المحدد له دوليا اقل من (40)ملغم/لتر كاقصى تركيز مسموح، اضافة الى المتطلب الكيمياوي للاوكسجين COD، والمعيار المحدد له دوليا اقل من (100) ملغم/لتر كحد اقصى له،[19] هذا ويمكن ملاحظة نتائج التحليل المعتمد من قبل العينات لمياه المطلقات الصناعية من هذه المنشات لعام 2005 والتي تم الاستعانة بمختبرات متخصصة تم بموجبها بناء الجدول (5-ملحق) , وللاعتبارات العلمية وعقد مقارنات موضوعية لنوعية المياه اثناء جريانه, فقد تم فحص عينة من المياه عند نقطة دخول النهر من شمال حدود امانة بغداد وبالتحديد (عند مدخل جزيرة بغداد السياحية) للتعرف على خصائصه الفيزكيمياوية ,حيث ساهم هذا الفحص بتلك النقطة على كشف مدى التلوث المائى الذى يتعرض له النهر اثناء جريانة داخل المدينة وخاصة بعد مروره بهذه المنشات قيد الدراسة في الصيف والشتاء , وهذا تحليل مكاني لكل معيار معتمد :

أ) درجة الحرارة (Cْ) :

تطرح المنشات الصناعية في منطقة الدراسة والمتمثلة في محطات توليد الطاقة الكهروحرارية ومصفى النفط مياه ذات درجات حرارة عالية تؤثر في المسطح المائي. حيث بلغ المعدل الفصلي لدرجات الحرارة لعينات المطلقات لكل المنشات المدروسة 33.5 درجة مئوية .سجل تباين في عينات الصيف والشتاء بلغت معدلات الدرجات على التوالي (40),(27)درجة مئوية, لاحظ جدول(5-ملحق).

اذ نجد هناك اختلاف في درجات الحرارة المصرفة الى النهر من تلك المنشات الصناعية ,فقد سجل اعلى معدل فصلى لدرجة الحرارة في مياه المطلقات الصناعية لمحطة كهرباء الدورة بحدود 40.5 درجة مئوية , بينما سجل مصفى الدورة معدل فصلى بلغ 32درجة مئوية ,اما محطة كهرباء جنوب بغداد فقد سجلت معدل بلغ 28 درجة مئوية . وعند مقارنة نتائج المعدلات العامة لمياه المطلقات الصناعية لبعض المنشات في منطقة الدراسة ، مع محددات نظام صيانة الانهار ضمن الحد المسموح والذى هو بحدود (اقل من 35ْ درجة مئوية)، نجد بان محطة كهرباء الدورة قد تجاوزت الحد المسموح به في المعيار المستخدم وهذا يعود الى استخدام المحطة الى 8 وحدات حرارية وغازية مما اثر في كمية المياه المستهلكة والمصرفة منه والبالغ 60000 م^3/ساعة. ناهيك عن ان الدرجات الحرارية العليا سجلت في الصيف اكثر من الشتاء وهي منطقية لارتفاع درجات الحرارة صيفا في المدينة مقارنة بالشتاء.لاحظ خارطة رقم _2_

ب) المواد الكلية الذائبة (T.D.S) :

يلاحظ اختلاف في تراكيز المواد الكلية الذائبة في مياه المطلقات الصناعية المطروحة من المنشات الصناعية في منطقة الدراسة، حيث سجل المعدل الفصلى لمياه المطلقات الصناعية ولجميع المنشات في منطقة الدراسة بحدود (1105.3) ملغم/لتر, سجل في الصيف والشتاء المعدلات الاتية (1428.3)(782.3)ملغم / لتر على التوالى ,لاحظ جدول(5-ملحق).

وعند مقارنة نتائج المعدلات العامة لمياه المطلقات الصناعية لجميع المنشات في منطقة الدراسة مع حدود نظام صيانة الانهار والذي بلغ الحد المسموح به لتركيز الـ TDS في الانهر بحدود 1500 ملغم/لتر، نجد بان موقع مصفى الدورة قد تجاوز الحدود المسموحة لدى المعيار فقد سجل في الصيف 1910 ملغم/لتر, لان المياه الداخلة الى وحدة المعالجة تتسرب منها نسبة من المواد النفطية والمواد السامة

خارطة رقم (2)

كالفينول, لقدم واندثار بعض من الانابيب الناقلة للمياه المعدمة . اضافة الى محطة كهرباء الدورة التى تجاوز فيها التركيز الحد المسموح له في فصل الصيف , فقد بلغ1650 ملغم/لتر بسبب طبيعة المياه المصرفة التى تتميز بارتفاع المواد العضوية ونسبة الاملاح المذابة والتى تكون ناتجة من مياه غسل المرشحات والمياه المتسربة من خطوط توليد البخار في وحدات المحطة وانخفاض منسوب الماء بسبب قلة التصريف النهري .لاحظ خارطة رقم ـ3ـ

ج) المواد الكلية الصلبة العالقة (T.S.S) :

لقد يلغ المعدل الفصلي للمود الكلية الصلبة العالقة في المياه المطلقة لكل المنشات مامقداره (71.6)ملغم /لتر ..سجلت المعدلات في الصيف والشتاء لكل المنشات (98))(45.6)ملغم /لترعلى التوالي...لاحظ جدول(5-ملحق)

ولكن لوحظ وجود تباين في قيم المواد الكلية العالقة خلال فترة الدراسة، فقد سجل اعلى معدل فصلى في محطة كهرباء الدورة بلغ (95) ملغم / لتر يليها محطة كهرباء جنوب بغداد (76) ملغم /لتر, ثم اقل المعدلات في مصفى الدورة (44) ملغم/لتر .

وعند مقارنة نتائج المعدلات العامة للمياه المطلقة من جميع المنشات الصناعية في منطقة الدراسة مع محددات نظام صيانة الانهار من التلوث والذي بلغ الحد المسموح به في مياه الانهر العراقية بحدود 60 ملغم/لتر، نجد بان جميع هذه المنشأت تحوي على نسبة عالية من المواد العالقة وخاصة محطة كهرباء الدورة نتيجة لتسرب طبقة نفطية طافية على سطح الحوض في وحدة معالجة المياه المتخلفة فرغم زراعة بكتريا خاصة يوفر لها الاوكسجين والغذاء للتخلص من العناصر السامة وخاصة الفينول لكن تتسرب جزء كبير منها الى النهر .فضلا على انخفاض منسوب الماء في النهر بذلك الوقت من السنة مما ينعكس ذلك على ارتفاع التراكيز السامة وعدم استيعاب المياه لجميع هذه المطلقات مما يؤثر على البنية الهيدرولوجية لنهر دجلة.لاحظ الخارطة رقم _4_

د) المتطلب الحيوي للاوكسجين (BOD) :

سجلت نتائج الفحوصات للعينة ان المعدل الفصلى للمتطلب الحيوى لكافة المنشات المدروسة بلغ17.3 ملغم /لتر ..تباين ذلك المعدل في الصيف والشتاء ..حيث بلغ المعدل الصيفى لكافة المنشات 28 ملغم /لتر في حين كان المعدل الشتوى 7 ملغم /لتر.لاحظ جدول (5-ملحق)

ولكن اظهرت نتائج تراكيز المتطلب الحيوي للاوكسجين BOD في المياه المطلقة من المنشات الصناعية في منطقة الدراسة بأن اعلى قيمة سجلت في المياه المطلقة لمحطة الدورة وبلغ بحدود (71) ملغم/لتر وادنى قيمة سجلت هو في محطة كهرباء الدورة كانت القيمة 2 ملغم /لتر ,وكذا الحال بالنسبة لمحطة كهرباء جنوب بغداد 2 ملغم /لتر

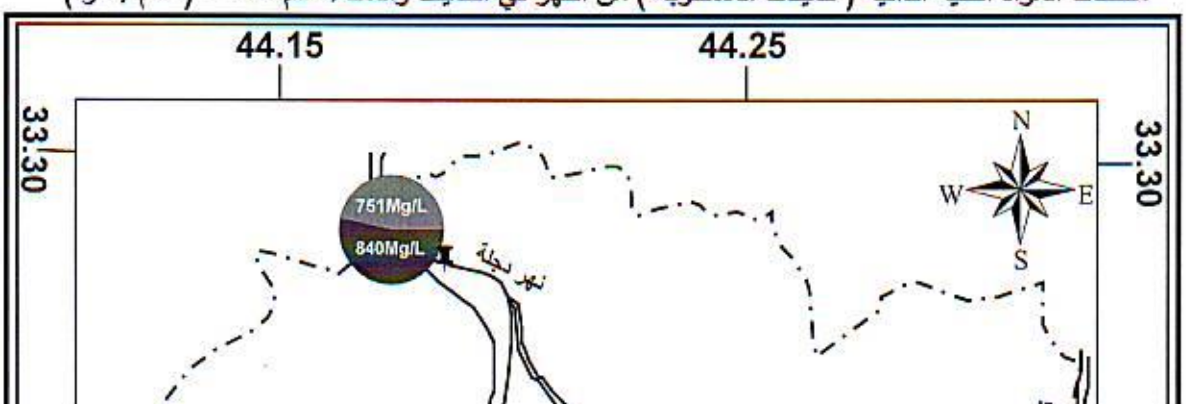
وبمقارنة نتائج المعدلات العامة لجميع مواقع المنشات الصناعية في منطقة الدراسة مع محددات نظام صيانة الانهار والبالغ (اقل من 40 ملغم/لتر) كاقصى تركيز مسموح به لمياه الانهار. نجد بان مصفى الدورة قد سجل اعلى معدل قد تجاوزت الحدود المسموحة بها في النظام ويعود سبب ارتفاع الـ BOD في هذه المنشأة الى طبيعة المطلقات الصناعية والتي تمتاز بارتفاع نسبة المواد السامة مما تعمل على استهلاك الاوكسجين الذائب DO في الماء وتقلل من نسبته وترفع بذلك من تركيز لمتطلب للاوكسجين BOD وهذا يرجع الى عدم كفاءة وحدات المعالجة في هذه المواقع لمعالجة تركيز الـ BOD التي تنتج قيم عالية تفوق الحدود الطبيعية المسموح بها. لاحظ الخارطة رقم _5_

هـ) المتطلب الكيمياوي للاوكسجين (COD) :

اظهرت نتائج التحليل المختبري للعينات المسحوبة ان المعدل الفصلي لتراكيز المتطلب الكيمياوى للاوكسجين بلغ 59.8 ملغم /لتر ولجميع المنشات الصناعية . اذ تباينت المؤشرات المسجلة في الصيف والشتاء حيث بلغت معدلات التراكيز (3.98)و(21.3)ملغم /لتر على التوالى ,وهى على العموم تبدو اقل من المعدلات المسموح بها دوليا , ولكن الصورة تاتى مغايرة عندما نتعرف على التراكيز لكل منشاة .لاحظ جدول (5-ملحق).. حيث بينت نتائج تراكيز المتطلب الكيمياوي للاوكسجين في

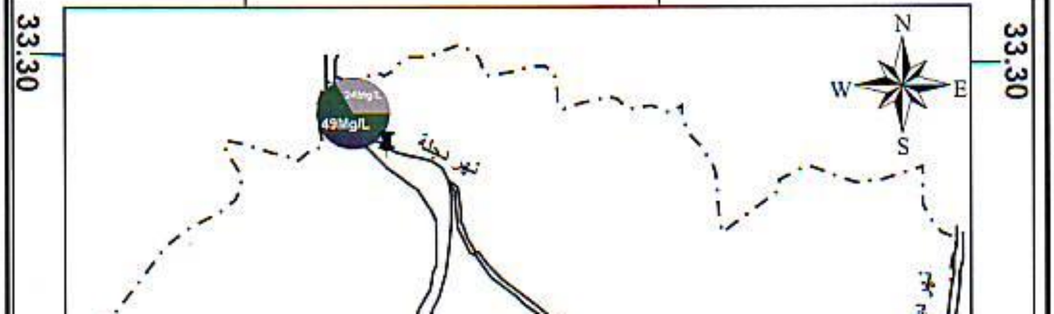
خارطة (٣)

مطلقات المواد الكلية الذائبة (للعينات المسحوبة) من النهر في الصيف والشتاء عام ٢٠٠٥ (ملغم / لتر)



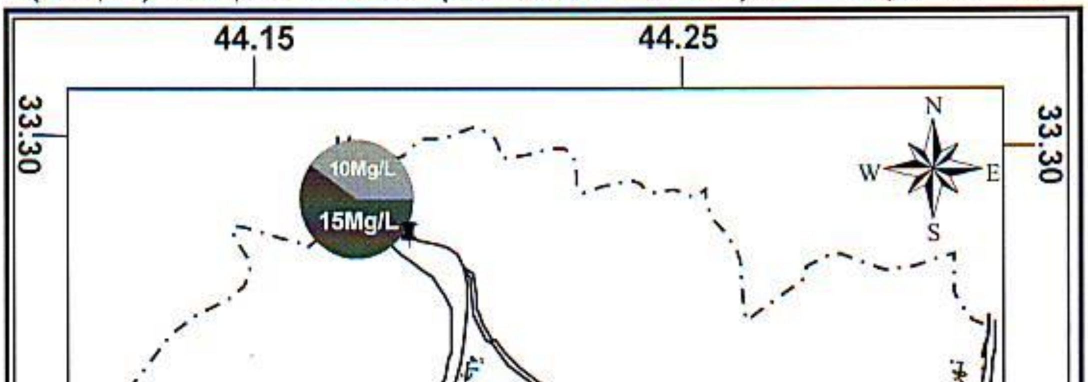
خارطة(٤)

مطلقات المواد الكلية الصلبة (للعينات المسحوبة) من النهر في الصيف والشتاء عام٢٠٠٥ (ملغم/ لتر



13

خارطة(٥)
المتطلب الحيوي للاوكسجين (للعينات المسحوبة من النهر) صيفاً وشتاءاً للعام٢٠٠٥ (ملغم / لتر)



مياه المطلقات الصناعية بان مصفى الدورة قد سجل اعلى قيمة (150) ملغم / لتر وادنى قيمة تركيز في محطة كهرباء الدورة وبحدود (4) ملغم/لتر على التوالي.

وعند مقارنة المعدلات العامة لتراكيز الـ COD للمنشات الصناعية في منطقة الدراسة مع نظام صيانة الانهار والبالغ (اقل من 100 ملغم/لتر) كاقصى حد مسموح به لتصريفه الى الانهر، نجد بان مصفى الدورة قد تجاوز الحدود المسموح له في النظام.ويعود سبب الارتفاع في تراكيز الـ COD في الموقع المبين اعلاه الى طبيعة المياه الصناعية والحاوية على نسبة عالية من المواد الكيمياوية والزيوت والشحوم , زيادة على ذلك وجود المواد المنظفة مما يؤدي الى ارتفاع تراكيز المتطلب الكيمياوي للاوكسجين في المياه المطلقة من المنشات الصناعية في منطقة الدراسة.لاحظ الخارطة رقم _6_

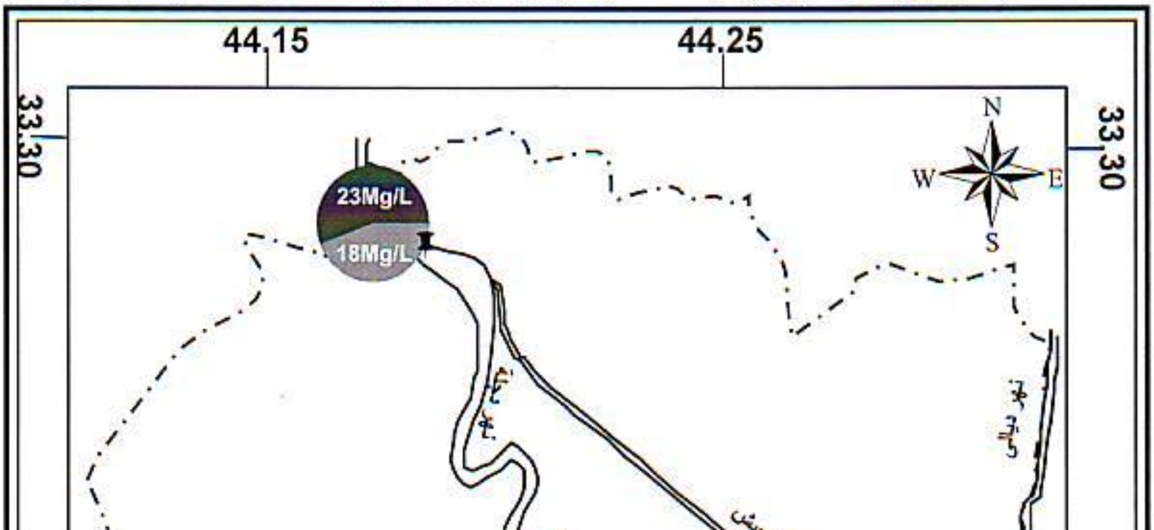
النتائج والمقترحات :

توصلت الدراسة الحالية الى صدق الفرضيات المعتمدة في البحث ,وان هذه المنشات تسبب تغيير فيزياوى وكيمياوى وبايولوجى في مياه النهر بشكل متباين خلال السنة ,ناتج من المطلقات الصناعية المنبعثة من المحطات الكهروحرارية والمنشات النفطية الموجودة في مدينة بغداد , والتى ارخت باثارها السلبية على اهم وسط مائى موجود في المدينة الا هو نهر دجلة , الامر الذى يستدعى وضع حدود لحماية البيئة المائية واتخاذ التدابير المناسبة خاصة في فصل الصيف لانخفاض المنسوب المائى بالنهر.. حيث يمكن ان تساهم في معالجة المشكلة ويقترح الباحث المعالجات التالية ,التى يمكن الركون لها لمعالجة الخلل وعلى المدى القريب والبعيد وهي:ــ

1. انشاء شبكات ووحدات متطورة نوعيا وتقنيا لمعالجة مطلقات المنشات الصناعية ذات الطبيعة الخطرة والسمية , وطرح المياه المعاملة ضمن المواصفات المسموح بها. وخاصة مصافى التكرير و المحطات الكهروحرارية. التى درست او اينما وجدت في القطر .
2. اصدار توجيهات مشددة الى المعامل التي لم تستكمل فيها انشاء وحدات معالجة المطلقات السائلة بوجوب نصب هذه الوحدات او تغييرها لاندثارها عبر الزمن, ومتابعة صيانتها دورياً. وفرض الغرامات الرادعة للمقصرين والمخالفين حتى وان كانت مؤسسات حكومية. من خلال تنشيط مؤسسات المجتمع المدنى وتعريف السكان بحال المياه التى يعيشون عليها ودور الصناعة بالتلوث .
3. التوجه لاستخدام معايير قطرية او دولية، رغم ما سيترتب على ذلك من اضافة مبالغ جديدة بسبب زيادة تكاليف الانتاج والمعالجة وقد يظهر ذلك واضحاً في المشاريع القديمة بسبب الحاجة الى اجراء تحويرات كثيرة، مع الاخذ بنظر الاعتبار التقانات الحديثة عند انشاء المشاريع مستقبلاً.
4. اقتراح المعايير البيئية الواقعية والقابلة للتطبيق، في معظم الاحوال، بدل المعايير المثالية. وينبغي النظر الى مكافحة المطلقات الصناعية بوصفه تحدى لقدرات الانسان , يهدف تحقيق التوازن بين اعباء التكاليف وتحسين مستوى البيئة .
5. في المستقبل القريب يمكن ترحيل المشاريع التى درست, والتى باتت تلوث الماء بشكل متراكم الى مناطق خارج بغداد .واستخدام محطات غازية كما موجود في شمال المدينة (محطة الراشدية الكهروحرارية)وهي صينية المنشا.
6. ربط العاصمة بغداد بشبكات كهرباء وطنية عملاقة خارجية و بخطوط انابيب ستراتيجية ناقلة للمحروقات من الشمال او الجنوب ، للتناسب مع حجم الالة الصناعية العاملة في العاصمة , ورفع المنشات القديمة من المدينة لتقادم اكثر وحدات معالجتها .

خارطة(٦)

المتطلب الكيمياوي للاوكسجين (للعينات المسحوبة)من النهر صيفاً وشتاءاً لعام٢٠٠٥ (ملغم / لتر)



7. زيادة تصاريف المياه في نهر دجلة في موسم الصيف لتعديل و تخفيف المطروحات الصناعية التي ترمى في النهر .وذلك بتفعيل العلاقات الخارجية مع دول الجوار الجغرافي ,حيث لوحظ ارتفاع نسب التراكيز في الصيف اكثر من الشتاء نتيجة لقلة المياه الجارية في نهر دجلة وارتفاع نسبة التبخر صيفا .مما يؤثر على المدن التي تقع جنوب العاصمة بغداد

.ان تنفيذ المشاريع اعلاه يكون حسب الاسس المألوفة والمتبعة.ومن المفيد ان نعود الى اجابة السؤال المتعلق من سيقوم بالعمل؟ للمؤسسة الصناعية المعنية دور اساسي للمرحلة الاولى من الخطة- التي اشرنا لها في الجانب النظري من البحث- فمن الضروري ان يكون لدى كل منشاة او معمل او مصنع , تنتج عنه مطلقات صناعية خطرة تؤثر على البيئة,, فريق فني متدرب باحدث الوسائل والتقنيات ,يتولى التعريف الكامل بكافة المطروحات وكذلك اجراء التحليلات المختبرية الاساسية لميزات خطوط الفضلات المختلفة وبشكل دوري (يومي او شهري). ان وجود مثل هذا الفريق العلمي , سيكون له دور اساسي في كل مراحل حل المشكلة. كذلك من

الممكن الاستعانة بالجهات العلمية في هذه المرحلة لمساعدة الفريق المعني في المنشاه (التي ستقوم بتنفيذ الفحص) لتحديد خصائص المطروحات او في اقتراح خطوات وبرامج للحد من التأثيرات البيئية على الموارد.

اما دراسة تقبل المطروحات للمعاملة فيتطلب الاستعانة بجهة متخصصة في البيئة وليس هنالك خيار للصناعة سوى الاستعانة بخبرات خارج الصناعة. اما المرحلة الثانية والثالثة–– التى اشرنا لها في الاطار النظري – فلا خيار للمنشاة فيها الا للجوء الى الاجهزة الاستشارية المتخصصة بمعاملة المطروحات الصناعية وذلك لغرض تصميم واختبار الوحدات. ويبدو ان الحل المرحلي لمشاكل التلوث الصناعي يضطرنا احياناً للاستعانة بالخبرات الاستشارية الاجنبية –اذا تعذر الامر عن كوادرنا الوطنية – ولكن يجب ان يتم هذا بمحددات ومراقبة عراقية خبيرة. وبذلك تطمئن الدوائر الصناعية بان الحلول المقدمة من هذه الجهات هي حلول منطقية ومناسبة للظروف الموضوعية للواقع الصناعي والاجتماعي والمناخي الحالي للقطر.

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[14] المصدر نفسه ,ص70

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ملحق جدول (1) توزيع المعدلات والنسبة المئوية للاستهلاك اليومي للماء في مدينة بغداد حسب الاستعمالات الاساسية (لتر/ شخص/ يوم).

الاستعمال	معدل الاستهلاك	النسبة المئوية %
1. سكني	340	68
2. تجاري	35	7
3. صناعي	40	8
4. خسائر	85	17

مجموع	500	100

المصدر:- امانة بغداد. مشروع التنمية الحضرية لمدينة بغداد الى عام 2025, تقرير اولي, دائرة التصاميم 1998. ص5.

ملحق جدول (2) كمية المخلفات المطروحة الى الانهار من معامل ومنشأت وشركات القطاع الصناعي لسنة 1996 .

القطاع	عدد المنشأت	كمية المخلفات المطروحة م^3/ساعة		عدد وحدات المعالجة	
		حسب التصميم	الكمية الفعلية	الموجودات	العاملة
1. وزارة الصناعة والمعادن	37	1996905	20700	31	1
2. وزارة الصناعة	4	15200	9000	3	1
3. هيئة التصنيع العسكري	20	-	113	13	13
4. التنمية الصناعية	641	2798	3000	46	46
المجموع الكلي	702	-	62813	93	61

المصدر:- خالد ابراهيم سعيد, تلوث مياه الانهار بالمخلفات الصناعية, بحث مقدم الى المؤتمر العلمي القطري لتلوث البيئة واساليب حمايتها, 5-6 تشرين الثاني – 2000, منظمة الطاقة الذرية, 2000, ص16.

ملحق جدول (3) الملوثات التي تحويها مخلفات المياه الصناعية

الملوثات	مصدره الصناعي

1. تلوث حراري	محطات توليد الطاقة الكهربائية, معامل غسيل الملابس, العبوات الزجاجية.
2.كمية عالية من المواد المترسبة	مصانع السكر, مناجم الفحم, مصانع الزجاج, المسالخ, مصانع الدباغة والجلود, مصانع المواد الغذائية, معاصر الزيتون.
3.كمية عالية من المواد الذائبة	صناعة تكرير البترول, تعدين الفحم, صناعة البوتلوس, مصانع الدباغة, الصناعات الكيمياوية. تصنيع الورق من لب الاخشاب وبعض الصناعات الاخرى . الصناعات الكيمياوية, الغزل والنسيج, البطاريات, صناعة الصابون.
4. الكبريتات	صناعة القطن والصوف, تصنيع المعادن .
5. الحوامض	الدباغة بأملاح الكروم .
6. القواعد	صناعة البطاريات, صناعة الاصباغ .
7 الكروم	صناعة الطلاء بهذه العناصر.
8.الرصاص	صناعات غذائية .
9. النحاس والنيكل والكادميوم والخارصين	صناعات غذائية, صناعات نسيجية .
10. السكر	بعض الصناعات النسيجية, تصفية النفط والصناعات الاخرى .
11. النشا	الغزل والنسيج, الدباغة, الصناعات الكيمياوية .
12. الزيوت والشحوم	البتروكيمياويات, معامل صناعة المطاط .
13. الفينول	معامل التقطير والتخمير .
14. الهيدروكاربونات	
15. احماض عضوية	

المصدر: أ. سامح غرايبة, يحيى فرحان, مصدر سابق, ص 224.

ملحق جدول (4) كمية المياه المستهلكة والمصروفة من المنشأت الصناعية في مدينة بغداد

المنشات الصناعية	كمية المياه المستهلكة م^3/ساعة	كمية المياه المصروفة م^3/ساعة
محطة كهرباء الدورة	60000	60000
مصفى الدورة	1650	550
محطة كهرباء جنوب بغداد	37000	73000

المصدر:) الدراسة الميدانية , كانون الثاني ,2005

ملحق جدول (5)نتائج الفحوصات المختبرية لمياه نهر دجلة من مناطق سحب العينات عند دخوله المدينة واثناء مروره بالمنشأت لتحديد المطلقات الصناعية في منطقة الدراسة (2005)

ت	المنشات الصناعية		Temp ℃	T.D.S ملغم/لتر	T.S.S ملغم/لتر	BOD ملغم/لتر	COD ملغم/لتر
1	محطة كهرباء الدورة	الصيف الشتاء المعدل	49 32 40.5	1650 607 1128.5	110 80 95	8 3 5.5	24 4 14
2	مصفى الدورة	الصيف الشتاء المعدل	36 28 32	1910 1149 1529.5	73 15 44	71 16 43.5	248 52 150
3	محطة كهرباء جنوب بغداد	الصيف الشتاء المعدل	35 21 28	725 591 658	111 42 76	3 2 2.5	23 8 15.5
	جزيرة بغداد السياحية نقطة دخول النهر الى حدود المدينة من الشمال	الصيف الشتاء المعدل	28 17 22.5	751 840 795.5	24 49 36.5	10 15 12.5	23 18 20.5

المصدر:1)الباحث _نتائج التتحليل المختبرى . في عام 2005

ملاحظة : عينات الصيف 15تموز و عينات الشتاء.15كانون اول و المعدل الفصلى.

AL ANSAB MBR SEWAGE TREATMENT PLANT: STEP TOWARDS GREENER MUSCAT

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Abstract

Reclaimed wastewater is the main source of water for Muscat beautification and landscape irrigation. Al Ansab sewage treatment plant (STP) is one of the premier facilities under Muscat Wastewater Scheme Project (2002-2017) that will provide Muscat governorate with a world class wastewater system. The plant utilizes immersed membrane bioreactor (MBR) technology using Kubota flat sheet membrane with an ultimate annual average daily capacity of 84,000 m^3/day making it the largest flat sheet MBR in the world up to date. The construction of the first phase of the plant of 55,000 m^3/day began in the first quarter of 2005 and is expected to start commissioning by the end of 2008. Due to the delay in the construction of the sewer network it is planned to commission the plant partially using 10,000 m^3/day of tankered sewage that will be taken from the adjacent existing STP. This is sufficient to commission one of the aeration trains and two membrane tanks of the plant's four aeration trains and eight membranes tanks to simulate the plant design conditions. Analysis of the tankered sewage influent has shown that equalization for 6 hours is necessary to dampen the fluctuations of the influent load close to the design values. No significant concentrations of metals that would inhibit the biological activity have been found.

Keywords: Al Ansab, Muscat, MBR, flat sheet membranes, Kubota, wastewater reuse

Introduction

The Sultanate of Oman is classified as an arid country with a mean annual rainfall of less than 100 mm (Ahmed et al, 2005). For this reason national regulations encourage the reuse of treated wastewater where ever possible. Muscat, the capital city of the Sultanate, relies heavily on treated wastewater for its greenery, beautification and landscape irrigation. Muscat is a governorate that consist of 5 provinces (wilayats) stretching along the coast west to east over 3,670 km^2 in which old Muscat town forms a very small area. Due to the topographical nature of the governorate, major populated areas are strip developments along the coast as the west of the governorate is hemmed in by mountains. The distance from the most northerly area, Manuma, to the most southerly area, Quriyat, is approximately 170 Kms. Consequently the governorate is served traditionally with a decentralized public wastewater system that consists of 10 collection and sewage treatment plants (STPs) connecting 15% of the governorate's population with a combined output of approximately 45,000 m^3/day. The remaining 85% of the population are served by private STPs or individual septic tanks which is another form of decentralized system. Under Muscat Wastewater Scheme Project (2002-2017), the governorate is divided into seven catchments with seven sewer networks and seven main STPs. The objective of the project is to connect 90% of the total governorate population by 2017. Most of the existing wastewater infrastructure (public & private) will be decommissioned under the new scheme. Al Ansab STP is one of the premier facilities in the new wastewater scheme. The first phase of the STP with a total capacity of 55,000 m^3/day is being constructed using Kubota flat sheet membrane bio-reactor technology and is expected to begin commissioning by the end of 2008. At its first phase capacity the plant is considered the largest MBR in the world to date exceeding the capacity of the largest MBR up to 2006 at Kaarst in Germany with a capacity of 50,000 m^3/day (Judd, 2006). The Kaarst MBR, which uses ZeeWeed® 500c hollow fiber membrane with a pore size of 0.04 μm as a filtration system, is designed to remove nitrogen and phosphorus from the wastewater.

Results from early plant's operation shown effluent quality of < 25 mg/L COD, < 10 mg/L TN, < 1 mg/L Ptot, < 0.5 NTU turbidity, under detection limit SS, and achievement of the European bathing water quality without further disinfection requirement (Engelhardt & Berpols, 2005). Needless to say that the largest wastewater recycling facility using membranes system is still the Sulaibiya plant in Kuwait with a current capacity of 375,000 m^3/day however the plant is employing tertiary side stream ultra-filtration (UF) followed by reverse osmosis (RO) and not MBR technology.

Al Ansab MBR plant is planned to be expanded to an ultimate capacity of 84,000 m^3/day in year 2014 when the first phase capacity is exceeded.

Process Selection and Plant Description

The new Al Ansab STP is being built adjacent to the existing 12,000 m^3/day Al Ansab tankered wastewater STP which was constructed in 1990 using extended aeration technology, Figure (1). Sequencing batch reactor (SBR), oxidation ditches (OD) and membrane bioreactors (MBR) were selected and evaluated for the new plant based on their capability of meeting Class A requirement for agricultural irrigation as specified by the national regulations MD 145/93, Table (1). Granular media and cloth media filters were evaluated as tertiary treatment for the SBR and OD. Due to severe site constraints and the desire to have very high quality effluent the MBR technology was shown to be favorable in addition to cost competitiveness. The MBR high quality effluent is expected to eliminate most of the physical problems to the irrigation networks in Muscat (such as clogging) and produce water that is almost free of bacteria and helminth ova. The pathogens most resistant in the environment are helminth eggs, which in some cases can survive for several years in the soil (WHO, 2006). Helminth eggs vary in size from 5 to 100 microns but most are about 20 microns in size. Granular media filters are efficient filters for particles down to 3 micron in size however some particles up to 20 micron can pass through the filter. A cloth media filter has a filtering media with about 10 micron pore size but buildup of material on the cloth causes particles smaller than 10 microns to be removed.

While both filtration systems suppliers claim to be effective for helminth egg removal, it is judged that membranes are the most secure option guaranteeing the removal of the helminth eggs according to the required standards of <1 egg per liter. Hollow fiber and flat sheets membrane with vertically oriented configuration are dominating the immersed membrane bioreactor technology market for domestic wastewater treatment application. Kubota EK400 flat sheet membranes of 0.4 μm pore size were selected. The selected process train is pre-aeration, screening, grit and grease removal, activated sludge biological nitrogen removal, membrane filtering and chlorine residual addition, Figure (1). The membranes will be installed in separate tanks after the biological aeration tanks. Forward flow to the membranes tanks is provided by pumps at the end of the biological aeration tanks. Uncoupling the membranes tanks from the aeration tanks provides important advantages at this large scale plant such as better utilization and control of facilities in various unit failure situations and keeping the floating materials such as foam, scum, and rising sludge out of the membrane tanks which may have negative impact on the membrane performance. Water will pass through the membranes by gravity (2m water head ≈ 0.2 bars). There will be 8 membranes cassette tanks with each cassette tank having 38 double stacked units. A total of 304 units will be used in the first phase of the plant development with over 12,000 flat sheet panels. For economic reasons, the membrane filtration and permeate pumping is not sized to evacuate peak hour influent flow. Rather, flow equalization is used utilizing the aeration and membrane tankage to smooth influent flow peaking and the size of the membrane/permeate pumping system. This integral flow equalization concept is complicated by the limitations of centrifugal blowers systems. Fortunately the plant is subject to rather limited flow peaks and the peak dampening required can be achieved in the aeration tanks with a liquid depth of 1.1 meter which is within the blower system operating limits. The MBR process design is based on an F/M rates of 0.11 considering the volume of the aeration tank and the membrane tank, combined.

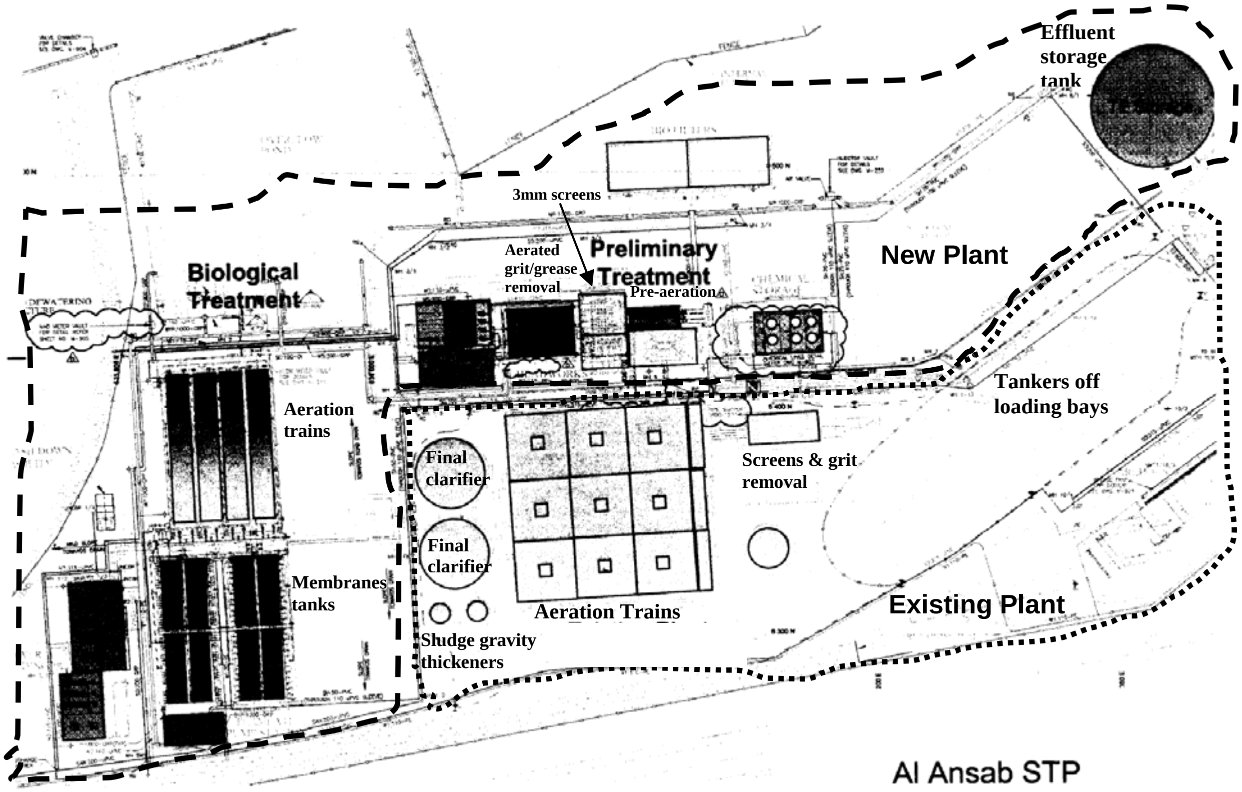

Figure 1: Layout of the new Al Ansab MBR sewage treatment plant

The plant equipment and tankage installed under the first phase is sized to serve an annual average flow rate of 55,000 m^3/day, while buildings, interconnecting piping and electrical power supply are sized to serve the ultimate plant capacity of 84,000 m^3/day. The construction of the first phase started on the first quarter of 2005 while the expansion to the ultimate capacity and the decommissioning of the existing plant would occur in year 2014. The plant is designed so that the effluent meets higher standards than the national permissible standards for agricultural irrigation, Table (1). In a pilot plant operated in nitification/denitrification mode using Kubota flat sheet membranes for the treatment of raw wastewater, Adham & DeCarolis (2003) reported that the Kubota MBR achieved BOD_5 permeate values below detection limit of 2 mg/L in 100% of the samples measured for a feed values ranged from 58 to 264 mg/l, turbidity permeate values of < 0.2 NTU in 100% of the samples measured for a feed values ranged from 36 to 210 NTU, total inorganic nitrogen permeate values of ≤ 4 mg-N/L in 90% of the samples measured for ammonia feed values ranged from 22.4 to 30.2 mg-N/L, and up to 6-log removal of total coliform bacteria. The study added that Kubota membranes achieved ≥ 1.1-log removal of seeded viruses when the membranes were working at a medium to high fouling conditions while failed to achieve any removal at low fouling conditions. Viruses are still not regulated in the national legislations however it is believed that Chlorination of the permeate water will further reduce the viruses concentration to under detectable limits.

