FINAL REPORT

Assessment of Direct and Indirect Impacts of Climate Change scenarios on water availability and quality in the Zarqa River Basin

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1. Executive Summary

Climate change in Jordan is real, in particular in relation to temperature increase. However, there is still a high degree of uncertainty when it comes to knowledge about specific changes and impacts, as well as the relative weight of global warming compared to other changes in the physical environment with potential implications for local climate, e.g. in local land use. This report aims to assess the direct and indirect impacts of Climate Change on water availability and quality in the Zarqa River Basin".

Climate trend analysis and climate change scenarios

In this part of the study various climatic regions in Jordan have been reviewed and described and the characteristics of the climatic elements also have been discussed. Then climatic trends of the important climatic factors in the kingdom mainly temperature and precipitation have been investigated, and the baseline scenarios (business as usual) of the climatic have been introduced.

Precipitation, maximum temperature, minimum temperature and mean temperature time series at selected six climatic stations have been used to investigate the business as usual (BAU) and the future climate scenarios in Zarqa River Basin (ZRB). These stations are Amman A/P, Mafraq, Wadi Dhulail from the Meteorological Department and AL0035 K. H. Nursery Evap. station (BAQ'A), AL0059 Um El-Jmal Evap. station and AL0066 Khirbet Es Samra Evap. station from the Ministry of Water and Irrigation (MWI). Trend analysis revealed obvious decreasing trends in the precipitation time series of most of the stations, the decrease in precipitation started in the decade 1970's. While temperatures showed increasing trends, the minimum temperature has increased more than the maximum temperature.

Climate baseline scenarios of the daily maximum temperature, minimum temperature, mean temperature and precipitation at the 6 locations in the ZRB have been generated for the 50 years baseline period 1961 – 2010 using the NCEP Reanalysis data, Hadley General Circulation Model (HadCM3) and the Statistical Downscaling Model (SDSM).

Future climate projections derived from the GCMs typically have too coarse resolution to examine the effects of local topography and land use, and to assess climate change impacts on station-scale sites. Therefore, in order to generate future temperature and rainfall scenarios at the 6 stations in the ZRB for the period from 2011 to 2099, we have employed the Statistical Downscaling Model (SDSM4.2) to downscale the HadCM3 General Circulation Model climate projections to the site-scale of each single location. The downscaled future scenarios were investigated within 3 periods: 2011 – 2099, 2011 – 2060 and 2061 – 2099.

Furthermore 20 incremental climate scenarios covering 50 years period 2011 - 2060 have been developed for each station in the study area as increases in temperature of +1°C, +2°C, +3°C and +4°C combined with no change, and with –20%, –10%, +10%, and +20% changes in precipitation.

The following important results were derived:

- The maximum, minimum and mean temperatures reveal significant warming trends at most of the stations. The warming trends of minimum temperature are greater than that of maximum temperature. As a result the mean temperature shows warming trends in all stations.
- The temperature increase ranges from 1-4 °C.
- The temperature increase is greater in the winter months.
- The temperature increase is greater in the period 2060 – 2099.
- The precipitation climate change scenarios are highly variable.

- The rainfall amount at Mafraq and Wadi Dhulail is expected to increase by 30 - 60 %. This result reflects the apparent uncertainty that characterizes the rainfall projections of the GCM and downscaling models.

- The future rainfall amount at Amman A/P is predicted to decrease by 15 – 30 %.

- 30 – 50 % decrease in rainfall at other locations is expected.

The reduction in rainfall amounts is expected through the winter months from October to April, which is a very important result in climate change in Jordan,while the months from May to September are exposure to increase in rainfall amounts. This result is not unusual in GCM modeling because summer months rarely record rain in Jordan. Since Jordan receives no rainfall amounts in summer season, any expected increase or decrease in the future rainfall is considered inapplicable for the country.

Impact of climate change on surface water availability

ArcSWAT was used as described earlier to build up the hydrological model for ZRB. The model was used to simulate surface runoff for the period 1970 -2009. The model perform well in simulating the surface runoff as indicated by the high coefficient of determination (R^2 = 0.95) and the good agreement between the observed and simulated flow.

Under the incremental scenarios where precipitation decreased by 20% and the temperatures increased by 1,2,3 and 4 degrees, surface runoff may drop up to 50% of the baseline scenario. On the other extreme of incremental scenarios showed that the amounts of surface runoff might increase up to 20% as a result of increasing precipitation with 20%.

