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Original Research Article

Climate Change Adaptation: a case study in Azraq Basin, Jordan

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A B S T R A C T

Jordan has been classified as the fourth scarce water country among the world. Azraq basin forms the largest resources of groundwater in the northeastern of Jordan. Intensive pumping carried out through the last 20 years has caused lowering of the basin's water table, which in turn increasing the salinity of the basin. Climate change impacts expected to be another challenges in Jordan in general and Azraq basin in specific. The excepted effect as stated in the studies increasing temperature about 2 ^{o}C and decrease rainfall about 20%. This study aimed to develop an integrated water resources management options as tool for climate change adaptation for Azraq basin in order to contribute to the sustainable management of the basin. Water Evaluation and planning programme (WEAP) is used as a tool to evaluate the current situation, project the future demands and provide management options. Four management scenarios were formulated namely; climate change; Red- Dead Sea canal project; improving irrigation water efficiency and stop pumping from illegal wells. Future demand projected for period from 2000 – 2050. The results of this research showed that water demand under climate change scenario increased dramatically because of the increasing of temperature and reduction of rainfall. While the other three scenarios results showed decreasing water demands. Set of recommendations were developed, such as, urgent need to implement red-dead sea canal project; introduce high irrigation system techniques to reduce water losses in the system; and enforcing the national by-law to control pumping from groundwater wells.

Keywords

Azraq Basin; Climate change; Over pumping; WEAP; Water demand; Irrigation efficiency; Red-Dead sea canal.

Introduction

Jordan is classified as the fourth water scarce country in the world. The available water resources per capita decreased from 3600 m^3/ cap/ year in 1946 to 145 m^3/cap/ year in 2008 and projected to decrease to about 90 m^3/cap/ year in 2025 (MWI, 2008). The Azraq Basin forms the largest resources of good quality groundwater in the northeast of Jordan. Intensive pumping through the last 20 years has caused lowering of the basin's water table and consequently increasing the salinity of the basin water. Azraq Basin supplies Amman and Zarqa governorates with about 20 MCM/Y. The rest amount of abstracted water is extracted by the farmers, and used for domestic uses in the basin area.

The Azraq Oasis is located in the heart of the basin and considered as part of RAMSAR site in Jordan according to the Convention on Wetlands (Ramsar Convention, 1971). The oasis is important for the migratory birds; more than millions of birds utilize the area during spring migration every year. However, the oasis is under severe pressure and ecosystem is in far stage of degradation. The main cause of the oasis deterioration over the past 20 years is the overexploitation of the basin. Therefore In 1994, an agreement between the government and the Royal Scientific Society for Nature Conservation was signed to reverse the pumping of water from the Ministry of Water and Irrigation wells into the Shishan pond, which re-created 10 – 15 % of the Shishan marches.

The intensive pumping has caused a depression of more than 40 meters in the north and more than 10 meters in the south, which was originally above ground surface (Ta'any 1996). The water table has fallen with a rate of 0.6 meter per year and two main springs; Druze and Shishan which was used to feed the Azraq Oasis completely dried. Moreover, the over-extraction also led to the deterioration of water quality due to the intrusion of water brine groundwater from the middle aquifer into the shallow aquifer. The absence of legal framework controlling agriculture expansion led to the increase of water pumping from illegal wells by the local famers throughout the past three decades. Within the current challenges on the water resources in general and in particular on Azraq basin and its surrounding ecosystem, raised the urgent need to review and foster the water management strategies and policies to optimize the use of the limited water resources as well as improving the agriculture and irrigation efficiency.

In this study, WEAP model was used as a tool to provide options for integrated water resources management. Both demand and supply site was assessed. Four potential management scenarios were proposed and evaluated. The result will hopefully provid management options and recommendations to be used by the policy and decisions makers. The research investigated the effect of climate change on both the annual recharge and the water table of the basin aquifers.

Materials and Methods

Location of the study area

Azraq Basin is an extensive inland drainage system lying in the steppe and desert to the east of Amman (Figure .1). The basin covers over 12,710 km^2, stretching from the lava peaks of Jebel Druze in southern Syria to the Wadi Sirhan in northern Saudi Arabia. This basin is situated between 250 to 400 E and 055 to 230 N (according to Palestine Grids). Azraq oases lies at its center and were formed around copious springs and an extensive playa lake which fills after winter storms (MWI, 2009).

Azraq Basin is a depression surrounded by hilly relief, and consequently all water resources drain in mudflat of Qa'a Azraq at an average elevation of about 500 m above sea level. Slopes in the basin are gently with an average slope of 1 % except in the north where gradient increase to 3%

Figure.1 Location map of Azraq Basin, (Source: Abdulla, and Al-Omari, 2008)