Table 1: Design criteria of Al Ansab MBR plant & Oman National Standards for reclaimed wastewater reuse

Parameter	Units	MBR Influent Design Values	MBR Effluent set and expected values*	MBR supplier Effluent values guarantee*	Class A (agricultural irrigation permissible limits) (145/93)
Minimum Flow rate	m^3/d	18,222	-	-	-
Average Flow rate	m^3/d	55,246	-	-	-
Max daily Flow rate	m^3/d	76,821	-	-	-
Membrane type	Kubota EK400, chlorinated polyethylene material and 0.4 μm pore size				
Flux rate	0.9 m^3/m^2.day (900 L/m^2.day)				
BOD	mg/l	312	5	10	15
TSS	mg/l	228	5	10	15
Total N as N	mg/l	50	8	9	21.3
NH_3 as N	mg/l	30	1	1	5
Organic N as N	mg/l	19	0	0	5
NO_3 as N	mg/l	1	7	8	11.3
Total P as P	mg/l	10	-	-	30
pH	-	6 – 8	-	-	6 - 9
Effluent Temp (min)	^oC	25	-	-	-
Effluent Temp (max)	^oC	36	-	-	-

Fats, Oils & Grease	mg/l	< 50	-	-	0.5
Total alkalinity (as $CaCO_3$)	mg/l	249	150	-	-
Faecal Coliforms	MPN/100 ml	-	< 2.2	2.2	200
Viable Helminth Ova	Number /L	-	< 1	< 1	< 1
Turbidity	NTU	-	< 0.5	-	-

* 95% of all effluent samples taken must comply and sampling may be as frequent as hourly

Commissioning Process

New Al Ansab STP is being constructed in parallel to the sewer network at Al Ansab catchment. Due to delay in the construction completion of the sewer network, and as the new plant is not provided with off loading bays for the sewage tankers, it is planned to commission and operate the plant initially using tankered sewage diverted from the adjacent old plant until the sewer network is completed.

Shock Concerns

The wastewater stream designed for the new Al Ansab STP assumed normal domestic wastewater with typical values of pollutant concentrations, Table (1). However there may be a concern about the instantaneous load impact of certain tankered wastewater. Without regulation of the flow from the tanker trucks, loads from a tanker or series of tankers could upset the plant. The variability of wastewater characteristics was evident from hourly grab sampling conducted in March 2006. Figures (2) through (6) show the variability of the waste stream. While this will likely not have much impact on the treatment in a large biomass environment, it is nonetheless outside the range of typical wastewater flow streams.

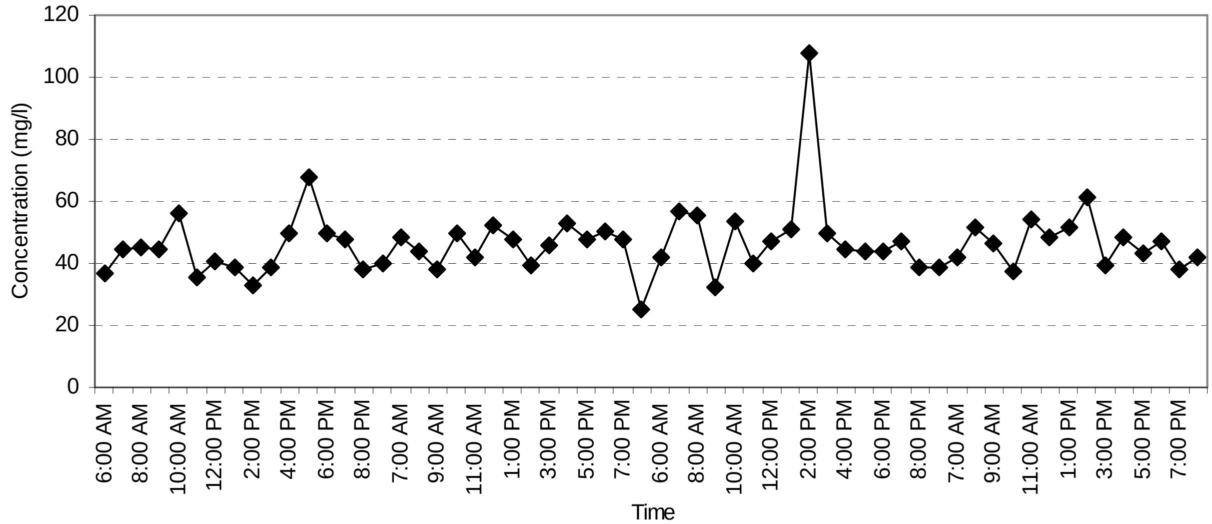

Figure 2: Influent tankered sewage Ammonia concentration at Al Ansab existing STP from 26 to 29 March 2006

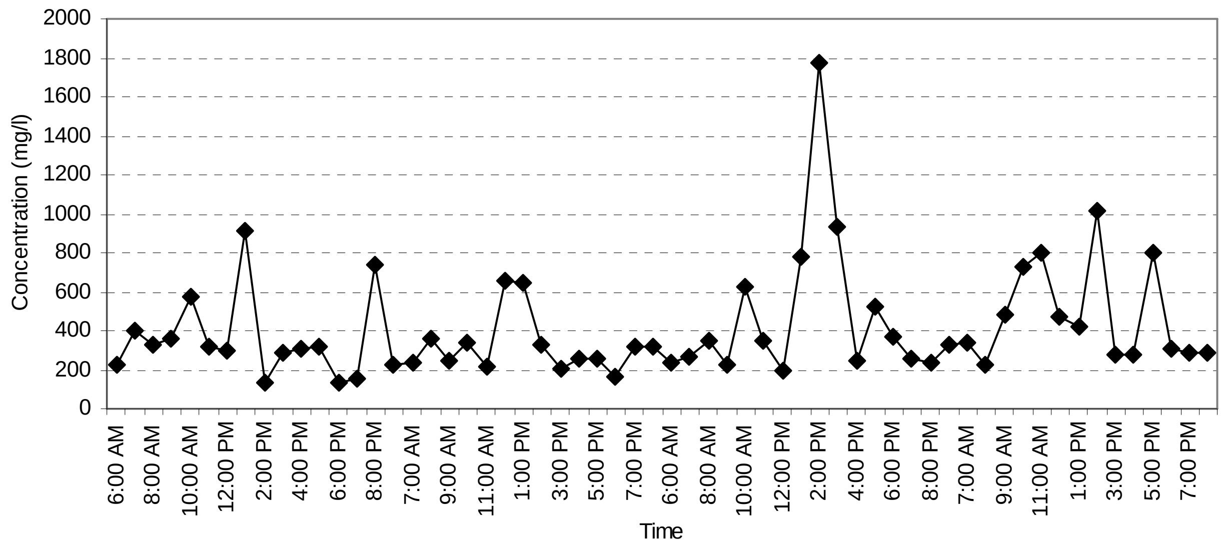

Figure 3: Influent tankered sewage suspended solids concentration at Al Ansab existing STP from 26 to 29 March 2006

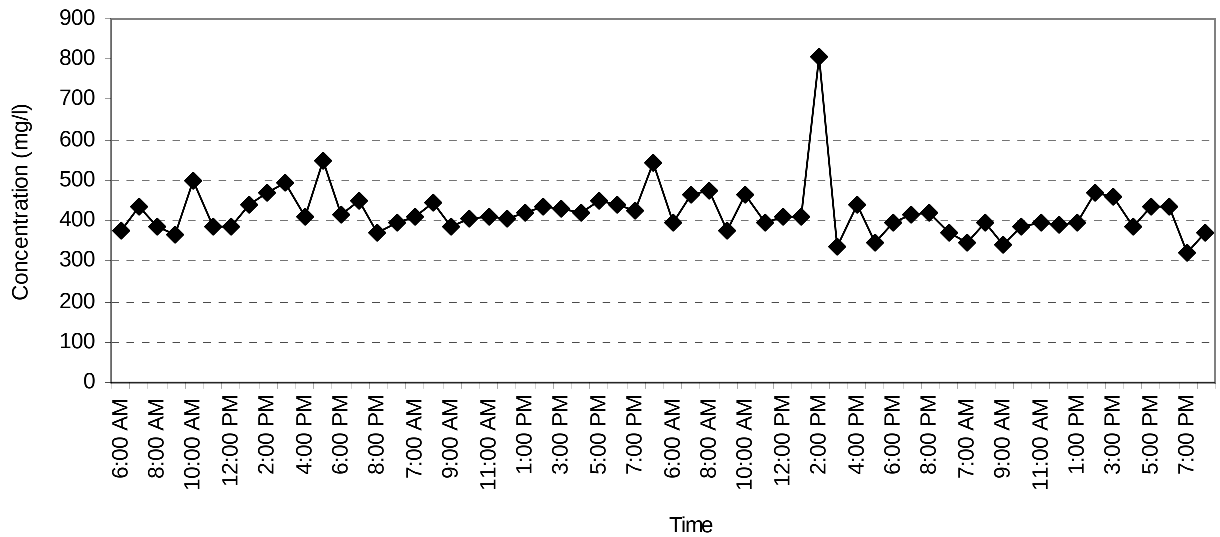

Figure 4: Influent tankered sewage alkalinity concentration at Al Ansab existing STP from 26 to 29 March 2006

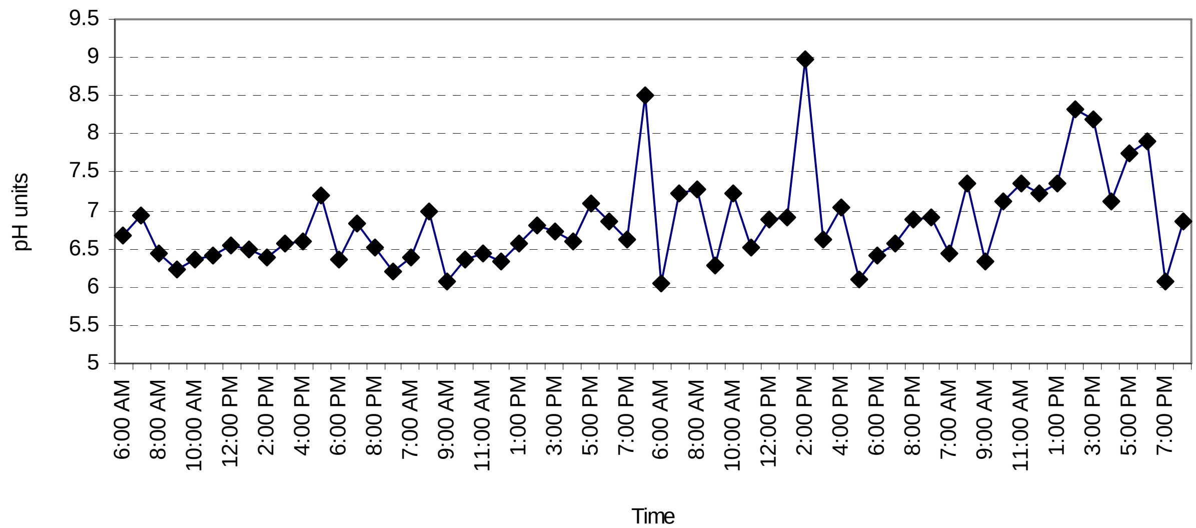

Figure 5: Influent tankered sewage pH at Al Ansab existing STP from 26 to 29 March 2006

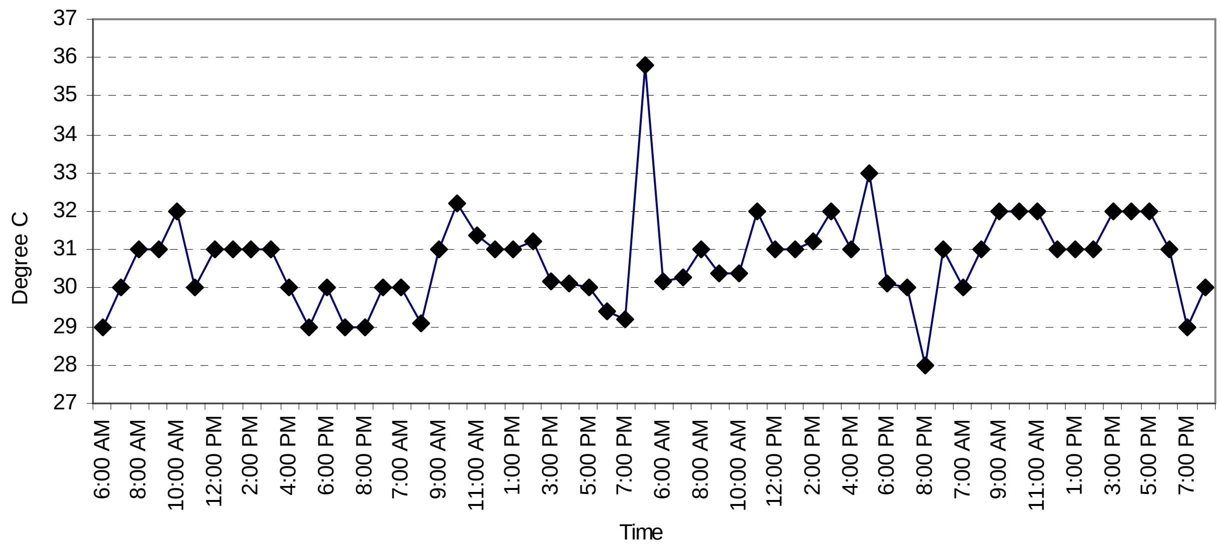

Figure 6: Influent tankered sewage temperature at Al Ansab existing STP from 26 to 29 March 2006

Analysis shown that the variability of the tankered influent concentrations drops dramatically after equalizing the wastewater for 4 or more hours to reach normal ranges for domestic wastewater. Figure 7 shows the impact of increased equalization periods on the influent loads.

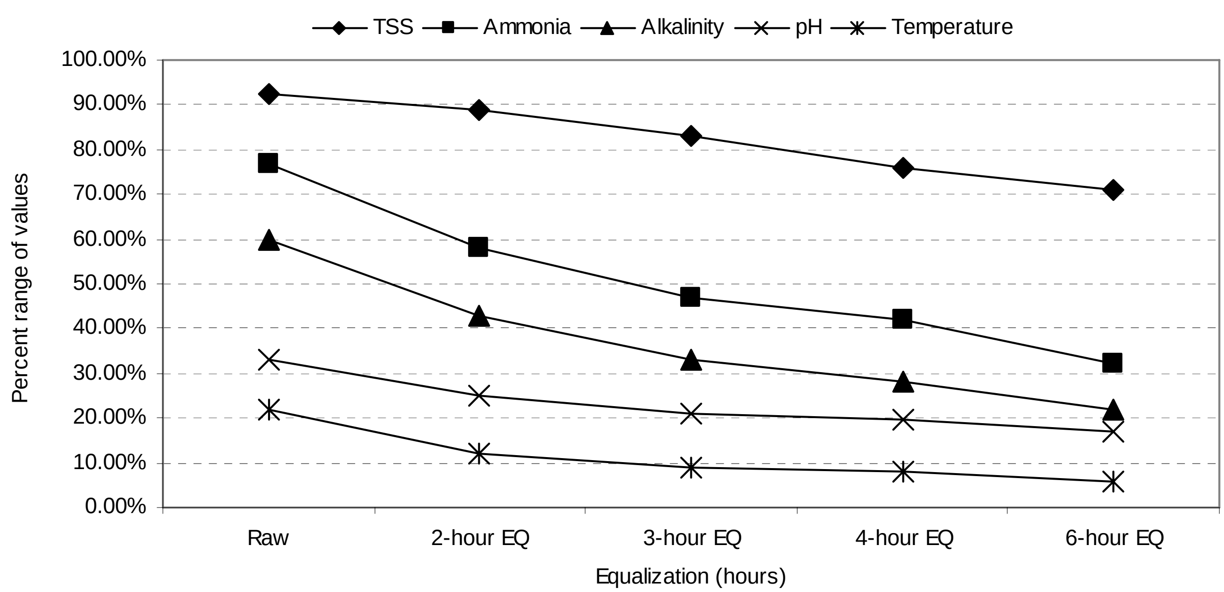

Figure 7: Influent tankered sewage load equalization

To confirm the equalization simulation, careful composite sampling has taken place during the past few months at the influent structure of the existing STP, Table (2). Generally, the influent samples indicate readily treatable domestic and commercial wastewater. The loading is about 26 percent higher than design value for influent BOD_5 and 64 percent higher for ammonia. Assuming oxygen demands of 1.1 kg/kg BOD and 4.6 kg/kg ammonia oxidized, this corresponds to a waste load 37% higher than the design loading. To match the design values for these waste streams, the corresponding flow should be approximately 73% of design flows to create comparable conditions.

Table 2: Existing STP influent wastewater analysis conducted using 24-hour flow composite samples

Parameter	26 – 27 April 2007 (7 am – 6 am)	27 – 28 April 2007 (7 am – 6 am)	28 – 29 April 2007 (7 am – 6 am)	29 – 30 April 2007 (7 am – 6 am)
BOD_5	381	478	347	363
COD	813	744	795	837
TSS	428	288	375	285
TDS	746	762	753	776
Electrical Conductivity	1491	1523	1506	1551
pH	6.45	6.91	7.00	6.76
Ammonia Nitrogen	51.63	50.22	46.24	49.11
Alkalinity	290	295	295	320

As a result of the equalization simulation and wastewater analysis one aeration train of the existing plant, which consists of three cells, will be taken out of service and used as an equalization and transfer facility for the new plant. This tank will not receive return sludge from the clarifiers, but will be aerated only. The existing Al Ansab STP is overloaded receiving an average of 18,000 to 20,000 m^3/d. Due to the limited available quantity of flow only a portion of the new facility will be commissioned to simulate the plant design conditions.

The design capacity of the MBR system is approximately 55,000 m^3/d with 4 aeration trains and 8 membrane tanks operating. This is equivalent to 13,750 m^3/d per aeration train and 2 membrane tanks operating. With a loading of 37% more than design loading, 10,000 m^3/d of tankered waste is virtually equivalent to 13,700 m^3/d of normal domestic waste. Therefore 10,000 m^3/day of tankered sewage will be equalized and diverted from the existing to the new plant to commission one aeration train and two membrane tanks leaving approximately 8,000 m^3/day of flow which is an optimum to operate the two remaining aeration trains at the existing plant. The volume of the three equalization cells is approximately 7,500 m^3, or more than 16 hours storage volume at a flow of 10,000 m^3/d. This should provide virtually complete equalization of daily loads for the commissioning period.

The existing plant will stay in service as it is not desired to decommission the existing plant to run the commissioning test on the new facility. Should there be a failure or upset at the new plant, the existing would have to be placed into service quickly. This cannot be done when the existing tanks are empty.

Quality Concerns

The other concern over using tankered wastewater, to commission the new Al Ansab STP, is the existence of compounds that might upset the process. Composite 6-hour samples (proposed equalization time) were collected over 14 days at the inlet structure of the existing STP and samples were analyzed for the required elements. Results have shown no significant concentrations of metals that would inhibit the biological activity.

Conclusion

Al Ansab MBR sewage treatment plant at its first phase capacity will be the largest flat sheet membranes sewage treatment plant in the world and all efforts are put to make the commissioning and operation of this plant as smooth as possible. The plant is expected to reduce the influent BOD, TSS and TN by 98.4%, 97.8% and 84% respectively producing an effluent quality that exceeds the national standards requirements.

The plant will be the most important and biggest source of treated wastewater to irrigate the landscaping and beautification in Muscat, increase the green spaces in the capital city of Oman, and an important step towards the completion of Muscat Wastewater Scheme Project.

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Analysis of Operation and Maintenance of Reverse Osmosis and Sewage Treatment Plants installed in one of the Government Referral Hospitals in Sultanate of Oman

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Abstract

Clean water is the key to a healthy life. There are many methods to treat the hard & impure water. Reverse Osmosis (R.O) is one among them. It is the ideal method for removing various undesirable particles from drinking water. Health care Premises are dependent upon water, to maintain a safe and comfortable environment for patients and staffs and for treatment at all levels of clinical and surgical area.

In a hospital in order to use the water effectively, recycling of water is carried out using STP (Sewage Treatment Plant). The process is based on the extended aeration variant of the activated sludge process, complete with and anoxic zone, following by sand filtration and chlorination. The recycled water is used for landscaping purpose in a hospital.

The success or failure of both STP & R.O Plants in the hospitals not only depends on efficient design, construction quality etc, but considerably depends on their operation and maintenance (O & M). Though most R.O and S T Plants have state of art equipment and employ latest technology they lag behind substantially in specific areas of hand-on experience of their operation personnel due to which certain critical aspects get neglected and overlooked. This paper attempts to outline many O&M factors of these critical plants based on practical tests, case studies and highlights the benefits such experience contributes to the R.O and S T. Plants performance, availability and consequently to its total water cost.

Key Words: *MOH, R.O. Plant, Sewage Treatment Plant, Membrane, Chemical dosing, Operation and Maintenance.*

Introduction

Water is one of mankind's most valuable resources and is a precious gift of nature. It is not only a natural resource but also act as a medium of dispersal of pollutants. As the population of the world is growing there is an ever-increasing demand for good quality of water for both domestic and industrial use. Health is one of the fundamental rights of every human being and the Governments are serious to provide the best possible opportunities for the people to achieve "health for all" mission. Hospitals being the major segment of the total health care system, where most resources are allocated, are expected to function efficiently and effectively to achieve this mission. Modern hospital is no more considered a place for the diagnostic and treatment of a patient's disease. Broadly speaking, it is a place for the diagnostic and treatment of human sickness, where health education, training research activities and many more activities are undertaken.

It is functionally a complex organization having multi faceted developments in the society [1]. In a hospital in addition to the normal human requirements of water, especially for drinking and washing purpose, there is a high demand on water for other applications like feed water for boiler, dialysis, make up water for HVAC applications etc. Therefore supply of safe water is the prime duty of the Engineering/Facilities department of the hospital. Health Technical Memorandum (HTM) 2027 provides recommendations, advice and guidance on the design, installation and maintenance of water distribution system in healthcare premises [2]. Various study shows that if the raw water TDS (Total dissolved salts) exceeds approximately 600-800 ppm, then it is advisable to use Reverse Osmosis System. Studies have also revealed that water treatment in health care units should be fail –safe and have sufficient instrumentation to monitor their operation continuously. Regular inspection and maintenance of water treatment regimens at correct intervals including proper records of inspection and testing both of equipment and water quality is a must in a typical health unit. In addition to this optimum water management is required to monitor the use of water effectively. Treatment of wastewater from the hospital and its effective use after recycling is very crucial in a hospital environment. The Ministry of Health (MOH), in Sultanate of Oman, is responsible for ensuring the availability of health care to the people of Oman. MOH expenditures accounted for 5.3% of the total Government expenditures. [3].

During the last three decades there is an exponential growth in the infrastructures of MOH. In most of MOH hospitals raw water source is from the nearby bore wells. Literature review indicates that all research papers are for the O & M of R.O plants of seawater and there are not many papers with stringent quality requirement of health care applications. Besides there is no proper document available in MOH pertaining to the O& M of R.O and wastewater treatment plants of hospitals. Therefore the main objective of this paper is to analyze the O& M of the R.O and S.T Plants installed in one of the regional hospitals based on the recorded data and the case studies during the last few years.

Literature Review

Mr. Mohammed Abdul Karim in his paper titled "Sea Water desalination-SWCC experience & Vision" has carried out an interesting historical overview of the desalination technology [4]. There are two types of membrane process used for desalination: reverse osmosis (RO) and electro dialysis (ED). In the RO process, water from a pressurized saline solution is separated from the dissolved salts by flowing through a water-permeable membrane. The permeate (the liquid flowing through the membrane) is encouraged to flow through the membrane by the pressure differential created between the pressurized feed water and the product water, which is at near-atmospheric pressure. The remaining feed water continues through the pressurized side of the reactor as brine. No heating or phase change takes place. The major energy requirement is for the initial pressurization of the feed water. The solvent flux through the membrane is proportional to the pressure gradient and is given by

$$\boldsymbol{Fm = W\,(\Delta P - \Delta\ P_0)} \text{ --------------------------------------- ---------- } \boldsymbol{(1)}$$

Where

F_m = *solvent flux through the membrane,*

ΔP = *imposed pressure differential across the membrane,*

ΔP_0 = *osmotic pressure differential across the membranes*

W = *membrane coefficient.*

In most cases, some amount of solute passes through the membrane by molecular diffusion, and its flux is given by

$$\boldsymbol{F_i = K_i\,\Delta C_i} \qquad \text{--- } \boldsymbol{(2)}$$

Where

F_i = *solute (impurity) flux through membrane*

ΔC_i = *concentration difference between solutions across the membrane,*

K_i = *Overall mass transfer coefficient that includes effects of membrane thickness.*

Equations 1 & 2 show that the water flux is dependent upon the applied pressure, whereas the solute flux is not directly pressure-dependent. As the pressure is increased, both the water flux and the degree of salt rejection tend to improve because of the constant solute flux [5]. For brackish water (well water like the hospital application) desalination the operating pressures range from 15 to 20 bar, and for seawater desalination the operating pressures range from 55 to 70 bar.

Mr.Kamran Chida from Saudi Arabia outlined the important O&M factors of R.O Plants based on practical result oriented experience in the technical paper titled “Reverse osmosis plants operation and maintenance experience in the Middle Eastern region” [6].

Burashi et al summarized their O & M problems of Addur R.O Plant & their experience during the rehabilitation of the plant in their technical appear titled " Seawater RO plant operation and maintenance experience: Addur desalination plant operation assessment" [7]. Agtmaala et al from Netherlands presented a technical paper titled "Four years of practical experience with Integrated Membrane System (IMS) treating estuary water" [8] during the EuroMed2006 conference on Desalination in South Mediterranean countries.

The paper focused on five years operational experience with the reverse osmosis train. The problems were elaborated with operational and process trends and the solutions to solve the problems, in some cases extensive alterations of unit operations, were presented in the paper. All these papers mostly focus on the seawater based R.O Units. There is not much literature available on the R.O plant as well as sewage treatment plants for Health care applications and this paper briefly summaries O &M problems of these two critical plants of a hospital through case studies and the manually recoded data sheets.

Brief description about the Hospital and the water supply system

Rustaq Hospital, which is a regional hospital, is largely a single storied building with a two-storied Administration block. Plant rooms are distributed on the Hospital roof. The main hospital building consists of Administration, Out-Patients Department (OPD), Accident and Emergency Department, Operating Theatres, Delivery suite, Intensive Care Unit (ICU), X-ray, Laboratories, Physiotherapy, Renal Dialysis, In-Patient Wards, Kitchen, Laundry, Central Sterile Supplies Department (CSSD), Theatre Sterile Supply Unit (TSSU) and Special Care Baby Unit (SCBU)., etc. An adjacent "service building" contains water storage and treatment plant, steam boilers, incinerators, medical gas plant, workshops, stores, emergency generators, mortuary and chiller compound etc. The Hospital Complex contains several two storied residential blocks for Junior and Senior Staff and also has "Rustaq Nursing Institute". The Plant & equipment of a Rustaq Hospital consists of the services of Electrical installation, Water supply, RO Plant, Air Conditioning, Sewage treatment plant, LPG distribution network, critical equipment such as Medical vacuum, Medical Oxygen, Nitrous Oxide, etc.

Figure 1 shows the schematic layout of existing water supply system in hospital. Potable water is provided to the site directly from Bore wells into ground storage tanks from where it is distributed around the whole site after filtration and reverse osmosis treatment. Details of these bore wells are shown in Table 1.

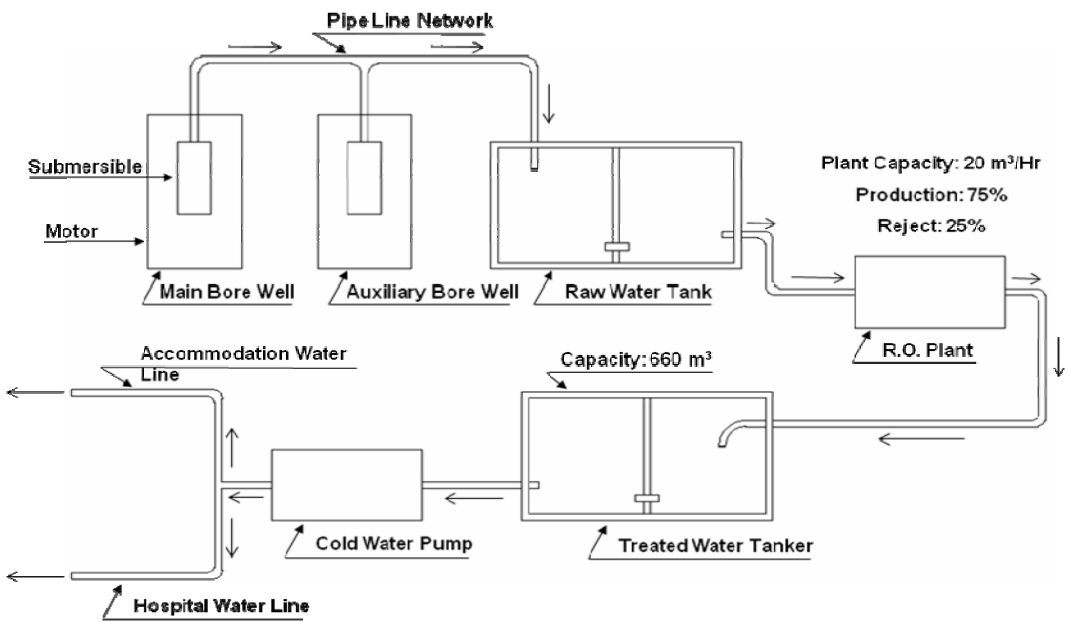

***Figure 1**: Schematic layout of existing water supply system in Rustaq hospital.*

***Table1**: Details of the Bore well (Source of Water to R.O Plant)*

Name of Bore Well	**Starting Year**	**Approximate* Yield m^3/hr**	**Depth (m)**	**Pipe size (mm)**
Main (Wadi)	1993	22	95	75
Auxiliary (Rustaq)	1993	09	95	50

**Yield of the main bore well has been reduced considerable since 2004 and to meet the requirement we buy raw water from the nearby source through tankers. We send regularly the samples of water to the Government recognized water testing laboratory and proper record is being maintained.*

Figure 2 shows the schematic layout of R.O. Plant of the Rustaq Hospital and Figure 3 shows its piping diagram.

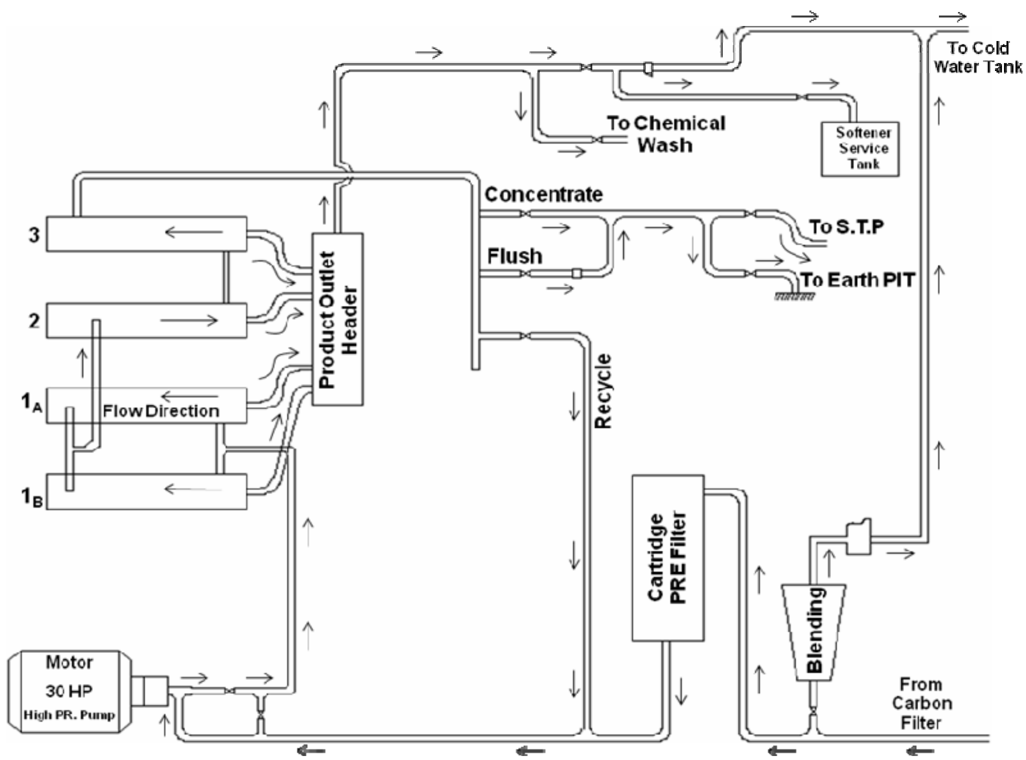

***Figure 2**: Schematic layout of R.O. Plant of the Rustaq Hospital*

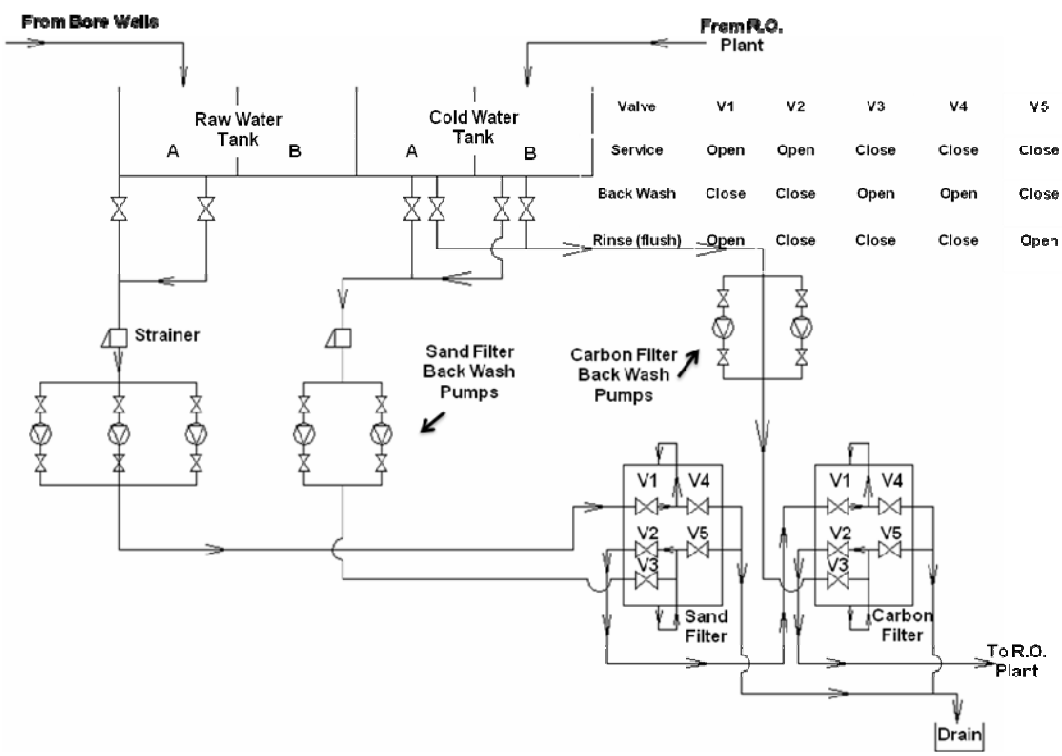

Figure 3: *R.O plant piping diagram*

Table (2) shows the list of few quality parameters, which we continuously monitor to maintain the quality of the treated water. Capacity of the R.O. Plant is 20 m^3 / hr.