HadCM3 downscaled scenarios A2 and B2 applied to show the impact of climate change on the surface runoff of ZRB. These scenarios were used as inputs of the SWAT to assess the impact of future climate changes on water arability at ZRB. The simulation was run from year 2011 until 2096. In the following is a summary of these findings

a) Both experiments (A2, B2) predict that the amounts of surface runoff are going to decreased with the next 90 years.

b) This decrease will be highly noticed after the year 2050

c) The two experiments show identical behavior about the future amounts of surface runoff.

d) The maximum amount of surface runoff would be received in 2032 based on the two experiments.

e) The maximum peak flow will drop from about 50 m^3/s recorded in the baseline scenario to less than 35 m^3/s in the future scenarios.

By comparing the long term monthly average values for future scenarios and compare them with baseline scenario, the following can be noticed:

a) Both future climate models predict that values of surface runoff amounts will be decreases for the main rainy months at ZRB (Dec, Jan, Feb and Mar). This drop of values may reach up 50% especially in February.

b) On the other hands, an increase in the surface runoff amounts will noticed on other months were usually get no or very little amounts of surface runoff like October and December.

Another important notice about the results of HadCM3 simulation results is that, it is expected to have more precipitation at summer season, which will result in surface runoff amounts in these months, while in fact this is not common at ZRB as can be seen from the baseline scenario results. The GCM models show that the precipitation will increase in summer season. But ZRB and even all the country receives no rainfall in summer months, which means that any expected increase or decrease in rainfall is meaningless and will not affect the runoff in these months. Therefore this result is not realistic for ZRB in summer months

Impact of climate change on water quality

The Impact of climate change on water quality is still considered a challenge for many researchers and investigators. Therefore, there are only limited number of studies that dealt with the impact of climate change on water quality. In addition, the fresh water chapter of the IPCC fourth assessment report did not consider the impact of climate change on water quality in a detailed manner. This is may be attributed to the fact that the research is still in its infancy in this area.

To understand the impact of climate change on water quality of ZRB, data on water quality of the ZRB were collected for the years 2005-2010 from various stations along the river. The data included flow rate, chemical oxygen demand (COD), Turbidity, Dissolved oxygen (DO), electrical conductivity (EC), Total Phosphorus and Total Nitrogen. To assess the impacts on various water quality parameters trend analysis of each parameter were carried out. The main findings are:

- There was an increase of 1, 1.5 and 1.2 ◦C in the average water temperature at stations M-9, M-10 and M-11, respectively. This indicates that water temperature is increasing with time which is reflecting the impact of the ambient temperature.
- There is a decreasing trend in the chemical oxygen demand (COD). In addition to the impact of temperature on the degradation kinetics, the decrease in COD may be also attributed to the fact that the performance of Kherbit Al Samra treatment plant which was converted into mechanical plant and put into operation in 2006.
- The COD value decreasing with increase in temperature as a result of organic matter degradation, while the TDS value is increasing. This is logical, as the solubility of solids is increasing with increase in temperature.
- Turbidity value was also observed to be decreasing with the increase in temperature. This is may be explained by the fact that most of the colloidal materials that are causing the turbidity, are of organic origin and consequently degrading with increase in temperature

Impact of climate change on groundwater

ZRB is considered one of the most important groundwater basins in Jordan with respect to its groundwater resources. The safe yield of ZRB aquifer is about 87.5 MCM which makes about 32% of the country's renewable groundwater resources. The aquifer is presently exploited to its maximum capacity where the overall groundwater abstraction slightly is around 155 MCM formulating around 177% of the safe yield. Around 75% of the groundwater is abstracted from the upper aquifers, which is the rechargeable aquifer. Due to the successive and over abstraction during the last years, groundwater levels dropped significantly in all the aquifers of ZRB.

Impact of climate change on groundwater resources was not addressed in the SNC but it was addressed in the First National communication for Azraq basin only. The availability of groundwater is measured by the safe yield of groundwater abstraction. The amount of the safe yield depends on the direct groundwater recharge (natural and artificial) and net of underground inflow-outflow of water. Trend analyses were carried out to assess the climate change impact on groundwater resources availability but were not useful. Therefore, the water balance approach accompanied with regression analysis is used to create a relationship between the rainfall amount and recharge. The impact of the climate change on the groundwater is a factor of the rainfall.

In this study impact of climate change on groundwater of ZRB is addressed using two approaches of regression analysis. Both approaches used the water balance approach to estimate the recharge amounts used to create the relationship. The incremental scenarios that were developed in this study are the input of the groundwater recharge model, where rainfall amounts were changed by -30%, –20%, –10%, +10%, +20%, and +30%. Temperature changes were not considered in development of the groundwater recharge scenarios since the preliminary trend analysis made on the temperature and recharge estimation did not show any correlation between those two parameters.