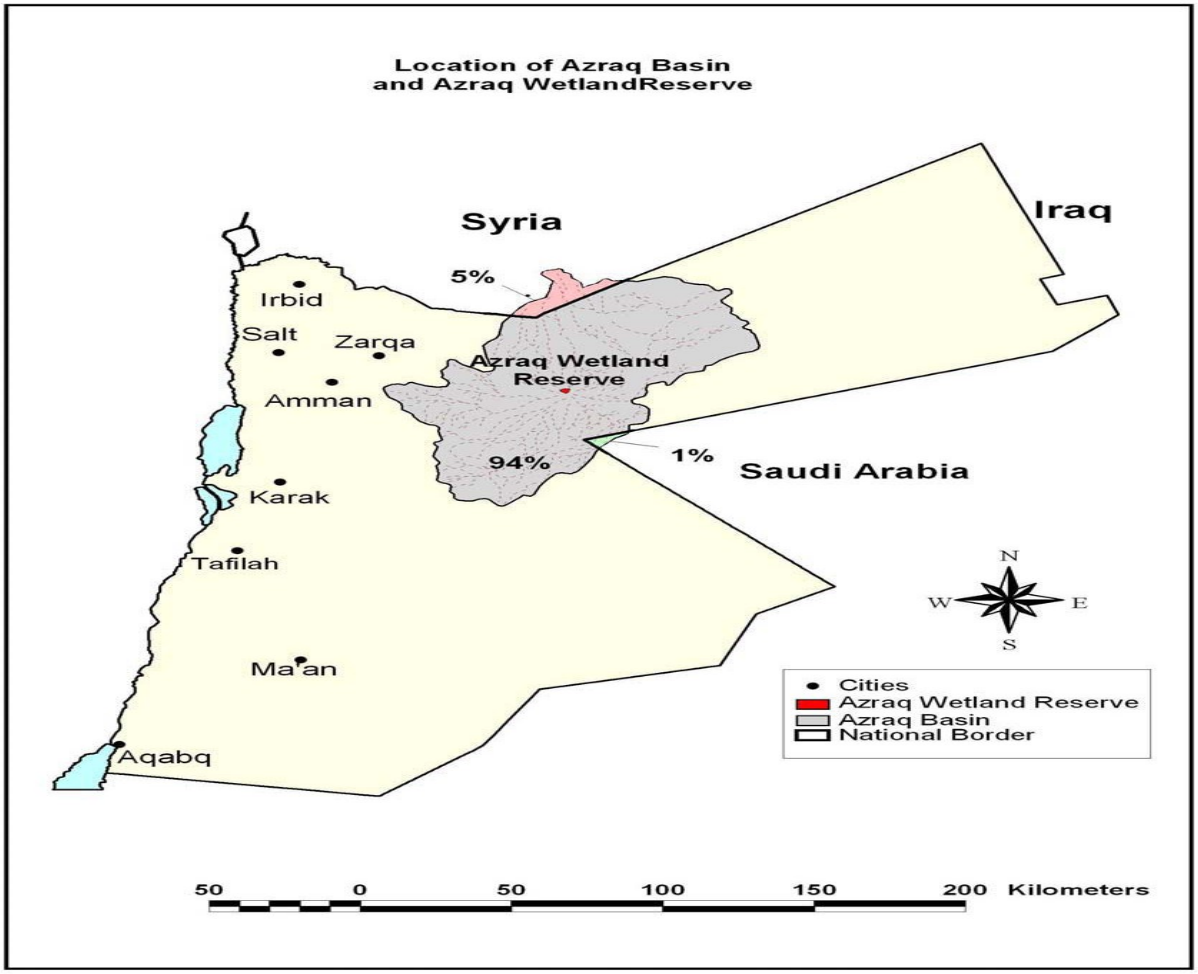


Table.1 Major Units of the Shallow Aquifer in the Azraq Basin Area

Age	Formation	Lithology	Thickness (m)	Potentiality
Recent - Quaternary	Alluvium	Sands	0-20	Aquifer
Late Tertiary	Basalt	Basalt	0-400	Aquifer
Late Eocene	Um Qirma (B5)	Weathered Limestone	0-15	Aquifer
	Wadi El Shallala	Marl and Chalk	160-430	Aquiclude
Mid Eocene	Um Rijam	Argillaceous silcified Limestone	170-300	Aquifer
Early Eocene	Muwaqqar	Marly limestone	> 100	Aquiclude

in the surrounding area of Syrian border (Ta'any 1996). All wadis drain into the mudflat of Azraq depression are characterized by wide shallow flow-beds with relatively low slops. Intermittent flow in the wadis occurs in the winter and drains into the depression, where it evaporates within few months (El Naqa, 2010).

Model Description

WEAP model (Water Evaluation and Planning System) is a water allocation model at river basin scale with limited physical processes included, but with a very strong focus on scenario analyses. WEAP has been developed by the Boston Center of the Stockholm Environment Institute in the USA. (WEAP, 2009).

The design of WEAP is guided by a number of methodological considerations: an integrated and comprehensive planning framework; use of scenario analyses in understanding the effects of different development choices; Demand-management capability; Environmental assessment capability; and Ease-of-use. In order to evaluate water demands and situation in Azraq Basin as well as provide options for the integrated water resources management in the basin, Water Evaluation and Planning Software (WEAP) was used. The methodology consists of the following four main steps:

Current Situation analysis:

This activity formulates the baseline information and corner stone for later activities. These include review of the situation of Azraq basin and identify the main current and potential challenges. Most of the previous studies were collected and addressed both in term of water quality and quantity in Azraq Basin and previous studies for using WEAP application. Moreover, the current water management strategies, policies and plans were collected and reviewed. The limited available Global Circulation *Models* (GCMs) for Azraq Basin was reviewed and the impacts were taking into consideration for identifying the major challenges.