Table 2: *Water quality parameters [9]*

S.N.	**PARAMETERS**	**World Health Organization Guidelines for Potable water**
1	pH	7.0 -- 8.5
2	TOTAL DISSOLVED SOLIDS (mg/L)	500
3	TOTAL HARDNESS (mg/L as CaCo3)	120
4	CALCIUM HARDNESS(mg/L as $CaCo_3$)	75
5	ALKALINITY(mg/L as $CaCo_3$)	120
6	FLOURIDE(mg/L)	0.5
7	FREE RESIDUAL CHLORINE (mg/L)	0.2
8	CHLORIDES(mg/L)	60 -- 200
9	TOTAL IRON(mg/L)	0.3

Table 3 & 4 show the average consumption of the treated water and raw water respectively during the years 2001 to 2006

Table 3: *Average Consumption of Treated Water / Day (m^3/hr) (Treated Water)*

Year	Hospital	Accommodation
2006	118.95	64.63
2005	135.81	64.62
2004	139.67	56.57
2003	131.45	71.52
2002	145.15	67.77
2001	178.9	68.77
2000	140.25	65.8

***Table 4**: Average Consumption / Day (CMH). (Raw water Pumped from bore wells)*

Year	Total Pumped Water Average / Day
2006	234.85
2005	269.4
2004	283.2
2003	323.1
2002	299.7
2001	307.7
2000	276.1

Case Study Experience with the R.O Plant

Though we have many interesting case studies during the operation and maintenance of the plant we present the most interesting one. Present R.O plant is 14 years old. Operation and maintenance of the R.O plants are very crucial for the smooth functioning of the hospital. 16 numbers of Film Tec BW-3—400 membranes were bought during September 1999 & stored in the Air-conditioned storage area in the hospital. During the end of year 2000 the service engineers who supplied these membranes installed them after removing the old membranes from the system. Within few days of commissioning of the new membranes the R.O Plant completely collapsed and the hospital faced a serious problem. The company investigated the problem, without analyzing the problem correctly, hastily concluded that most of the membranes were damaged and to be replaced with new ones. They have not shown required interest to guide and rectify the problem with the intention of promoting their sale of membrane, which put the hospital in deep trouble. We studied and analyzed the problem very carefully and approached the case technically. We suspected due to improper commissioning of the plant there could be huge scaling on the membrane and we carried out continuous chemical cleaning of the membrane. After that the membrane became normal and served till the year 2006. Figure 4 shows the condition of these membranes during the year 2006.

Figure 4*: Membranes condition during the year of 2006.*

During the year 2006 all the membranes of the plant (16 Nos) were replaced with new ones. This time we faced a problem of the vessel. Original vessel was Stainless steel vessel and due to wear and tear it needed replacement. We replaced it during the year 2007. Figure 5 shows these pictures.

Figure 5: *Original stainless steel vessel and new replacement*

Operating Cost of the plant

The operational Roles of the Plant Maintenance include Maintain production capacity; Increase plant availability (uptime); Reduce plant down time; Increase overall plant reliability; etc, and the Maintenance Roles of the Plant Maintenance include Avoid breakdowns ; Increase or maintain equipment effectiveness; Control plant/equipment deterioration; Extend the plant/equipment life time. Cost of chemical dosing, regenerating chemicals, neutralizing chemicals, membrane replacement etc are some of the elements of operating cost of R.O Plant. Chlorine dosing is done to remove the biological impurities from the raw water. The antiscalant dosing is done to keep the fouling particles not to settle down on the membrane and comes out along with the reject water.

Acid dosing is done to keep the feed water pH within the limit before it enters to the membrane. SMBS (Sodium Meta Bisulphate) dosing is done to remove any chlorine traces in the post-treated water. The empirical formulas used to calculate the recovery rate, reject rate, are given below. Various parameters of the plant are logged every hour and analysis of data is carried out regularly to transform the data into information.

$$\text{Recovery rate} = \frac{\textit{Permeate flow rate}}{\textit{Feed water flow rate}} x100 \text{ -------------------------- } \textbf{(3)}$$

$$\text{Rejection rate} = \frac{\textit{Product conductivity}}{\textit{Feed conductivity}} x100 \text{ -------------------------- } \textbf{(4)}$$

Usually Hospital plants are designed with 75% Recovery rate. Operating cost of R.O cost depend on the recovery rate. The more the recovery rate the less the operating cost as we consume less chemical dosing due to less running of the plant. When we were operating the plant with 55% recovery rate during the vessel problem our operating cost went up by 30%. Table 5 shows the average annual consumption of the chemicals, which are used for the maintenance of the hospital R. O Plant.

Table 5*: R.O. Plant Yearly Consumables:*

S. No	Chemicals Name	Annual Consumption	Cost In Riyal Omani.
1	Antiscalant (Flocon 135)	400 liters	900
2	Hydro chloric acid	4800 liters	840
3	Caustic soda	240 Kgs	204
4	Chlorine		
	a). Pre-Chlorine	180 Kgs	200
	b). Post-Chlorine	180 Kgs	200

We plan to replace the existing high pressure pump with a new one to save the energy. Existing one is 30 h. p motor. Proposed one is 15 H.P motor, which means we save 50% of the energy. We plan to keep this pump as a standby pump. Proposal is under consideration and we may execute it during the next year.

Hospital Sewage Treatment Plant (STP)

There are numerous chemicals used in various areas such as laboratories, dialysis, pathology and necropsy, central sterilization and infectious waste, patient care areas, pharmacy, X-ray, radiation therapy, and radioactive waste, facilities waste etc in a hospital. Most of the hospitals in Oman have its own STP except few. The Rustaq hospital has its own Sewage Treatment Plant of the Activated Sludge Extended Aeration type having a capacity of approximately 350 m^3/day. Figure 6 shows the layout of sewage plant of the hospital. Treated effluent is stored in a holding tank for subsequent irrigation use. Excess effluent being discharged to an underground soak away.

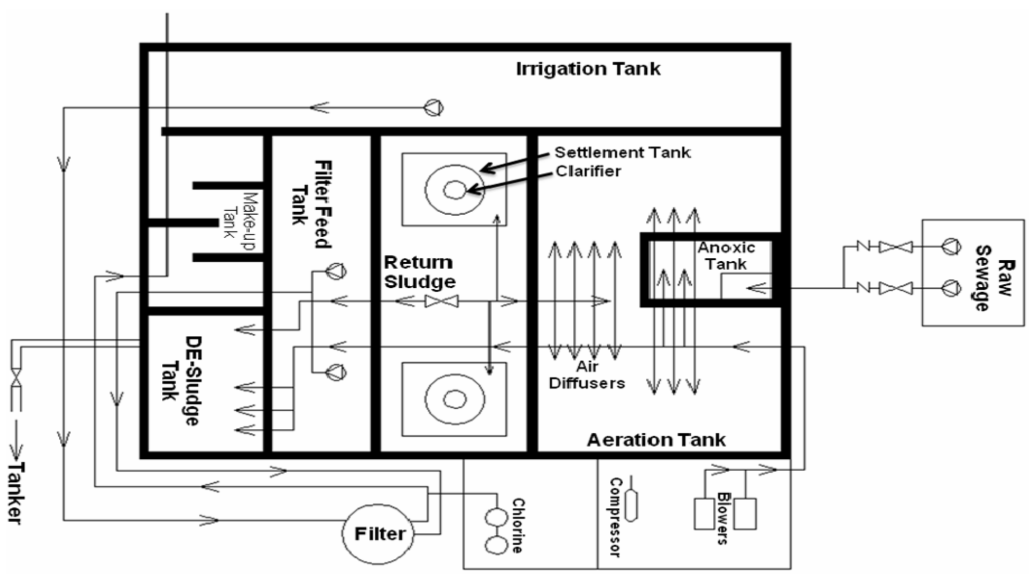

***Figure 6**: Layout of sewage plant of Rustaq hospital*

The plant has been designed according to the following criteria: -

Influent:

Source	*Domestic / hospital sewage*
Volume	*300m³ / day*
Organic loading	*75 Kg BOD/ day =250 mg/L*

Peak flow	*$36m^3$ / hr.*
Ammoniacal nitrogen	*25 – 50mg/L*
Total nitrogen	*40-85mg/L*
Grease	*150mg/L*

Effluent:

BOD	*10mg/L max.*
Suspended solids	*10mg/L max.*
Ammoniacal nitrogen	*1mg/L max.*
Residual chlorine	*0.5mg/L min. after 60 mins.*

Basic process of Sewage Treatment is usually grouped as the primary treatment, the secondary treatment, and the tertiary or the advanced waste treatment. Primary treatment removes identifiable suspended solids and floating matter. In the secondary treatment, also known as the biological treatment, organic matter that is soluble or in the colloidal form is removed. Advanced waste treatment may involve physical, chemical or biological processes or their various combinations depending on the impurities to be removed.

Raw sewage enters the raw sewage sump, from which is pumped by two (duty/standby) submersible pumps, via a flow meter, to the anoxic tank. The pumps are operated according to the water level in the sump, the standby unit being automatically started in the event of the incoming flow exceeding the capacity of the duty pump or failure of the unit. In the anoxic tank, the sewage mixes with a mixture of micro-organisms (activated sludge), both flows being conveyed via vertical pipes to the base of the anoxic tank. In the anoxic tank, the microorganisms in the activated sludge are deprived of oxygen and use nitrate in the water to oxidize organic material in the sewage, reducing the nitrate content and converting it to nitrogen gas. Incoming flows into the anoxic tank displace the mixture of sewage and activated sludge (the mixed liquor) into the aeration tanks, where it is mixed and aerated by air introduced via sintered plastic diffusers and provided by duty/standby blowers.

The activated sludge organisms use the organic material present as food, converting them into carbon dioxide, water, inorganic salts and more organisms. From the aeration tank, the mixed liquor flows into the settlement tank, where activated sludge is removed by gravity, whilst settled effluent flows via a weir to the filter feed tank. Settled sludge is returned back to the anoxic tank by airlift pumps. Effluent is transferred from the filter feed tank to the sand filter by duty/standby pumps working under level control. Filtered effluent passes through a flow meter and calcium hypochlorite solution is injected into it before it flows to the chlorine contact tank from which it passes to the irrigation storage tank. Backwash water for the sand filter is drawn from the irrigation storage tank and returns to the raw sewage sump for treatment. In the course of the activated sludge process, a gradual increase in the amount of sludge solids takes place and it is therefore necessary to 'waste' surplus activated sludge from time to time. This is done periodically diverting the return sludge stream into the sludge sump, where it is aerated to prevent odors and to allow digestion of the sludge. The sludge sump is provided with decant facilities to allow thickening of the waste sludge. Decant water is returned to the raw sewage sump. Since presence of oxygen is a prerequisite to aerobic composition and its quantity determines the rate of decomposition. The amount of free oxygen required for the complete decomposition of organic materials into in organic materials is termed as Biochemical Oxygen Demand (BOD). The most widely used and accepted measure of biodegradable organic content of wastewater is the 5-day, 20°C BOD value [10].

Another important parameter to be monitored in the operation of STP is the sludge volume index (SVI). It is defined as the volume in milliliters occupied by one gram of sludge after it has settled in one-liter cylinder for 30 minutes. SVI has units of mL/g .SVI varies from 40 to 100- for a good sludge, but may exceed 200 for a poor sludge having a tendency towards bulking [11].

Problem & Its Solution with STP as a Practical Case Study

Problem Defined

❖ In the clarifier tank, we observed a leakage in the Air Hose Pipe at the Return Sludge Line.

- ❖ Return Sludge has not been properly transferred to Aeration tank. Due to this settlement productivity becomes less, and also sludge quantity increased (this creates sludge particles to float in the tank) in the settlement tank.

Constraints to attend the Problem

- ❖ Proper drawing is not available.
- ❖ Not possible to shut down the plant for long time.
- ❖ Safety.
- ❖ Disposal of waste water (approximately $70m^3$) through tankers.

Since proper drawing was not available, we do not have any idea about the connection details of hosepipe. (i.e. Top & bottom connection). We presume that we may have to dispose off huge amount of wastewater. On inspection at site we found that the settlement tank water was almost 70% of treated water, so we planned to transfer this water into irrigation tank, bypassing the filter tank. Then we arranged a temporary transfer pump, and started transferring the water from settlement tank to irrigation tank at 5:30pm.After that we transferred the sludge in the Aeration tank to the desludge tank, through that, we transferred it to the soak pit. Within 3 hours we were able to locate the pipe connection and removed the defective hose and replace it with a new one. Some of the photos taken during the execution of this work are given below.(Figs 7-10) We monitor the various critical parameters of the plant and log the data for every 2 hours. Every fortnightly samples are collected and sent to the authorized lab for testing. Sometimes the plant suddenly deteriorates, performs badly for a little while and then corrects itself. With our experience we conclude that this may be due to:

- ❖ The presence of a toxic chemical in the influent, which may have destroyed the microorganisms of the activated sludge.
- ❖ A sudden change in the loading of the system particularly during the wet weather. This is usually because large quantities of water are entering the system and overloading it hydraulically.

 

***Figure 7**: View of the Clarifier Tank. Figure 8:View of the pipe after removing*

the hose

 

***Figure 9:** Insering New Hose at bottom end.   Figure 10: New Hose clip Fixing*

Conclusion:

While carrying out the literature review it was found that not much work is reported on the O& M of the R.O plant and Sewage Plant pertaining to health care applications. Operation for the existing R.O plant of a regional hospital is briefly explained and an interesting case study reported. From the case study it is concluded that by investigating the problem more technically we could use the membranes for six years, which were supposed to be replaced as per the company Sales people recommendation. Repairing rather than replacing concept is highlighted in this case study. By operating the R.O plant within the design parameters we could save the cost of chemicals by 30%. It is proposed to replace the existing energy consuming high-pressure pump system by an energy efficient latest pump system to save 50% of the energy.

Case study of the STP concludes that collective effort and teamwork of the maintenance team could solve the so-called big problem smoothly without affecting the day today functioning of the hospital.

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Contribution of Large Scale Desalination Facilities in Integrated Coastal Zone Management

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Abstract

Coastal zone management is now a hot issue all over the world. The human activities in the natural coastal system and the mismanagement of the coastal zone lead to serious problems in the natural coastal resources and adversely affect the fishery, tourism and the marine ecology. Coastal zone management aims at managing the human activities along the coast to limit the negative impact of the human activities on the coastal areas. The coastal zone management plan should involve all authorities and societies benefit from the coastal system. The paper gives an overview on the integrated coastal zone management and its importance. A case study on the negative impact of human activities on the marine ecology is present. The possible contribution of The Water & Power Research Center of Abu Dhabi Water & Electricity Authority in the Integrated Coastal Zone Management in Abu Dhabi Emirate will be enhanced.

Keywords: water quality, coastal zone management, models

1. Introduction

Coastal zone is the transitional area between land and sea. It is defined as a strip of land and sea of varying width depending on the nature of the environment and management needs. It seldom corresponds to existing administrative or planning units. The natural coastal systems and the areas in which human activities involve the use of coastal resources may therefore extend well beyond the limit of territorial waters and many kilometers inland. The worldwide average width of the coastal zone on the terrestrial side is said to be 60 km. The zone occupies less than 15% of the Earth's land surface, yet it accommodates more than 60% of the world's population. Furthermore, only 40% of the one million-km of coastline is accessible and temperate enough to be habitable. As a result, coastal zones are marked by high concentrations of people and economic activity.

Coastal zones contain unique, irreplaceable ecosystems. At the same time, coastal zones are subject to intense use by humans-for transportation activities, resources and energy procurement, industrial uses, and recreation. Furthermore, coastal zones are the first lines of defense against inland disasters. They are buffer zones against the ravages of tsunamis, rough waves, flooding, and erosion. In short, there are three functional aspects-provisions of ecological services, disaster prevention, and human utilization-which are part of the human relationship to coastal zones. Each of these aspects is intricately linked. Consequently, humans must monitor and manage these three facts of the coastal zone in an integrated manner to ensure that the human relationship to coastal zones remains harmonious. This is what so called coastal zone management. The relationship between important geological, oceanographic characteristics and the various coastal landscapes, formations/systems and groups of habitat types; this resulted into a preliminary classification of coastal systems. A proper coastal zone management plan should be set up based on the classification of the coastal system in a certain region.

The paper gives an overview on the integrated coastal zone management. The paper presents a case study on negative environmental impact made by human activities. The possible cooperation of The Water & Power Research Center of Abu Dhabi water & Electricity Authority in Coastal Zone Management Plan in Abu Dhabi Emirate will be emphasized.

Overview on coastal zone management

The coastal zone system is an integrated complex of marine, coast and land sub-systems. Coastal Zone Management needs to anticipate the effects of current natural and human processes. It should respond to the various processes effectively and without delay, with the overall aim of maintaining functions and using resources in a sustainable manner. To this end, Coastal Zone Management views concern for socio-economic values and the preservation of environmental quality as integral parts of a single system. This means that practical knowledge of the mechanisms driving both the coastal zone system as a whole and its constituent sub-systems is necessary for effective Coastal Zone Management. Figure 1 shows the main subsystem for coastal zone management.

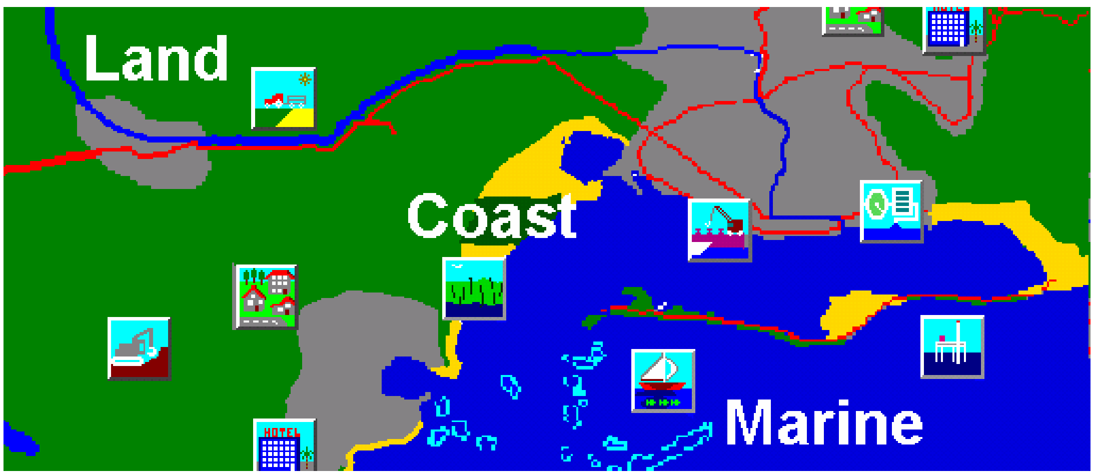


Figure 1: Coast sub-system

Marine sub-system

The marine sub-system is the band of ocean (water and submerged land) adjacent to the land in which terrestrial processes and land use affect marine processes and use.

Characteristics of the marine sub-system

1. water depth
2. waves and tide
3. water and sediment movement
4. sea bed composition
5. marine habitats, e.g. coral reefs

Resources and uses	Problems
Exploitation of fishery resources	disturbance and destruction of marine habitats by fishing, mining, diving, anchoring, dredging and dumping
exploitation of oil and gas reserves	depletion of fish stocks
exploitation of potential for tourism and recreation	disastrous and routine oil spills
navigation	Spatial conflicts (tourism, fishery, navigation, etc.)
waste discharges	deterioration of coastal water quality as a result of waste discharges

Coast sub-system

The coast sub-system is the relatively narrow and dynamic transitional zone between the marine and land sub-systems. It includes the foreshore, the beach area and natural coastal protection systems such as dunes and mangroves.

Characteristics of the coast sub-system

1. typical coastal profiles
2. hydraulic regime (storm surge water-levels)
3. wind and wave climate
4. coastal habitats, e.g. dunes and mangroves

Resources and uses	Problems
sand extraction from beach and dune areas	disturbance and destruction of coastal habitats by mining, water extraction, wood-cutting, settlement and infrastructural development
water extraction from dune aquifers	degradation and loss of beaches by accelerated coastal erosion
exploitation for tourism and recreation	degradation of natural flood protection by mining and woodcutting
exploitation of wood resources (mangroves)	spatial conflicts
human settlement	deterioration of coastal water quality
land reclamation	
port development and related industrial activities	
aquaculture	

Land-subsystem

The land sub-system is the band of land adjacent to the ocean in which marine processes and use directly affect terrestrial processes and land use.

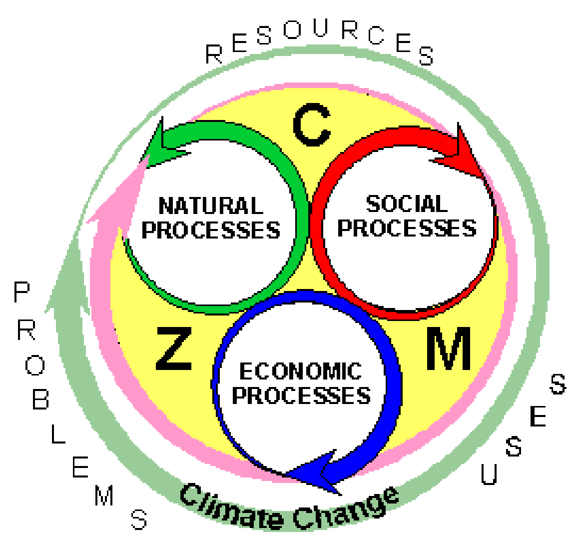
Characteristics of the land sub-system

1. topography
2. soil types
3. aquifer structure, groundwater resources and salinity
4. surface water resources
5. land-related habitats, e.g. wetlands

Resources and use	Use of water resources	Problems
use of land resources	domestic and industrial use	destruction of land habitats
agriculture and aquaculture	irrigation	irrigation
human settlement	hydropower	flooding
land reclamation	navigation	shortage of freshwater resources
industry		salinization of freshwater resources
infrastructure facilities		deterioration of groundwater and surface water quality

The challenge of integrated management

The coastal zone is an interactive and dynamic complex of sub- systems. Human activities in one sub- system may adversely affect other sub-systems. For this reason, the various parts of the coastal zone cannot be considered in isolation. The following is an example of a mangrove ecosystem. The mangroves as an example are found along low-lying, flat tropical coasts, both emerging and submerging. Mangroves, which commonly act as sediment sinks, are essential and natural elements of coastal protection. Mangrove ecosystems are the breeding grounds for fish and shellfish and provide local populations with wood and fuel supplies. Cutting mangroves beyond sustenance levels destroys important coastal habitats and the loss of mangroves may lead to coastal erosion and increased flooding, in turn causing serious damage in local settlements: loss of human life, arable land and livestock, infrastructure and capital generally. There is a growing awareness that coastal zones need to be managed as complete systems. Ultimately, management of the coastal system is driven by the demands of society, expressed in terms such as water quality standards, annual fish harvests or height of dike crests. The various resources in a specific coastal area and their utilization are so interlinked, however, that they need to be managed as parts of one and the same system if sustainable output is to be guaranteed. The challenge of good management resides precisely in this integrated approach. Investors, developers, farmers, tourists, nature conservationists, policy-makers and decision-makers all need to Communicate, Coordinate and Cooperate. This example shows that coastal processes are closely interwoven and that interventions in the system should be made with care and with a profound knowledge of the dynamic forces and linkages that exist. Sectoral management solutions will not produce long-term solutions. Only integrated approaches taking into consideration all the characteristics and processes that typify and change the coastal zone have any chance of securing a sustainable function. Coastal zone management should consider the coastal resources, uses and the problems which may happen due to the processes relevant to the uses.



Case Study on the negative impact

a) Plant description

Taweelah Power and Desalination Plant is one of the main plants in Abu Dhabi Emirate. The Plant is located at the coast of the Arabian Gulf, as it can be seen in Fig. 2. The plant produces 1000 MW and 100 MIGD of power and water, respectively. It is proposed to extend the plant capacity by 66.5 MIGD.

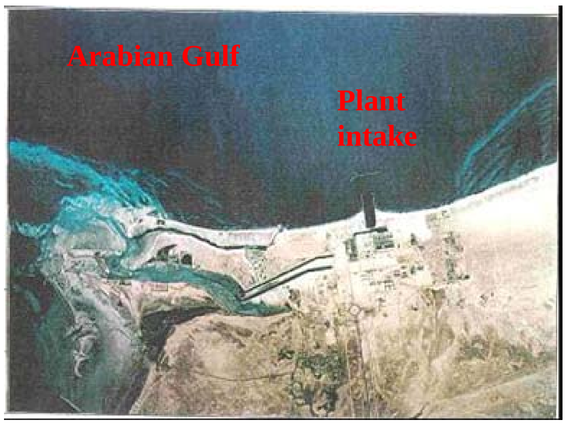


Figure 2: General layout of Taweelah plant

Sea water quality modeling and ecological study were carried out to evaluate the impact of the proposed capacity extension on the water quality and the marine life in the plant vicinity. An ecological reach and unique sea area with coral reefs, dense seagrass, mangroves and aquatic life is located at Ras Ghanada, which is about 1 km east of the plant intake [1]. A biotopes survey was carried out in the vicinity of the plant to collect information on the species and habitat living in this area. Figure 3 shows the biotope map of the habitat in the vicinity of the plant.

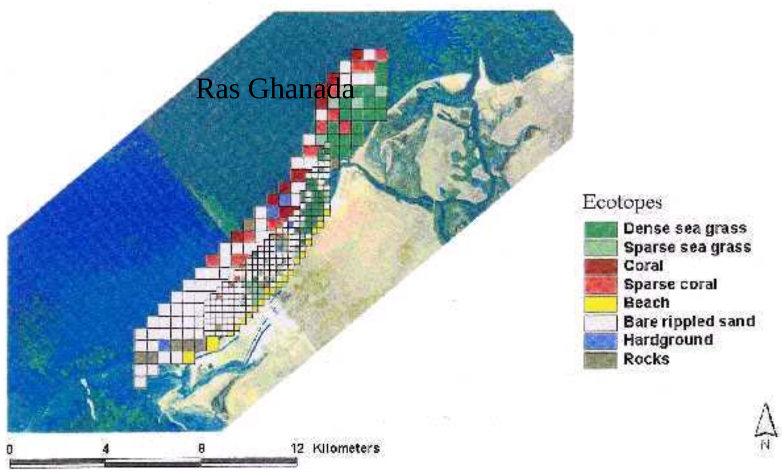


Figure 3: Ecotopes at the marine environment near Taweelah Plant

Data was digitized and mapped into a GIS. Ecological information was gathered on their specific sensitivities and threshold values for abiotic parameters, such as temperature, salinity and oxygen. A sea water quality model was developed describing the transport, diffusion and dispersion of a number of typical pollutants associated with the power and desalination plant. The results from the water quality model serve as an input for the study to assess the impact on the environment and quality of local habitats.

Set up of the sea water quality model

The water quality model was set up after the feasibility of the hydraulic extension is confirmed [2] and [3]. The water quality calculations use the same model grid as used in the hydrodynamic model. The basis for the water quality model is the hydrodynamic model. The water quality simulations use the computed water levels and velocities from the hydrodynamic computations as an input. A number of the important substances for the marine life were modeled. These substances are the fraction of water from the discharge, age of water from the outlet, dissolved oxygen in water and chlorine concentration. Modeling considers the effects of the loads of the plant discharges as given in Table 1.

Table 1: Concentration of substances in the outfall discharge

	Discharge conc.	Peak conc.	Remarks
Oxygen	2.68 (mg/l)	-	67% saturation
Chlorine low decay	0.15 (mg/l)	-	
Chlorine high decay	0.15 (mg/l)	0.6 (mg/l)	Peak 1 hour at High tide
Acid wash	-	5.7×10^{-4} (m^3/m^3)	10 minutes at high tide
Fraction water	1.0 (m^3/m^3)		

Three situations are modeled as follows:

1- The present situation (reference);

2- T03: proposed extension is a hybrid of RO + MSF plant. The intake of the RO is an offshore pipeline at about 3.8 km offshore and it uses the existing outfall. The intake of the MSF is onshore at about 1200m to north-east of the existing intake and the outfall of the plant is about 2 km from its intake.

3- T32: same as T03 but the intake of the RO is at 2000 m offshore and the outfall of the MSF is moved 2000 m further north east.

The water quality results are presented as a contour plots comparing the extension scenario with the present design capacity for the two wind conditions. Figures 4 to 5 show example of the study results. The figures show the spreading and the distribution of two of the main substances influence the eco-system.

These substances are seawater dissolved oxygen and the residual chlorine, respectively. Table 2 presents the area violating the water quality standards as computed by the water quality model.

Table 2: Summary of water quality results as compared to water quality standards. Worst case situations for each parameter is indicated as a shaded area

	Area violating WQ standard (ha)					
	Oxygen (<4mg/l)	Chlorine (>13 ug/l)	Chlorine (>7.5 ug/l)	Temperature (>+2 °C)	Temperature (>+3 °C)	Temperature (>+5 °C)
Reference-a	840	72	114	1871	1061	199
Reference-b	1313	74	119	2305	1396	280
T03-a	471	98	156	1944	726	90
T03-b	991	96	166	2456	1123	113
T32-a	452	110	169	1932	692	76
T32-b	1018	108	172	2560	1045	109

a) daily wind cycle b) no wind

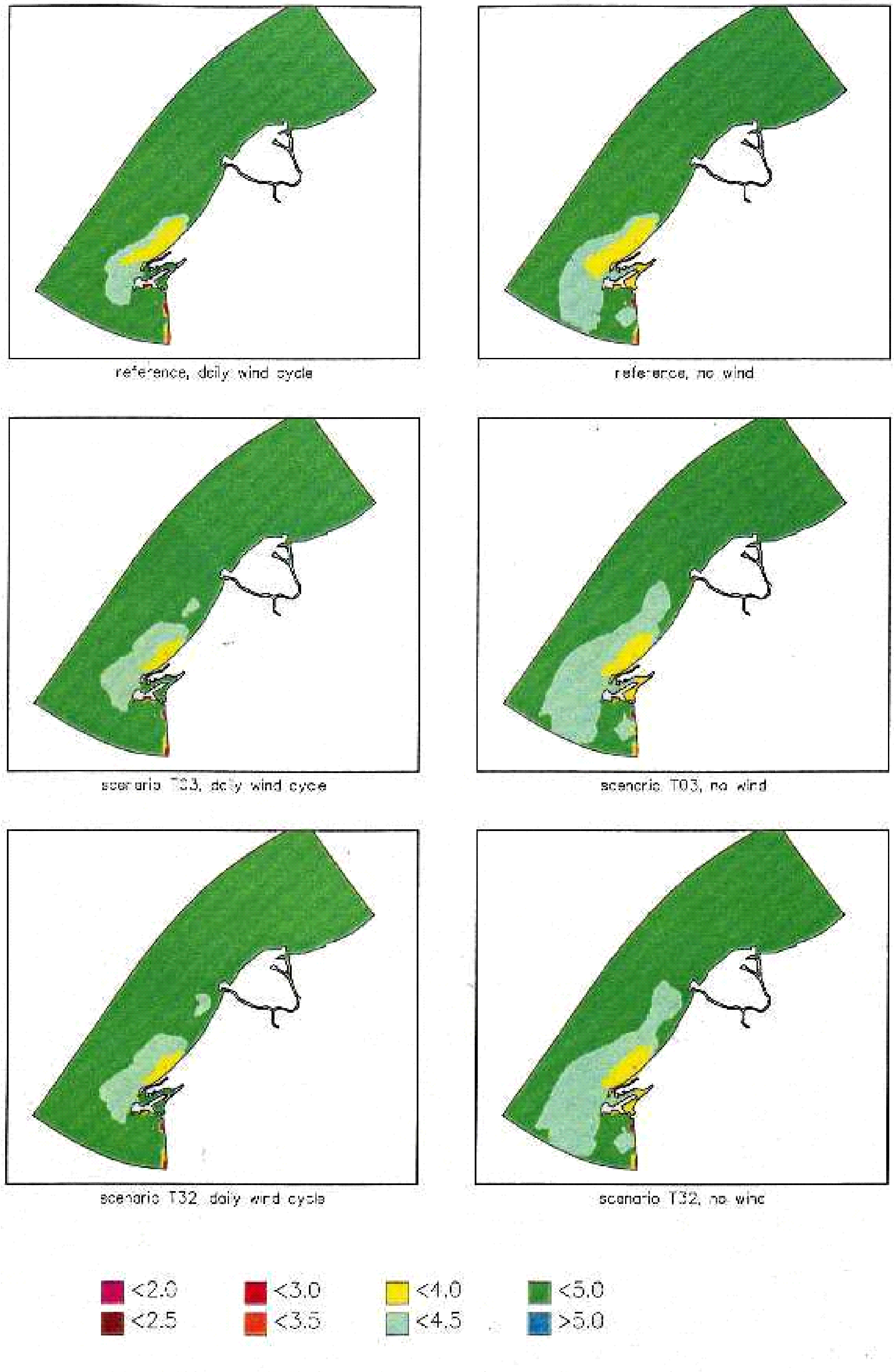


Figure 4: Distribution of dissolved Oxygen

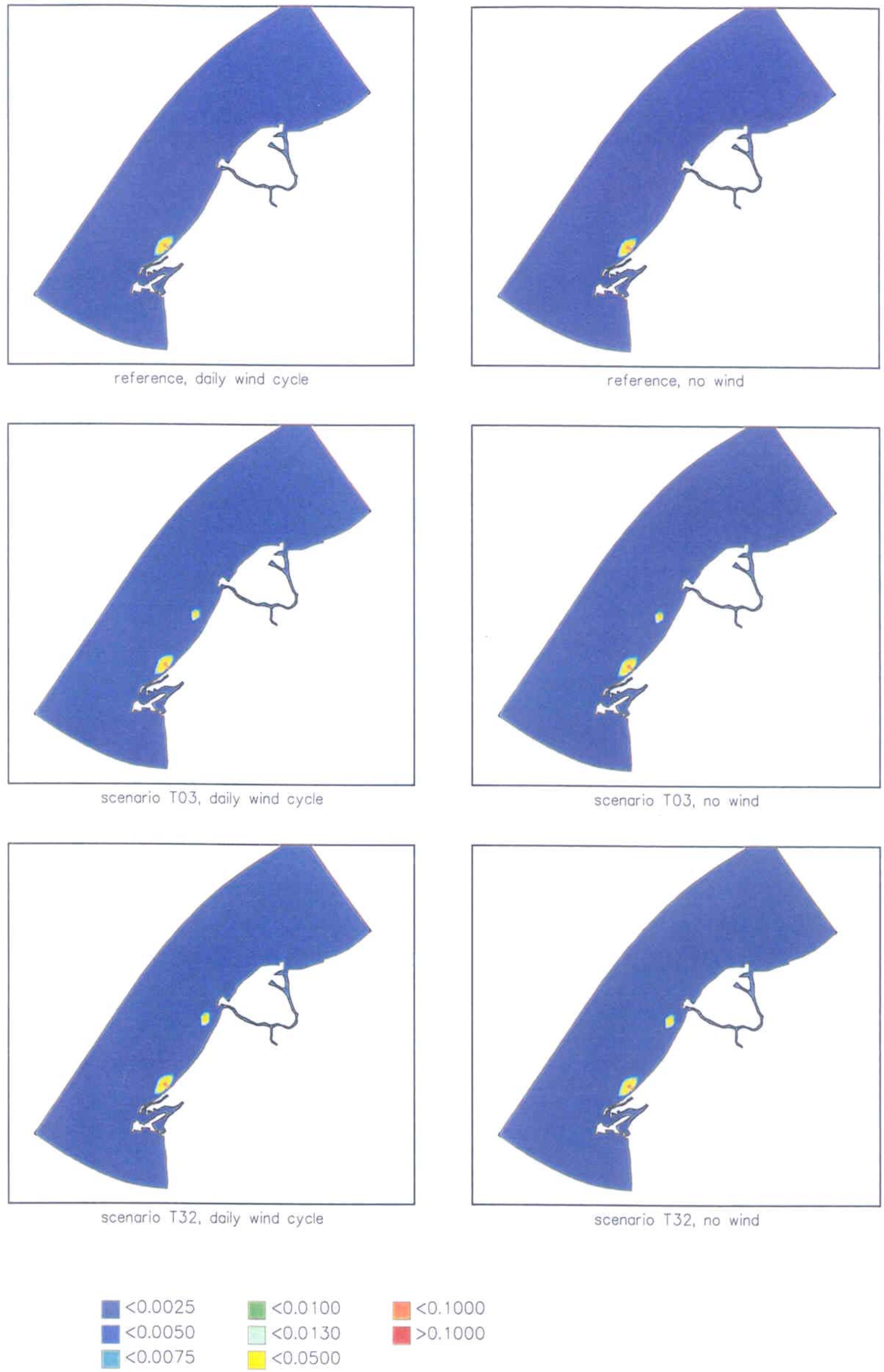


Figure 5: Distribution of Residual Chlorine

The Role of Water and Power Research Center of ADWEA in Coastal Zone management

The water and Power Research Center of Abu Dhabi Water and Electricity Authority (ADWEA) has the tools and capabilities to conduct hydrodynamic, water quality and ecological modeling for the coastal projects in the framework of the Integrated Coastal Zone Management Plan. The Research Center can also conduct morphological study to predict the effect of the coastal structures on the change in the shoreline caused by the erosion and accretion processes. Monitoring of the water quality and marine life can be done by the staff of the Research center using the available survey equipment.

Conclusion

The Integrated Coastal Zone Management is very essential to reduce the conflict between the deterioration in the coastal resources and the human activities in the coastal zone. The plan of the Integrated Coastal Zone management should be setup and approved by the decision makers from different organizations and societies involved in using the natural coastal resources. A feasibility study must be carried out for any coastal project to determine the long-term effect on the marine life and the environment. The results of the study should be presented to the decision makers to get the approval based on the optimum performance and negative impact on the environment.

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MATERIAL SELECTION AND STRESS-INDUCED CORROSION IN DESALINATION AND POWER PLANTS

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ABSTRACT

The key factor in selection of structural alloys in desalination industry is their capability to resist corrosion and erosion under environment(s) prevailing in seawater handling and processing plants. In dual type of desalination-power plants, the carryover impurities in feed water and/or steam have pivotal role in material selection for power plant. In desalination and power plants, the material and component failure by corrosion is a familiar feature and the mechanism involves a variety of chemical/electrochemical processes depending upon the nature of material, operating parameters and environmental conditions.