In the first approach the historical daily rainfall data for the representative rainfall stations is used to firstly calculate the monthly rainfall for all years. The monthly recharge is also estimated using SCS methodology and based on storm by storm data. The regression equation between the monthly rainfall and the monthly recharge developed for each rainfall station are then used to estimate the recharge for different climate change scenarios. The results show that there are large variations in the level of the climate change impact on the groundwater recharge among rainfall stations and among the months. The results indicated that a reduction in the rainfall amount by 30% resulted in reducing the safe yield by around 35%, while 10% reduction in the rainfall resulted in about 12% reduction in the safe yield. In the second approach the average monthly rainfall and average monthly recharge quantities for each rainfall station is used to assess the relationship using quadratic regression analysis. The reduction in the rainfall amount by 30% resulted in reducing the safe yield by around 48%, while 10% reduction in rainfall resulted in about 17.5% reduction in the safe yield. On the other hand, the increase of the rainfall by 30% led to an increase in the safe yield by 62%. The second approach predicts a large impact of climate change on groundwater in comparison to the first approach. Additionally, the impact level of the rainfall change investigated using the first approach of the regression analysis is similar in both ways (increase or decrease), while the impact level of rainfall increase is high then the impact level of rainfall decrease in the second approach. The quality of groundwater was not tackled in a detailed manner due to the lack of the data obtained from concerned agencies.

1.0 INTRODUCTION

1.1. Project Understanding

In Jordan, climate change is expected to affect the quantity and quality of the country's water resources. International studies, including reviews by the intergovernmental panel on climate change (IPCC), have reported that regions with already scarce water resources, such as the Middle East and North Africa, will suffer even more from water scarcity. Previous regional and local studies of past weather records already show an increase in mean temperatures, and in the magnitude and frequency of extreme temperatures.

Increasing temperatures, coupled with changing precipitation patterns, are expected to decrease surface water availability, and, acting on top of other stresses, increase water scarcity in the country. Jordan is ranked among the poorest countries in the world in water availability, with a per capita availability of 145 m^3/year in 2007 as reported by the Jordan's Water Strategy 2008-2022, which is- approximately 1/10th that of, for example, any Western European country. In addition, the Jordanian population continues to grow and there are greater than ever demands on its water supply. Current water usage in Jordan exceeds available water rights and groundwater wells are being exploited at unsustainable rates.

Adverse impacts of climate change will negatively affect progress toward development in a number of key areas including agriculture and food security, water resources, public health, climate-related disaster risk management and natural resources management. The Government of Jordan (GOJ) should take these impacts into account in all its national planning efforts. In addition, it is anticipated that climate change will constrain the ability of developing countries to reach their poverty reduction and sustainable development objectives under the United Nations' Millennium Development Goals (MDGs). The achievement of the MDG targets will depend on effective planning for managing climate risks.

A number of constraints exist with regards to ensuring resiliency of the MDGs in the context of emerging climate change pressures. Within this context Jordan needs to face various important issues, such as: weak capacities of national agencies, local authorities and vulnerable communities to develop coping mechanisms and strategies on adaptation and risk management; lack of tools and systems to enable appropriate planning and implementation of climate change adaptation; and a general lack of information on technological adaptation and sustainable development.

Jordan has signed the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, ratified it in 1994 and committed itself to the success of the global environmental 15 management system. The Ministry of Environment (MoEnv) became the national focal point for climate change issues and UNFCCC. Jordan started its efforts within the framework of the UNFCCC in 1996 with a GEF-UNDP supported programme for national capacity building in documenting national emissions of greenhouse gases and preparing Jordan‟s national communication to the UNFCCC. The first national communication was submitted in 1998. It was the first national communication to be prepared by a developing country party to UNFCCC. The national communication included an inventory of greenhouse gas (GHG) emissions from all sectors including energy, industry, transport, agriculture, establishments and households. The programme included developing national scenarios for greenhouse emissions for the upcoming 30 years based on various modeling systems. It has also included developing national mitigation measures for reducing the effects of climate change and a national action plan to reduce greenhouse emissions and turning into sustainable energy resources.