Data collection

Required data were collected from the relevant institutions such as Ministry of Water and Irrigation, Ministry of Agriculture, Statistic Department, Jordan Meteorological Department, Royal Scientific Society for Nature Conservation, International Union for Conservation of Nature (IUCN) and Food and Agricultural Organization (FAO). The collected data include water use; ground water abstraction and use; monthly rainfall and long term average precipitation; agricultural data include irrigated areas and water requirements for crops and population growth rate.

Building the Model

Current account were developed, the year 2000 was identified as the current year account. All the needed data were inserted to the model. Reference scenario established from 2000 to 2050. The module were validated and calibrated for 2001 – 2007 to ensure that the system data and assumptions accurately reflect the observed operation of the system. Four scenarios were formulated namely, climate change; improve irrigation water efficiency; red – dead sea canal project and stop pumping from illegal wells. Key assumptions were identified and assessed.

Formulate the management options and recommendations

Different scenarios were formulated and operated. The findings were illustrated in form of tables and figures. Comparative analyses were finalized and set of recommendations and management options were developed and discussed.

Hydrogeology

Ground water aquifers in Jordan were divided into three main hydraulic complexes (MWI, 2009). These main aquifer complexes are, the Shallow Aquifer System (Upper Aquifer) comprising Quaternary and Tertiary Formations (Basalt, Rijam and Sirhan); the Upper Cretaceous (Middle Aquifer System) Amman Wadi Sir Hydraulic Complex; and the Deep Sandstone (Lower Aquifer System), Kurnub and Disi Hydraulic Complex. The main aquifer systems of the Azraq Basin are shown in Table.1 (WAJ, 2004).

The Upper (Shallow) Aquifer and the Middle Aquifer Systems are separated by the Muwaqqar (Aquiclude) Formation (B3). The Upper Aquifer System is an unconfined aquifer and forms the major aquifer of the Azraq Basin. The aquifer consists essentially of four different members partly separated from each other by low permeability layers partially connected. These are Quaternary sediments, Basalt, Shallala (B5) and Rijam (B4). Two major groups of springs were existed in the central part of the Azraq Basin comprising the main discharge outlets of the Shallow (Upper) Phreatic Aquifer.

The basalt extends from the center of the basin to the north and ends up in the highlands of Syria. The basalt is hydraulically connected to the underlying calcareous rocks of the B4 (Rijam) Formation. The groundwater flow is from north towards south and the groundwater moves from all directions towards the Azraq depression, (Bajjali and Hadidi, 2005). The upper aquifer system is under water table condition. The depth to the ground water table is from few meters in the center of the oasis to 400 m in the northern catchment area.

The Middle Aquifer System, locally known as Amman/Wadi Sir (B2/A7) Aquifer System. This aquifer is a confined aquifer due to aquiclude bituminous marl of the (B3) formation. The aquifer system underlies the Upper Aquifer System and outcrop in the western part of the basin. The Amman Formation (B2-Aquifer) is composed of chert, chalk and limestone.

The upper shallow fresh water basalt aquifer (i.e. the target aquifer of this study) is currently under the threat of salinization due to overexploitation, the middle limestone brackish water aquifer (600 to 15,000 mg/l) of ages more than 30,000 years and the deep sandstone aquifer which has low yields and poor quality water, (WAJ, 2004).

Water Abstraction

Amman Water Sewerage Authority (AWSA) starts to pump water to Amman in 1982 at rate of 1.5 MCM/yr. In 1982, AWSA starts pumping to Amman and Zarqa for domestic use by drilling 15 wells located in the northern part of Azraq Oasis. Municipal abstractions have been constant since 1983, and range from 23 – 24 MCM/yr. which is equal to 25 % of Amman's drinkable. However, agricultural abstraction by private wells increases by the year and currently consumes more than

55% of the total abstracted water as shown in Table .2. The main groundwater abstraction from private wells takes place from April to October each year. Azraq Basin suffers from groundwater over-abstraction by around 250 % of its safe yield (MWI, 2009).

WEAP model Setting for Azraq Basin

WEAP applications include several steps; the study area set up; time frame, spatial boundary and identifying demands and supply sites. The first step in identifying the temporal scale is to identify the current year account, that's mean the actual water demand and the actual available water resources that currently exist in the system and represent the base year of the model. The current year consider as the data sets for all scenarios developed. Current year account provides a snapshot of actual water demands and supplies for the basin. Scenarios were constructed and evaluated consisting of alternative sets of assumptions.

WEAP schematic developed as shown in figure 2, showing all components needed in the models; water supply resources & demand sites and catchments. The model consists of two main ground water resources that are connected to five demand sites by transmission links. Two catchment areas were considered in this model. Detailed description of the model components are mentioned below:

Groundwater is the main resource supplying Azraq basin, mainly (B4 and Basalt aquifers). The ground water in the model represented by green square nodes as shown in Figure 2. The maximum withdrawal from the groundwater was considered from the MWI files and data base.

The model is divided to two catchments area, one was considered in the north and the second in the south. The catchment nodes are presented in green circular. The catchments simulate run off to the wadis through the effective precipitation parameter that allows a percentage of precipitation to bypass evapotranspiration. The wadis are modeled with blue arrows and they are connected to the groundwater aquifers with blue arrows and they are connected to the groundwater aquifers to simulated water infiltration from catchments to the ground water.