Out of many different types of corrosion, corrosion under stress related conditions, popularly known as stress corrosion cracking (SCC) is often responsible for the failures in desalination and power plants. In desalination plants, components like shaft, column and elbows of seawater pumps, valves, gear and other dynamic parts are affected by SCC or corrosion fatigue. In power plants, boiler tubes and turbine components show failure due to SCC.

During plant operation, the corrosion and erosion behavior of materials under stress related servicing condition is perhaps the prime factor in material selection. Amongst the structural materials used in desalination/power plants, carbon steels are prone to SCC in carbonate, bicarbonate, acetate, phosphate and ethanol amines. In low alloy steels, oxygenated water at high temperature, alkaline chloride solution and deposit carryover steam cause SCC. SCC of austenitic stainless steels is a familiar problem in plants. AISI 304 and 316 SS are highly susceptible to SCC in HCl and H_2SO_4. Ni-base alloys like C-276 and 825 are quite susceptible to SCC in HCl oxidizing solution at high temperature.

The cupronickel alloys are subjected to SCC in environments like ammonia, SO_2, bromide and organic complexing agents.

This paper reviews the failures in SWCC desalination and power plants due to stress-induced corrosion occurred during the last 20 years. Some important or representative cases of failure have been discussed in the light of criteria for proper material selection. The performance of new materials, which have either been used in recently built plants or replaced the original materials in old plants, is also discussed.

Keywords: Stressed-induced corrosion, Material selection, Stress corrosion cracking (SCC), Corrosion fatigue, Pitting, Desalination and power plants

Introduction

The structural materials employed in seawater handling or processing plants including desalination plants are invariably exposed to corrosive environment due to chemically active nature of natural seawater. The corrosivity of seawater owes to the presence of immensely high concentration of a wide variety of electrolytic salts particularly chloride, sulfates and carbonates, and biologically active ingredients and organic constituents. The geographical location and environmental parameters such as temperature, flow/turbulence, wind direction and speed, and seasonal variations are some important factors which influenced the aggressivity of seawater.

Metallic materials such as carbon steels, stainless steels, copper-based alloys and titanium and non-metallics such as polymers, composites and ceramics form the bulk of conventional constructional materials of present day seawater thermal and reverse osmosis desalination plants. Proper materials selection plays a most important role in restricting the physical and chemical deterioration of plant constructional materials, thus prolonging the service life of the plants and maintaining the high efficiency of the plant as envisaged by the users. Localized corrosion which is mainly comprised of pitting and crevice corrosion and stress induced corrosion which include stress corrosion cracking(SCC) and corrosion fatigues form the majority of the corrosion processes which are responsible for the failures of components in desalination and power plants.

Stress induced failures in the components occurred as a result of the presence of internal stresses/residual stresses culminating in the so-called stress corrosion cracking(SCC). The stresses generated in dynamic components bring about fatigue failures. The study of stress induced failures forms an integral part of the realm of corrosion investigations on materials. Material selection, operational parameters, environmental conditions and design are some of the important factors that influence the stress induced failures. In desalination plants, components like shaft, column and elbows of seawater pumps, valves, gear and other parts are affected by SCC or corrosion fatigue. In power plants, boiler tubes and turbine components show failure either due to SCC or corrosion fatigue or simply failed by mechanical fatigue.

SCC is a stress assisted anodic process as a result of synergistic action of ions such as Cl^-, Br^-, S^-, SO_4^{--}, etc. present in the medium. The susceptibility to SCC is influenced by factors like environmental conditions, temperature hardness of the material, level of applied stress and microstructure of the material. The failure characteristics in SCC are most consistent with a hydrogen embrittlement where the fracture modes are mostly intergranular but mixed modes (trans and intergranular) are not uncommon. The crack branching is a regular feature of the failure in which crack usually initiates from pits. Amongst the structural materials used in desalination/power plants, carbon steels are prone to SCC in carbonate, bicarbonates, acetates, phosphates and ethanol amines. In low alloy steels, oxygrated water at high temperature, $NaNO_2$ – Na_2SO_4 solution, alkaline chloride solution and deposit carryover steam causes SCC [1,2]. Synergic effect of low concentration chloride in bicarbonate solution [3] and low concentration of sulfate [4] causing SCC in low alloy steels have also been reported.

Austenitic AISI 304 and 316 SS are highly susceptible to SCC in HCl and H_2SO_4 [5]. Ferritic SS of type AISI 405 were reported to SCC at 288°C in aqueous environments [6]. Ferritic steels of type AISI 430 showed less susceptibility to SCC in chloride solution when compared to sulfate solution [7]. Martensitic SS type 420 were found to prone SCC in H_2S environment and resistant to CO_2 environment. In duplex SS, SSC is severe at 160°C in 25% NaCl containing H_2S and also in aerated brine solutinon [8]. Ni-base alloys like C-276 and 825 are susceptible to SSC in HCl oxidizing solution at high temperatures. The cupronickel alloys are subjected to SCC in environment like ammonia, SO_2, Br^- and organic complex agents [7]. Austenitic nickel cast irons also known as Ni-resist have been found to undergo stress corrosion cracking in seawater at temperature above 40°C [9]. Different grades of Ni-resist cast iron under designation ASTM A436 have been used in seawater applications particularly pumps due to their good corrosion and erosion resistance [10]. In recent years, there were spate of failures in seawater pumps using Ni-resist alloys [11,12]. The mode of failure was SCC and presence of internal/residual stresses appeared to be the main cause of the problem.

In some of the plants, Ni-resist has been replaced by other materials like duplex steels which have better strength and superior corrosion resistance particularly to SCC.

As discussed in the above section, the stress-induced failure has been quite a familiar phenomenon in desalination and power plants, a considerable number of cases related to stress related failures are reported from various SWCC plants every year. In the following section, five cases related to stress failures are discussed in detail. These cases represent typical stress-induced corrosion failures in different SWCC desalination and power plants. An account of the background of the failure, investigation outlines, results, discussions, conclusions and recommendations are included for each case.

PUMP FAILURES – SOME CASE STUDIES

1. Failure of a Shaft of a Brine Recirculation Pump in an MSF Desalination Plant

A case of failure of a shaft of a brine recirculation pump was reported. An examination of the damaged shaft revealed two major circumferential cracks passing through the almost entire shaft cross-section, but did not separate into several pieces (Fig. 1). The cracks had occurred near the end of the shaft where it is coupled to the electric motor. Apart from large cracks, there were also few smaller cracks covering small portions of the circumference. Some of the cracks had also passed through the two keys that had been used to assemble the joint between the shaft and coupling (Fig. 2). A piece of the damaged shaft was vertically cut into several sections and examined through a stereomicroscope. The fracture surface showed beach marks (Fig. 3). The Microstructural studies of the sections showed transgranular cracks with branching (Fig. 4). The emanation of the crack from the corroded edges was also observed (Fig. 5).

Results and Discussion

The results of various tests carried out and the observations made, as presented above clearly indicate that the failure of the shaft basically occurred due to corrosion fatigue cracking in chloride containing environment. The occurrence of corrosion fatigue is evidenced by two observations: (1) typical branching cracks, emanating from corroded metal edge, and (2) the typical beach mark observed on the fracture surface. However, the possibility that some of the cracks being occurred due to mechanical fatigue alone cannot be ruled out. The conditions necessary for the occurrence of corrosion fatigue were also existed, namely, the dynamic loading of a rotating shaft and presence of aggressive chloride ions in the environment.

The ingress of the chloride ions at the locations where crack initiation occurred appeared to play a significant role. While the major part of the shaft, which was constantly in contact with the brine being pumped, did not show any sign of corrosion or cracking, the recess under the keys in the key slot became the site for the corrosive attack. The keys are used to make the joint assembly between the shaft and the coupling on the driving motor. The ingress of chlorides into the crevice of the key slot recess caused intense localized corrosion in this area giving rise to stress concentration sites for attack initiation.

Conclusions

1. Failure of the shaft has occurred mainly due to corrosion fatigue cracking.
2. Ingress of chloride containing fluids into the key-slot recess through the coupling provided the aggressive medium for corrosion fatigue to occur.

Prevention

The remedial action to prevent such failure in future would require to eliminate any chances of chloride ingress inside the key slot recess. This may require slight modification of the assembly between the shaft and the coupling.

Figure 1. Cracks on the shaft of a brine recirculation pump

Figure 2. Section of the Shaft showing the cracks. Corrosion is seen on the key slot surface and on the corners

Figure 3a. Fracture surface of a section showing two even surfaces. The lower portion near the center of the shaft shows beach marks type lines.

Figure 3b. Fracture surface at the other side (side 2) of the section showing similar features.

Figure 4. Photomicrograph of the shaft specimen transgranular nature of the cracks is evident 50X

Figure 5. Photomicrograph taken from near the edge of specimen showing the emanation of fine, branching cracks from the corroded edge

2. Failure of Main Seawater Cooling pump in a MSF Desalination Plant

The occurrence of failure of a column pipe belonged to one of the six pumps of main cooling water intake system. These pumps had been in operation since 5 years. On the particular day of failure, it was noticed that pump was behaving abnormally. The current was fluctuating, vibration and noise levels were more than the specified limits. Subsequently, the pump was switched off and inspected. It was found that the column pipe of the pump was damaged. A large portion of the pipe measuring approximately 1.5 meters length, 0.7 meter width had come off from the main body leaving a big hole in the pipe (Fig. 6).

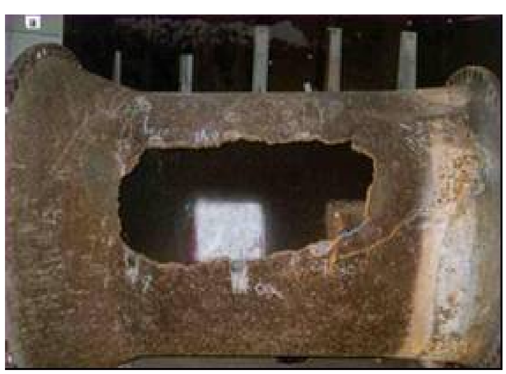


Figure 6. Photograph showing damaged pipe

The specifications of the pump are given below:

Type: Vertical mixed flow pull out. Type [Model KVP-180P]

Discharge Capacity : 26300 m3/hours

Total Head : 28.5 meters

Dimension of the column pipe : 1.6 m dia

2.8m long

25 mm thick

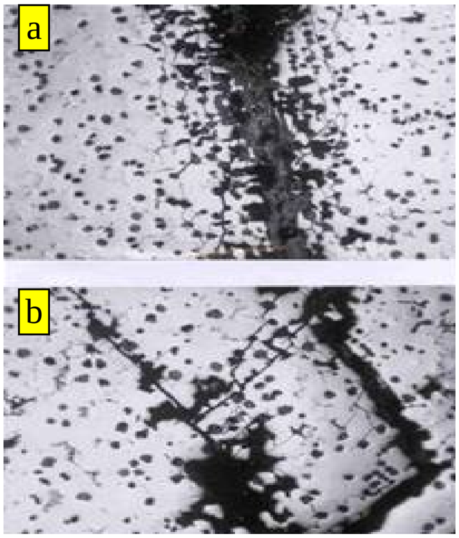
Column pipe material : Ni-Resist D2W

Physical Inspection

The failed column pipe was an intermediate pipe between impeller casing and L bend pipe leading to common header. It had diverged end flanges for coupling. A close up view of the damaged area showed a major crack extending up to one of the end flange (Fig.7). The fracture consisted of dull and bright regions suggesting mixed mode namely, ductile and brittle fracture. The fracture path was highly irregular.

Figure 7. Close view of the damaged column pipe showing crack extending up to the end of the flange

The microstructural examination of the main crack showed: (i) crack propagation along graphite nodules (Fig. 8a) and (ii) transgranular branching of crack intersecting graphite nodules (Fig.8b). SEM studies of a cross section of failed pipe show pitting and the presence of graphite nodules and lamellar carbides in the austenitic matrix (Fig.9). Figure 10 shows EDX spectrum of corrosion deposits collected from the inner surface of the cracked region of the pipe. The deposits are rich in chlorides.



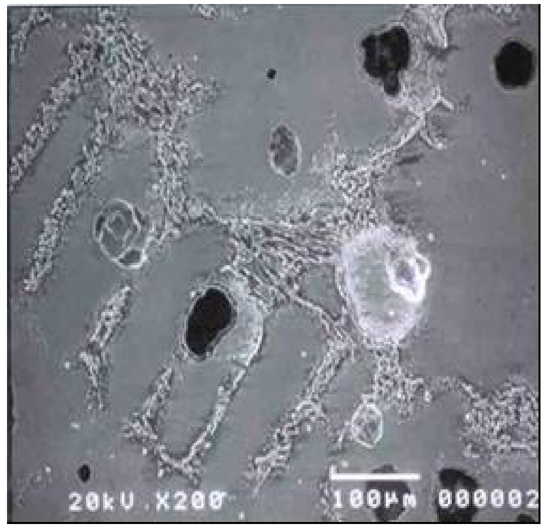


Figure 8. Photomicrograph of main crack showing :
(a) Crack propagation 50X
(b) Transgranular branch

Figure 9. SEM photomicrograph of a cross-section of failed pipe showing graphite nodules,
des in austenite matrix

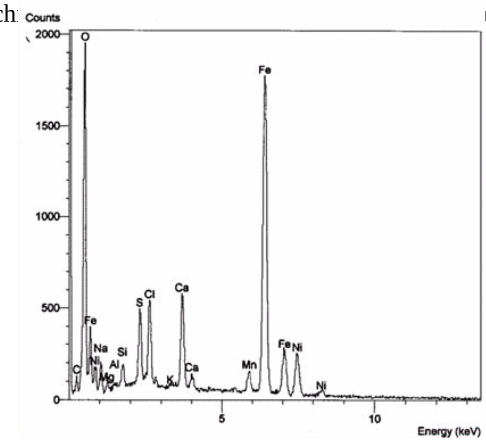


Figure 10. EDAX spectrum of corrosion deposits collected from the inner surface of cracked regions of the pipe

Discussion

Initiation of cracks could be originated from stress raisers such as pits, initial microcracks, surface discontinuities, porosity and improper welding. The prime source of pits and subsequent cracking appears to be the residual stresses in the pipe body due to improper heat treatment during manufacturing.

Cracking in this investigation was found in the form of large longitudinal cracks with extensive sub-branching. The cracks have initiated in the intergranular mode and culminated transgranularly at some location, intersecting the relatively soft phase of graphite module which is typical of stress corrosion cracking.

Besides residual stresses, the internal stresses may also develop over a time due to “hammer effect” arising from sudden opening or closing of the valves in the common header line during the operation.

Mechanism of Failure

The failure mechanism is consisted of two steps:

(1) Initiation of pits due to presence of chloride and internal stresses in Ni-Resist alloy.

(2) The pits act as stress raisers and subsequently cracks initiate and progressively propagate from inner surface to the outer surface of column. The corrosion products collected from crack show considerable concentration of chloride.

Conclusions

(1) The column pipe of main cooling pump had failed due to SCC as a result of synergic action of internal stresses and corrosive species (mainly chloride) in seawater.

(2) The internal stresses had been induced in the body due to shortcoming in the manufacturing process which in consequence resulted in the development of pits.

(3) The internal stresses might have also developed due to “hammer effect”.

Recommendations

It was recommended to consider cast duplex steels like 2205, 2507 DP3W or similar alloys as column material, which have much better SCC resistance than austenitic Ni-Resist cast iron.

3. Leakage in a Control Oil Piping Steam Turbine system

The pipe had been in service for five years and it was used to carry oil from the control oil unit to the steam turbine control valves servomotor. The control oil Pump delivered 23 litters of oil per minute at 120 bars to distribution lines. The failure of one of the line pipes occurred. Oil operating temperature was 75^{o}C, the outside environment around the pipe was atmosphere. The pipe material is A312 TP 304L, [Cr-16.2, Mn – 1.4, Ni – 11.4, Fe ~ 62.0].

The photograph of the pipe often dyepenetration test shows a small pit (Fig. 11). A photogrtaph of the pipe after removal of the dye shows crack propagation horizontally along the pipe (Fig. 12). The piece of the splitted latitudely shows oil contamination deposits at the inner side of the tube (Fig. 13).

Figure 11. Closer view showing nucleation of pits after dye penetration test

Figure 12. Crack propagation horizontally along the tube

The Microstructural studies of the cross-section of the pipe shows crack propagation inside the pipe with normal austenitic structure (Fig.14). It appears that the crack was initiated from outside the surface of the pipe and propagated to inner surface. The matrix of the pipe shows cracks branching as revealed by scanning electron micrograph (Fig.15).

Figure 13. Splitted tube showing oil deposits inside

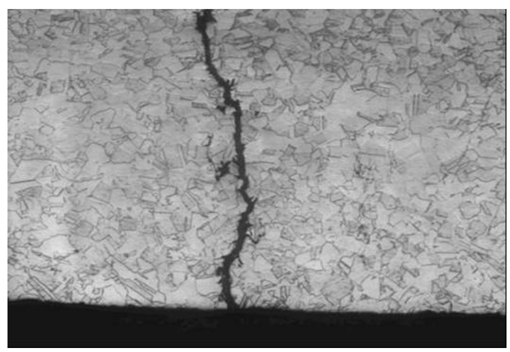


Figure 14. Crack 1 started from outside pipe X100

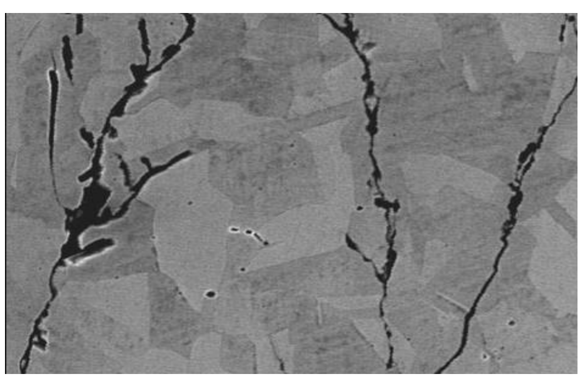


Figure 15. SEM Image showing branching crakes at the matrix X750

Discussion

There are cracks and pits on pipe pieces at the outer surface .The main reason of pipe failure appears to be stress corrosion cracking (SCC) which effected the pipe and created oil leakage. SCC was initiated from outside of the pipe and propagated inside the pipe with branching. The reason of crack propagation horizontally along the pipe surface (Fig. 4) was due to the high pressure (120 bar) exerted by the tube internal. The outer environment in contact with pipe was atmosphere which was enriched in chloride ions due to proximity to seashore. Therefore, Cl ions appeared to be responsible for pitting and SCC of the pipe.

Conclusions

1. The failure was due to SCC to which austenitic stainless steel 304L is susceptible.
2. Outer environment contaminated with chloride ions supported with stresses developed due to high internal operating pressure in the tube appear to be the main cause of SCC.

Recommendations

1. In order to prevent the pipe from SCC failure it is recommended to use a suitable coating which can act as a barrier against chloride ions attack on the pipe surface.
2. Upgrading the material to high stainless steels is another alternative to reduce the attack of atmosphere contaminated with chloride ions.

4. Failure of Main Seawater Pump Intermediate Bearing Support

Failure of main seawater pump intermediate bearing support in a desalination plant was reported. During overhauling it was found that cracks have developed in the intermediate bearing support block near the arm and the rim joint and thus made it unsuitable for future service. The bearing support has normally lasts for full life time of the pump which was estimated to be 25 years.

The cracked intermediate bearing support block was examined. The central support hub was supported by rim through equally spaced 5 numbers of tapered arms of 60 mm thickness. Out of the 5 arms, 2 arms had developed several cracks at the rim and interface (Fig. 16). Other arms and rim joints were visually inspected and no cracks were apparently observed. The intermediate bearing support material has the chemical composition: C-1.8%, Mn-=1.2%, Si-0.2%, Ni-27.8%, Cr-1.7% and Fe-balance. The composition corresponds to Ni-resist cast iron, grade ASTM-A439 type D-2.

The general microstructure of the sample showed spheroids of graphite and even distribution of carbide network essentially made of chromium carbide in austenite matrix (Fig. 17). The sample for microstructure studies were prepared by cutting the portions of cracked parts. The Microstructural examination of the cracks has revealed that the main cracks were propagated along the grain boundaries. The branching of cracks have taken place often across the grains (Fig.18).

Figure 16. Photograph of main seawater pump intermediate bearing support. Arrows indicate the area where cracks have developed during service

Figure 17. Photograph of cut up portions of intermediate bearing support block shows the cracks at arms and rim interface.

The SEM picture of the section of the sample showed cracks associated with transgranular branching (Fig.19). The typical branching of the cracks from the main cracks associated with corrosion suggests typical material failure due to stress corrosion.

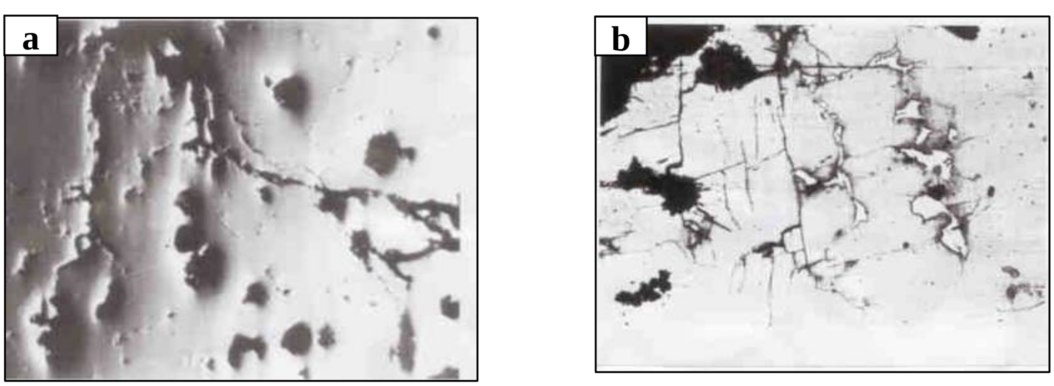


Figure 18. Photomicrograph shows main crack and branching of cracks:(1) uneched and (b) etched. Note the transgranula cracks emanating from the carbides & graphite nodules X 100

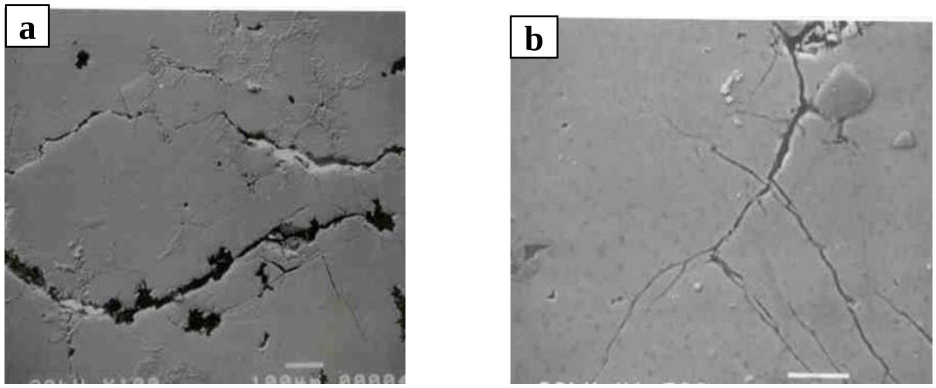


Figure 19. SEM picture showing cracking along the grain boundaries and transgranular cracking

Discussion

It is seen from the investigation carried out on the component that the several micro cracks have been originated at the region where there is considerable variation in the section size. These areas are however are more vulnerable for the development of high residual stresses during manufacturing process. Hence, proper care had to be exercised in the design and also in the heat treatment to relieve the stresses soon after the casting. If proper stress relief heat treatment had not carried out, local internal stresses closed to the yield strength of material would make the material prone to stress corrosion cracking (SCC). The branching of sub-cracks from the graphite nodules in transgranular mode and the presence of macrocracks connecting the graphite strongly suggest that the local residual internal stresses accumulated at those regions where cracks were initiated. The metallography carried out on the sound portion on the component suggests that there is no material inhomogeneity in the component. The macro hardness measurements taken near the cracked regions as well as the sound portion of the components were also found to be uniform. Therefore, the observed cracks could be due to internal stresses developed during the casting process and the material has not been sufficiently stress relived by heat treatment.

Conclusions

1. The developments of cracks in the component are predominantly due to the combined effect of stress and corrosion leading to stress corrosion cracking (SCC).
2. The reason of SCC may be due to the presence of residual stresses at

the regions where there is large variation in section size of the component.

Recommendations

It is suggested to make use of duplex stainless steel as an alternative material for the component. These steels have good strength and better corrosion resistance to seawater particularly to SCC.

5. Failure of Blades in Turbine

During routine shut down maintenance of turbine #81 from C-8 power plant, the turbine was cleaned by means of alumina blasting. However, after the cleaning, cracks were noticed on some blades of the 9th stage. The 9th stage turbine, manufactured by Mitsubishi Heavy Industries (MHI) has a configuration in which 6 blades have a common shroud (Fig. 20). The blades were examined by dye penetration test and 6 blades of stage #9 were found to have cracks. In all the cases, the cracks had started at the trailing edge of the blade and progress up to about 1/3 to ½ of blade width (Fig.21). No blade was completely broken and no pitting was observed on any blade. Subsequently, the cracked blades were removed from 9th stage of the turbine for investigation (Fig.22). Substantial deposits of dark-brown color were found at the recess area between the tennon and shroud.

Figure 20. Overall view of stage 9 of turbine # 81, C-8 Power Plant

Figure 21. Photograph of blade No. 4, stage 9, three cracks are visible

Figure 22. Four cracked blades from 9th Stage of turbine #81

Results

Results of the chemical analysis by AAS provide an average composition of the blade material as: Fe-78.4, Cr-13.8, Ni- 4.4, Mn-0.29 and Cu-3.1 which corresponds to 17-4 pH grade stainless steel. The chemical analysis of the deposits indicates that deposits are predominantly consisted of iron compounds (58%) along with significant concentration of Cu (10.3%) and Ni 2.5%) with low concentration of Cr and Mn(<1.0). The chloride has relatively very low concentration (0.058%, 580 ppm) but has significant influence on the failure mode of the blade.

The X-ray diffraction of the deposits indicate strong presence of Fe_2O_3. Visual observations of the cracked blades show crack branching at both concave and convex sides of the blade. On the concave side some very small chipping of the metal was observed. The stereomicrograph of the ruptured surface indicated the presence of beach marks which is the characteristic of fatigue or corrosion fatigue.

Microstructural studies were carried out on various cross-sections of the blades so as to cover all the cracks. Very interesting as well as intriguing microstructures were observed while examining the specimens. Single, multiple and branched cracks were observed in the microstructures of the damaged blades. In general, the different cracks seen are likely to be the branches coming from the original main crack, intersecting the plane of the specimens at different portions. Cracks were both intergranular and transgranular types at different locations (Figs.23 and 24).

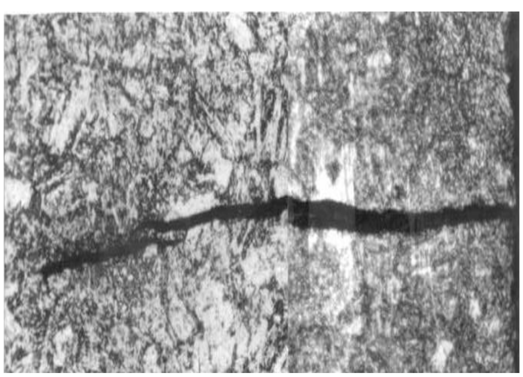


Figure 23. Photomicrograph of the cross-section of crack # 2 of blade # 4 showing a large single crack, transgranular X 570

Figure 24. Photomicrograph of crack # 3 of blade# 4 multiple branched cracks are visible, which are both transgranular & transgranular 280X

Using scanning electron microscope (SEM) fractographic studies were conducted on the cracked blade specimens to have a close look at the crack surfaces and to find out the nature and source of the crack. The studies clearly revealed the presence of beach marks (Fig.25) and also the fractured surface dimples. It also appeared from the studies that cracks have originated from some of the shallow pits (Fig. 26).

Discussion

A systematic investigation mainly based on metallographic analysis was carried out to determine the cause and mode of cracking in some of the blades of 9th stage, # 81 turbine. The investigation reveals the following information regarding the nature of cracks:

(1) Some blades contain large cracks very clearly visible by naked eye, these cracks are penetrated deep and could be seen on both sides (convex or concave) of the blades.

(2) Microstructural studies (Optical and SEM) reveal the presence of different types of cracks, large, straight or curved cracks with few or no branching which are normally associated with fatigue failure. In some other cases, fine cracks in the form of branches emanating from large cracks which are characteristic of stress corrosion cracking were also found.

(4) Examination of the cracked surfaces showed the presence of beach marks characteristic of fatigue failure.

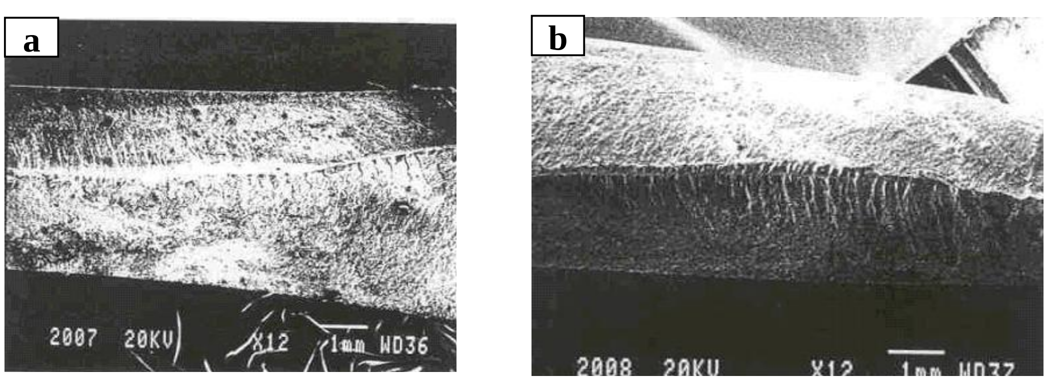


Figure 25. SEF pictures of the crack surface of a specimen from blade #17, showing beach marks: (a) before cleaning and (b) after cleaning

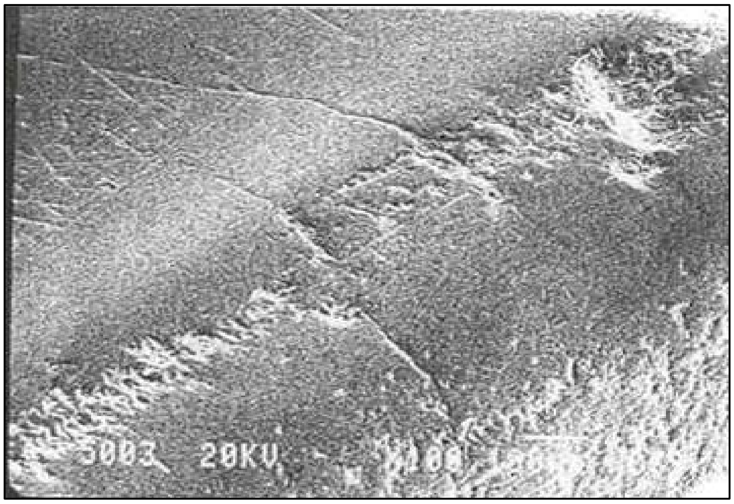


Figure 26. SEM of trailing edge of the blade # 19, showing the initiation of some more cracks from pits 100 X

(5) From microstructural studies there is overwhelming evidence that transgranular is the predominant mode of crack propagation.

(6) SEM studies on the trailing edge of the blade revealed the presence of a substantial number of small and large pits and initiation of cracks from some of the pits.

Failure of blades through mechanical fatigue appears to be the predominant cause of the crack propagation, this contention is based on the following evidences: (i) most of the large cracks are deep, straight and with little or no visible branching. (ii) the mode of failure is brittle fracture which is revealed through transgranular cracking. (iii) the cracked surfaces show prominent beach marks which is characteristic of fatigue failure. However, there is some microstructural evidence (emanation of branching cracks emanating from main cracks) regarding failure due to SCC but it may not be the prime cause of failure. It has been cited in literature that 17-4 pH is through a high strength -corrosion resistant material but it has the tendency to undergo SCC. There is a strong possibility that the cracks initiated as SCC cracks from pit but later on propagation as fatigue cracks sustained by the cyclic nature of loads - the initial crack acting as a sharp stress raiser.

Conclusion

There is an overwhelming experimental evidence to support the view that the mechanical fatigue is the predominant cause of some blades in the 9th stage # 81 steam turbine. SCC or corrosion fatigue might have played a secondary role in initiating cracks which would have acted as stress raiser. The cracks invariably initiated at the trailing edge because the latter is the thinnest section where maximum stress concentration occurred.

General Conclusions

The role of stresses in initiating the cracking or breaking process in static and dynamic structures has been overemphasized. The results of 5 cases representing typical stress related failures have illustrated the importance of this subject. Material selection, stress level of the material, design, environment and operational parameters appear to play their role(s) on the performance of the unit. The key-points of the investigations are summed up as follows:

(1) In seawater pumps, synergic action of internal stresses and corrosive species (chloride) in seawater play pivot role in failure. Apart from stress free materials, the material should have fairly good corrosion resistance to seawater. Material selection appears to play very important role.

(2) In the second case, deficiency in design of the key slot in the shaft of brine recycle pump which resulted in the ingress of chloride appears to be the major cause of the problem. The ingress of chloride into key slot recess created condition for onset of corrosion fatigue.

(3) In the third case, leakage of control oil piping steam turbine system occurred. Cracks propagated horizontally along the pipe surface, as a result of abnormal stresses developed due to high pressure (120 bar) exerted on the tube internals. The stresses along with Cl^- rich environment near the store at the outer of the pipe created suitable condition for SCC. Material selection appears to very important factor in combating corrosion by selecting appropriate alloy.

(4) Failure of intermediate bearing in seawater pump due to crack developed near the rim and joints appeared as a result of the combined effect of residual stress and corrosion leading to SCC. The residual

stresses developed at the region where there are large variations in section zone of the components.

Improved design size and use of better corrosion resistant and high strong material such as duplex steels appear to be the best measures to combat failure.

(5) In the fifth case, failure of 9^{th} stage blade of #81 back pressure steam turbine was investigated. The cracks invariably initiated at the trailing edge because the latter is the thinnest section where maximum stress concentration occurs. It was concluded that mechanical fatigue was the predominant cause of failure.

For preventing reoccurrence of such failure in turbine blades, design of the turbine blades and operation procedures have to be reviewed.

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Performance of a Domestic Membrane Bioreactor Unit

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ABSTRACT

One of the important advantages of membrane processes is that they are modular in nature and can be implemented for various scales of operation. Membrane Bioreactors (MBR) are an example of such processes. MBR units are typically compact and consume less foot print compared to conventional sewage treatment processes. Combining this characteristic with the modular nature of membranes, make the MBR a potential candidate for decentralized sewage treatment especially at locations with severe space limitations or where superior effluent quality for reuse is stipulated. MBR is a recent technology that has rapidly gained popularity during the past ten years. Operating at high Mixed Liquor Suspended solids (MLSS) and employing either Micro or Ultra filtration for solids separation allows them to produce effluents of very high quality. Performance of the most popular MBR systems has been the subject of many studies. However, more data are still needed to verify the performance of the various MBR systems under various operating conditions and different types of wastewater. The objective of the current work was to study the performance of a small scale commercial MBR used for treatment of wastewater intended for direct unrestricted reuse of the treated effluent in non-potable applications. The unit was installed in a social center. It uses ultra filtration (UF) flat sheet membranes with 38 nm separation size. Measurements of operational parameters and product quality were regularly taken. The data collected over a period of four months indicate a steady operation in terms of filtration rate of 70-80 liters/minute and trans-membrane pressure (TMP) of 0.3 bars and in terms of product quality measured as COD of less than 50 mg/l, total suspended solids (TSS) of less than 1 mg/l and nitrogen (NH_3) of less than 5 mg/l.

Key Words

MBR Wastewater Treatment Unrestricted Reuse

1. INTRODUCTION

Fresh water resources are very scarce in Bahrain. The Electricity and Water Conservation Directorate (EWCD) are very active in helping the community to optimize the use of water and reduce wasting. It was observed that a large proportion of municipal water is consumed for garden watering in many facilities used by the public such as educational institutions (schools, colleges and universities), recreational facilities such as sports clubs and public parks, and in commercial sites such as hotels and shopping Malls. One possible method of optimizing water use in these facilities is the Treatment and Reuse of wastewater for irrigation. Wastewater treatment and reuse is practiced throughout the world to optimize the use of water and overcome scarcity of fresh water resources thereby allowing for sustainable development. There are a number of guidelines for the treatment and reuse of Treated Sewage Effluent (TSE) established by renowned international authorities such as the WHO and national authorities such as U.S.EPA and California Department of Health Services (CDHS) [1-3]. Title 22 of the California Code of Regulations - Recycled Water Criteria has the world's most stringent TSE reuse requirements. Sections 60301.320 and 60301.230 of the regulation (adopted December 2000) define the filtration performance and disinfection requirements for the production of TSE suitable for irrigation of food crops, parks, playgrounds and many other reuse applications. There are many commercially available wastewater treatment technologies with varying efficiencies especially under conditions of sharp daily fluctuations in hydraulic and organic loading prevalent in the types of public facilities listed above. One of the most promising recent treatment technologies is the Membrane Bio-Reactor (MBR). It is claimed that this technology has the advantages of having superior effluent quality, reduced foot print and minimum operational, maintenance and sludge wasting problems compared to conventional wastewater treatment systems. These claims were investigated in a number of extensive studies [4-10]. This study **investigates the technical and economic feasibility of using the MBR technology for the treatment of wastewater and effluent reuse mainly for garden watering in facilities used by the public under the environmental conditions prevalent in Bahrain such as high temperature, salinity and hydraulic loading and low organic loading**.