The MoEnv implemented between 2004 and 2006 the second phase of the capacity building programme under the title of “enabling activity” which included an inventory of current technologies. In 2009 the Ministry of Environment presented the Second National Communication (SNC) on greenhouse gas emissions that also includes suggested adaptation and mitigation measures for the first time in Jordan. The SNC project has contributed towards the development and enhancement of national capacities to fulfill Jordan‟s commitments to the Convention on a continuous basis; enhance general awareness and knowledge of government planners on issues related to climate change and reduction of GHG emissions, thus enabling them to take such issues into account in the national development agenda; and mobilize additional resources for projects related to climate change and mitigation of Greenhouse Gases.

The legislative framework in Jordan does not, at present, incorporate adaptation to climate change and awareness of climate change risks is limited within the MoEnv and public at large. Until now, no national policy for climate change was prepared. Efforts are, however, being made to rectify this situation.

In order for adaptation to climate change to become part of the national policy and decision-making routine, the key prevailing gaps and capacities need to be addressed. The UN system in Jordan has risen to help in these efforts through initiating and developing a Joint Programme (JP) by four UN organizations working in Jordan including UNDP, WHO-CEHA, FAO, and UNESCO. The JP was submitted to and later funded by the UNDP/Spain MDG Achievement Fund under the MDG-F Environment and Climate Change thematic window. The key national partners in this programme include the Ministry of Environment (MOEnv), Ministry of Health (MOH), Ministry of Agriculture (MOA), Ministry of Water and Irrigation (MWI) and Ministry of Education (MOE). The programme will also be supported by the UNDP Water Governance Facility at SIWI as it is in line with the strategy for UNDP‟s water governance programme. Other institutions, societies, and NGO‟s will be involved in the programme activities also.

This Joint Programme is designed to help Jordan through achieving the following **strategic outcomes:**

a) Sustained access to improved water supply sources despite increased water scarcity induced by climate change

b) Strengthened adaptive capacity for health protection and food security to climate change under water scarcity conditions.

These outcomes address identified barriers to adaptation and provide support to Jordan's national strategies and action plans for sustainable management of its natural resources; reducing poverty; and enhancing health indicators.

This project refers to Outcome 2 of the joint prgramme which has four outputs. The specific focus of this assignment is Output 2.4 titled "Adaptation capacity of Zarqa River Basin to climate change is piloted and strengthened" is to be implemented by the Ministry of Environment (MoEnv), Ministry of Water and Irrigation (MWI), Zarqa Governorate, and local municipalities and communities with assistance from the UNDP in the Zarqa River Basin.

In order to achieve this output many activities will be carried out in a series of studies and consultations. This specific consultation is designed to achieve the objective below and its associated tasks and activities.

1.2. Project objective

Assessment of the Climate Change situation in the Zarqa River Basin and its impacts on the water resources availability and quality in the Zarqa River Basin.

1.3. Background information

1.4. Description of the Study Area

The Zarqa River Basin (ZRB) (Figure 1) is the second main tributary to River Jordan after Yarmouk River Basin, and thus one of the most significant basins in the country with respect to its economical, social and agricultural importance. The Basin is located in the central part of Jordan and extends from Jabal Druz east to the river of Jordan in the Ghor west. The ZRB is located between 213 to 319 East and 140 to 220 North and covers an area of 3567 km^2 from the upper northern point to its outlet near King Talal Dam (KTD), and part of five governorates, namely; Amman, Balqa, Jarash, Mafraq and Zarqa and it hosts three major cities (Amman is the largest) where about 40% of the country population are living.

The basin is the most complex resource system in Jordan. At the lower end of the basin the King Talal Dam (KTD) with a capacity of 85 Million Cubic Meter (MCM) is located. The stream flow conditions of river are governed by torrential discharge characteristic with very low base flow that ranges from 0.5 to 1.0 m^3/s contrasted with irregular flood caused by rain storms of about 54 MCM. The water sources for King Talal Dam are the base flow, flood flows and the effluent of the wastewater treatment plants in the catchment area. King Talal dam is the main source for the irrigation water in middle Ghore area of Jordan Valley (about 120000 dunum). The water quality of King Talal dam is variable all over the year and governed by the blended ratio of water from the different sources. The best quality occurs when the floodwater in the dam is dominant and the waste quality occurs when the effluent of the wastewater treatment plant is dominant.