Infiltration rate used as calibration parameters due to the absence of constant flow in Azraq basin, the infiltration rate ranges from 4% to 1.5 %. The effective precipitation was adjusted in order to minimize the gap between the WEAP calculated groundwater recharge and the estimated recharge from Ministry of Water and Irrigation records. The results showed close matching between the theoretical and actual ground water yield.

Water Supply sites

More than 500 wells out from 1430 wells are illegal groundwater wells constructed by the farmers (MWI 2009). Ministry of Interior starts now to monitor these wells and gave the order to terminate these wells with the help of a committee represented by police, representatives from Ministry of Interior and Department of Land and Survey.

Water Demand Sites

Five demand sites were considered in this model and presented in red nodes (Fig. 2) as the following:

Domestic water demand sites were divided into three categories:

Azraq Domestic site

Mafraq Domestic site
Amman Domestic site
Agriculture Demand
Azraq Oasis Demand

The consumption rate for all demand sites are considered to be 100 % due to the lack of water treatment plant. The leakage from the distribution network is considered to be very low with zero effect of the consumption rate. While the agriculture demand site loses rate is affected by the irrigation efficiency which equal to 70 %. The demand sites are linked with the supply sites with transmission links showed in green arrows.

Domestic Demand Sites

Azraq, Mafraq and Amman demand sites are considered as domestic sites. The domestic uses in Azraq relatively low comparing to Amman and Mafraq due to the low population rate. The total water abstraction rate for domestic use equal to 23 MCM, The average water use considered in the model as per capita rate except for Amman demand site which represent the water transmitted from the basin to greater Amman is about 17 MCM per year. While Mafraq and Azraq demand site represent the amount of water consumed yearly per capita, which is equal to 31.1 m^3 per capita per year.

Agriculture Demand Site

Due to the low rainfall rate in Azraq, agriculture mainly depends in irrigation water. The net irrigation requirement for the cultivated crop is very high. The return value for water consumption is very low. Agriculture sector is the main water consumption sector from Azraq Basin which consumes more than 65 % of the total water supplies (MWI, 2008).
The cultivated area in 2000 was 2736 ha and is expanded to 8425 ha by 2009 (MWI, 2009). The major crop pattern cultivated in Azraq are, Olive, grapes, vegetables and field crops. The crop pattern in the basin is highly consuming water and water productively is very low. An urgent need to review cropping pattern and water valuing is one of the major option will contribute to the sustainable and effective use of the water in Azraq basin. Table.3, shows the percentage of cultivated areas by crops.

Azraq Oasis Demand site

The average pumping rate from Azraq basin to the oasis is around 1.5 MCM per year. The total area of the oasis is about 7372 hectare (ha).

Catchments area

The model divided the basin into two catchment areas, the first one is in the north and the second is in the south. The catchment nodes are presented in green circular. The catchments simulate runoff to the wadis through the effective precipitation parameter that allows a percentage of precipitation to bypass evapotranspiration. The wadis are modeled with blue arrows and they are connected to the groundwater aquifers with blue arrows and they are connected to the groundwater aquifers to simulate water infiltration from the catchments to the groundwater.

Model Calibration and validation

The model was calibrated and validated for the years from 2001 – 2007. Infiltration rate used as calibration parameters due to the absence of constant flow in Azraq basin, the infiltration rate ranged from 4% to 1.5 %. The effective

Table.2 Water Abstraction from Azraq by Governorate and Sectors (MWI, 2009)

Governorates	Abstraction (m^3)				
	Domestic Use	**Irrigation**	**Industrial**	**Pastoral**	**Total**
Amman	1777699	1379664	-	27643	3185006
Mafraq	5111725	8017452	24096	61842	13215115
Zarqa	17072569	19913136	299088	55359	37340152
Total	**23961993**	**29310252**	**323184**	**144844**	**53740273**
Percentage (%)	**44.6**	**54.5**	**0.6**	**0.3**	**100.0**