To be defined as disinfected tertiary recycled water suitable for the reuse applications mentioned above according to Title 22 of the California Code of Regulations - Recycled Water Criteria, TSE from MBR systems must meet the following requirements:

1. Has been passed through a micro, nano, or RO membrane following which the turbidity does not exceed 0.2 NTU more than 5% of the time within 24 hours and 0.5 NTU at any time.

2. Has been disinfected by an approved disinfection process such as chlorination or UV.

3. The median concentration of Total Coliform Bacteria in the disinfected effluent dose not exceed an MPN of 2.2 per 100 ml utilizing the bacteriological results of the last 7 days for which analyses have been completed and the number of Total Coliform Bacteria does not exceed an MPN of 23 per 100 ml in more than one sample in any 30 day period. No sample shall exceed an MPN of 240 Total Coliform Bacteria per 100 ml.

The current study will investigate the ability to meet these requirements using an MBR system under the prevalent conditions in Bahrain.

2. METHODS

2.1 Site selection

The site for installing the system must have the following characteristics:

a. It must be a facility for public use with relatively high water consumption and irrigation demand to make the system economically feasible.

b. Have sufficient free space to install the system.

c. Access for installation, operation, maintenance and sampling is possible at all times.

Dar Al Manar was a suitable site. It is a public center with a daily water consumption of upto 9 m^3/day of which upto 4 m^3 is used for garden watering. The site is served by two sewers. One of the service sewers collects discharge from the kitchen/cafeteria and some toilets and the other collects toilet discharges only. It was decided to intercept and divert the mixed flow because it is more representative of wastewater from public facilities of the types mentioned above and of smaller flow (0.8-1.5 m^3/day).

2.2 Selection of Treatment system

There are a number of commercially available small package MBR systems. The Huber MembraneClearBox® is one of these systems but has the advantage of achieving CDHS water reuse criteria and has minimum operational requirements [9,11 & 12]. Depending on the number of membrane units used, the system can be designed to treat wastewater flows from 0.6 to 8 m^3/day of domestic nature. It operates on the principle of the activated sludge process and membrane filtration and designed to be installed in a multi-compartment tank. The experimental system installed at Dar Al Manar comprised the following components:

a. Multi-Compartment Tank

The treatment system consisted of an underground three compartment tank (Figure 2.1). The first and second compartments are used for settlement to remove settleable solids that may damage the membranes. They also act as anaerobic degradation tanks that convert complex solids into readily available organics. The third compartment acts as an aeration tank for the oxidation of organics and ammonia. This compartment housed the membrane module and aeration system.

b. Membrane system

The membrane system used is Huber's MembraneClearBox® 8 PE (Figure 2.2). It consists of two parts. The submerged part which comprises the ultrafiltration (38 nm) membrane module (VUM module), fine bubble aerator, air scouring box and two float switches to monitor the water level in the membranes' tank and hence control the mode of operation (Low, Normal or High Load) to prevent overflow or dry running of the membranes.

The second part is installed above ground and comprises the PLC that controls the operation of the plant, aeration and scouring blowers (one each), a permeate pump, a flow meter to indicate the permeate flow rate, and a pressure gage to indicate the trans-membrane pressure (TMP). The system also included a Trojan UVMAX™ disinfection system.

2.3 Sampling

Samples were collected three times a week (Sunday, Tuesday and Wednesday) for the following analyses:

a. influent and effluent COD

b. influent and effluent NH_3 and NO_3

c. effluent Total Coliforms (TC)

d. effluent Total Suspended Solids (TSS)

In addition to the above, air and wastewater temperature, pH, trans-membrane pressure, permeate flow rate and permeate pump run hours were also monitored.

3. RESULTS & DISCUSSION

Although initial startup of the plant began in March 2007, but due to a number of operational problems, it was not officially commissioned until May 2007. Operational parameters such as air and wastewater temperature, TMP, flow rate, operation hours were monitored on daily basis during working days (Figure 3.1). Samples for influent and effluent COD, NH_3 and NO_3 and effluent TC and TSS were collected three times a week. The results of the study are presented in the following sections.

3.1 Removal of Suspended Solids

The permeate suspended **s**olids content during the study period is presented in Figure 3-2. The solids content in the permeate was always below detection limit (< 1 mg/l).

3.2 Removal of Organics

The Huber MCB unit achieved excellent organics removal throughout the study period. Figure 3-3 presents the influent and effluent COD. The influent COD ranged from 174 to 666 mg/l with a median of 442 mg/l while the effluent COD was in the range of 30 to 48 mg/l with a median of 40 mg/l.

3.3 Nitrification

During the study, the MCB unit was operated in nitrification mode only. Figure 3.4 and 3-5 shows that the MCB achieved full nitrification. The influent NH_3 ranged from 32 to 58 mg/l with a median of 40 mg/l and the effluent NH_3 ranged from 0.3 to 5 mg/l with a median of 1.1. The effluent NO_3 was in the range of 13 to 28 mg/l with a median of 18 mg/l.

3.4 Total Coliform Removal

The Total Coliform (TC) content of the effluent from the MCB unit was below detection limit in all permeate samples collected during the study.

4. Conclusions and Recommendations

The results obtained from this study showed that The Huber MCB unit was capable of the following:

1. Removal of biodegradable organics (BOD) to below detection limit of 2 mg/l.
2. Full oxidation of ammonia to nitrates.
3. Removal of suspended solids and coliform bacteria to below detection limit.

Similar results were obtained by Adham et al. [11].
Accordingly, with regards to the technical feasibility of using an MBR system for the treatment of wastewater for reuse, it can be concluded that TSE from the Huber's MCB unit meets CDHS Title 22 Water Recycling Criteria.

From an operational point of view, since its official commissioning in May 2007, the system has been in continuous operation maintenance free. This is a very important characteristic of Huber's Flat Sheet MBR systems. Similar observations were made by Babcook et al. [9].

However, from a strictly financial point of view, considering the very low tariff of municipal water in Bahrain, the cost of using a small MBR system to treat wastewater for reuse could be relatively expensive to the consumer at the time being.

The capital cost of installing the MCB 8 PE (civil works, electrical, mechanical, instruments and controls) including the disinfection system is estimated at 3000 BD. The cost of operation and maintenance for a period of 20 years is estimated at 1500 BD. Accordingly the wholelife cost becomes 4500 BD. Based on an average daily flow of 1.2 m^3/day the total production of the unit in 20 years will be 8760 m^3. The cost to the government of an equivalent amount of tap water at the current water production and distribution cost of about 0.38 BD/m^3 (1 US $) will be 3330 BD. It must be clarified that this cost does not include a price for groundwater and there are no charges on wastewater collection and treatment. Therefore, from a pure financial point of view at the current prices the system can not be considered economically feasible to the consumer. However with increased market demand for various reasons and as the technology is mastered by many manufacturers, competition will substantially reduce prices thereby reducing the payback period. Further reduction in costs can be achieved if some components are purchased/manufactured locally instead of importing the whole system. Also larger capacity plants are expected to be more economic than the small ones. Finally, if the cost of wastewater collection and treatment is to be considered the use of such units is likely to be economically feasible.

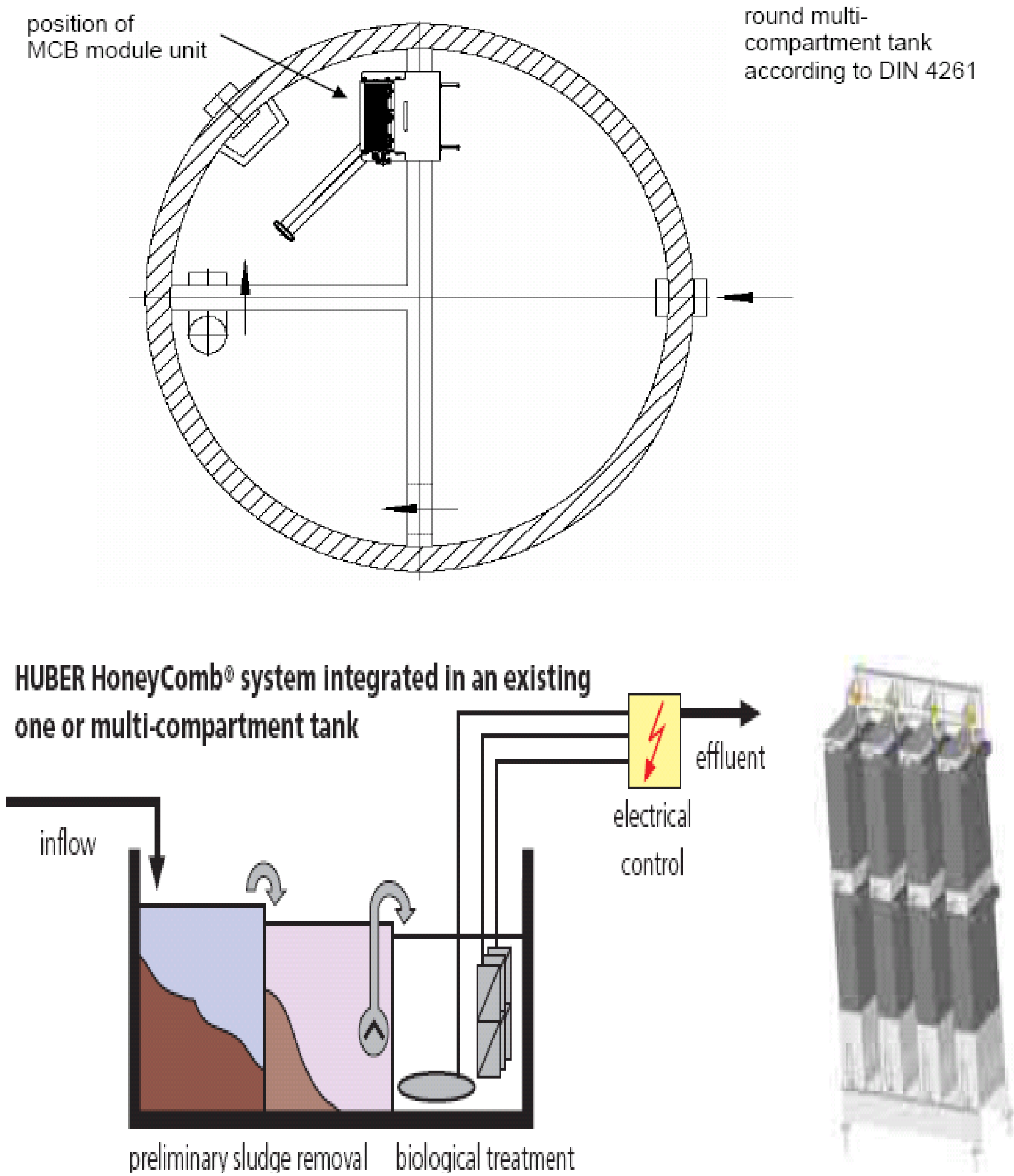
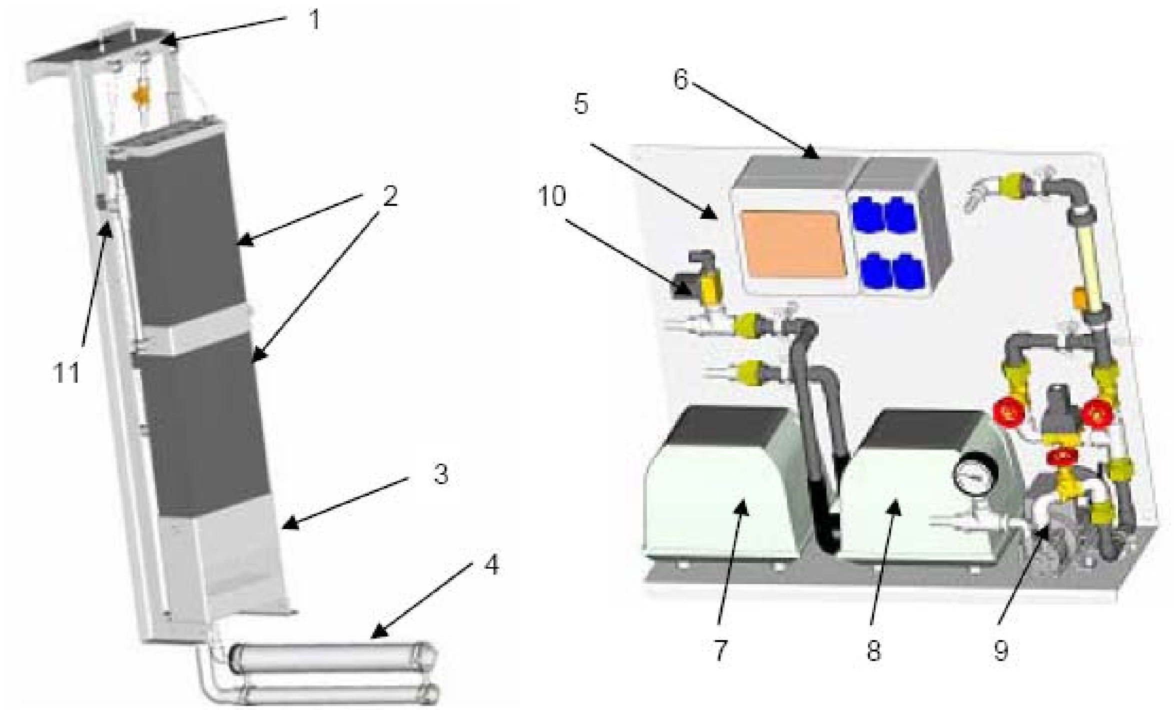


Figure 1.1 Schematic of multi-compartment tank for installation of Huber's MCB unit



The MCB module unit consists of:

- Airlift line to the excess sludge discharge (optional, 11)
- Fine-bubble pipe membrane aerator mounted on an adjustable telescopic pipe (4)
- Scouring box with scouring air connection for cleaning of the membrane surfaces (3)
- Ultrafiltration membrane module(s) with 4 or 6 m², membrane material. PES, with 38 nm separation size (2)
- Support frame for the complete MCB module unit, adjustable in height (1)

The complete MCB module unit is installed directly in the last compartment of the multicompartment
septic tank.

The aggregate unit consists of

- Mounting plate for aggregate unit (5)
- Electrical control for MCB plant (6)
- Aeration blower (7)
- Scouring blower (8)

• Permeate pump (9)

• Airlift solenoid valve for excess sludge (optional, 10)

These two components together form the MembraneClearBox® sewage treatment plan.

Figure 1.2 Components of Huber's MembraneClearBox® system

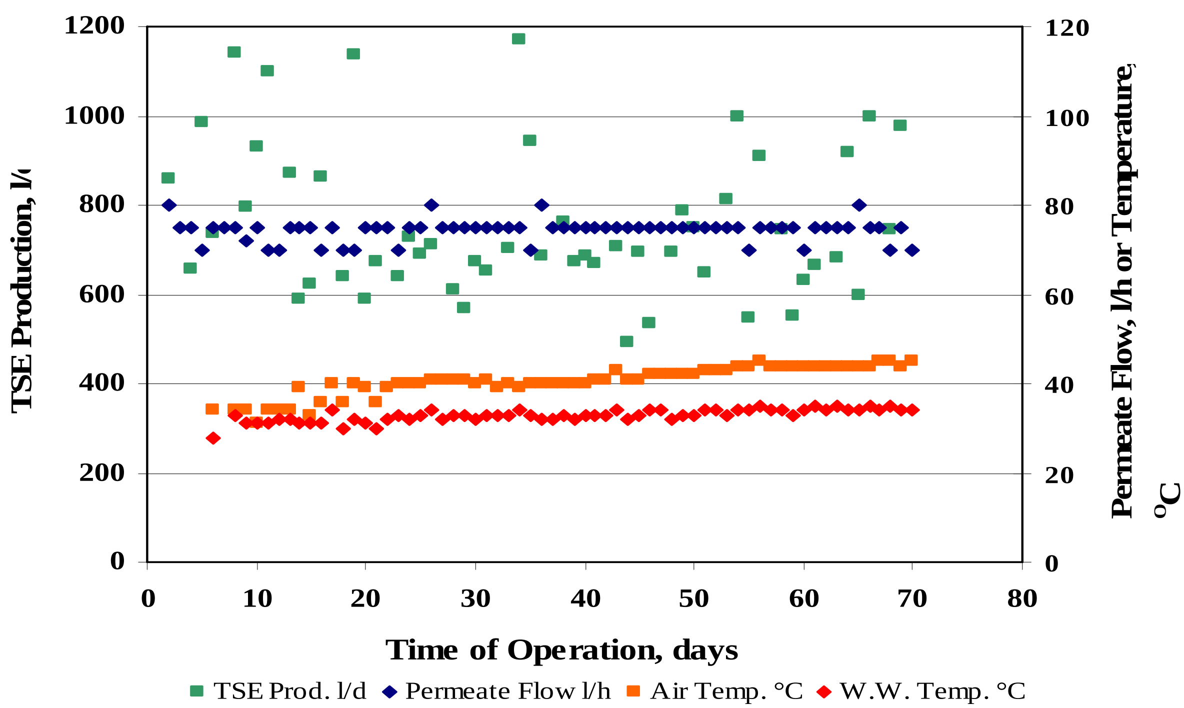


Figure 3.1 Air and Wastewater Temperature, Permeate Flow Rate and Average Daily TSE Production

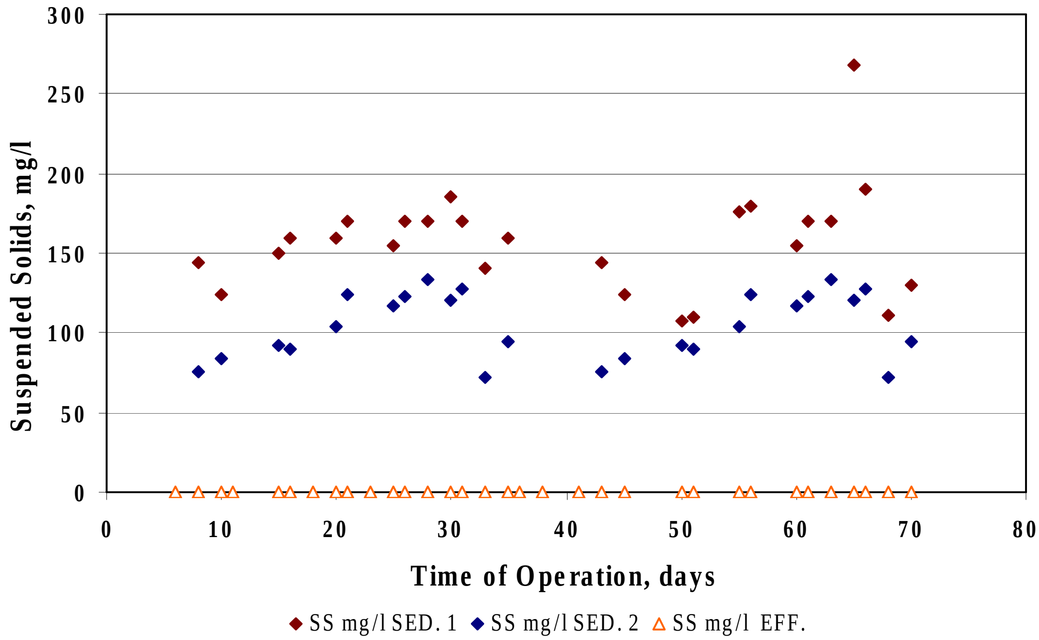


Figure 3.2 Influent and Effluent SS concentration

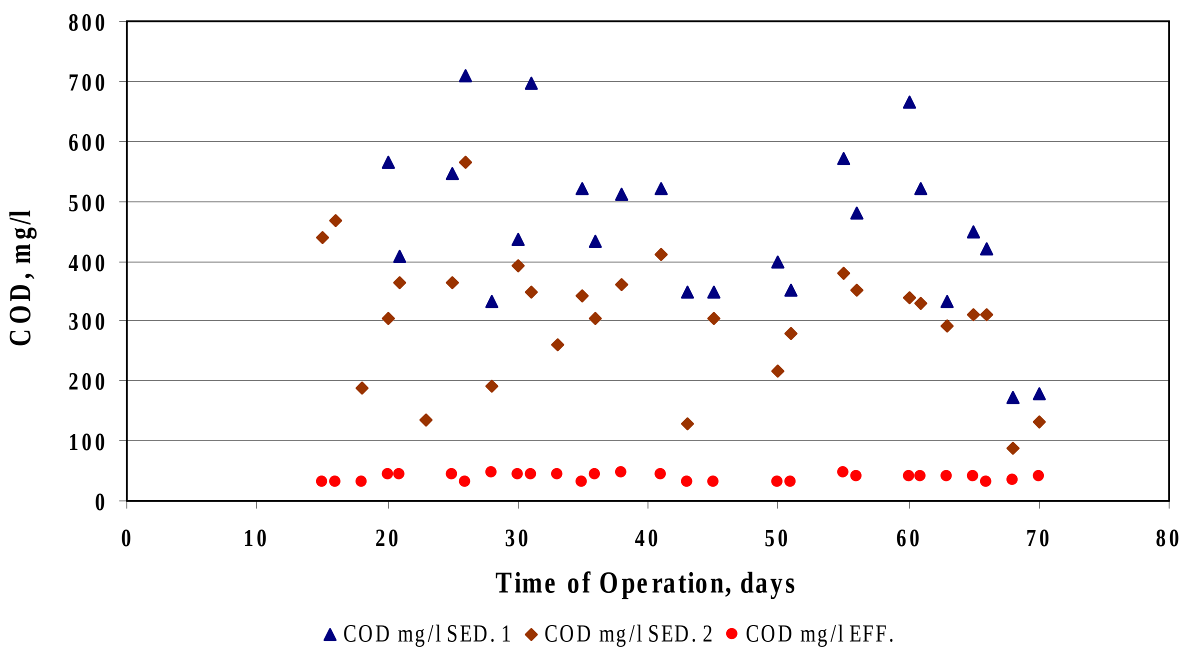


Figure 3.3 Influent and Effluent COD concentration.

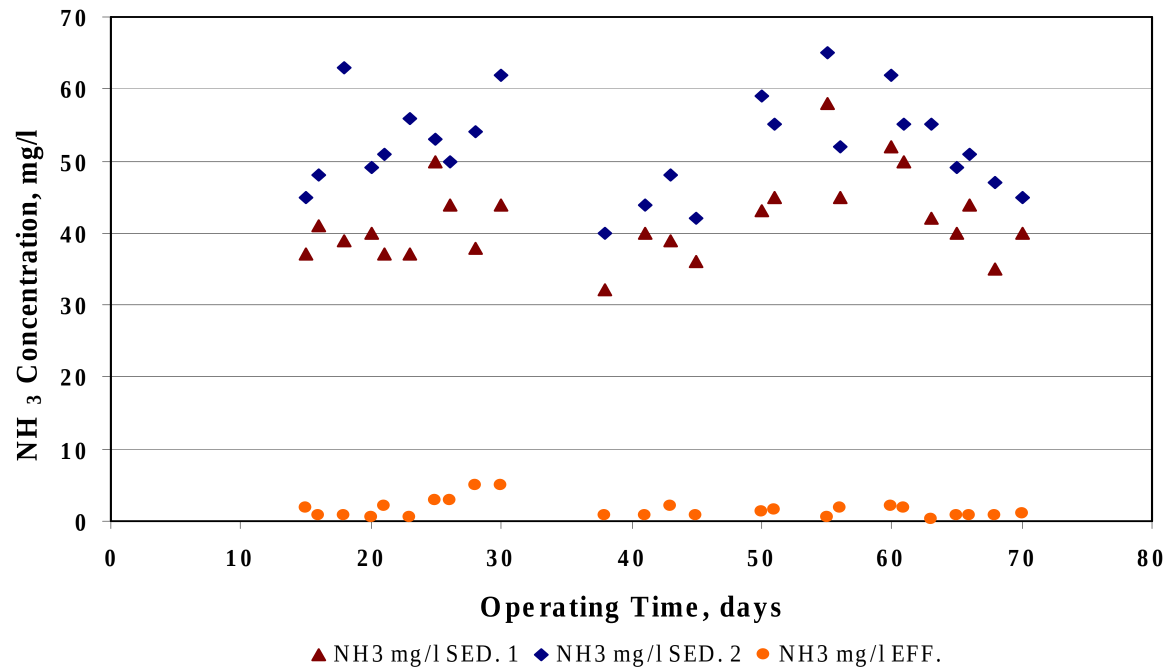


Figure 3.4 Influent and Effluent NH_3 concentration.

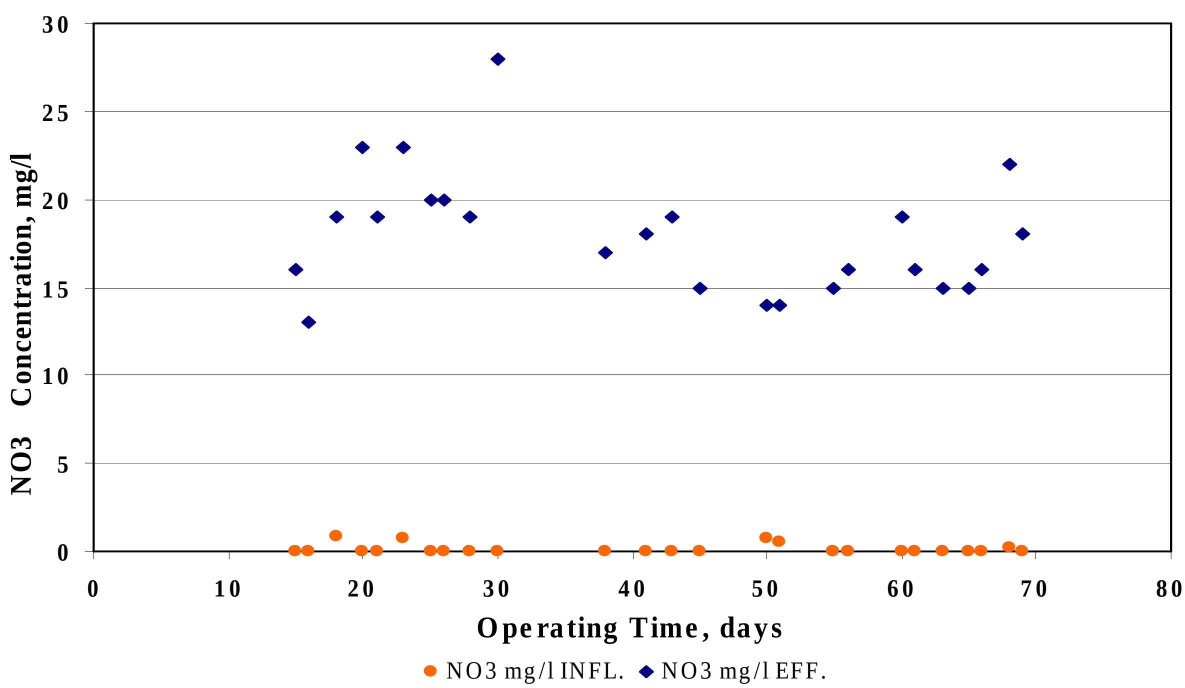


Figure 3.5 Influent and Effluent NO_3

concentration

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التقييم البيئي لمحطات تقطير المياه
دراسة حالة- دولة الكويت

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رئيس قسم المشاريع التنموية-إدارة التخطيط والمردود البيئي
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تقع دول مجلس التعاون الخليجي في منطقة من أقل مناطق العالم أمطارا وأكثرها جفافا وارتفاعا في درجات الحرارة وهي بالتالي تكاد تنعدم فيها المياه السطحية العذبة ما عدا بعض الجداول في مناطق المرتفعات وما جاورها في المملكة العربية السعودية و سلطنة عمان وبصفة عامة تعتبر المياه العذبة من أندر الموارد الطبيعية في المنطقة. وفي إطار التنمية الاقتصادية والاجتماعية التي شهدتها منطقة الخليج بشكل عام ودولة الكويت بشكل خاص وتلبية لحاجاتها أدخلت مصادر جديدة للمياه العذبة هي تحلية مياه البحر. وقد اعتمدت دولة الكويت على محطات تقطير المياه كمصدر أساسي في توفير المياه العذبة حيث تصل نسبة مياه البحر المحلاة إلى 95% . ويهدف البحث إلى توضيح دور محطات تقطير المياه في تلبية احتياجات الموارد المائية في دولة الكويت وتوضيح إيجابيات تلك التقنية كأحد البدائل المتاحة وفي المقابل توضيح الآثار لبيئية السلبية التي قد تنتج من تلك المحطات وذلك عن طريق تطبيق دراسات تقييم المردود اليبئي.
وتعتبر دراسات تقييم المردود اليبئي أداة من أدوات الإدارة البيئية الفعالة و التي تستخدم في مرحلة التخطيط لاقامة مشروع إنمائي أو تطبيق سياسة أو تنفيذ برامج وذلك للتنبؤ بالتأثيرات المتوقعة و شرحها وتحليلها واقتراح وسائل التخفيف للحد أو التقليل من التأثيرات السلبية المتوقعة على الصحة العامة وسلامة النظم الايكولوجية التي يعتمد عليها الإنسان . ومن أهم خطوات دراسة تقييم المردود البيئي الذي تناولها البحث ما يلي : وصف شامل للبيئة الطبيعية والظروف المناخية في دولة الكويت ، وصف للعمليات الفنية لتقطير المياه ونوعية التكنولوجيا المستخدمة ، والوضع الحالي لمحطات تقطير المياه في دولة الكويت ، وتحديد وتحليل الآثار البيئية الناتجة عن تلك المحطات وأخيرا تحديد الحلول المقترحة وتقييم البدائل . تبين نتائج البحث أن تقنية معالجة المياه من إحدى أهم التقنيات التي من شأنها تلبية الاحتياجات من المياه العذبة كما لها عدة مميزات من أهمها أن لها القدرة على معالجة وتحويل مياه البحر والمياه المالحة الأخرى إلى مياه ذات نوعية ممتازة صالحة للشرب ولذلك فهي تخلو من العوائق السياسية والاجتماعية أو القانونية كتلك العوائق التي تتعلق باستغلال الموارد الطبيعية المشتركة مثل الأنهار.كما أنها متوفرة بأحجام متنوعة وتقنيات مختلفة بحيث يمكن استخدام المناسب منها للغرض المطلوب لتلبية احتياجات المياه . ومن الجانب الآخر فان هناك عدة تأثيرات سلبية على البيئة قد تنتج عن تلك النوعية من الأنشطة والتي يجب الحد منها عن طريق إجراء دراسات تقييم المردود البيئي وذلك لاقتراح الوسائل الممكنة لمنع التأثيرات السلبية أو التقليل منها وتحقيق مستوى اكبر من الكفاءة في استخدام الموارد الطبيعية بطريقة مستدامة.

(1) مقدمة

وضح مؤتمر قمة الأرض الذي عقد في ريو دي جانيرو عام 1992 أهمية التنمية المستدامة وحماية البيئة مع وضع أولويات
هذا القرن لحماية البيئة والصحة العامة والمهنية، وذلك بإدخال البعد البيئي ليس فقط في المشروعات الصناعية ولكن أيضا في
حياتنا اليومية حفاظا على الموارد الطبيعية والموارد البشرية فهما أساس التنمية المستدامة التي "تحقق تأمين تنمية اقتصادية تفي
باحتياجات الحاضر وتحقيق التوازن بين متطلبات المستقبل لتمكين الأجيال المقبلة من استيفاء احتياجاتهم". لذلك فإن التنمية
الاقتصادية توفر الظروف التي يمكن من خلالها تحقيق حماية أفضل للبيئة، وبالتالي فإن التنمية الاقتصادية بالتوازن مع حماية البيئة
ضرورة لجعل النمو الاقتصادي مستديما .

و تعتبر المياه العذبة من أندر الموارد الطبيعية في منطقة الخليج العربي ، حيث تقع دول مجلس التعاون الخليجي في منطقة من أقل
مناطق العالم أمطارا وأكثرها جفافا وارتفاعا في درجات الحرارة وهي بالتالي تكاد تنعدم فيها المياه السطحية العذبة ما عدا
بعض الجداول في مناطق المرتفعات وما جاورها في المملكة العربية السعودية و سلطنة عمان وفي إطار التنمية الاقتصادية
والاجتماعية التي شهدتها منطقة الخليج بشكل عام ودولة الكويت بشكل خاص وتلبية لحاجاتها أدخلت مصادر جديدة للمياه
العذبة هي تحلية مياه البحر. وقد اعتمدت دول الخليج العربي على محطات تقطير المياه كمصدر أساسي في توفير المياه العذبة
حيث تمثل مياه البحر المحلاة أكثر من 75% من المياه المستخدمة في دول الخليج العربي بينما ترتفع النسبة إلى 95%
في دولة الكويت .

(2) هدف الدراسة :

يتناول هذا البحث واحدا من أهم موضوعات التنمية المستدامة بل أنه يمثل أحد الأدوات اللازمة لضمان استدامة
المشروعات الصناعية والتنموية وهو "تقييم المردود البيئي" وأهميته في مختلف المشروعات. وقد اكتسبت دراسات المردود
البيئي أهمية خاصة مع التوجه الكوني للتنمية المستدامة، واعتبار سلامة البيئة من مستلزمات استمرارية التقدم والازدهار
للإنسان والأوطان. ويستعرض هذا البحث أهمية وفوائد دراسة تقييم المردود البيئي (والتي تسمى في بعض الأحيان بدراسة
الجدوى البيئية)، وتاريخ نشأة دراسات المردود البيئي ، والخطوات التي يجب إتباعها لعمل دراسة تقييم المردود البيئي ومضمون الدراسة ومحتوياتها. كما يستعرض البحث تطبيق ذلك على دراسة حالة {استخدام المردود البيئي في تقييم الوضع البيئي الحالي لمحطات تقطير المياه في دولة الكويت} وذلك لتوضيح أهمية دراسات المردود البيئي في التسهيل على متخذي القرار باتخاذ قرارات اقتصادية سليمة مبنية على دراسات بيئية تعمل على حماية البيئة وتحقق التنمية المستدامة بما يتعلق بالموارد المائية .

(3) ما هي دراسات المردود البيئي :

تعتبر دراسات المردود البيئي من العلوم الحديثة نسبيا (لا تتجاوز الفترة التي تواجدت فيها قواعد البيانات المرتبطة بها
والتجارب التي يمكن الاستفادة منها 25 عاما) إلا أن مجموعة من الكوارث قد حدثت من صنع الإنسان سواء على مستوى
العالم ككارثة "تشير نوبل"، أو على مستوى المنطقة مثل حرق آبار النفط الكويتية، أو على المستوى المحلي كظاهرة نفوق
الأسماك الكويتية في جون الكويت، مما خلق وعيا بأن تكون التشريعات المتعلقة بالمردود البيئي تشريعات ملزمة ومن متطلبات
الترخيص لأي مشروع إنمائي (اقتصادي، صناعي، زراعي، سياحي أو إسكاني).

(3-1)تعريف[1] :

نوع من النشاط يستخدم في مرحلة التخطيط لإقامة مشروع إنمائي أو تطبيق سياسة أو تنفيذ برامج وذلك للتنبؤ بالتأثيرات
المتوقعة وشرحها ونشر المعلومات عنها واقتراح وسائل التخفيف من التأثيرات السلبية المتوقعة على الصحة العامة وسلامة
النظم الأيكولوجية التي يعتمد عليها الإنسان لمقومات حياته. ويجب النظر إلى دراسات المردود البيئي وسيلة لتحسين أسلوب
اتخاذ القرار حيث تستقطب آراء المواطنين وتستخدم ما يلزم من المعلومات الأخرى بما يضمن أكبر قدر من العدالة والتوازن
عند اتخاذ قرار نهائي.

(3-2) فوائد وأهمية دراسات المردود البيئي :

تتضمن الفوائد التي تنتج عن إعداد دراسات المردود البيئي للمشروعات الإنمائية ما يلي :

- تحقيق مستوى أكبر من الكفاءة في استخدام الموارد الطبيعية بطريقة مستدامة، تقليل نفقات المشاريع الإنمائية على المدى
البعيد (تفادى التغييرات المكلفة في المستقبل) مع التقليل من احتمال حدوث كوارث بيئية وعمليات تنظيف باهظة
التكاليف.
- تفادي الإجراءات التصحيحية التي يتم التخطيط لها أو تنفيذها مستقبلا لتقليل التأثيرات السلبية على البيئة الطبيعية
والاجتماعية.
- رفع مستوى الحماية للبيئة والتقليل إلى الحد الأدنى من التأثيرات السلبية على الصحة نتيجة التشاور بين الأطراف المعنية مما
يؤدي إلى المحافظة على مستويات المعيشة أو رفعها.
- تحسين مستويات التخطيط مستقبلا للمشروعات الاقتصادية والإنمائية.

و يرجع تاريخ نشأة التقييم البيئي كآلية بيئية متطورة لمعالجة المردودات البيئية للمشروعات إلى النصف الثاني من القرن الحالي،

وقد برز الاهتمام بالبيئة بالدول الصناعية وبعد ذلك في الدول النامية. وذلك نتيجة محدودية الموارد الطبيعية وانعكاس ذلك
على الاقتصاد وهو ما اتضح في السبعينات (مؤتمر استكهولم عام 1972 الذي نظمه برنامج الأمم المتحدة UNEP
فقد بدأت الولايات المتحدة الأمريكية في أوائل السبعينات استخدام البعد البيئي في تقييم المشروعات الإنمائية. كما تبنت
كل من كندا وأستراليا ودول المجموعة الأوروبية هذا الآلية، ووضعت تشريعا تلتزم بموجبه بضرورة التقييم البيئي عند تخطيط
وتنفيذ المشروعات الإنمائية.