The groundwater safe yield of the basin is about 90 MCM while the abstraction rate amounts to about 158 MCM. Part of the deficit in Baqa'a and Amman-Zarqa aquifers may be compensated from seepage due to leaks in pipe network or excess irrigation. Amman area receives about 40 MCM from the basin groundwater for municipal uses. Industries in the basins pump about 8 MCM. Extractions for irrigation are estimated at 110 MCM. The annual effluent of the wastewater treatment plants totals about 85 MCM where most of it flows into KTD while only about 5 MCM are used in the basin and along the river banks for restricted irrigation. Municipal use, including Amman, totals about 180 MCM/yr. Industries use about 8 MCM coming mostly from groundwater (SNC, 2010).

Four wastewater treatment plants (WWTPs) (As-Samra, Baq’a, Jarash and Abu Nuseir) are located in the ZRB. As the largest WWTP in Jordan, As-Samra plant serves about one third of Jordan’s population (US Geological Survey 1998; Rahbeh 1996). The effluent from the four WWTPs constitutes a significant input to the ZRB dominating the runoff during the summer season.

The topography and runoff in Zarqa River area are dominated by the Amman-Zarqa synclinal structure, which forms a long depression starting in Wadi Abdon west of Amman and runs towards the northeast and then widens gradually. The ground level elevations fall from 800 to 550m a.m.s.l. along the syncline. Zarqa River originates in the upstream part of Amman area at elevation of about 800 m a.m.s.l to form Sail Amman and Sail Al Zarqa and then Zarqa River with the other tributaries. Zarqa River drains to the Jordan River at an elevation of 350 m below sea level.

The average annual precipitation in the western part of Zarqa river basin reaches about 400 mm, while in the eastern part it rarely exceeds 150 mm. The bulk amount of precipitation falls is in the winter season (i.e., between October to May). This area is mainly categorized as semi humid to arid type, covered sparsely with shrub type vegetation. A variety of crops are planted along the river, using some of the available water resources in the basin.

The soil types in the ZRW can be classified into four texture groups (clay, silty clay, silty clay loam, and silty loam). Soil layer thickness ranges from 50 to 250 cm. In certain parts of the basin soil thickness can be less than 50 cm (Abdulla et al., 2009).

1.5. Previous climate change and modeling studies in ZRB

Two major studies on vulnerability and adaptation of water resources to climate change were conducted in Jordan. These are the first national communication report (1999) and the second national communication report (SNC, 2009). Both studies included ZRB as major water resources of Jordan. In both studies climate change scenarios were developed without downscaling, groundwater and water quality issues were not addressed in these studies. Abdulla and Al-Omari (2008) presented a study on the impact of climate change on the monthly runoff of ZRB. Also, Abdulla et al. 2009 investigated the impact of climate change

The ZRB has been the focus of several studies (Al-Abed et al. 2005; JICA 2001). The watershed lies in a semi-arid region which is expected with high confidence to experience significant reduction in precipitation and water availability under potential climate change as indicated by the Intergovernmental Panel on Climate Change (IPCC) in their recent report on climate change and water (Bates et al. 2008). These conclusions support earlier findings by leading GCM models (Ragab and Prudhomme 2002) which points to a climate change induced pattern of prolonged and severe drought in the Middle East and North Africa (MENA) region.

As ZRB is the mostly developed and heavily populated basin in Jordan, in addition to the fact that the basin plays a central role in the water resources management in Jordan, the water resources in the basin have received great attention from researchers as well as from decision makers over the last two decades. Several studies that evaluated the available water resources in the basin were conducted i.e. safe yield of ground and/or surface water (BGR 1994, 1998; USGS 1998; Al-Abed et al. 2005; Al-Abed and Al-Sharif 2008). Other studies proposed management scenarios that considered both sides of the equation; the resources and the demands, their quantities and quality in addition to the socio-economy of the basin (Grabow and McCornick 2007). Furthermore, unconventional water resources such as reuse of treated wastewater, desalination of brackish water and grey water reuse were evaluated by several researchers as a promising option to bridge the continuously enlarging gap between fresh water resources and demands (Gur and Al-Salem 1992; Mohsen and Al-Jayyousi 1999; Jaber and Mohsen 2001; McCornick et al. 2002; Al-Jayyousi 2003; Fatta et al. 2006; Mohesn 2007).

Despite the relatively large number of studies that tackle the different aspects of the water resources and demands in the ZRB, no single study that integrates all the available resources and demands that takes into consideration the socio-economic development of the basin for the purpose of developing a water resources management plan at the basin level has been performed. The study presented by Al-Omari et al. (2009) aimed at the development of a WMSS for ZRB that integrates all the resources both conventional and non conventional, and all the demands as well. The study considered the year 2007 conditions of water availability as well as the possible evolution of new resources and new demands for the year 2025. The socio-economic development of the basin over the next twenty years is taken into consideration as well.