Figure.2 WEAP Model Scheme for Azraq Basin

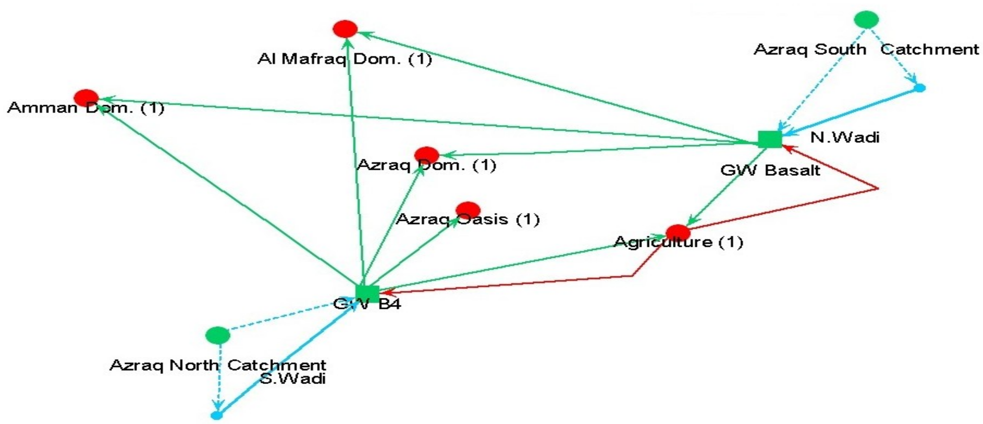
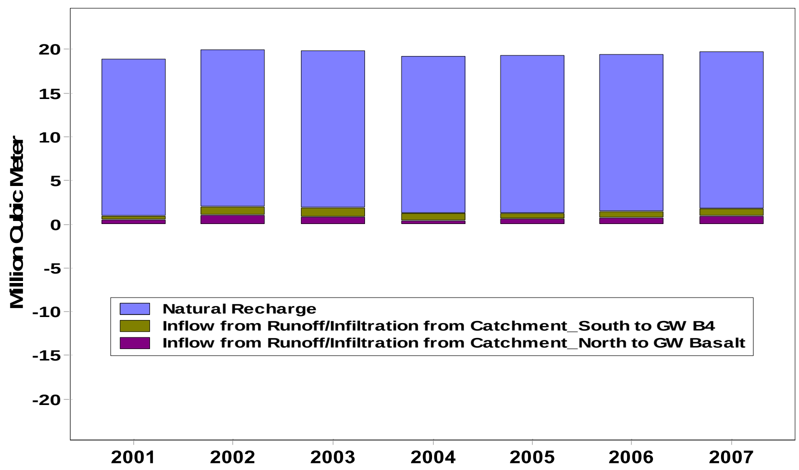


Table.3 Percentage of cultivated areas by crops in Azraq Basin.

Crop Pattern	Area in hectare (ha)	Percentage of Cultivated Areas by crops
Olive	7333	87.04
Grape	600	7.12
Vegetable	357	4.24
Field Crops	135	1.60
Total	**8425**	**100**

Figure.3 Groundwater recharge in Azraq Basin



precipitation was adjusted in order to minimize the gap between the WEAP calculated groundwater recharge and the estimated recharge from Ministry of Water and Irrigation records. The results showed close matching between the theoretical and actual groundwater yield as shown in Figure 3.

Developing Scenarios

Developing scenarios defined as tool able to predict how a future system might evolve over time in particular setting conditions and policy and management conditions. Scenarios considered as the main part of WEAP tool which allows assessing the current situation and predicting the future situation under particular management condition.

Scenarios were formulated based on the recommendations from the water strategy 2008 – 2022 and national water master plan. Future challenges and the potential water supplies sources considered in developing the scenarios.
Four scenarios established as the following:

Climate change scenario
Red – Dead Sea Canal Project
Improve irrigation efficiency
Stop pumping from Illegal wells

Reference scenario represents the future predication from 2001 to 2050 and generated from the current year account (2000) data. It provides us with future predications without any management interventions.

Reference Scenario

Reference scenario developed using the current year account data and predicts the future the future projection from 2001 until 2050. The population growth rate used in the reference scenario is shown in Table 4, (Department of Statistic, 2010).

Azraq population projected to increase from 25711 capita in 2000 to 63473 capita in 2050. Increasing in population leads to increase both water demand and the unmet demand for Azraq basin. Results showed that the total water demand will increase from 42.9 MCM to 89.2 MCM in 2050 as shown in Table 5. Results also showed that agriculture demand is the same value after 2009, this refer to the lack of data from the Ministry of Agriculture regard to the prediction of agriculture land in Azraq basin. Amman demand as well as Azraq Oasis demand is constant due to the fix amount pumping from the basin, Figure 4. Unmet water demand will increase from 22.2 MCM in 2000 to 77.2 MCM in 2050. This is due to the increases of the water demand while the water supply is constant. Water supply requirement defined as the requirement at each demand site, after demand site losses, reuse and demand-side management savings are taken into account. The results show that water supply requirement increased from 45.1 MCM in 2000 to 97.5 MCM in 2050, Figure 5.

Climate Change Scenario

Changes in annual rainfall varied among regions in Jordan. This suggests that specific regional factors might play an important role in the local climatic trend (Freiwan and Kadioglub 2008; MOE, 2009). A decreasing trend in the annual precipitation by 5-20% in the majority of the stations was apparent, which provide evidence to a climate change in Jordan during the last 45 years. According to assessment of vulnerability and adaptation to climate change on water resources in Azraq Basin (Abdulla, et al., 2008) investigated the effect of climate change on both the annual recharge and the water table of the basin aquifer.

The results for Azraq Basin reveal that the scenarios associated with temperature increased by 2^{o}C and precipitation decreased by –20%.

Limited studies on the impact of climate change on Azraq basin was conducted, lack of data and comprehensive research leads to the absence of accurate projection of the impact of climate change in Jordan in general and in Azraq basin in specific. The scenario established in this research was to assess water shortage and potential implications of climate change in water demand and supplies for Azraq basin. The scenario built three key assumptions:

Decrease precipitation by 20 %
Decrease groundwater recharge by 20 %
Increase evaporation by 20%

Results showed increasing in water demand from 49.2 MCM in 2000 to 96.5 MCM in 2050. Water demand under the climate change scenario is higher than water demand under the reference scenario. The comparison between the water demand under the reference scenario and under climate change scenario is shown in Figure 6. The unmet demand increased under climate change scenario to 89.9 MCM comparing to 77.6 under the reference scenario. Figure 7 Shows the deficit of 12.3 MCM between the unmet demands under both reference and climate change scenario.