وقد برزت أهمية تقييم المردود البيئي في دول مجلس التعاون الخليجي ممثلة في بروتوكول حماية البيئة البحرية الخليجية من

التلوث الناتج من مصادر البر في 21 فبراير عام 1991 حيث نصت المادة الثامنة منه على أن {تلتزم الدول الأعضاء على
أساس الأولوية بإدراج تقييم الآثار أو المردودات البيئية المحتملة أو المتوقعة أثناء مراحل تخطيط وتنفيذ مشاريع إنمائية مختارة في
أراضيها وبخاصة في المناطق الساحلية التي قد تسبب مخاطر جسيمة للتلوث من مصادر في البر لمنطقة البروتوكول وذلك
لضمان اتخاذ تدابير مناسبة لمنع أو تخفيف مثل هذه المخاطر}.

وقد تم إدخال مبدأ دراسات المردود البيئي وبدأ تطبيقه لتقييم مشاريع التنمية منذ العام 1990 في دولة الكويت وذلك
إيمانا بالسياسات والمبادئ العامة لحماية البيئة التي صادر عليها المجلس الأعلى لدول مجلس التعاون في القمة السادسة بمسقط –
البند السادس - والذي ينص على "اعتماد مبدأ التقويم البيئي للمشاريع وإعداد دراسات التقويم البيئي ضمن الجدوى، وربط
ترخيص المشاريع والمرافق بموافقة الجهة المسئولة عن حماية البيئة على نتائج هذه الدراسة".

<u>(3-3)الخطوات المتبعة لإجراء دراسات تقييم المردود البيئي</u> :

تبدأ خطوات تقييم المردود البيئي بصورة فورية عند إعداد دراسات جدوى المشروع وتخصيص الموقع، وقبل إعداد
التصميمات النهائية له، ويتم في هذه المرحلة المبدئية حصر الموارد الطبيعية بالمنطقة ومعرفة استخدامات الأراضي المجاورة،
وتحديد المشاكل البيئية وأولوياتها.

وتنبع أهمية هذه المرحلة من وضع أسس ومعايير لاستثمار هذه الموارد أو على الأقل الحفاظ عليها وتترجم نتائج هذه
المرحلة بواسطة استشاري المشروع في صورة مخطط عام والذي يبدأ على أساسه وضع المكونات المختلفة للمشروع من

تصميمات للبنية الأساسية وطرق وأساسات وغير ذلك.

وبعد الوصول إلى التصور شبه النهائي للتصميمات وقبل الشروع في تنفيذ المشروع، يتم عمل دراسة تقييم المردود البيئي
والتي تشمل تقييما شاملا لكل عناصر البيئة المحيطة، ووضع أساليب التخفيف من أية آثار سلبية ناشئة عن التصميمات
المقترحة أو التكنولوجيا المستخدمة في الصناعة.

ويشمل إجراء تقييم المردود البيئي الجوانب التالية كما هو موضح في الشكل أدناه ونوجزها فيما يلي :

- تحديد الحاجة إلى المشروع من الناحية الاقتصادية.
- وصف المشروع المقترح : وصف تفصيلي لمكونات المشروع والعمليات الصناعية المختلفة مع الاستعانة
بالكتالوجات والرسومات التوضيحية كلما أمكن مع توضيح المدخلات من مواد خام وطاقة ومياه، والمخرجات
من منتجات أولية وثانوية.
- الاعتبارات القانونية التشريعية : يتم وصف القواعد التنظيمية والتشريعية المعمول بها حاليا والتي تنظم نوعية البيئة
وحماية المناطق الحساسة وحماية الكائنات المهددة بالانقراض والتي لها علاقة بدراسة تقييم الأثر البيئي مع توضيح
مدى توافق المشروع مع خطط التنمية والمخطط الهيكلي للدولة.

- وصف البيئة المحيطة : وصف شامل للبيئة المحيطة بالمشروع ابتداء من البيئة الطبيعية وتشمل الهواء، ومصادر المياه
والتربة الجيولوجية والأحوال الجوية .. الخ. إلى البيئة الحيوية من نباتات وحيوانات .. الخ، إلى البيئة الاجتماعية
والثقافية لمنطقة المشروع والمناطق المجاورة.
- دراسة البدائل : النظر في البدائل المتاحة وتحديد الآثار البيئية المحتملة لكل البدائل الممكنة، وتعتبر دراسة البدائل
المتاحة من أولى الخطوات التي يجب أن تتم في عملية الأثر البيئي، وتشمل بدائل الطاقة، وبدائل الموقع (حتى لا
يتأثر بالأنشطة الموجودة حوله أو يؤثر فيها)، وبدائل العملية التصنيعية، وبدائل المواد الخام التي تنتج أقل
مخلفات.
- الآثار البيئية : لتحديد التأثيرات البيئية (إيجابية أو سلبية) وتحليل هذه التأثيرات من أجل الوصول إلى أهم هذه
التأثيرات البيئية ومدى تأثيرها على بيئة العمل والبيئة المحيطة. وعند تقييم المردود البيئي يجب الأخذ في الاعتبار
التأثيرات السلبية والإيجابية، والتأثيرات طويلة المدى وقصيرة المدى، ومقدار هذه التأثيرات، والتأثيرات المباشرة
وغير المباشرة والمخاطر المحتملة.

- التخفيف : يجب وضع خطة لإدارة التخفيف من الآثار البيئية السلبية، ويجب إدخال تكنولوجيا الإنتاج الأنظف
- خاصة إعادة تدوير المخلفات وتقليل الانبعاثات حتى تتوافق مع القوانين البيئية.
- الرصد البيئي: هو الجمع المخطط و المنهجي للبيانات البيئية من اجل الوفاء بأهداف واحتياجات بيئية محددة .

<u>(4) تقييم الوضع البيئي الراهن لمحطات تقطير المياه في دولة الكويت باستخدام دراسات المردود البيئي</u> :

(4-1) وصف شامل للبيئة الطبيعية والظروف المناخية في دولة الكويت (Description of Affected Environment, DAE) :

تقع دولة الكويت ضمن الإقليم الصحراوي المتمثل في مناخ شديد الحرارة شحيح الأمطار وبيئة قاسية وفقيرة في مصادر
المياه العذبة، الأمر الذي حدا أهل الكويت ومنذ القدم بأن يتجهوا للبحر ليكون مصدر رزقهم ومعيشتهم ونشاطهم.
وتنحصر المصادر التقليدية للمياه العذبة بدولة الكويت في كمية ضئيلة من مياه الأمطار والتي يقدر متوسطها بحوالي
115مم سنويا وكمية محدودة من المياه الجوفية تستخرج من مجموعة الكويت والدمام وغالبيتها مياه قليلة الملوحة وناضبة، لذا
اتجهت دولة الكويت إلى الاعتماد على المصادر غير التقليدية للمياه فتوسعت في إنشاء محطات تحلية مياه البحر لإنتاج المياه
العذبة للأغراض المختلفة فضلا عن إعادة استخدام مياه الصرف الصحي بعد معالجتها لأغراض محددة مثل الري والزراعة. لذا
تعتمد دولة الكويت لدرجة كبيرة على الموارد غير التقليدية للمياه مثل تحلية مياه البحر بصفة أساسية .
واهتمت الدولة بتوفير المياه العذبة لتلبية الاحتياجات المتزايدة نظرا للنمو السكاني والعمراني والتنمية الاقتصادية الشاملة في
دولة الكويت.

وتنحصر الموارد المائية في دولة الكويت فيما يلي:

- مياه عذبة منتجة من البحر باستخدام طرق التحلية .
- المياه الجوفية العذبة وقليلة الملوحة .
- المياه القريبة من السطح .
- مياه الأمطار.
- مياه الصرف الصحي المعالجة

<u>نبذة تاريخية عن مياه التحلية</u>
تبرز أهمية المياه لدولة الكويت نتيجة وضعها الجغرافي والمناخي والهيدرولوجي ، حيث تقع في منطقة صحراوية لا تتوفر

فيها المياه العذبة الطبيعية بكميات يمكن استغلالها لسد الحاجات المتزايدة منها . مما أعاق تطور الكويت لسنوات عديدة
حتى توفرت الإمكانات المادية اللازمة لتوفير المياه العذبة بكميات كبيرة عن طريق التقنية المكلفة لتحلية مياه البحر.
ويرجع تاريخ إنشاء أول محطة لتقطير المياه إلى العام 1951 والتي أنشأتها شركة نفط الكويت في ميناء الأحمدي بطاقة
إنتاجية قدرها 80000 جالون يوميا . ثم تولت وزارة الكهرباء والماء مهمة توفير مياه الشرب وذلك بتشغيل أول محطة
تقطير بسعة كبيرة نسبيا تبلغ مليون جالون يوميا عام 1953 . و استمر توسيع وتطوير الطاقة الإنتاجية حتى بلغ مجموع
الطاقة الحالية 234 مليون جالون إمبراطوري يوميا (1.1 مليون متر مكعب /يوم) باستخدام تقنية التطاير الفجائي
متعدد المراحل، وبلغ أقصى استهلاك يومي 203 ملايين جالون إمبراطوري في صيف 1995 .

إن التطور الاجتماعي والاقتصادي الذي شهدته الكويت خلال العقود الأربعة الماضية اعتمد على مصدر ثابت للمياه
العذبة باستخدام تقطير مياه البحر. والمتتبع لأرقام وبيانات وزارة الكهرباء والماء بشأن الاستهلاك المتزايد للمياه العذبة
يدرك مدى ضخامة الاستثمار المادي و البشري التي توظفه الدولة لتأمين حاجة المواطنين من المياه الصالحة للشرب ، وفي
نفس الوقت يدرك مدى الهدر الذي تتعرض له موارد المياه حاليا عندما يتم مقارنة الاستهلاك المتزايد من المياه بعدد
السكان .و المثال التالي يوضح مدى الإسراف الحاصل في استهلاك المياه ، فدولة الكويت تستهلك 20% من استهلاك
جمهورية مصر العربية الشقيقة من مياه الشرب في حين أن عدد سكان مصر يعادل خمسين مرة عدد سكان الكويت .

(2-4) وصف فني لعمليات تقطير المياه ونوعية التكنولوجيا المستخدمة والمعدات (Project Description and Need, PDN)

إن التقنيات المستخدمة في تقطير المياه في المحطات التابعة لوزارة الطاقة في دولة الكويت تقنيات متشابهة تعتمد على عمل
المقطرات لإنتاج المياه.وقد ارتبطت تقنية تحلية مياه البحر في دولة الكويت بالنظام المزدوج (Dual Purpose) الذي
يشترك في إنتاج هدفين معا هو الماء والكهرباء وذلك بتوفير 20 - 30% من التكلفة مقارنة بانفراد كل نظام.

عمليات تقطير وإنتاج المياه :

التقطير هو عملية تبخير لمياه البحر المالحة ثم تكثيف البخار المتصاعد ليتم الحصول على المياه القطرة.
و لقد تم اعتماد تقنية التطاير الفجائي (التقطير الوميضي) متعدد المراح(Multi-Stage Flash Distillation) لتحلية
مياه البحر منذ أكثر من 40 عاما، وقد أثبتت فعاليتها وكفاءتها وتم تطويرها حتى أصبحت دولة الكويت من أوائل الدول
ذات الخبرة العلمية الواسعة بهذه التقنية.

عملية التقطير (Distillation Process)

- تسحب مياه البحر الباردة من منطقة مآخذ مياه البحر بواسطة مضخة مياه البحر إلى الغرف الحرارية ليتم تسخينها.
- يعاد جزء من مياه البحر ويستخدم الباقي لعملية التقطير.
- يتم حقن المواد الكيماوية في المياه زائدة الملوحة التي يتم سحبها بواسطة مضخة المياه المالحة الدوارة ويتم ضخها إلى الغرف الحرارية لتسخينها.
- بعد دوران المياه زائدة الملوحة في المراحل المختلفة تدخل إلى المسخن الخاص بالمقطرة حيث يتم رفع درجة حرارتها ثم
- تدخل إلى حيز التبخير في مختلف المراحل، فتتطاير الأبخرة من هذه المياه بفعل انخفاض الضغط، فيمر البخار المتصاعد

متوجها إلى مكثف المرحلة الأولى إلى المرحلة الأخيرة ليتم سحبها بعد ذلك بواسطة مضخة المياه المقطرة.

- في المرحلة الأخيرة يتم التخلص من المياه العالية التركيز بواسطة مضخة تصريف المياه المركزة.

(3-4) الوضع الحالي لمحطات تقطير المياه وتوليد الطاقة الكهربائية (Base Line Study) :

تتميز محطات القوى في دولة الكويت أنها ثنائية الوظيفة بمعنى أنها تقوم بإنتاج الكهرباء والماء باستخدام التبخير الحراري لمياه
البحر (Flash Distillation) وهي مقامة في مناطق ساحلية على الخليج العربي في شمال وجنوب ووسط دولة الكويت.
وتوجد حاليا في الكويت خمس محطات لتحلية مياه البحر هي (محطة الشويخ ، محطة الشعيبة الجنوبية ، الدوحة الشرقية ،
الدوحة الغربية ، الزور الجنوبية) تشمل ثماني وأربعين وحدة تحلية (مقطرة) تصل السعة الإجمالية لها 258 مليون جالون
إمبراطوري يوميا (1,18 مليون متر مكعب يوميا) من المياه المقطرة في حالة التشغيل الطبيعي ؛ وإلى 283,2 مليون جالون
إمبراطوري يوميا(1,29 مليون متر مكعب يوميا) في حالة التشغيل القصوى في درجات الحرارة العالية .

كما أن هناك محاولات لا زالت في طور البحث والتطوير لإنتاج المياه عن طريق التناضح العكسي، حيث تقوم المحطة

التجريبية في الدوحة بإنتاج بعض الكميات القليلة من هذه المياه بواسطة هذه الطريقة، إلا أنه لم يتم تصميم ذلك بشكل تجاري
حيث أنها لا زالت في طور الاختبار.

الموقع	الوقود المستخدم	إنتاج المحطة	عدد الوحدات		تشغيل أول وحدة تقطير مياه	تشغيل أول وحدة توليد كهرباء	الطاقة الإنتاجية		ملاحظات
			توليد قوى	تقطير المياه			للمياه (م.ج.أ) باليوم	للكهرباء (م/س)	
الشريط الساحلي لمنطقة الزور	الغاز الطبيعي زيت الغاز الزيت الثقيل النفط الخام	كهرباء مياه	8	16	1987	1986	115.2	2511	
الشاطئ الشمالي لمدينة الكويت	الغاز الطبيعي زيت الغاز الزيت الثقيل النفط الخام	كهرباء مياه	8	16	1983	1983	110.4	2400	
الشريط الساحلي لمدينة الكويت	الغاز الطبيعي زيت الغاز الزيت الثقيل النفط الخام	كهرباء مياه	7	7	1978	1977	42	1158	
الشريط الساحلي لمنطقة الشعيبة	الغاز الطبيعي زيت الغاز	كهرباء مياه	6	6	1971	1970	30	720	
الشريط الساحلي لمنطقة الشعيبة	-	-	-	-	1965	1965	-	-	واقفة عن العمل للدمار
منطقة الشويخ على ساحل البحر	الغاز الطبيعي زيت الغاز	مياه	-	3	1960	1954	18	-	إنتاج مياه فقط حاليا
شمال دولة الكويت	الغاز الطبيعي زيت الغاز الزيت الثقيل النفط الخام	كهرباء	8	-	-	1988	-	2400	
			37	48			315.6	9189	إحصائيات لنهاية عام 2003م

والجدول رقم (1) يوضح الطاقة الإنتاجية لمحطات تقطير المياه في دولة الكويت والوقود المستخدم في كل محطة (إحصائيات لنهاية عام 2003).

جدول رقم (1)

محطات توليد الكهرباء وتقطير المياه

*م.ج.أ = مليون جالون إمبراطوري

* م/س = ميجاوات بالساعة

(4-4) تحديد الآثار البيئية الناتجة عن محطات تقطير المياه وتوليد القوى الكهربائية (Identification of Potential Impact, IPI) :

(1-4-4) التأثير على جودة الهواء :

- تعتبر الانبعاثات الغازية الناتجة عن احتراق الوقود الأحفوري المستخدم في محطات الطاقة وتقطير المياه هي أهم
المشاكل البيئية التي تواجهها هذه الصناعة والتي ربما تؤدي إلى تلوث الهواء بخليط من المركبات الضارة. ومن
المعروف أن محطات القوى تستخدم خليطا من زيوت الوقود (Fuel Oils) المنتجة من قبل مصافي تكرير
البترول المحلية. وتحتوي هذه الزيوت عادة على نسب عالية من الكبريت والمحتوى الكربوني مقارنة بأنواع
أخرى من الوقود الأحفوري الأنظف، كزيت الغاز (Gas Oils) أو الغاز الطبيعي. وينتج عن ذلك انبعاث
الغازات المحملة بنواتج احتراق الوقود سواء الاحتراق الكامل أو غير الكامل. والذي قد يحتوي على
أكاسيد الكبريت ومركبات كبريتية أخرى (Sulphur Compounds) بالإضافة إلى أكاسيد
الكربون وذرات هبائية من مركبات المعادن النزرة (Trace Metals) الذي يحتوي عليها الوقود.وإلى جانب
انبعاث الملوثات الغازية في الأفران والمداخن فقد تصدر بعض الملوثات من الوحدات الأخرى كالغلايات
البخارية ووحدات التبريد أو أثناء نقل الوقود في داخل المحطة، إلا أن هذه الكميات لا تكاد تقارن لقلتها
بالكميات الضخمة التي تقذف بها مداخن الاحتراق إلى الهواء الخارجي.

- كما تساهم الملوثات الغازية برفع درجة حرارة الهواء المحيط مساهمة كبيرة نظرا لارتفاع درجة حرارتها، وقد
وجد أن المنطقة التي تحتوي على تلك المحطات تزيد فيها درجة الحرارة ما يعادل 5 درجات فهرنهيت عن
المناطق البعيدة عن المدينة.

  - كما أن بخار الماء المتصاعد من وحدات التبريد قد يسبب في تكثيف الملوثات الأخرى الموجودة في الهواء الجوي ونزولها إلى سطح الأرض أو قريبة منه، أو سقوطها على شكل قطرات من الماء.

- ويصاحب عملية التبريد أيضا استخدام كميات كبيرة من الهواء التي قد تتشبع ببخار الماء وتسبب تكوين الرذاذ أو السحب
الملوثة، وقد ينتج عنها مشكلة انخفاض مدى الرؤية في المناطق المجاورة للمحطة.

(2-4-4) التأثير على البيئة البحرية :

مما تم استعراضه أعلاه من الوصف الفني لعمليات تقطير المياه في دولة الكويت يتضح أن هناك طريقتان لاستخدام مياه

البحر في عمليات تقطير المياه وأسلوب معالجتها وطرحها للبحر مرة أخرى والتي تتمثل بالآتي :

- مياه البحر المستخدمة في تبريد وحدات إنتاج الطاقة الكهربائية وتحتوي المياه الراجعة على بقايا الكلور ين المحقون بمآخذ
مياه البحر.

- مياه مركزة خارجة من وحدات تقطير المياه (Brine) وهي مياه مالحة مركزة بدرجة حرارة تتراوح بين 30 - 40°م،
وبتركيز يتراوح ما بين 36000 إلى 73000 جزء في المليون حسب فصول السنة وتحتوي هذه المياه الخارجة على بقايا
الكلورين المحقون في مآخذ المياه لمعالجة مياه التغذية، ومواد المعالجة الكيميائية المحقونة لوحدات
التقطير (Oxygen Scavenger, Anti-Scale, Anti-Foam).
ويتم حقن الكلورين في مآخذ المياه لمعالجة التغذية الداخلة للمقطرات ومياه التبريد المستخدمة في مكثفات التوربينات بكميات
قليلة وفقا للمقاييس والأنظمة البيئية للتخلص من العوالق البحرية الحية، ويتراوح تركيز الكلورين في مآخذ المياه بين 0.5 إلى
1.5 جزء في المليون لتصل هذه النسبة عند مخارج المياه إلى البحر (Out-Fall) ما بين 0.0 إلى 0.1 جزء في المليون.

<u>لذا، يمكن تحديد الآثار البيئية المباشرة على البيئة البحرية كالتالي</u> :

- التلوث الحراري : ارتفاع درجة حرارة المياه المصروفة إلى البحر.

- التأثير على جودة مياه البحر : درجة الأس الهيدروجيني، الملوحة، الكدارة ونسبة الأكسجين الذائب في المياه.

- صرف المياه المحتوية على الكلورين إلى البحر (التلوث الكيميائي).

- التأثير على الكائنات البحرية وإنتاجية الحياة الفطرية في البيئة البحرية وفي منطقة المد والجزر (البلانكتونات، بيوض الأسماك).

- التأثير على نوعية المياه وحرارتها وعمقها وحركة التيارات البحرية ومعدلات التغيير نتيجة حركة الأمواج أو حركة المد.

(4-5) تقييم وتحليل الآثار البيئية الناتجة عن محطات تقطير المياه وتوليد الطاقة الكهربائية (Impact Assessment and Evaluation) :

مما تم ذكره مسبقا في مرحلة تحديد الآثار البيئية (IPI) يتضح أن أهم الآثار البيئية السلبية التي يجب التركيز عليها ودراستها بالتفصيل ما يلي :

(1-5-4) تلوث الهواء بالانبعاثات الغازية :

تعتمد محطات تقطير المياه ، على عملية حرق الوقود وبكميات هائلة بأنواعها المختلفة. وتعتبر عملية الاحتراق هي أهم
مصدر من مصادر التلوث في تلك المحطات ، وإن الملوثات الصادرة منها هي : أكاسيد الكبريت، وأكاسيد النيتروجين، و أول
أكسيد الكربون والمواد الهيدروكربونية غير المحترقة والجسيمات الصلبة.
وتشكل الغازات المنبعثة المذكورة أعلاه، خطورة صحية وبيئية وخاصة غاز ثاني أكسيد الكبريت ذو التأثير السلبي على
صحة الإنسان حيث يقلل من كفاءة الجهاز التنفسي ويؤدي إلى أمراض الربو والالتهاب الرئوي المزمن والتهاب العيون كما
أن للغاز تأثيرات سامة على الورق والنسيج والأحجار وهو أساس الأمطار الحمضية .

الانبعاثات الغازية الناتجة عن محطات تقطير المياه وتوليد الطاقة الكهربائية في دولـة الكويت :

لوحظ في السنوات الماضية الأخيرة، تزايد الانبعاثات الغازية الملوثة من محطات تقطير المياه وتوليد الطاقة، وبالأخص ارتفاع
مستويات تركيز غاز ثاني أكسيد الكبريت في الهواء الجوي المحيط. ويمكن أن يعزى تزايد الانبعاثات الغازية من محطات توليد الطاقة إلى التوسع في استخدام زيت الوقود (Fuel Oil) ذي المحتوى العالي من الكبريت (حوالي 4%) كوقود في محطات القوى الكهربائية، والذي بدوره يعزى إلى كون سعره أقل بكثير
من البدائل الأخرى للوقود، كزيت الغاز مثلا (Gas Oil) أو الديزل، مما يؤدي إلى تقليل تكلفة تشغيل المحطات. هذا إلى
جانب توفر زيت الوقود بكميات كبيرة من قبل مصافي تكرير البترول المحلية وسهولة الحصول عليه.
كما أكدت البيانات المسجلة بالمحطات الثابتة لرصد تلوث الهواء التابعة للهيئة العامة للبيئة، والقريبة من محطتي الدوحة (محطة المنصورية، محطة الجهراء) ارتفاع مستويات تركيز غاز ثاني أكسيد الكبريت .

(2-5-4) التلوث الحراري لمياه البحر :

ينتج التلوث الحراري نتيجة تصريف مياه التبريد الساخنة الناتجة عن عمليات محطات تقطير المياه وتوليد الطاقة الكهربائية
إلى البيئة البحرية مما يسبب ارتفاعا ملحوظا في درجة حرارة مياهه، ومما يزيد من هذه الظاهرة، ضحالة أعماق المياه في الخليج
العربي وخاصة في منطقة جون الكويت، ومنطقة الشعيبة الصناعية، حيث قلة خلط مياه البحر بسبب ضعف حركة الأمواج.
وهذا بلا شك يؤدي لاحتفاظ مياه البحر بدرجة الحرارة المرتفعة لفترة زمنية أطول، وهذا التأثير واضح أثناء حالات الجزر،

وارتفاع درجة حرارة الجو أيام فصل الصيف يؤدي إلى صعوبة انتقال الحرارة من سطح مياه البحر إلى طبقات الهواء وهذا
بدوره يجعل مياه البحر تحتفظ بدرجة حرارتها المرتفعة لفترة زمنية أطول.
للتلوث الحراري مخاطر كبيرة على الكائنات الحية، المائية منها والحيوانية والنباتية. فالزيادة في درجة حرارة مياه البيئة
البحرية يدي إلى خلل في البيئة البحرية وأكثرها وضوحا هو نقص في كمية الأكسجين المذابة . ويؤثر ارتفاع درجة الحرارة في تغير الأنماط الحيوية للأسماك لتغير البيئة التي تعيش فيها فتكون غير ملائمة لها فتموت أو تقع تحت تأثير رحمة المفترسات، أو من الممكن إصابتها بأمراض وفيروسات مختلفة تحت تأثير درجة الحرارة العالية.

وتشير التوقعات إلى أن الاختلاف في درجات حرارة مياه البحر بسبب وجود محطات التقطير يصل ما بين 2 - 15°م،
وهذا بدوره يؤدي إلى ضرر بالكائنات البحرية خاصة خلال شهور فصل الصيف، حيث أن درجة حرارة الجو تصل إلى
(40°م) مثل هذه الزيادة تؤدي إلى زيادة في درجة حرارة البحر فوق المعدل المسموح به والتي ما بين (35 إلى 46°م).
كما أن ارتفاع وانخفاض في درجات حرارة مياه البحر تقع تبعا للخواص الفيزيائية لمياه البحر، واتجاه وسرعة الرياح
وسرعة التيارات المائية إلى جانب عمق مياه البحر وقربها أو بعدها عن الساحل الكويتي.

(3-5-4) التلوث الكيميائي لمياه البحر :

(أ) التلوث بمادة الكلور : يعتبر غاز الكلور (الكلورين) من المواد السامة، ذو رائحة مميزة وأثقل من الهواء بحوالي 2.5 مرة
بينما وهو سائل يكون أثقل من الماء بحوالي 1.5 مرة. ويحقن الكلور السائل في مياه التبريد لمحطات تقطير المياه وتوليد الكهرباء
للتخلص من العوالق البحرية الحية، ويزداد تأثير غاز الكلور في الماء بانخفاض قيمة الأس الهيدروجيني.
وتتم عملية ضخ غاز الكلور إلى مياه التبريد بتركيز يصل في بعض الأحيان إلى حوالي 8 مليجرام لكل لتر لفترة تقدر
بحوالي 20 دقيقة لكل 8 ساعات تكون كافية للقضاء على نمو الكائنات الحية غير المرغوب بها وهذه طريقة متبعة تقريبا في
جميع محطات تقطير وتوليد الكهرباء في الكويت.

(ب) التلوث بمركبات هلوميثان :
عند تصريف مياه البتريد من محطات تقطير المياه وتوليد الكهرباء تكون غنية بغاز الكلور
فتتفاعل مع المواد العضوية الذائبة والعالقة في مياه البحر فتكون مركبات هلوميثان السامة في البيئة البحرية الكويتية ويصل
تركيزها إلى حوالي 90 ميكروجرام لكل لتر بالقرب من مخارج محطات تقطير وتوليد الكهرباء.

(ج) كما تصرف مع مياه التبريد ملوثات تتمثل بالزيوت الناتجة عن المضخات نتيجة للعمليات الصناعية، وملوثات أخرى

ناتجة عن مواد تنظيف استخدمت في تنظيف السخانات والآلات المختلفة بمحطات التقطير، وهذا بدوره يؤدي إلى ضرر في
الثروة السمكية.

(7-4) الحلول المقترحة وتقييم البدائل :
استكمالا لعملية تقييم المردود البيئي لمحطات تقطير المياه في دولة الكويت، فلا بد من وضع حلول وإجراءات تخفيفية للحد
أو التقليل من الآثار البيئية السلبية الناتجة عن تلك الأنشطة في دولة الكويت (Mitigation Measures) .

لذا، فإن الحلول والبدائل المقترحة كالتالي :

1. تقليل عوادم حرق الوقود وبنسب قد تصل إلى 20% وذلك بواسطة تحسين أداء محطات توليد القوى الكهربائي بواسطة
رفع كفاءة أداء أفران الحرق والغلايات.
2. المراقبة المستمرة للملوثات الغازية المنبعثة من محطات تقطير المياه وتوليد الطاقة الكهربائية باستخدام المحطات الثابتة لرصد
تلوث الهواء التابعة للهيئة العامة للبيئة وتحليل نتائج الرصد.
3. تحسين أو استبدال نوعية الوقود المستخدم في المحطات عن طريق توفير وقود الغاز الطبيعي والذي يعتبر أحد أنظف أنواع
الوقود الأحفوري بسبب قلة نسبة الشوائب التي يحتوي عليها وخصوصا مركبات الكبريت والمحتوى الكربوني والمعادن
النزرة واحتراقه احتراق شبه كامل تحت ظروف تشغيلية عادية.
4. تركيب وحدات إزالة الكبريت حيث تستخدم تلك الوحدات إضافة إلى وحدات التنقية في محطات تقطير المياه لمعالجة
الغازات الطاردة إلى الهواء بإزالة أكاسيد الكبريت والمواد العالقة .
5. فيما يتعلق بالمياه المعادة إلى البحر فلا بد من الرقابة المستمرة لنوعية المياه الخارجة من محطات تقطير المياه وتوليد
القوى الكهربائية الموجودة على السواحل شمالا، جنوبا ووسط البلاد وذلك للتأكد من مطابقتها للمعايير البيئية في دولة
الكويت والتأكد من عدم تجاوز تراكيز الكلور عن المقاييس البيئية في مداخل ومخارج المحطات حفاظا على الحياة
البحرية.والتأكد من سلامة منطقة مآخذ المياه للمحطات من التلوث لضمان استمرار إنتاج الماء وذلك عن طريق الحد من
الملوثات التي تعيق عمل المحطات كمخلفات الموانئ، التلوث الكيميائي من المصانع، والتسرب النفطي من أنابيب الوقود
والبواخر النفطية.

نتائج البحث و التوصيات :

ومن خلال الدراسة السابقة، هناك عدة نتائج يمكن تلخيصها كالتالي :

1. إن دول الخليج العربي هي دول ساحلية مما يعطيها ميزة وجود مصدر للمياه بكميات لا حدود لها يمكن تحليتها والاعتماد عليها كمصدر أساسي للمياه.
2. تمتاز تقنية تحلية مياه البحر بأنها متوفرة بأحجام متنوعة وتقنيات مختلفة بحيث يمكن استخدام المناسب منها للغرض المطلوب لتلبية احتياجات المياه و في المقابل لنواتج محطات التحلية وتوليد الكهرباء آثار بيئية سلبية مما يتطلب إعداد دراسات المردود البيئي قبل إنشائها وتشغيلها واختيار التقنية الأفضل .
3.يستوجب على دول الخليج العربي أن تعطي موضوع تنمية الموارد المائية والمحافظة عليها الأولوية القصوى عند وضع استراتيجيتها الاقتصادية وأن يكون موضوع " الأمن المائي " على رأس قائمة الأولويات ، وذلك بسبب قلة الموارد المائية التقليدية مما يستدعي المحافظة على هذه الموارد ومحاولة تنميتها و إيجاد موارد مائية بديلة .
4 .على أصحاب القرار أن يقوموا بتقييم تقنية تحلية المياه بناء على الجوانب البيئية والاقتصادية مما يسهل اختيار البديل المناسب عن طريق تطبيق دراسات المردود البيئي بصورة عملية فعالة والتي يمكن أن تكون أداة فعالة لتحقيق أهداف التنمية المستدامة .
5. إن النمو السكاني من جهة والصناعي من جهة أخرى، سيؤدي إلى ضغط متزايد على موارد الطاقة وعلى أنماط استهلاك الطاقة، والتي قدرت بحاجة الكويت إلى بناء محطة تقطير المياه بحجم المحطات الحالية كل عشر سنوات تقريبا. مما يعني زيادة مضطردة في استهلاك الوقود لتشغيل تلك المحطات و زيادة الضغوط على عناصر البيئة المحلية وقد يساهم في تدهور المحيط الحيوي مما يتطلب إعداد خطة قومية بعيدة المدى لادارة الموارد المائية بما فيها المحافظة عليها.
6. ضرورة تامين افضل التقنيات لتحلية المياه من الناحية التقنية والاقتصادية والبيئية حيث تشهد تقنيات تحلية المياه تطورا مستمرا وانخفاضا ملحوظا في التكلفة.
7.ضرورة وجود إجراءات توعوية لبيان مدى أهمية المياه وتلوثها والإقلال من الاستهلاك والحفاظ عليها .

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Abstract

Water resources are very limited in the Arabian Gulf region . State of Kuwait as other Gulf countries depends on the desalination of sea water to provide fresh water for drinking , and domestic use , and to supply water for the developmental activities .The percentage of this water reaches 95% in the state of Kuwait.

This research aims to show the role of desalination plants to cover the demand of fresh water in the state of Kuwait ,and to discus the positive and negative impacts of this technique by using the Environmental Impact Assessment (EIA).

the EIA is defined as the systematic identification and evaluation of the potential impacts (effects) of proposed projects, plans, programs, or legislative actions relative to the physical-chemical, biological, cultural, and socioeconomic

components of the environment. The purpose of an EIA is to ensure that all development options under consideration are environmentally sound and sustainable and that any environmental consequences are recognized early.

At project level, environmental impact assessment is generally considered as a planning tool and could assist planners in anticipating future impact of a development project. The EIA includes beneficial impacts and to mitigate adverse impacts on the environment in early stages and to be taken into account in project design.

The research results show that the desalination technology has many advantages that able to satisfy the demand of fresh water , it also can treat the sea water to produce high quality of drinking water, It is available in different sizes and techniques .On the other hand it has a lot of negative impacts on the environment which can be prevented or reduced by applying EIA studies that can suggest the mitigation measures , recommend the solutions of the negative impacts, and to set up an environmental management plan .

The Water Crisis in the Gulf Area: Seawater Desalination a Path to a Partial Solution.

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With the start of the twenty first Century, the world is faced with many challenges. Among the serious challenges facing the world today is the shortage in fuel supply, shortage in raw materials, the greenhouse effect, and the important challenge of freshwater supply shortage.

The freshwater shortage is mainly faced in the Middle East, where it has reached the stage of a real crisis especially in the arid area of the region. As the Gulf area is considered to be an arid area, all the Gulf counties have reached the stage of a real crisis because of the water shortage. All the Gulf countries are under the water poverty line; renewable water resources are even lower than 500m^3/capita, and in some countries the water available per capita is not more than 10m^3/ year [1] [2]. As this deterioration in water supply was detected in the Gulf States in the end of the last century most of these countries have built large seawater desalination plants to meet the high fresh water demand. Comparing seawater desalination with other water resources makes it a limited solution that will only meet a limited percentage of the water demand. Therefore the adoption of a total water management schemes is considered to be a necessity in the region. The main goal for such a scheme is to create a lasting balance between the water demand and the available water supply, including sea water desalination. This paper will discuss the water crisis in the Gulf States, with respect to the supply and demand issues; also the possible total water management scheme will be discussed, taking into consideration the future trends in seawater desalination.

Keywords: Water Crisis, Worldwide Water Assessment Program (WWAP), Domestic Use, Industrial Freshwater Use, Agricultural Freshwater Use, Seawater Desalination, Integrated Water Resource Management (IWRM).

Introduction:

The world is at a crisis. This simple phrase has been overused in many situations, but this sentence is true when it refers to the water situation in the world. The world is truly facing a real water supply crisis. More than 1.1 Billion people worldwide have no access to a safe freshwater source, 2.6 Billion people worldwide have no access to sanitation, and 6000 children die each day because of water related diseases [1]. These figures clearly show how serious the situation is becoming. It has been estimated that the annual freshwater supply per capita in the year 2025 will reach 4800 m^3 from a comfortable 7800 m^3 in the year 1990 [5]. What makes the situation even worse is the simple fact that the available freshwater is not equally distributed globally [5].

In the heart of this worldwide crisis are the Middle East and the Arab countries. Most of the Arabic countries are nowadays under the water poverty line of 1000 m^3 per capita. In fact all the GCC countries have a freshwater supply less than 400 m^3. The high population growth in the GCC countries makes things even worse. The renewable water resource are very limited in the Gulf area, it is not foreseen at any time in the next 15 -30 years that the in land water resource will fulfill the water demand in the GCC countries, even if rainfall is used as a source of fresh water, the rainfall in the GCC is less than 250 mm/year which is considered to be very low [1].

Early on it has been decided that other water resource alternatives should be investigated for a more suitable method to supply fresh water. Seawater desalination has been adopted as the most suitable method for the supply of fresh water, which is limited to fulfill a few notches in the gap between the renewable water resource and the poverty line limit. The GCC countries are still far away from fulfilling the UN millennium human development target " There is now less than 10 years to go to the 2015 target date for achieving the Millennium Development Goals—the time-bound targets of the international community for reducing extreme poverty and hunger, cutting child deaths, getting children an education and overcoming gender inequalities. Progress in each of these areas will be conditioned by how governments respond to the crisis in water" [UN-HDR 2006, Page 4].