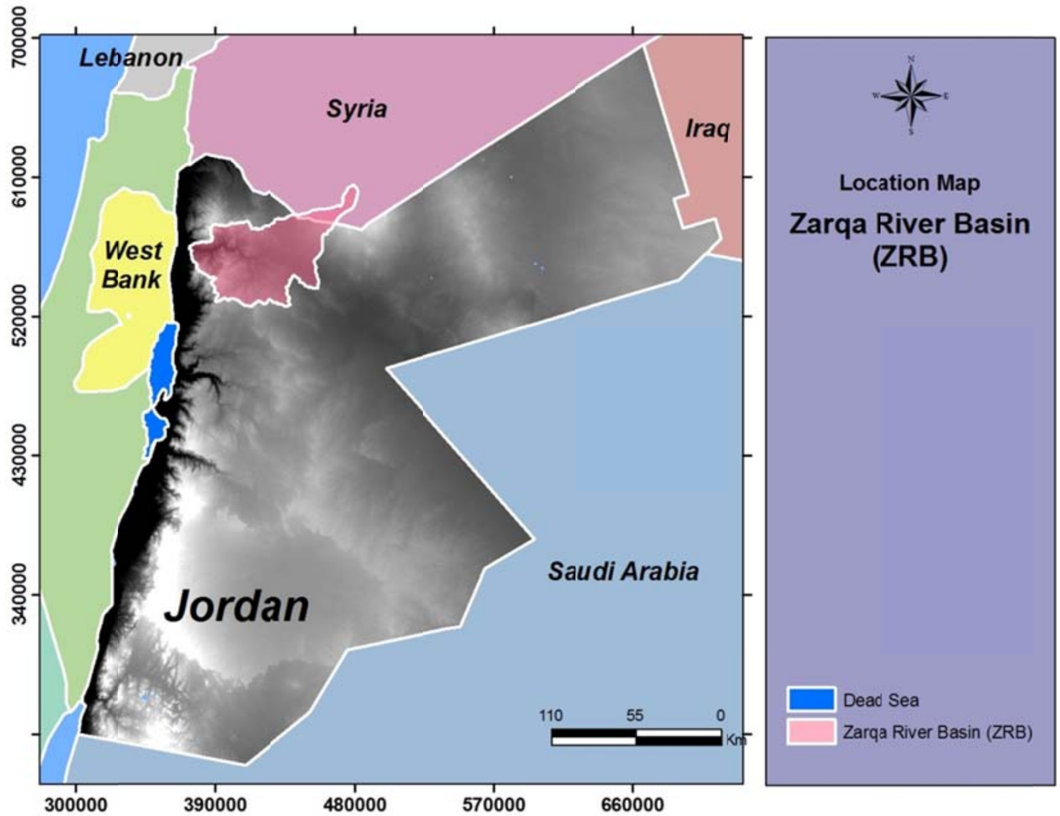


Figure (1): Location map of Zarqa River Basin (ZRB)

2. METHODOLOGY

2.1. Introduction

This section describes the overall methodology that was followed in the analysis of the potential direct and indirect impacts of climate change on water availability and quality in Zarqa River Basin (ZRB). The proposed methodology is consistent the analytical framework developed by the Intergovernmental Panel of Climate Change (IPCC, 2007). The approach begins with the definition of the scope of the problem and the assessment process. Steps 2 and 3 of the IPCC are selecting and testing methods. Step 4 is concerned with climate change scenarios selection. Steps 5 & 6 are concerned with conducting the climate change assessment process which includes:

- Assess biophysical impact (direct and indirect impact)
- Assess socioeconomic impact

The last step is concerned with evaluating the adaptation strategies.

Description of the major steps in the IPCC methodology which are necessary to be incorporated in the ZRB vulnerability and adaptation to climate change study is presented below. This project is focusing on the vulnerability part of the assessment.

This report describes the potential implication of climate change on water resources sector (availability and quality issues) of the ZRB. The following tasks were carried out:

1. Conducting trend analysis of important elements of the climate
2. Construct realistic climate change scenarios including BAU. These scenarios include:
   a. Baseline scenario (BAU).
   b. Scenarios based on the General Circulation Models (GCMs). The suitable scenarios for ZRB will be selected based on the IPCC guidelines for climate change scenarios development. Output of the selected GCMs will be downscaled to ZRB using an appropriate statistical downscaling procedure. The selected downscaled climate variables will be compared to the observed climatic variables in ZRB. The GCMs that have good agreement with observed climatic data in ZRB will be used in the assessment of direct and indirect impacts of climate change on water availability and quality in the ZRB.
   c. Incremental scenarios based on Jordanian experience
   d. Climate change scenarios will be downscaled using appropriate statistical method.
3. Investigate under the different climate change scenarios the direct and indirect impacts on water availability (surface and groundwater) and quality in ZRB.
4. Develop an educational Presentation to the MoEnv and UNDP professionals on the findings of the whole assignment findings, results, and recommendations..