The water supply requirements increased in all demand sites except for Amman demand site since water pumped as bulk of 17 MCM from Azraq to Amman. Agriculture demand is the highest water supply requirement due to high water demand for agriculture in addition to the losses due to evaporation and low irrigation efficiency. Figure 8, shows supply requirement under climate change scenario.

Red Dead Sea Canal Project Scenario:

Red-Dead Sea canal project designed to provide alternative water resources to Amman and in the same time to restore the Dead Sea from the shrinking. The proposed project is to construct 112 mile pipeline to transfer 1900 MCM/Y of water pass through Wadi Araba. Sea water will be pumped from Gulf of Aqaba to an elevation of 170 meters above the sea level then flow by gravity to the Dead Sea at 400 meters below sea level. The 570 meters head would generate 550 megawatts of electricity which will be used to power the initial pumping, generate hydrostatic pressure for desalination of 850 MCM/y. Potable freshwater will be delivered to Amman to cover the deficit in water demand.

The desalination plant will be located south Dead Sea with production rate of 850 MCM/Y, about 570 MCM will be diverted to Amman through conveyance. The project planned to be implemented in 2022. This project will satisfy the water demand for Amman, therefore, pumping from Azraq basin will be reduced of 17 MCM which could be used to met the other water demands site without exceed the safe yield of the basin.

The model predicted the water demand from 2022 – 2050 after satisfying Amman demand. The results show decreased of water demand under the reference scenario

(89.9 MCM) and the Red – Dead Sea Canal project (72.2 MCM) as shown in Figure 9.

Improving Irrigation water efficiency Scenario:

Agriculture activities in Azraq consider as the largest development sector after the shrinking of the Salt factory. The most important crops include vegetables, cereals and fruit trees. According to the Ministry of Agriculture, the cropped area in Azraq region is 3984 km^2, which is dependent on groundwater. Irrigation system in Azraq is managed by farmers through private owned ground water wells. Improving irrigation water efficiency is one of the main priorities for the government of Jordan. Ministry of water and irrigation formulates intervention policy for the management of irrigation water. Irrigation water policy came after the formulation of Jordan water strategy and in conformity with its long-term objectives. The policy emphasized on the importance of maximizing overall irrigation efficiency. The supply requirement at each demand site, after demand site losses, reuse and demand-side management savings are taken into account decreased as shown in Figure 10 from 97.5 MCM to 84.1 MCM.

Stop pumping from Illegal wells Scenario:

According to (MWI,2009), more than 900 wells were drilled in Azraq, of which 600 wells are illegal pumping wells. Pumping from illegal wells is 55 % from the overall pumping from the basin and directed to the agriculture activities. The absence of specific policy controlling agriculture expansion has led to dangerous spread of agricultural investments threatening sustainable water use in the future. The most important reasons behind investment in agriculture are land inheritance, availability of water and low priced land. This scenario built on the urgent need of stop the illegal well and on the ongoing effort of WAJ to control the over pumping from Azraq basin. The pumping for agriculture demand will be reduced to 50%. The supply requirements decreased also from 97.5 MCM to 66.2 MCM due to the decrease of agriculture water requirement as shown in Figure 11.

These results lead as to consider management option to convert water consumption from the agriculture sector to other sectors such as tourism and industrial sectors. Decrease in the agriculture productivity of all agriculture crops in Azraq cause low contribution of the agriculture sector to the local economy especially in terms of direct and indirect benefits. Agriculture consumed 65 % of total water supply while it just contributes only 2.5 % to the GDP. While considering increase water supply to the industry sector in Azraq basin contributing 20 % to the GDP and consumes only 3%.

Conclusions

Reference scenario developed using the current year account data and predicts the future projection from 2001 until 2050. According to the Reference scenario, the projected population will be 63473 capita in 2050. This scenario built on the actual data and considered as the baseline for all scenarios. Supply requirements equal to 97.5 MCM.

The Climate change scenario evaluated the impacts of the climate change by identifying three key assumptions, reducing precipitation by 20%, increasing temperature by 2^{o} C and reducing

Table.4 Projected Growth rate (%)

Years	Growth Rates (%)
2004 - 2005	2.6
2005 - 2008	2.3
2008 - 2015	2.2
2015 - 2050	2.0