The Water Supply Issue:

The water shortage situation in the Gulf area was well known to every authority in the Gulf area from a long time ago, but the WWAP reports of the years 2003, 2006 have put things into perspective. As the reports states, there are three main uses for water that are recognized in any country: domestic use, use for agriculture purposes, and industrial uses. The domestic use takes up to 8% of the total water supply, the agricultural use takes 70% of the total water supply, and the industrial use takes up to 22% of the total water supply. (Most of the world countries are averaging these same figures) [1] [2].

In the coming three sections of this discussion these three main issues of the fresh water demand scheme will be discussed.

Domestic Water Use:

One of the most important water demand issues is the uses of water for basic human needs like drinking, cooking, washing….etc. The water used for these purposes have to maintain a certain degree of quality that meets the basic requirements of international standards like the world health organization standard (WHO). It has to be free of any water related disease as a basic requirement. As in many countries of the world the use of water for this purpose is related to urban areas, or in areas where there are population concentrations like villages, small towns, small cities, and what are called megacities. The growth of these areas is related directly to the ability to supply water for the basic human needs. The population growth is the most important challenge that faces the concerned authorities of the GCC countries. The Gulf area is considered to be a domestically stressed area with three of its main cites having a population over one million people [1] [2]. The amount of drinking water used per Capita ranges between 200 and 300 liters per day which amounts to 73 - 101 m^3 per year [6].

This rate of usage is considered to be very high compared to the amount used in other countries. In some cases, one of the main reasons for this high consumption rate is the inner city network leaks (e.g. Riyadh, and Jeddah cites have a leak percentage of more than 30% in its inner city water network) [6]. In addition to the irrigational use of the domestic water. There are some efforts that have been done to control the use of water in the urban areas (e.g. awareness campaigns, Installation of treated wastewater networks for inner city landscaping…etc), and because of such measures it is expected that certain drops in the consumption rate will occur. This is to be seen in the near future.

The main source of freshwater for domestic uses comes from the ground water wells, which is not considered to be a renewable water resource. The only renewable water resource for this purpose is the rainfall, which is very low in the arid areas of the Gulf States [1] [2].

Agriculture uses:

One of the most critical human development issues is agricultural growth in a country, where there is a direct relation between agricultural growth and some of the main indictors for human development [3]. Issues such as population health and a citizen income are greatly influenced by the growth in the agricultural sector. The need to sustain and improve this sector is directly related to the available water resources, soil type, land conditions, and the climate conditions. As in most of the countries worldwide agricultural growth consumes over 70% of the available water resource [1] [2].

Food security is an issue that is taken seriously in the Gulf countries, as most of the countries in the Gulf States depend on outside sources when it comes to securing food. At the moment this issue is not considered as critical, because of the high income enjoyed by the Gulf States. In addition to the high cost needed to truly invest in the agricultural sector compared to the low price of importing goods from outside sources.

This simple fact will not be true in the future, because of the high increase in population noticed in the Gulf countries and the continuous increase of food importing cost [1] [2] [3]. Although there is undeniable efforts from the Gulf States to develop the agricultural sector, for example the long term development plan adopted by the Saudi Arabian government, that resulted in the establishment of more than 4.3 million Hectares of farmland out of a possible 51 Million Hectares, and a per capita income of 463 US Dollars in the year 2005, these figures are according to ministry of agriculture in the kingdom of Saudi Arabia [7]. The disadvantage of this development was the impact it had on the withdrawal of the ground water wells level, which are considered to be the only source of irrigation in the Gulf States. As stated in Table1, the fresh water withdrawal for agricultural use is very high in the Gulf area. The renewable freshwater resources dependency rate is very low; clearly this is because of the amounts of water needed to sustained agricultural growth in the Gulf States. Growing crops or cattle is considered to be very expensive in the Gulf States [1].

Table 1: Gulf States values of key indicators in securing the food supply (Reference: WWAP Report 2003, Page 207)

Country	Number of People undernourished1990-1992 (Millions)	Number of People undernourished1997-1999 (Millions)	Proportion of undernourished in total population 1990-1992 (%)	Proportion of undernourished in total population 1997-1999 (%)	Cultivated land area in 1998 (1000 ha)	Irrigated land area in1998 (1000 ha)	Irrigated as % of Cultivated land in 1998	Agricultural water withdrawal in 1998 (KM^3/year)	Total renewable water resources (KM3/year)	Agricultural water withdrawal as % of Total renewable water resources in 1998
Bahrain	0	0	0	0	6	5	83	0.17	0.12	147
Kuwait	0.5	0.1	23	4	7	6	86	0.2	0.02	1000
Oman	0	0	0	0	77	62	81	1.23	0.99	125
Qatar	0	0	0	0	21	13	62	0.21	0.05	398
Saudi Arabia	0.3	0.4	0	0	3785	1620	43	15.4	2.4	643
United Arab Emirates	0.1	0.1	3	0	132	74	56	1.53	0.15	1021

The cost of water to produce a single crop may be equal to double or triple the cost of production else- where in the world, since the renewable water resources are not reliable to make up the large water withdrawal, Table 2 gives a simple example of the amounts of water needed for growing some of the most essential goods needed in the Gulf area.

Table 2: Water requirement equivalent of main food products (Reference: WWAP Report 2003, Page 203)

Product	Unit	Equivalent water in m3 per unit
Cattle	Head	4000
Sheep and goats	Head	500
Fresh beef	kg	15
Fresh lamb	kg	10
Fresh poultry	kg	6
Cereals	kg	1.5
Citrus fruits	kg	1
Palm oil	kg	2
Pulses, roots and tubers	kg	1

As it is shown in Fig.1, The blue colored areas are considered to be major groundwater basin with highly-productive aquifers; most of the Gulf States use these underground large aquifers as a source of freshwater for agricultural purposes, which in many cases was associated with water treatment measures. The large withdrawal of these aquifers would have been with an acceptable degree of risk, but the fact that the rainfall is low and there are no potential renewable resource of freshwater make these withdrawals a futuristic threat in the region, if these aquifers were to be used without an effect legal framework to control withdrawal amounts from these aquifers.

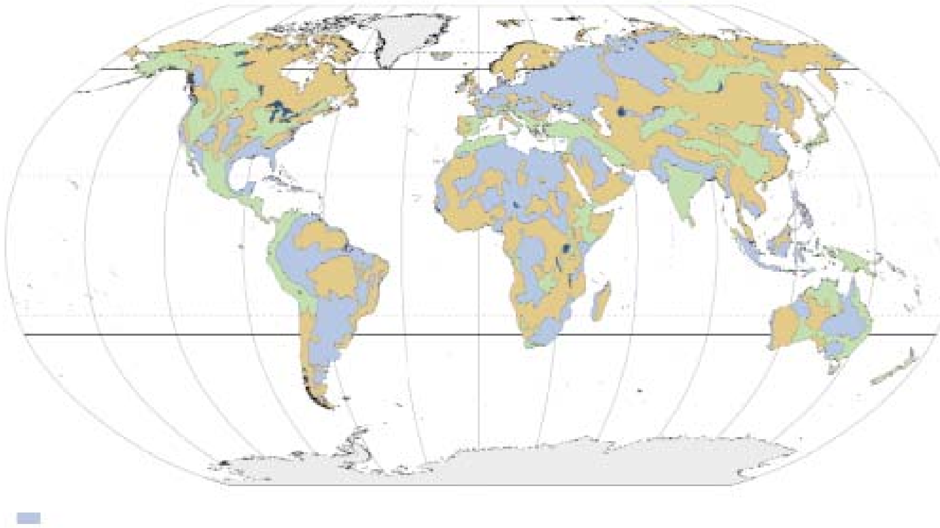

Fig. 1: the large water aquifers in the Gulf area colored in light blue (Reference: WWAP Report 2003, Page 79)

Industrial Uses:

The Gulf States are considered to be upper middle to high income countries, which means that there is a tendency from the countries of this region to demand more water for use in the industries, compared to the use in the agricultural sector. The main industry trends are the very large investments in the oil and natural gas sector and its associated industries. The food processing industries also demand large quantities of freshwater. In addition to the requirement of other industries that demand large quantities of freshwater. As a result of this prediction, the water demand trends in the future will tend to increase in the industrial sector; this is also true for the water demand in the power generation sector. Fig. 2 illustrates the relation between the water demand in each of the potential sectors and the country income situation.

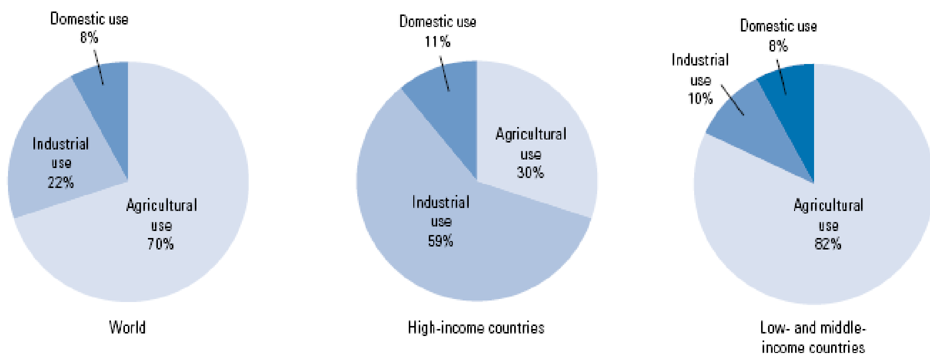

Fig. 2: Industrial use of water increases with country income, going from 10 percent for low- and middle-income countries to 59 percent for high-income countries (Reference: WWAP report 2003, Page 228)

Beside the challenge of the increase in water demands due to the growth in the industrial sector, the water pollution as a result of industrial by-products is another of the important challenges that need to be targeted in the area. At present there is no legal framework that controls the use of freshwater in the industries in almost all of the Gulf States.

The Water Situation in The year 2003 (An over view):

All the Gulf States are under the water poverty line, there is not one single Gulf country that has renewable freshwater resources above 400 m^3/ Capita/year. All the surface water resources available in the Gulf area are the limited quantities of water as result of direct rainfall. The only inland source of water available in the Gulf States is the underground water basins, which are not considered to be a renewable source of freshwater. Table.3 Shows the overall water situation in each of the Gulf States, also the overall ranking of the Gulf States is shown in the 2003 WWAP report.

Table 3: Renewable water resources in the Gulf countries (Reference: WWAP report 2003, Page 74)

Ranking Out of 182 Countries	Country	Total Internal Renewable Water Resources (km3/year)	Ground Water Produced Internally (km3/year)	Surface Water Produced Internally (km3/year)	Overlap Surface And Groundwater km3/year	Water resources Total Renewable km3/year	Water resources Total Renewable Per Capita (m3/capita year)	Dependency Ratio (%)	Land Area (km2)	Population in 2000 (1000 inh)	Population Density in 2000 (inh/km2)
165	Oman	0.99	0.96	0.93	0.9	0.99	388	0	212460	2538	12
169	Bahrain	0.004	0	0.004	0	0.12	181	97	690	640	928
173	Saudi Arabia	2.4	2.2	2.2	2	2.4	118	0	2149690	20346	9
176	Qatar	0.05	0.05	0.001	0	0.05	94	4	11000	565	51
178	UAE	0.15	0.12	0.15	0.12	0.15	58	0	83600	2606	31
180	Kuwait	0	0	0	0	0.2	10	100	17820	1077	107

The renewable water situation as per the WWAP report of 2006:

The first report highlighted the magnitude of the freshwater crisis in the Gulf area, while this second report showed the further deterioration in the water situation in the Gulf area. The main reason for this deterioration is the large increase in the population of the Gulf countries [1] [2].

The water situation in the Gulf states (Over View):

As it can be seen from table 4, overall available per Capita water volume has been reduced in all the Gulf countries, while the population in all the countries have increased. The increase in population is approximately 15-20%, the reduction of the available fresh water per Capita is between 10-20%, which may be taken as the possible future trend expected in the Gulf States. The available freshwater resources remained constant during the period between both reports, by compiling and analyzing data given by both reports the foreseen impact on the three main water demand category can be predicted for the future.

Table 4: Renewable water resources in the Gulf countries (Reference: WWAP report 2006, pages 132 -136)

Country	Population (1,000,000s)	Precip Rate1 (mm/yr)	TARWR Volume 2005 (km2/yr)	TARWR Per Capita 2000 (m3/yr)	TARWR Per Capita 2005 (m3/yr)	Surface water % TARWR*	Ground- water % TARWR*	Overlap2 % TARWR*	Incoming Waters % TARWR	Outgoing Waters % TARWR	Total use % TARWR
Bahrain	739	100	0.1	181	157	3%	0%	0%	97%	0%	258%
Kuwait	2.60	100	0.2	10	8	0%	0%	0%	100%	0%	2.227%
Oman	2.94	100	1	388	340	94%	97%	91%	0%	0%	137%
Qatar	619	100	0.1	94	86	2%	94%	0%	4%	0%	554%
Saudi Arabia	24.9	100	2.4	118	96	92%	92%	83%	0%	6%	722%
UAE	3.05	100	0.2	58	49	100%	80%	80%	0%	0%	1.538%

*: **Total Actual Renewable Water Resources**

Impact on Domestic use:

The increase in population will indeed result in a water demand increase in all the Gulf States. In the year 2000, the total Gulf population was 27.8 million with a domestic water demand of 3.04 billion m^3/year.

With the increase in population to 34.9 million the expected water demand will be 3.82 billion m^3/year [1] [2]. This is calculated at a consumption rate of 300 liters/day /person. If the consumption rate is 200 liters/day/person the water demand will drop by more than 30% to reach 2.55 billion m^3/year. As it can be seen the main challenge facing the domestic water demand sector is the increase in population vs. the control of the daily consumption per person in an urban area. Furthermore one of the most important issues in fresh water supply is its quality, which is a major issue that can have a harmful effect on the population in an urban area [2]. The water monitoring issue is a consideration that cannot be ignored for any water supply authority. Strict complains with (WHO) is a mandatory requirement.

Impact on the industrial use:

Like all developing countries the trends in the Gulf area are the same fig. 3 shows the increase in water demand for the industry worldwide. The society as a whole is changing from a society with a farming culture to a society with an industrial culture, which means that it is expected in the following two to three decades that the investments in the industrial sector will increase. Therefore this in turn will result in an increase in water demand. Some of these industries will demand water with a certain quality that is near or similar to the water quality demanded for the domestic use. The power generation industry for example demands a very high water quality for the steam generation boilers used in this industry. The same requirement is important for the food industries. The request of international recognition of quality control adoption is increasing in the Gulf area. These international standards will have very strict requirements for water quality and effects of pollution on the environment.

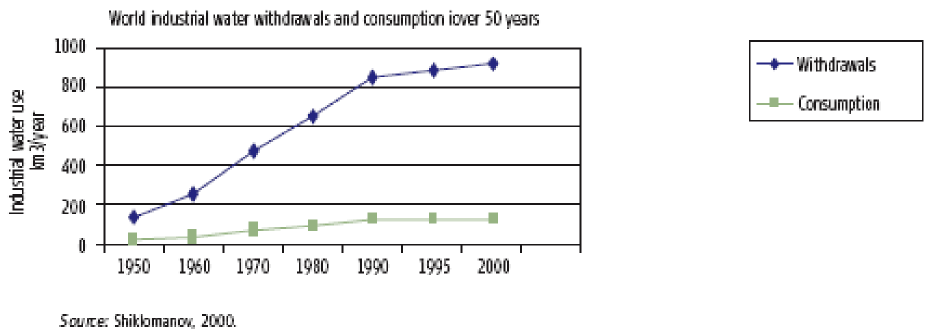

Fig. 3: Total world industrial water use, 1950–2000 (Reference: WWAP Report 2006, page 278)

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The impact on the Agricultural Use:

The most important consideration when dealing with the agricultural demands and supply is the nourished and undernourished percentages of a society. The basic principle that governs an adequate nutrition intake for a person is balanced nutrition requirements and enough quantities as in terms of energy requirements. The average intake requirement or dietary energy supply (DES) per person is 2800 Kcal/person/day [2]. This is considered as the threshold or the nutrition limit line. As in Fig. 4 most of the Middle Eastern countries are above this limit line, and all the Gulf countries have an undernourished percentage of less than 0.5% [2]. Depending on outside sources for food supply may seem to be the most inexpensive solution at the moment. This may prove to be unfeasible in the future, by looking at the trends in the food supply market and the continuous decrease in available freshwater resources worldwide [2].

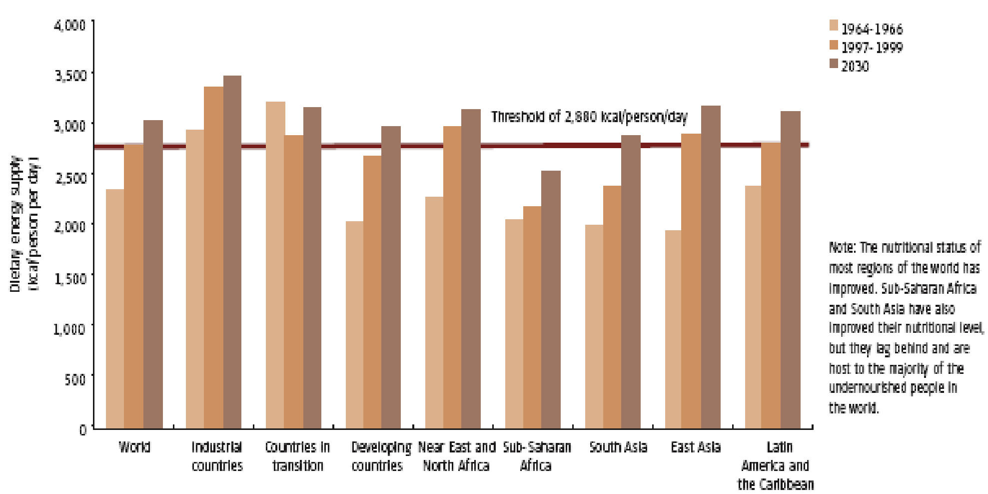

Fig. 4: Per capita food consumption by region, 1965–2030 (Reference WWAP report 2006, page 247)

It is important to look at the possible trends of the agricultural use of water by looking at the different water requirements expected in the future. This can be done by looking at the past and present food supply trends and compare it to the daily habits practiced by the average citizen in his food intake. This is one of the most important steps to secure one of the basic needs of the population in the Gulf area. The obvious need for planning of the available water resource for agricultural uses depends greatly on the behavior expected in daily dietary trends.

Sea Water Desalination in the Gulf States:

It was evident in the late seventies and early eighties of the last century that there was a need for additional fresh water resources in the Gulf States. The most promising technology found was by all accounts, seawater desalination. Nowadays seawater desalination is one of the most established sources of freshwater in the Gulf area. Of the 27.4 Mm^3/day produced worldwide 17.2 Mm^3/day is being produced in the Gulf area, which makes up to 62% of the freshwater produced from seawater desalination, and 37% of the 46,9 Mm^3/day desalinated water produced from different types of water [4].

The installed capacities vary from small multi-effect distillers, or reverse osmosis, to very large multi stage flash units. The largest plants and units are mainly installed in the Gulf area. It is estimated that over the next twenty years the Gulf area will invest up to 100 billion US dollars in the freshwater and power sector a major part of this investment will be in Seawater Desalination [1]. Seawater desalination has become a major part of the freshwater supply scheme in the Gulf area.

The main use of the freshwater produced from seawater desalination is in urban areas, or in main cities in the Gulf States. This means that most of the water produced from seawater desalination plants is used for domestic proposes. In some cases the desalinated water is used in industrial plants either as a raw material or as an auxiliary material required for the plant operational process.

The main disadvantage of using desalination plants is the high initial installation cost, the high fuel cost, and the high maintenance /operation cost. In general, the cost of producing one single cubic meter of desalinated water is high varying between 0.50 – 1.0 US$ depending on the plant size (these figures are only valid for large size plants, the costs for small size plants is even higher [8, 9, 10]). This fact has its impact on the development in the domestic, agricultural, and industrial use of the desalinated water. For example, it is required to use 1.5 cubic meters of water to grow one kilogram of wheat [1], therefore if desalinated water is used this means that the cost of wheat production will vary between .75 - 2.25 US$, which is considered to be high. The same principle can be applied for growing cattle and sheep. The cost will also be high. The same high cost can be observed in domestic and industrial use of desalinated water. Hence desalinated water has its limitation when its used to fulfill the fresh water demand.

The IWRM scheme a path to a total solution:

The dimension of the water crisis issue has been discussed and the use of seawater desalination has also been discussed. It is evident that there is a need to adopt a scheme that takes into consideration the very delicate balance between the fresh water supply, and the fresh water demand in the Gulf area. This balance can be established, using integrated water resource management schemes that have a controlling influence on the freshwater usage.

The water supply issue:

To establish a balance in the water supply, a road map of the possible water resources has to be established that includes, seawater desalination, waste water treatment, water reuse process, balanced use of the ground water aquifers, and the possible use of different water recirculation schemes.

The continuous supply of freshwater is an important issue that has to be taken in to consideration when planning for future development in the Gulf area. The cost of freshwater production and supply influences the economics of the freshwater supply scheme. Continuous development of low cost supply methods is essential for the feasibility of different water supply schemes.

Seawater desalination is proven as a possible path to the solution of the water crisis in some of the main categories of fresh water use, but due to its very high cost, it cannot be considered as a complete solution. Investment in cheaper methods of seawater desalination is a must. The establishment of research and development organizations in the Gulf may prove to be decisive in reaching methods of seawater desalination that are cheaper and can be used to fulfill a wider scale of freshwater demand requirements.

Efficient domestic water networks with minimum or no water leaks are part of the solution. Efficient water irrigation systems are also a solution, the Gulf States must encourage research in these fields.

Specially, for agricultural uses of freshwater, other methods of freshwater supply may be considered. Waste water usage in agricultural uses for example has a very high potential. Controlled usage of the underground aquifers is part of the solution if it is used rationally.

The Private sector investment in the freshwater supply, can lead to major developments in the water supply/demand scheme. The desalination plants constructed and operated by the Private sectors have a high feasibility record compared to plants controlled by the public sector, where feasibility and profit is not an issue. The future investment of the Private sector in the different water supply schemes may help in achieving the desired development goals.

The water demand issue:

This issue can be summarized in one simple sentence "Rational planning of freshwater demand". In other words, the present freshwater consumption rate has to be reduced.

The real challenge in the water demand issue is that development and growth have to be sustained or improved, which means more use of freshwater.

The development of urban areas, and urban area growth, can be fulfilled by seawater desalination. This can be done by increasing desalination plants production capacities, but due to the high cost of freshwater from this method, reduction of consumption rates must be considered as an ongoing process. This reduction can be done by proper tariffs, and the adoption of awareness campaigns as a part of the solution. The establishment of a legal frame work that controls the water usage in different sectors of the usage scheme is essential, under both the normal and the water shortage periods that also takes in to account the high and low seasons of freshwater use.

Crop planning and crop control is also part of the water demand equation; the encouragement of usage of the state of the art irrigation systems should be a controlling issue in establishing farm lands.

The same idea should be implemented when investing in the industrial sector, usage of water recirculation methods whenever possible, should be considered as a main plant feature. The possible usage of seawater desalination whenever possible should be a part of approving industrial plant design schemes.

Overview and Conclusions:

It is evident that the Gulf States have to adopt a number of controlling measures that will help the public and private sectors in the proper development of the water supply schemes, with respect to domestic, industrial, and agricultural uses of the supplied freshwater. The cost/benefit feasibility of different freshwater supply schemes will be influential on the overall development of the Gulf States.

The strategic planning of the available conventional and nonconventional freshwater supply schemes is a mandatory requirement to sustain and improve the overall development of the Gulf States.

Seawater desalination is considered to be one of the mean pillars in solving the water crisis in the Gulf area, but on its own it is not considered as a complete solution. The investment in lower cost seawater desalination methods could lead to a breakthrough in the water supply scheme. The development of research and development centers in the Gulf States may prove to be a decisive factor in this regard (e.g. The SWCC Saline Water Desalination Research Institute (SWDRI) is responsible for many breakthroughs in the seawater desalination field).

The adoption of a total integrated water resources management scheme is needed to enhance the different water supply schemes. The main goal of adopting a total integrated water resource management is to achieve a lasting balance between the freshwater supply and the freshwater demand that includes the effective use of seawater desalination plants in the Gulf area.

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OUTLINES FOR WATER SAVING PRACTICES IN KUWAIT

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ABSTRACT

The increasing imbalance between water supply and demand has compelled the Arabian Gulf Countries to augment supplies through sea-water and brackish-water desalination, reuse of renovated waste water, groundwater-recharge schemes, and the implementation of water-conservation measures. The demand for water continues to increase rapidly in Kuwait with expanding population base and steep rise in per capita consumption. The country is trying to meet this increasing demand by installing more desalination capacity at high cost and exploiting its non-renewable groundwater resources in large quantities, causing depletion of these resources. Reducing water consumption will avoid the costs for installation and operation of additional desalinated utilities, and will delay costly investments in water systems which typically involve the expansion of water treatment, storage and distribution facilities. Moreover with the competition for water among various sectors becoming more and more complex, the efficient distribution and use of available supplies are essential. When compared with the cost of expanding existing facilities or developing new water sources, the most cost-effective alternative is conservation. The aim of this paper is to address the relevant guidelines for designing an effective water conservation program that can be implemented in the Gulf countries in general and in Kuwait in particular. These guidelines cover many alternative methods of conserving water including the supply and the demand management methods. The supply management methods would include the 1) network leakage/ loss control,

2) use of especial plumbing equipment, 3) adoption of behavioral practices at users' end that conserve water, 4) use of renovated wastewater for irrigation and other non-potable purposes, and 5) water metering. The demand management methods should include 1) pricing, 2) information and education, 3) water use regulations and 4) water use audits. In order to alleviate future water shortages, current supply-augmentation schemes and demand-management methods need to be enhanced with respect to coverage and enforcement. In addition, further efforts need to be made towards the development and management of water resources, based on an integrated approach.

Key Words: *guidelines, management, supply, demand, plumbing, pricing, education.*

I. INTRODUCTION

Many countries in the Arabian Peninsula have virtually tapped all their natural water resources and are depending on the desalination of seawater to meet the major part of their water needs. The potential for developing other renewable sources is limited. Developing alternative water resources is costly and unaffordable for many countries. In this critical situation, approaches to water development must give way to integrated water resource management with emphasis on a partnership between decision makers, water suppliers and water users and on the conservation of both quantity and quality.

Water conservation entails a complex interconnected system that includes a variety of aspects ranging from consumer education to introduction of advanced technological equipment. It should include: programs and techniques designed to curb domestic, agricultural and industrial water use; wastewater reduction, treatment and reuse; and understanding of supply-demand relationship, energy consumption and environmental concerns. All aspects must be considered in relation to economic, social, religious, political, legal and aesthetic ties.

In Kuwait and in the countries of the Arabian Gulf Cooperation Council (GCC), demand for water has increased dramatically as a result of rapid development, an improved standard of living and diversification of economic activity. To meet this increase in demand, desalination is being developed extensively. The cost of sophisticated desalination plants is putting pressure on the governments of the GCC countries. A shift in societal values from development to conservation of water resources is occurring.

The main objective of this paper is to set up relevant guidelines for designing a water conservation program that can be convenient for implementation in Arabian Gulf countries in general and in Kuwait in particular. These guidelines cover many alternative methods of conserving water including the supply and the demand management methods.

II. SUPPLY MANAGEMENT METHODS

The supply management methods would include the 1) network leakage/loss control, 2) use of especial plumbing equipment, 3) behavioral practices at users' end that conserve water, 4) use of renovated wastewater for irrigation and other non-potable purposes, and 5) water metering.

II.1. Network Leakage/Loss Control

Old and poorly constructed pipelines, inadequate corrosion protection, poorly maintained valves and mechanical damage are some of the factors contributing to leakage. One effect of water leakage, besides the loss of water resources, is reduced pressure in the supply system. Raising pressures to make up for such losses increases energy consumption. This rise in pressure makes leaking worse and has adverse environmental impacts. Of the many options available for conserving water, leak detection is a logical first step.

There are different types of leaks, including service line leaks, and valve leaks, but in most cases, the largest portion of unaccounted-for water is lost through leaks in the mains. The possible causes of leaks can be due to the material, composition, age, and joining methods of the distribution system components. Water conditions are also a factor, including temperature, aggressiveness, and pressure. External conditions, such as stray electric current; contact with other structures; and stress from traffic vibrations around a pipe can also contribute to leaks.

Leak detection and repair is an opportunity to improve services to existing customers and to extend services to the population not served. Potential benefits of leak detection and repair can be obtained by increasing the knowledge about the distribution system, more efficient use of existing supplies, improving environmental quality; reducing property damage, legal liability, and insurance; and reducing risk of contamination.

In Kuwait, there were 1195 instances of water pipe breakages during 2005 of which only 16 were accidental due to excavation or construction work not related to pipe network (MOE, 2006). The rest were due to normal decay, corrosion and the end of life time. Majority of these breakages (1027) was for asbestos pipes. The replacement of the asbestos pipe by ductile pipe has yielded dividends in Kuwait with leakage percentage registered in single digit number in areas where such replacement has taken place in a recently made survey by Kuwait Institute for Scientific Research (KISR). The number of water connections needing repair during 2005 was, however, 31963 (MOE, 2006) and better performance is needed in this area through the use of better workmanship, material and maintenance procedures.

II.2. Plumbing

Significant water conservation by residential users can be achieved through the use of efficient indoor plumbing fixtures and equipment. Low-flow plumbing fixtures and retrofit programs are permanent, one-time conservation measures that can be implemented automatically with little or no additional cost over their life times (Jensen, 1991). Plumbing programs usually include the use of low flush toilets, low-flow showerheads, faucet aerators and pressure management.

II.2.1.Low-Flush Toilets

Residential demands account for about three-fourths of the total urban water demand. Indoor use accounts for roughly 60 percent of all residential use, and of this, toilets (at 12 liters per flush) use nearly 40 percent. Toilets, showers, and faucets combined represent two-thirds of all indoor water use. Conventional toilets use 12 to 20 liters or more of water per flush, but low-flush toilets uses only 6 liters of water or less. Since low-flush toilets use less water, they also reduce the volume of wastewater produced (Pearson, 1993). In new construction and building rehabilitation or remodeling there is a great potential to reduce water consumption by installing low-flush toilets. Even in existing residences, replacement of conventional toilets with low-flush toilets is a practical and economical alternative.

II.2.2.Toilet Displacement Devices

Plastic containers can be filled with water and placed in a toilet tank to reduce the amount of water used per flush. By placing one to three such containers in the tank more than 4 liters of water can be saved per flush. A toilet dam, which holds back a reservoir of water when the toilet is flushed, can also be used instead of a plastic container to save water. Toilet dams result in a savings of 1 to 2 gallons of water per flush (USEPA, l991b).

II.2.3.Low-Flow Showerheads

Showers account for about 20 percent of total indoor water use. By replacing standard 17 liters per minute showerheads with 10 liters per minute heads, a family of four can save approximately 75000 liters of water per year (Jensen, 1991). Although individual preferences determine optimal shower flow rates, properly designed low-flow showerheads are available to provide the quality of service found in higher-volume models.

II.2.4.Faucet Aerators

Faucet aerators, which break the flowing water into fine droplets and entrain air while maintaining wetting effectiveness, are inexpensive devices that can be installed in sinks to reduce water use. Aerators can be easily installed and can reduce the water use at a faucet by as much as 60 percent while still maintaining a strong flow. More efficient kitchen and bathroom faucets that use only 5 to 6 liters of water per minute unlike standard faucets, which use 12 to 20 liters per minute, are recommended.

II.2.5.Pressure Reduction

Reducing excessive pressures in the distribution system can save a significant quantity of water. Reducing water pressure can decrease leakage, amount of flow through open faucets, and stresses on pipes and joints which may result in leaks. Lower water pressure may also decrease system deterioration, reducing the need for repairs and extending the life of existing facilities. Furthermore, lower pressures can help reduce wear on end-use fixtures and appliances. Pressure management and reduction strategies must be consistent with state and local regulations and standards, as well as take into account system conditions and needs. Obviously, reductions in pressure should not compromise the integrity of the water system or service quality for customers.

The Ministry of Electricity and Water (MEW), Kuwait, in cooperation with Kuwait Institute for Scientific Research (KISR) is in the process of developing and adopting a plumbing code for the residential consumers with an aim to conserve the supply of freshwater to the residents of Kuwait. It is also going to retrofit a large number of faucets in the residential units with aerators on an experimental basis to study their effects on water consumption.

II.3. Behavioral Practices

Behavioral practices involve changing water use habits so that water is used more efficiently, thus reducing the overall water consumption in a home. These practices require a change in behavior, not modifications in the existing plumbing or fixtures in a home. Behavioral practices for residential water users can be applied both indoors in the kitchen, bathroom, and laundry room and outdoors.

II.3.1.Kitchen

In the kitchen, for example, 40 to 80 liters of water a day can be saved by running the dishwasher only when it is full. If dishes are washed by hand, water can be saved by filling the sink or a dishpan with water rather than running the water continuously. An open conventional faucet lets about 20 liters of water flow every 2 minutes (Florida Commission, 1990).

II.3.2.Bathrooms

Water can be saved in the bathroom by turning off the faucet while brushing teeth or shaving. Water can be saved by taking short showers rather than long showers or baths and turning the water off while soaping. This water savings can be increased even further by installing low-flow showerheads. Toilets should be used only to carry away sanitary waste.

II.3.3.Car Wash

Additional savings of water can result from car washing, sweeping sidewalks and driveways instead of hosing them down. As much as 600 liters of water can be saved when washing a car by turning the hose off between rinses. The car should be washed on the lawn if possible to reduce runoff and to reuse the wash water for lawn irrigation. Washing a sidewalk or driveway with a hose uses about 200 liters of water every 5 minutes (Florida Commission, 1990). If a home has an outdoor pool, water loss from evaporation can be prevented or reduced by covering the pool when it is not in use.

II.3.4.Landscape Irrigation

Lawn and landscape maintenance often requires large amounts of water, particularly in areas with low rainfall. One method of water conservation in landscaping uses plants that need little water, thereby saving not only water but labor and fertilizer as well (Grisham and Fleming, 1989). A similar method is grouping plants with similar water needs. Scheduling lawn irrigation for specific early morning or evening hours can reduce water wasted due to evaporation during daylight hours. This is especially true for arid conditions of the Arabian Gulf countries where daytime evapotranspiration in summer can be very high. Another water use efficiency practice that can be applied to landscape irrigation is the use of cycle irrigation methods to improve penetration and reduce runoff. In cycle irrigation, water is supplied at fixed times in a day for a fixed duration ensuring availability of right amount of water at the right time and place, for optimal growth.

Another way that can reduce water use is through the implementation of efficient landscape irrigation engineering practices. There are several general ways that water can be more efficiently used for landscape irrigation, including the design of landscapes for low maintenance and low water requirements, the use of water-efficient irrigation equipment such as drip systems or deep root systems, the proper maintenance of irrigation equipment to ensure that it is working properly, the distribution of irrigation equipment to make sure that water is dispensed evenly over areas where it is needed, and the scheduling of irrigation to ensure maximum water use.

In implementing the changes in behavioral practices of using water in Kuwait and other countries of the Arabian Gulf region, the special factor that should be taken into considerations is that in many residences here, water is mainly used by hired manpower that has generally lower education levels and little understanding of the value of this commodity. It should primarily be the responsibility of the home owners in these cases to make their employees aware of the need of the water conservation and instill in them the behavioral changes in water use, called for this purpose.

II.4. Use of Waste Water

The reuse of wastewater or reclaimed water is beneficial because it reduces the demands on available water resources (Strauss, 1991). Perhaps the greatest benefit of establishing water reuse programs is their contribution in delaying or eliminating the need to expand potable water supply and treatment facilities (USEPA, 1992). Water recycling is the reuse of water for the same application for which it was originally used.

The use of water for cooling in industrial applications represents one of the largest water uses in the world. The most water-intensive cooling method used in industrial applications is once-through cooling, in which water contacts and lowers the temperature of a heat source and then is discharged. Recycling water with a re-circulating cooling system can greatly reduce water use by using the same water to perform several cooling operations. The water savings are sufficiently substantial to result in overall cost savings to the industry.

Given the limited available water resources and the increasing demand, treated municipal wastewater can play a special role in maintaining and increasing the water resources of Kuwait, especially since the wastewater effluent is estimated to be 70 to 80% of the freshwater consumption per capita (Al-Awadi et al., 1992).

Treated wastewater effluents are free from health hazards and must be considered as valuable water resources for irrigation of certain crops, greening enhancement, landscaping, land reclamation, car washing, industrial process, and toilet flushing. This can be especially effective and feasible where the supply depends on desalinated water, as the resultant wastewater generally tends to be low in dissolved solids. The TDS content of wastewater in Kuwait typically ranges between 1,000 and 1,300 mg/l. Wastewater has been recognized as a possibly important source of several major plant nutrients such as N, P, and K, which can lower fertilizer consumption when the land is irrigated with treated wastewater (Berry et al., 1980; Shuval et al., 1985; Lapena et al., 1995).