The following sections explain the detailed tasks and activities that were carried out to meet the objectives of this project and the methodology above.

2.2. Data Collection and Preparation

Available data and information needed for this project were collected and tabulated in proper format for further analysis (see Table 1). The collected data was checked for completeness, accuracy and representation so as to make it reliable for the application in the study.

The data collection include the climatic, hydrological data (streamflow data), treated wastewater and information about the water treatment plants, king Talal dam basic and operational data and all monitoring data for ground and surface water as well as the use of these waters. Previous studies indicated that climatic and hydrological data for Zarqa River basin are available for the 50 years. Long record of data will improve the outcome of this study.

The data collected and used in this project was put in CD and will be provided to the MoENV and UNDP.

Table 1: Sample of data used in the project

Examples of Simplified Meteorological, Hydrological, Morphological Data and Data on Water Quality Needed for Scenarios and Vulnerability assessment		
Climate Data – Rainfall, temperature, Pan A exportation, wind speed, relative humidity, etc – GCM Output Data **Morphological Data** – Topographic Data – Land use – Soil Data **Satellite Imagery** – Multi spatial, spectral and temporal satellite images (e.g Landsat ETM+)	**Water resources data** – Hydrological data (streamflow data) – Groundwater data (water levels, groundwater abstraction, number and locations of wells etc) – Water supply data by various sectors – Water demand data by various sectors **Water Quality data** – Physical, Chemical and Biological parameters, Like BOD, COD, Nitrates, TDS, pH, alkalinity ..etc. – Bio-Indicators. – Influent and effluent quality parameters of the Waste Water Treatment facilities in ZRB.	**King Talal Dam Data (KTD)** – Monthly inflow & outflow rates evaporation losses and net storage. – Annual sedimentation – Monthly and annual contribution of WWTPs effluent to King Talal dam waters – Quality of treated wastewater into KTR from WWTPs – Elevation-area- volume relationship – Average yearly of KTR water quality from 1988 to 2009. – Soil analysis

3. Climate, climatic trends and climate change scenarios

3.1. Introduction

Global surface temperature has increased by about 0.3 – 0.6°C since the late 19th century and about 0.2 – 0.3°C over the last 40 years in the 20th century (Houghton et. al, 1995). The global temperature has risen rapidly during the period beyond the year 1970 up to the end of the second millennium and similarly during the first few years of the third millennium. The surface temperatures do not increase uniformly. Therefore the regional and local consequences of the global climate change differ from place to place over the planet's surface. Climate change studies in Jordan show that the minimum temperature has increased at a rate as higher as than twice the rate of maximum temperature increase (Freiwan and Kadioglu, 2008-b). Also it is found that the rate of warming varies from one region to another on the earth surface and the precipitation shows either increasing or decreasing rates in various regions on the earth's surface.

Few studies have investigated climate change and climate variability in Jordan. (Tarawneh and Kadioglu, 2002; Freiwan and Kadioglu, 2006; Dahamsheh and Aksoy, 2007; Freiwan and Kadioglu, 2008-a) have studied the temporal and spatial analysis of precipitation in Jordan. (Bani Domi, 2005; Freiwan and Kadioglu, 2008-b) have investigated the trends of the precipitation, temperature and other climatic variables in Jordan. These studies show that the temperature time series exhibit increasing trends while the precipitation time series reveal decreasing trends in the majority of the meteorological stations in the country.

Climate change scenarios in Jordan have been investigated in fewer studies; Ragab and Prudhomme (2002) expected a reduction of precipitation about 20 – 25% in the dry season (April – September) and 10 – 15% in winter time with temperature increase about 1.5°C in Jordan during the current half of the century.

In the First national communication (FNC) study, climate change scenarios were developed using the projections of two GCMs for a 30 years period, 2000 – 2030. Downscaling methods were not used in developed climate change scenarios.