Figure.4 Projected Water Demand under reference Scenario 2000 - 2050

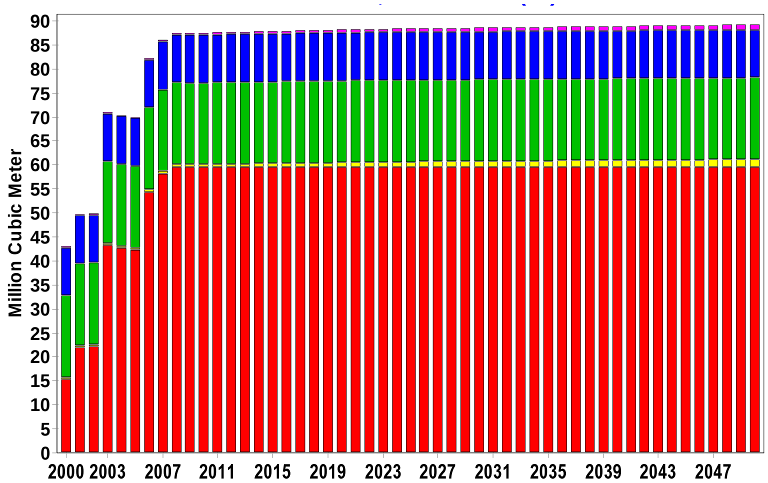


Figure.5 Projected Water Supply Requirement 2000- 2050 in Azraq Basin

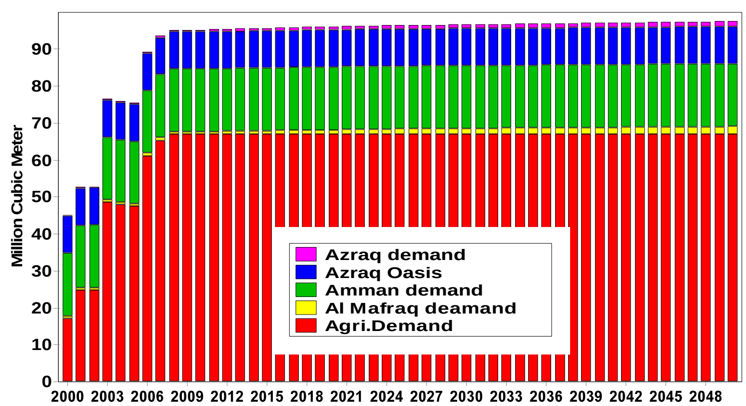


Figure.6 Projected water demand under reference scenario and climate change scenario

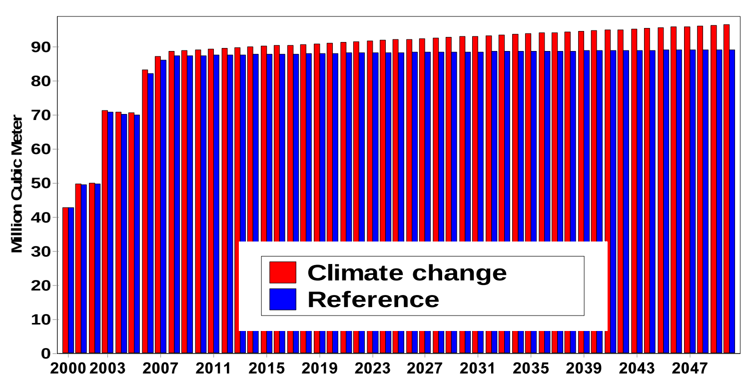


Figure.7 projected unmet demand under climate change scenario and reference scenario

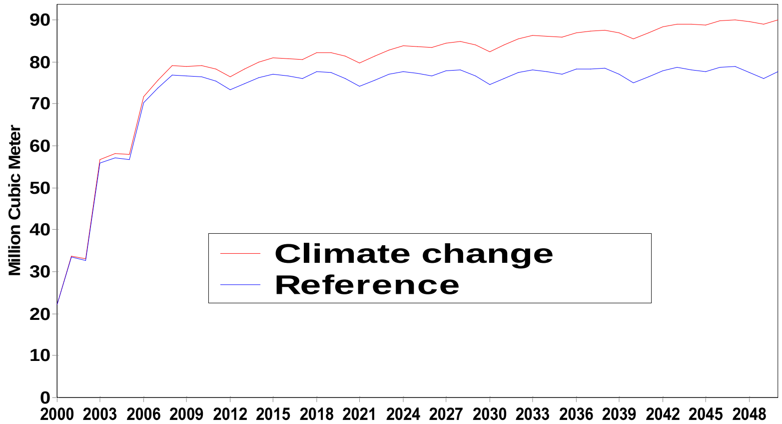


Figure.8 Supply requirement by demand sites under climate change Scenario

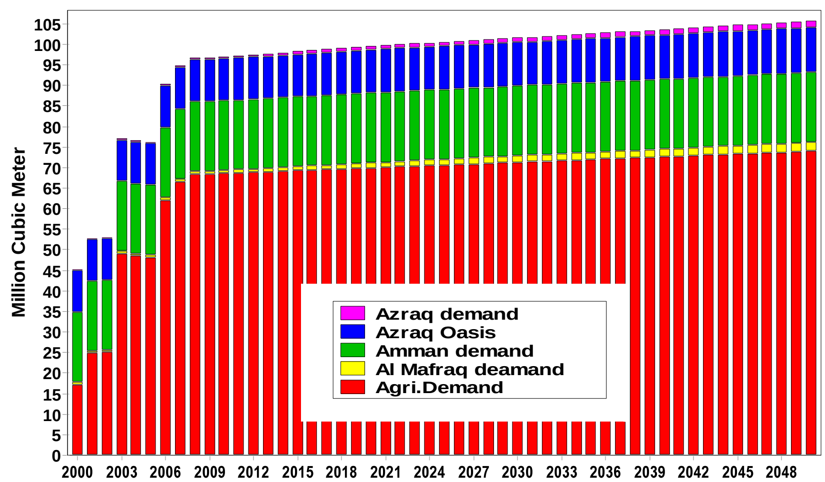


Figure.9 Projected water demand under the reference scenario and Red-Dead Sea Canal