In Kuwait, the municipal wastewater is processed to the tertiary level at the three treatment plants in operation. Till recent dates (2004), part of this treated water (about 30%) used to be utilized for landscaping and producing alfalfa and animal feed in farms near to the collection center for the treated wastewater. The rest used to be discharged to the sea. To increase the utilization of the treated waste water, field trials have taken place to demonstrate the applicability of the soil aquifer treatment (SAT) technique to improve the quality of treated wastewater in Kuwait (Al-Senafy et al., 2005). It was concluded from the study that the technique is capable of improving the quality of the treated wastewater to the extent that the SAT-treated water can be used for irrigation with slight to moderate restriction (FAO, 1985) and for other non-potable purposes. Based on the study by Abdel-Jawad et al. (1999), a plant for the processing of the treated wastewater using reverse osmosis (RO) technique has been commissioned in 2004 at the private sector on Build – Operate – Transfer (BOT) basis. The plant is producing about 320,000 m3/d of water that is comparable in quality to desalinated water. The production should increase to 643,000 m3/d by the year 2025 (Mohammad et al., 1999). Part of the treated water from this plant is currently being supplied to the agricultural farms in the Abdaly area near the Iraq border for irrigation. Plans are afoot for the laying of a pipeline to supply the Wafra Agricultural area adjacent to the border with Saudi Arabia with water from the plant for the same purpose.

II.5. Water Metering

Metering makes water users more aware of how much water they use and its cost, and tenants who conserve water can benefit from lower water use costs. Metering is reported to reduce water usage by 20 to 40 percent (Rathnau, 1991). Kuwait has a policy of installing meters both at the supply and the consumer ends to monitor the water utilization. Recent surveys in connection with the estimation of network leakage have, however, revealed various problems like poor installation practice, effects of pumps on the supply pipe on meter readings, effects of normal wear on minimum recorded flows, damaged meters and improper choice of meters that are affecting the meter readings. Additionally, use of only one metering device in the commercial apartment buildings is affecting the data quality. A comprehensive review of metering policy is called for covering meter selection and sizing, installation details, allowable pump arrangements, meter replacement programs and multiple occupancy situations to resolve the issues related to metering and arriving at a reliable estimation of water utilization and network leakage.

III. DEMAND MANAGEMENT METHODS

The demand management methods should include 1) pricing, 2) information and education, 3) water use regulations and 4) water use audits.

III.1. Pricing

Costing and pricing are conservation strategies because they involve understanding the true value of water and conveying information about that value, through prices, to water customers. The use of user charges often is considered a necessary (but not always sufficient) part of a water conservation strategy. Systems should conduct a cost analysis to understand what types of usage drive system costs. For example, systems should analyze patterns of usage by season and class of service. Systems also should consider whether their current rate structures promote water usage over conservation; non promotional rates should be implemented whenever possible in order to enhance the conservation signal of rates.

Conservation-oriented pricing requires planners to make certain assumptions (based on the available empirical evidence) about the elasticity of water demand, or the responsiveness of water usage to a change in price. Elasticity is measured by the ratio of a percentage change in quantity demanded to a percentage change in price. Burney et al. (2001) carried out a regression analysis exploring the dependence of annual water demand in Kuwait on factors like real gross national product (as a proxy for income), population and real price index for water (nominal price of water divided by the consumer price index) based on the historical data. The regression equation explained 98% of the variation in freshwater consumption. The coefficient with respect to the real water price index was a negative number with its absolute value greater than unity, suggesting that water demand should be 'price elastic', i.e., it should fall with increase in the price index.

Kuwait is actively considering the implementation of tariff structure that will encourage scaling down the water demand in consumer units where water usage is particularly high. Based on the analysis of the historical data on water consumption, real gross national product, price index for water (relative to other commodities) and population, Burney et al. (2001) has shown that fresh water consumption in Kuwait is price elastic. Adoption of a suitable pricing structure for water should, therefore, result in reduction in water demand in Kuwait.

III.2. Information and Education

Public information and education are important components of every water conservation plan. Consumers are often willing to participate in sound water management practices if provided with accurate information. Furthermore, providing information and educating the public may be the key to getting public support for a utility's water conservation efforts. An information and education program should explain to water users all of the costs involved in supplying drinking water and demonstrate how water conservation practices will provide water users with long term savings.

III.2.1.Informative water bill.

Customers should be able to read and understand their water bills. An understandable water bill should identify volume of usage, tariff rates, total charges and other relevant information. An informative water bill goes beyond the basic information used to calculate the bill based on usage and rates. Comparisons to previous bills and tips on water conservation can help consumers make informed choices about water use. Systems can include inserts in their customers' water bills that can provide information on water use and costs. Inserts also can be used to disseminate tips for home water conservation.

III.2.2.School program.

Water administrators can provide information on water conservation and encourage the use of water conservation practices through a variety of school programs. Contacts through schools can help increase in awareness in young people about the value of water and conservation techniques, as well as communication with parents.

III.2.3.Public education program.

A variety of methods to disseminate information and educate the public on water conservation can be used. Outreach methods include speakers' bureaus, operating booths at public events, printed and video materials, and coordination with civic organizations. In case of Kuwait and other GCC countries, diwaniyas of citizens can be very suitable venues for spreading the message of water conservation. The cultural associations of different expatriate groups in these countries can be the conduits for spreading the same message within this community. MEW in Kuwait has already initiated preliminary steps in public campaign for the conservation of electricity and water through newspaper, radio, TV, billboards and banners under its 'Tarsheed' program and public response is appearing to be positive.

III.2.4.Workshops

Workshops can be hold for industries that might be able to contribute to water conservation efforts. These might include, for example, workshops for plumbers, plumbing fixture suppliers, and builders or for landscape and irrigation service providers.

III.2.5.Advisory committee

A water conservation advisory committee can involve the public in the conservation process; potential committee members include elected officials, local business people, interested citizens, agency representatives, and representatives of concerned local groups. The committee can provide feedback to the decision makers concerning its conservation plan and develop new material and ideas about public information and support for conservation in the community.

III.3. Water-Use Regulation

Regulations should be in place to manage water use during droughts or other water-supply emergencies. In some cases as in perpetually water stressed regions like arid Kuwait, utilities may find it desirable to extend water-use regulations to promote conservation even during non emergency situations. Examples of water-use regulations are:

- Restrictions on nonessential uses, such as lawn watering, car washing, and filling swimming pools.
- Restrictions on commercial car washes, nurseries, hotels, and restaurants.
- Standards for water-using fixtures and appliances

Another type of regulation is to impose standards on new developments with regard to landscaping, drainage, and irrigation practices. In general, restrictions on water use should be justified by the system's circumstances and should not unduly compromise the customer's rights or quality of service. Water use regulations can be summarized in the following steps:

- Promote the adoption of a water conserving ordinance which requires the installation of water-saving plumbing fixtures and fittings in all new buildings constructed or in existing homes where building permits are issued for kitchen or bathroom remodeling work.
- Institute requirements for the installation of water-saving plumbing fixtures and fittings as a condition prior to hook-up for new customers.
- Encourage the wise use and management of water during peak use summer periods by restricting lawn/garden watering to non-daylight hours.
- Institute fines for the unauthorized use of water such as illegal hookups and hydrant discharges.
- Promote land use regulations which protect critical groundwater recharge areas and potential well locations.

III.4. Water-Use Audits

Water-use or end-use audits that strive to achieve a break-down of water usage as per the point of use (e.g., kitchen, bathroom, toilet, garden, washing machine, dish washer, etc.) at the consumer end, can provide water systems and their customers with invaluable information about how water is used and the areas where water usage is excessive and might be reduced through specific conservation strategies. Water audits can be widened to include selective end-use audits by customer class, focusing on typical water-use practices within each class. An audit program can be selective in terms of targeting customer groups that have particular needs or for which water conservation could be particularly beneficial. Audits targeted to older housing, for example, can be particularly beneficial in terms of identifying and fixing plumbing leaks. End-use audits also can be tailored to the usage practices within user groups. For example, residential water audits (breakdown of water usage in residential buildings) may focus on plumbing fixtures, lawn and garden water practices, and customer behavior. Residential water audits can be used to make immediate repairs and retrofits. All water audits should include a written report to the customer that includes specific ideas for conservation. Utilities can facilitate water audits for large-volume users, both commercial and industrial. Water audits should begin by identifying the categories of water use for the large-volume user, followed by identifying areas in which overall water use efficiency can be improved through alternative technologies or practices.

Kuwait has very little information on water use by different sectors of its society and economy (e.g., residential, commercial, government, industry, agriculture, nationals, expatriates, etc.) and collection of such information through auditing is a high priority to understand the water use pattern and to identify areas where conservation efforts should be implemented in earnest.

IV. CONCLUSION

Improvements in the standard of living and urban migration, coupled with the absence of conservation programs in the Arabian Gulf Countries in general and in Kuwait in particular, have resulted in excessive domestic water consumption. Current programs in these countries are focusing mainly on the development of water resources rather than management, in order to meet rising water demand. To cope with future water demands there is a need to thoroughly evaluate and implement means of augmenting supplies, devoting serious effort to management approaches that will provide optimal allocation and efficient utilization of water resources. Water managers in this region might have opportunities to consider and implement measures that can accomplish integrated resource management, where water conservation is jointly accomplished with the conservation of other resources like electricity and fuel used to generate both electricity and desalinated water. This should be accomplished by taking both supply and demand management measures for water and power so that the operation of the water and electrical production is optimized and the demand for both is controlled without compromising the living standards.

On the supply-side, the utility can institute operating practices (including various automation methods, strategic use of storage to smooth out pressure on the desalination units during high demand periods, and other practices like reduction of water leakage from the network) that achieve energy, chemical, and water savings. Source-water protection strategies, including land-use management methods, can be used to conserve water resources and avoid costly new supplies. Water and wastewater utilities can jointly plan and implement conservation programs to realize savings and share in the benefits. Integrative practices also can be accomplished on the demand side. Water and energy utilities can conduct comprehensive end-use audits and jointly promote conservation practices by end-users. Large-volume users can work with the utility to make adjustments to processes that reduce water and energy usage and wastewater flows, while saving other resources as well.

Kuwait has already initiated some of the steps needed for the better management of its available water resources with emphasis on conservation and is considering implementing others in the near future. It is hoped that positive outcomes from these steps will be apparent soon.

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Community Involvement as a Tool for Integrated Water Resources Management in the Greywater Use for the Middle East and North African Region

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Abstract

The Middle East and North Africa (MENA) region are facing continuing decline of national per capita water availability due to high population growth rates that demand extra water and food consumption, improved living standards, and industrialization. Many research attempts to improve water management and increase efficiency of water use by all sectors are being made. Modern research proved that community involvement, if well implemented, can be an effective tool in the Integrated Water Resources Management (IWRM) process.

Jordan is among the most water scarce in the MENA region, but it has made significant achievements over the past two decades in restructuring the water sector and adopted a clear water strategy. This strategy clearly identified wastewater as a resource that has to be treated and used effectively while safeguarding public health and the environment. Within this scope of wastewater strategy of Jordan, the Ministry of Water and Irrigation as well as the Ministry of Planning and International Cooperation supported the "Greywater Treatment and Use for Poverty Reduction in Jordan (Phase II)" funded by International

Development Research Centre (IDRC), Ottawa, Canada and implemented by the Inter-Islamic Network on Water Resources Development and Management (INWRDAM). Greywater research conducted by INWRDAM since 1999 in Jordan and other countries proved to be of high potential benefits for many countries in the MENA region and other parts of the World.

The main aim of this paper is to share useful lessons learned in greywater use research with special concentration on the community participation and involvement as an effective tool of IWRM. It is hoped that the documented experience of INWRDAM greywater research can be replicated in other countries.

Introduction

Jordan covers a land area of 89,342 km2 extending from the borders with Syria in the north to the tip of the Red Sea in the south and from the Jordan River border in the west to the deserts of the east bordering Iraq and Saudi Arabia (Figure 1).

Figure 1. The Map of Jordan.

Water resources in the Jordan are characterized by scarcity, variability, and uncertainty. The rainfall period starts in October and ends in May, with a maximum rainfall during December to February. The annual variations in precipitation are quite high. Average rainfall in eastern mountain range is from 600 mm to 400 mm/year and in the eastern plateau is from 400 mm to 50 mm/year.

Jordan has always had scarce water resources, but high population growth over the last twenty years has pushed its per capita water availability to below 198 m3/capita/year. This is far below the benchmark level of 1000 m3/capita/year often used as an indicator of water scarcity; below this a country is likely to experience chronic water scarcity on a scale sufficient to impede development and harm human health.

Water management in Jordan had undergone a paradigm shift in terms of how water is valued and managed. Historically, water was viewed as a free good as reflected in the evolution of irrigation water pricing. In the last two decades, however, the concept of food sufficiency has transformed to food security. Currently, the Water Strategy for Ministry of Water and Irrigation (MW&I) calls for covering the operation and maintenance (O&M) cost for supplying, treating, and distributing water; water has an economic value. Water conservation and wastewater treatment and reuse are considered among the priority list for water demand management.

Jordan reuses nearly all wastewater collected by public sewer systems after treatment and mixing with fresh water stored in dams and reservoirs. More than 60% of the population is not yet served by sewerage services.

Jordan has a moderately high human development index that is higher than the average for developing countries. Nevertheless, seven per cent of Jordanians earn less than the international poverty line of US$ 1/day. Further more, Jordan's high population growth and unprecedented urbanization rate threaten its recent economic gains.

Jordan's economy had experienced decline since the middle of the last decade. The Jordan Dinar (JD*) was devalued in 1988 against foreign currencies by 60% and resulted in inflation and a sharp increase in the price of commodities. Although the economic reforms achieved success and the local currency was stabilized,

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* One JD is equal to about US $1.4

these reforms impacted significant portions of the Society and unemployment and poverty increased. Jordan's population growth is 2.7%, and the proportion of its population living in urban areas, already 73%, is expected to reach 80% by 2015[1]. This trend has greatly threatened the food and water security of the poor, who increasingly find themselves in towns and cities. The unemployment rate in 1996 was 12% and 35% of all families were below the absolute poverty line. The absolute poverty income limit for households in Jordan is 119 JD/month based on a family size of 6.8 persons[2].

Centralized sewerage systems, the preferred choice of planners and decision makers, are inappropriately provided to individual communities and wastewater is transported from several scattered communities to centralized facilities. A World Bank review of sewerage investment in eight capital cities in developing countries found that costs range between US$ 600-4000 per capita (1980 prices) with total household annual cost of US$ 150-650[3]. The conventional sewerage systems are more costly in small communities. Because of their size and layout, small communities do not enjoy the economies of scale associated with building large systems. The low population density means that longer sewers are needed to serve each household. The per household cost in Jordan Valley rural sanitation project was projected at US$ 2200, four times the average of all urban wastewater projects constructed in Jordan between 1976 and 1996[4]. The high cost of conventional sewers is regarded as one of the major constraints to expanding wastewater services to small communities and is a challenge to implementing the Millennium Development Goals (MDG) adopted by UN General Assembly to reduce world poverty by 50%. The World Summit on Sustainable Development (Johannesburg) announced as a target a 50% reduction of the number of people lacking adequate water and sanitation.

Conventional sewerage systems are designed as waste transportation systems in which water is used as transportation medium. Reliable water supply and consumption of 100 liters per capita per day (lpcd) are basic requirements for problem free operation of conventional sewerage systems. Conventional sewerage is not appropriate for small communities in the Middle East region where water supply are intermittent and only limited amounts of water are available. By transporting the wastewater away from the generating community, several reuse opportunities can be lost. Reuse opportunities are often located within the generating community for landscape or for agriculture. Recent research and development in the field of wastewater management suggests that centralized wastewater management is environmental unsustainable[5].

Jordan is known to be one of the most water scarce countries in the world, where water shortage has become of permanent nature and meeting water demands is a challenge. Jordan has reached its water crisis; present water use already exceeds the renewable freshwater resources by more than 20%. After the year 2005, freshwater resources will be fully utilized and there remain no more known resources within the country to develop.

Tourism is one of the most promising economic activities world-wide, generating about 15% of the global turnover of financial capital. As a result of the progress in the peace process, the Middle East, generally speaking, is experiencing unprecedented growth rates in the tourism sector; while Jordan, in particular, has witnessed unparalleled growth with the number of tourists exceeding one million in less than a year. Although we find the increased interest in Jordan very promising, we are also determined not to advocate tourism at the expense of our environment, which is why we are focusing our efforts on developing and applying the principles of eco-tourism. Eco-tourism occurs when people travel to relatively undisturbed or uncontaminated natural areas to enjoy the natural and cultural heritage of the area with minimum disruption to the natural and social environment. From an economic point of view, it is a sound venture as it stimulates economic activity and growth in remote and rural areas without entailing large-scale investment and ensures a more sustainable future for a relatively unaffected site – this is an important point for us considering our limited resources.

Jordan's Water Resources

Jordan’s Renewable freshwater resources are estimated at about 850 MCM/year, consisting primarily of surface and ground water. Options for non-conventional water resources that can be mobilized are modest where nearly all of Jordan’s renewable water resources have been developed and most citizens in Amman receive water only once a week. The options for augmenting water supply are limited; some additional rainwater can be harvested and some brackish water can be pumped from sandstone aquifers. The per capita share of renewable water resources is among the lowest in the world, and is declining with time. It is projected to fall from 140 /capita/year at present to 90 m3/capita/year by 2025[6].

Surface Water Resources

Surface water resources in Jordan are unevenly distributed among 15 basins. The largest source of external surface water is the Yarmouk River, at the border with Syria. Originally, the annual flow of the Yarmouk River was estimated at about 400 million m (of which about 100 million m^3 are withdrawn by Israel).

Total flow is now much lower than 400 million m^3 as a result of the upstream Syrian development works which have been done in the 1980's.

The Yarmouk River accounts for 40% of the surface water resources of Jordan, including water contributed from the Syrian part of the Yarmouk basin. It is the main source of water for the King Abdullah canal and is thus considered to be the backbone of development in the Jordan valley. Other major basins include Zarqa, Jordan riverside wadis, Mujib, the Dead Sea, Hasa and Wadi Araba.

Groundwater Resources

Groundwater is the major water resource in Jordan; it is the only water resource in some areas within the country. Twelve groundwater basins have been identified in Jordan.

Most basins are comprised of several aquifer systems. About 80% of Jordan's known groundwater reserves are concentrated mainly in the Yarmouk, Amman-Zarqa and Dead Sea basins. Most renewable groundwater resources presently are exploited to their maximum capacity. In some cases abstraction exceeds the safe yield of the aquifer. Over exploitation of aquifers has contributed significantly to the degradation of groundwater quality.

The agricultural development in Jordan started since the early 1970s and nowadays around 70% of the abstracted groundwater is being used for irrigation (noting that the inputs of agriculture does not exceed 4% of annual GDP). The increased agricultural land use brought about a deterioration of groundwater qualities in many areas through the application of fertilizers and pesticides.

The main non-renewable aquifer with a presently safe yield is the Disi aquifer (sandstone fossil) in southern Jordan estimated at 125 MCM/year for 50 years. Other non-renewable water resources are found in the Jafer basin, for which the annual safe yield is 18 MCM.

Water Situation in Jordan

Jordan's renewable water resources have been developed to combat factors contributed to the increase of water scarcity. These main factors are population growth and increase, unplanned agricultural activities and over abstraction from groundwater basins. In Jordan, fulfilling the needs of domestic water supply sector has the priority over industrial and agriculture water sectors, respectively.

The Jordanian Tourism Strategy[7] indicated in its vision that Tourism is an essential and vibrant growth sector that will contribute to improving the long-term economic and social well-being of Jordanians. Therefore, Jordan will develop a sustainable tourism economy through a partnership of government, the private sector, and civil society to expand employment, entrepreneurial opportunity, social benefits, industry profits and state revenue. The goal of this strategy is to double Jordan's tourism economy by 2010. This strategy mentioned the need for public-private-partnership to ensure that various stakeholders are aware of their respective roles and responsibilities, and that strategic initiatives are incorporated into their annual plans. Therefore, the strategy confirmed the importance to open efficient communication and coordination channels between public and private sector organizations to ensure smooth implementation of strategy recommendations. The strategy also confirm that the private sector should be allowed to take a more active role in tourism sector investment, development, management, planning, and legislation.

Although the Jordan's National Tourism Strategy did not mention water needs by tourism sector, however, the Ministry of Water and Irrigation (MWI) has mentioned tourism water needs as part of its water strategy. The MWI has two entities dealing with water in Jordan; the Water Authority of Jordan (WAJ), in charge of water supply and sewer networks, and the Jordan Valley Authority (JVA), responsible for the development of the Jordan Valley. MWI has always been supported by several donor organization projects that have assisted in the development of water policy and water master planning.

The Government of Jordan has adopted a comprehensive water strategy supplemented with a set of policies and measures to help mitigate the water situation. MWI is committed to ensure an integrated policy of water resource management that is sustainable in economic, ecological and social terms.

Jordan's Water Strategy stresses on the need to tap the full potential of surface and ground water to a feasible extent, the marginal quality and brackish water support irrigated agriculture, seawater desalination produce additional water for municipal, industrial and commercial consumption. The strategy also ensures that wastewater is collected and treated to standards that allow its reuse in unrestricted agriculture and other non-domestic purposes, including groundwater recharge. Resource management aims at achieving the highest possible efficiency in the distribution, application and use of water. Previously developed resources must be sustainable and used with special attention to the protection against pollution, quality degradation and depletion. The government adopts a dual approach of demand management and supply management. Priority in water resources allocation is given to the basic human needs; as such first priority is given to allocation of a modest share of 100 litres/capita/day to domestic water supplies, followed by tourism and industrial sectors.

Community and IWRM

The total population of Jordan is about 5.480 millions and Population growth rate is about 2.8%. The average household size is 5.7 and this number highly increases in the households of rural and peri-urban communities. Although Jordan is facing severe water scarcity however, the percentage of households connected with Electricity Network is around 99.5% the percentage those households connected with Water Network are about 97.7%. While the percentage of households connected with Sewage System is only 60.1% and most of these households are concentrated at the centers of main cities and the 12 governorates of Jordan. The above-mentioned percentages, specially the number related to households served with water networks, are considered very acceptable and might mislead of the actual water situation in Jordan. Therefore, a deeper investigation and discussion will be needed to clarify the actual water situation in Jordan. In fact, although almost all households in the whole country are served with water networks, however, the frequency of pumping water to households is minimal in many areas and the Ministry of Water and Irrigation of Jordan (MWI) do all efforts to satisfy the households need of water throughout the year and this has resulted in households receiving water for one or half a day over a period of one week. This action has resulted in that people in Jordan helped the government in responding to the severe water scarcity in many ways: for instance, because tap-water is no longer pumped during the whole week [only once or twice a week], people, even the poorest, responded by installing new water storage tanks on the roof of their house and sometimes on the ground (with pump) to increase water storage and overcome low pressure in the water supply network, respectively. This can simply mean that community members, whether we accept it or not, are forced and are becoming "water managers" at their household level, they are no longer out of the loop and they are partners (key stakeholder) in optimizing the management of water resources. The government was forced to limit pumping of water due to water resources scarcity and the community were forced to respond by installing storage tanks. Therefore, this is a clear example were two groups of key stakeholders (in this case the government and the community) are cooperating and both of them are forced to take actions (respond) to water scarcity without any pre-coordination. This really also proves that "water is a shared responsibility".

The involvement of community in water related projects is one of the key successes for IWRM component of any project. Basic research topics should build ownership of the project by the local community and lead to project scale up practices by the communities at national and regional levels. For example, the community component of INWRDAM greywater project is designed to fulfill the objectives of the project by training and capacity building of the beneficiaries to enable them to continue to address their water needs, beyond both the scope and the duration of the project. The location of INWRDAM's project, which was funded by the International Research Centre, Ottawa, Canada (IDRC), is at the Al Amer Villages (110km South of Amman). This loacation was selected because it met the site selection criteria previously investigated and developed by an external evaluation team. Meetings were held with local leaders, the municipality, local NGO and Al Amer CBO, and relevant local government officials in order to create support and acceptance of the project among the community.

A list of potential beneficiaries from the six villages was prepared and then a final list was refined based on field visits to assess suitability of households for greywater separation and use in their home gardens, income and interest to participate in the project. Interested community members were trained on features of the greywater treatment systems and how to conduct beneficiaries' selection surveys and how to separate greywater at households level.

At project start up the selected community members were active and showed interest but it was noticed that this combination did not include, apart form a municipality representative, local government agencies who are important stakeholders of the project. Therefore, the project contacted local authorities such as representatives of ministries of health, environment, agriculture and representative of local governorate and included them as this would be useful for the long-term sustainability of the project. The reason for this was that the recommended agencies are responsible for monitoring health, pollution and other issues in the governorate and involving them with the community would lead to increased horizontal and vertical knowledge sharing and awareness about greywater use at community level in Jordan.

This action was implemented along with the establishment of a project office in the community resulted in progressive improvement in pace of implementing the project and the community component in particular. It appears that the beneficiaries felt more assured that the project is monitored by local governmental agencies and they therefore, many beneficiaries became more involved in training and care for their units. An important lesson-learned from this action is that communities, specially rural and peri-urban communities, would feel more secure when governmental agencies are supporting development projects in their area.

The project plan estimated that about 300 beneficiaries from the six villages would be targeted and provided with greywater systems. This did not happen due to a number of reasons; basically the project took more time than anticipated to sort out best way to approach the community and what form of local stakeholder body would be best for the satiation, second, some shift occurred in the methods used to ensure beneficiaries financial contributions to the project and beneficiaries selection criteria. It was also observed that due to the agrarian nature of most beneficiaries, and during spring time members of family had to go after grassing their animals, planting wheat, and other seasonal work and results in less time available for them to attend training and other project activities. To overcome these seasonal burdens on community members, the project intensified training of women on operation and maintenance (O&M) of the systems because they do not generally have to do farm work and stay at home. This is emphasized by encouraging women to attend training and capacity building and caring for the greywater units, drip irrigation and home gardening. Therefore, majority of attendants of regular training sessions are women. The project team conducts regular visits to beneficiaries and discusses with them how they apply what they learn in the training. It is apparent that women in the project area very intelligent and hard working and willing to learn more about greywater and ways to support their family's income.

Technical Component Review of Greywater Research

INWRDAM (www.inwrdam.org) is involved since February 2000 in greywater applied research activities in Jordan[8] and is assisting its research partners in Middle East countries to conduct similar activities by sharing of know how and by mutual learning and networking. INWRDAM greywater activities were funded mainly by the International Development Research Centre (IDRC) in Ottawa, Canada, European Union grants and other international donors and the private sector in Jordan, Lebanon, Palestine and Yemen. Training and capacity building of individuals and institutions is one of the main activities of INWRDAM. Many training workshops, expert group meetings on greywater applications are conducted at regional level. These training activities were supported by various international organizations among which are the Islamic Development Bank in Jeddah, Saudi Arabia, IDRC, The Islamic Educational, Scientific and Cultural Organization and others.

Greywater is defined as wastewater that is generated from use of domestic water in activities such as washing clothes and dishes, bathing and other households water uses. However, it does not include black wastewater from toilets or that generated from the washing baby diapers. In most western countries, USA, Australia and Europe kitchen wastewater (including dishwater effluents) is considered as black water. Excluding kitchen water is not a practical option in Jordan and other MENA countries because kitchen is a source for plenty of water consumption as dishwashing habits are different from that in West (not a soak and wipe dry as in the West). The practice of greywater use for irrigation is also not completely new in the region. Peri-urban dwellers face water shortages and are compelled to use raw greywater to irrigate crops they grow around the house. INWRDAM observed that some rural community members separate greywater from black water because of some common Islamic beliefs that food remains should not be mixed with human waste and this is manifested in separating kitchen greywater from black water into a stream used for irrigation.

Greywater from low income households in rural areas is usually not contaminated with heavy metals and toxic chemicals that could pollute wastewater in urban areas. Good house keeping practices such as using small screens to capture food in kitchen sinks, removal of oils and fats from dishes before washing can lead to considerable reduction of organic pollution of the greywater and facilitate the application of low cost treatment with good treatment results. Generally houses in rural areas of the Middle East are usually simple and allows for greywater separation from black water with minimal modification of sanitary installations inside the house. Greywater separated from a house is collected at a point located in a place that is in the direction of dominant wind so that odor from the treatment unit is blown away from the house.

During 2000 to 2003, IDRC provided INWRDAM with financial grants to enable it to conduct a comprehensive evaluation of the potential for greywater reuse in rural areas of Jordan. This evaluation resulted in initiating Phase I of greywater research project that was implemented in the peri urban areas of Tafila Governorate, southern Jordan. This resulted in intensified work for developing and evaluating different types and configurations of small on-site greywater treatment units suitable for single households. Experiments were conducted to optimize methods of low cost for single home greywater treatment situations. Five different types and configurations were tested and evaluated over a period of five years. Two designs out of the five units/modules were selected as potential units for further improvement and scale up. This was based on low cost and ease of construction and quality of effluent possible to achieve from these units. One module is now known as the 4-barrel unit and the other module is known as the confined trench (CT). Figures 2 to 4 show barrel, concrete images and Figures 5 and 6 show construction details of 4- barrel and CT greywater treatment units, respectively.

Figure 2. Four barrels greywater treatment

Figure 3. Concrete greywater treatment-cirucular design

Figure 4. Concrete greywater treatment-rectangular design

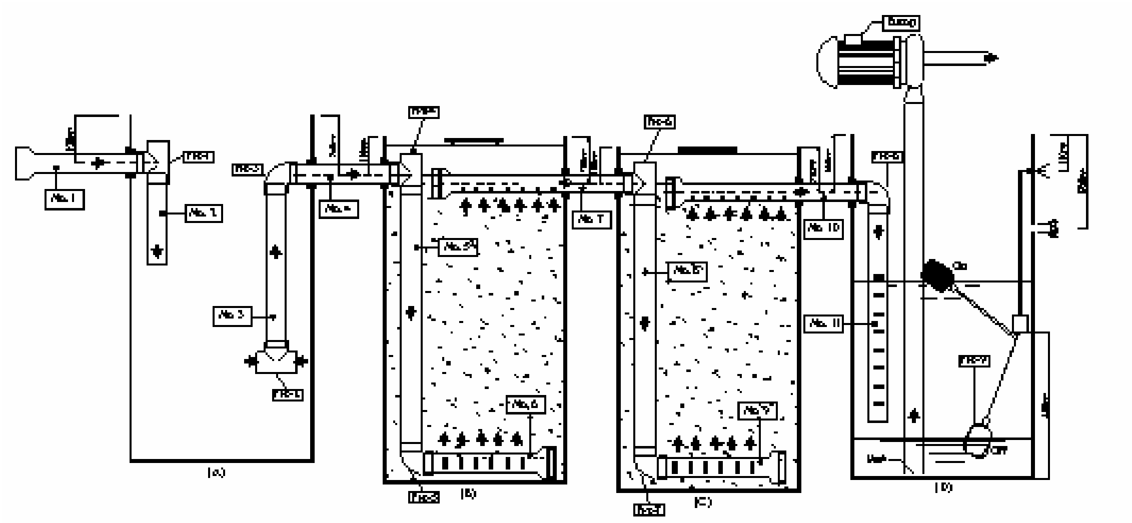

Figure 5. Four barrels construction details

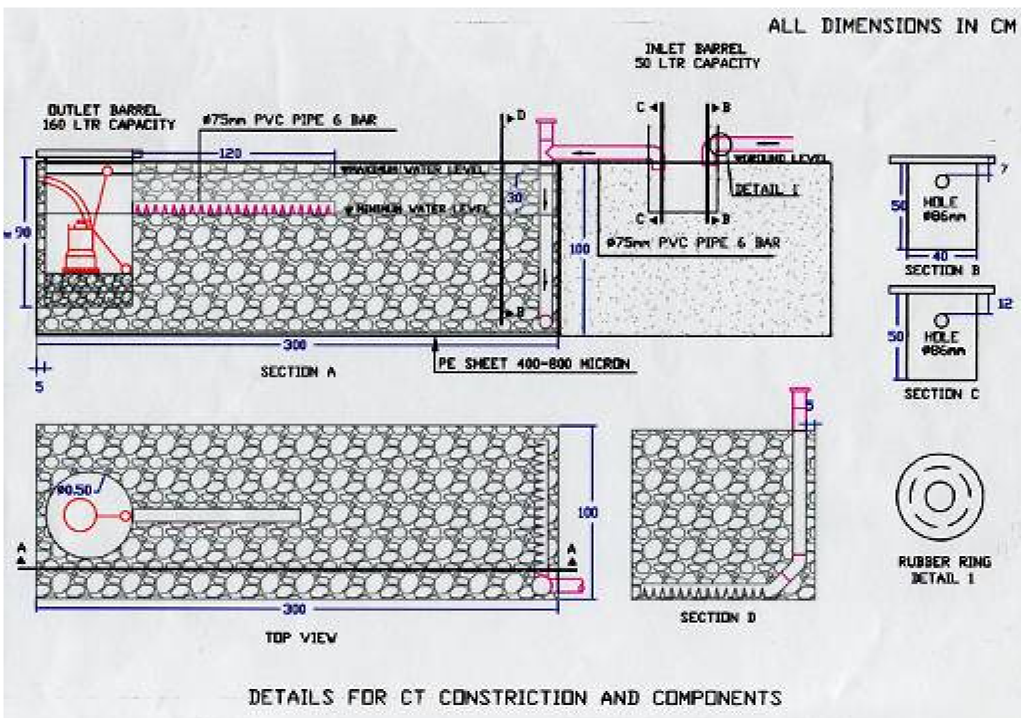

Figure 6. CT construction details

A 4- barrel unit consists of four recycled polyethylene (PE) plastic barrels connected together by 3" diameter plastic pipes. A first barrel of 50 liter capacity receives greywater coming from the house and removes grease, oil and settable solids.

After that, two-200 liter volume barrels are connected by pipes in such a way that greywater passes in an up flow mode through a bed of crushed stones or gravel media of 2-3 cm diameter size range and achieves physical and biological treatment over two to three days under anaerobic conditions. A last barrel of 160 liter capacity is fitted with a small electric pump and float switch that delivers treated greywater to a trickle irrigation system serving a small garden of trees. The treatment is achieved over a period of two days under anaerobic conditions.

The CT is a modification of the 4- barrel type achieved by increasing the hydraulic loading by increasing the volume of the gravel media up to 8 times that leads to longer detention times in the anaerobic stage. The modification is accomplished by replacing the second and third barrels in the 4- barrel unit with a dug trench lined with thick impermeable plastic sheet of about 400 micron meter thickness filled with about 3 M^3 gravel media of same size. Treated greywater is then pumped automatically through a trickle irrigation system to a home garden. The construction of a 4-barrel unit and related drip irrigation systems costs about US$ 350 and can treat about 150-200 liters per day of greywater for a household of 6 members that of a CT unit costs about US$500 and can treat 200-500 liters per day of greywater for a household of 10 members. In both cases treated greywater is compatible with WHO quality guidelines for restricted irrigation. The 4- barrel and the CT are well accepted by the users and can last up to ten years with little care and maintenance and minimal running costs.

When low cost methods are considered for wastewater treatment the quality of treated effluent depends much on quality of raw feed. Accumulated research findings on quality of raw greywater indicates that for a family of six persons and with an average 50 liter per capita domestic water consumption per day, the quality of raw greywater is roughly of 700 to 1500 $mg.L^{-1}$ biological oxygen demand and treatment using methods developed by INWRDAM can reduce it to below 300 mg- L^{-1} biological oxygen demand, which is a main parameter of concern when greywater is applied for restricted irrigation.

In 2003 the Ministry of Planning and International Development in Jordan funded INWRDAM and CARE International- Jordan to install over 750 greywater units of 4-barrels type designed by INWRDAM for the benefit of low-income families in more than 90 villages in Jordan. This resulted in introducing greywater use practices in many rural areas of Jordan. The aim of the Ministry of Planning greywater project was to increase social productivity of the poor by utilizing greywater for irrigation of home gardens.

During February 2004 to October 2007 IDRC provided a grant for INWRDAM to conduct a scale up greywater project at community level to serve about 110 households. The goal of that project was "To help peri urban poor to conserve precious fresh water, create income, contribute towards household food security and save the environment". This project (the Karak project) attempted to answers research questions related to long term sustainability of greywater use practices, benefit cost ratio of the greywater systems, ability of the peri urban poor to spend their little financial resources against promised returns, health impacts, social acceptability and technical reliability of the systems. In addition to continue monitoring long term impact of greywater on soil and plants. This project aimed at scaling greywater use at community level in a cluster of villages in the Karak Governorate in southern Jordan. These villages are peri urban settlements spread over an area of about 17 km^2. The total population of these villages is approximately 8000 mainly of low income poor farmers and active and retired civil servants.

There are no natural water sources in the area or in the vicinity such as springs, flowing streams or piped irrigation water supplies except a few deep wells used to supply domestic water. This area is not served with sewer networks and all households use septic tanks or cesspits for disposal of sewage. Al houses are connected to electricity grid and to domestic water supplied. Due to unreliable nature of domestic water supply during summer seasons some families purchase water for domestic sources to irrigate few olive trees cultivated in their home gardens. Cost of water purchased from private vendors is approximately US$2.5 per cubic meter. The majorities of houses in the project area are simple and surrounded by a small garden area of about 1000 M^2 planted traditionally with olive trees. Separation of greywater from black water in most low income areas is possible without much alternation of floor tiles construction.

Conclusions and Recommendations

Community involvement in the IWRM process proved to be crucial component and would greatly contribute to sustainability. Lesson-learned from implementing these projects must be properly documented.

Accumulated experiences must be considered in any new implemented IWRM processes. For example, Low cost greywater treatment methods at household level in rural areas proved to be an essential and feasible option and could be effectively and widely used in many parts of countries of the Middle East and North African Region in order to enhance the efficient implementation of IWRM principles, particularly, those related to community and women participation.

Methodologies, strategies and techniques used by researchers to involve the community in their water related projects must be flexible and suite with local culture of the target community.

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