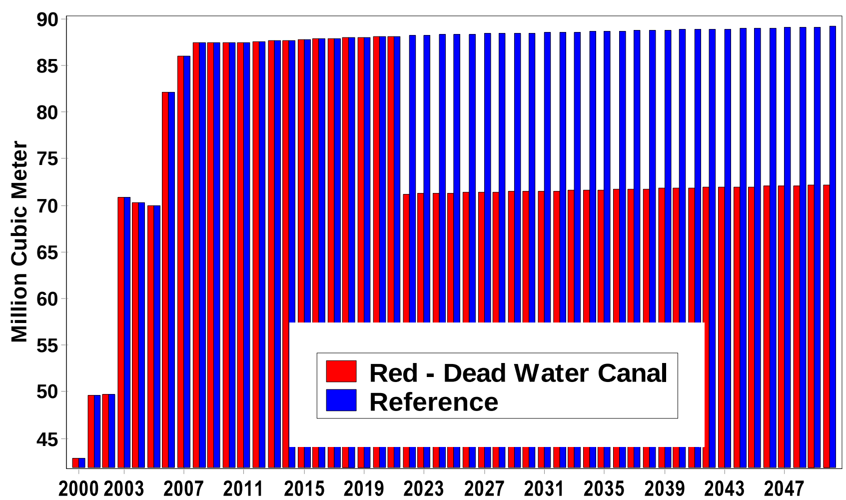


Figure.10 Projected Supply requirements under improving water irrigation scenario and the reference scenario

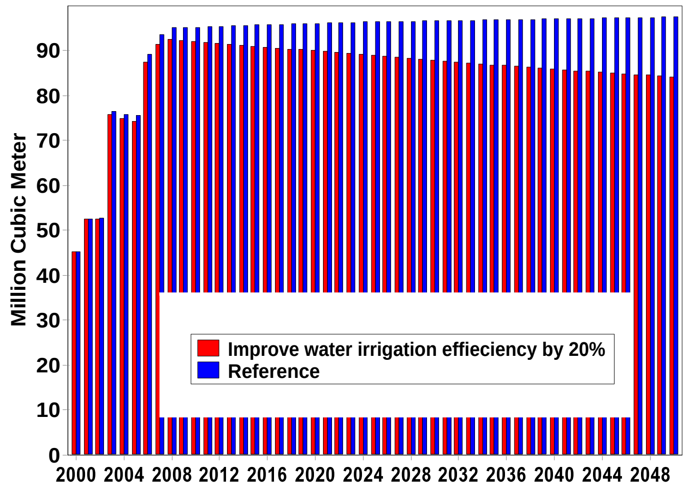
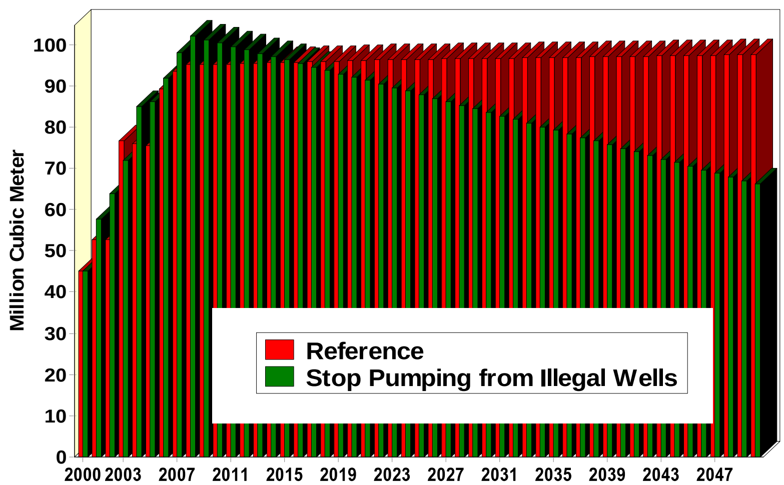


Figure.11 Supply requirements under both reference scenario and stop pumping from illegal wells.



groundwater recharge by 20%. The scenario showed clear impact of climate change in water resources in Azraq Basin. Water demand increased to 96.5 MCM, while the unmet water demands increased to 89.9 MCM. Supply requirements increased with 105.6 MCM for all the demand sites expect Amman due to the bulk pumping from Azraq Basin.

Red Sea Canal Project Scenario built on projection of the alternative water resources through red-dead sea canal, other demand sites did not affect by the which will contribute for additional water supplies for Amman equal to 500 MCM/y. This assumption translated in the scenario by stop pumping 18 MCM to Amman from Azraq basin.

Improve irrigation efficiency scenario built on the assumption of reduces the loss in agriculture system by increasing the irrigation water efficiency by 20 %. The unmet water demand for agriculture was reduced from 64.5 MCM to 51.3 MCM. The unmet water for the improving irrigation efficiency.

Stop pumping from illegal wells scenario based on the rate of pumping from illegal wells, which is equal to 55 % from the overall pumping from the basin, and directed to the agriculture activities. The scenario illustrates this fact by reducing the amount of water pumped for agriculture demand to 50%. The results showed that the overall unmet demand reduced by 59 % and for agriculture reduced to 37.9 MCM and 4.6 MCM for Azraq Oasis.

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