In the Second National Communication (SNC) study, climate change scenarios were developed using the projections of three GCMs for a 45 years period, 2006 – 2050. One of the major uncertainties in the previous climate change scenarios studies was how to increase the resolution of the models or to increase the number of the models grid points in a small area like Jordan or even in a smaller region like a river basin. In the recent study SNC, the resolution of the GCMs was increased using interpolation methods and the grid point number was increased from one grid over the whole country to 9 grid points over Amman-Zarqa River Basin and the Jordanian part of the Yarmouk Basin. Downscaling methods were not used in the developed climate change scenarios.

In order to assess the impacts of climate change on water availability and quality in the Zarqa River Basin, this study reviews the climate of Jordan, then investigates the climatic trend of the important climatic factors in the kingdom mainly the temperature and the precipitation, Introduces baseline scenarios (business as usual) and finally generates future climate change scenarios of some climatic elements in the Zarqa River Basin downscaled separately to each single observation station using the Statistical Downscaling Model (SDSM).

3.2. Climate of Jordan

Jordan is located about 80 km to the East of the Mediterranean Sea, between 29°10’- 33°45’N and 34°55’–39°20’E with an area of 89,329 km^2. The country has a unique topographic nature that might not be found anywhere else. The Western part of the country is the world lowest valley that lies north – south between two mountain ranges with a length of about 400 km and a width varies from 10 km in the North to 30 km in the South and elevation between 170 – 400 m below Mean Sea Level. Jordan River passes through this valley from north to south down to the Dead Sea. Just to the east of the Jordan Valley the North – South mountain range reaches about

1150 m above MSL in the Northern parts and about 1500 m above mean sea level (MSL) in the Southern parts of the kingdom. To the East of this mountain range a semi desert plateau extends to cover approximately 80% of the total area of the country. Most of Jordan (90%) is arid and semi arid areas that characterized by remarkable rainfall variation with total annual rainfall averages less than 200 mm.

The climate of Jordan is predominately of the Mediterranean type; it is characterized by a hot dry summer and rather cool wet winter, with two short transitional periods; the first starts around October and the second around mid of April. The rainy season starts by October and ends by May. Therefore, the rainy season comprises two fiscal years, for example the rainy season 2005/2006 comprises October, November and December of 2005 and January, February, March and April of the year 2006.

According to the geographic and topographic characteristics, Jordan can be divided into three main climatic regions. The first one is the Jordan Valley or the Ghore Region (which means low land); the second is the Highlands Region; and the last is the Badia and Desert Region. A description of these regions has been provided. In addition, the spatial and temporal distribution of precipitation that reflects the climatic characteristics of the different climatic regions of the kingdom has been described.

3.3. Climatic regions of Jordan

The Ghore (The Lowlands): The Ghore is part of the Great Rift Valley. Its length is about 400 km extending from North to South, which is almost parallel to the eastern coast of the Mediterranean. The Ghore consists of three parts: The Jordan River, the Dead Sea (The lowest elevation on earth) and Wadi Araba. The elevation of the Ghore ranges from 197 m below MSL in the north to more than 400 m below MSL at the Dead Sea. The width of the Ghore is approximately 15 km in the north expanding gradually to about 30 km in the south. The area of the Ghore east of River Jordan and Dead Sea is about 3000 km^2.

The Highlands and Marginal Steeps Region: The Highlands Region extends north - south to the east of the Ghore. About 88% of human settlement of Jordan lives in this region. The highlands region can be divided into the Mountainous Region and the Marginal Steeps Region. The Mountainous Region extends from the Yarmouk River in the north to Ras El-Naqab in the south; the mountain ranges are dissected at several locations by valleys such as: Zerqa River, Wadi Mujib and Wadi El-Hasa. The elevation of the peaks of these mountains varies from 1150m above MSL in the north (Ras Muneef) to about 1365m above MSL in the south (Al–Shoubak), some peaks exceeds 1500m above MSL (El-Qurain). The total area of the mountains regions is about 7900 km^2.

The Marginal Steeps Region stretches from north to southeast the Mountainous Region, from the Syrian borders in the north to Ras Al-Naqab in the south. It has an area of 9000 km^2. This region is the most potential rangeland of Jordan.

The Badia and Desert Region: This region is a plateau extending north - south from the foot of the Highlands eastward. The total area of the Badia and the Desert is about 70000 km^2, with an elevation of about 600-750 above MSL, the annual rainfall of the Badia ranges from 50 to 100 mm. The south–east of the region is true desert with annual rainfall less than 35 mm, the total area of the Jordanian Desert is 30000 km^2.

3.4. Precipitation characteristics over various climatic regions

Figure 2 obviously shows that the rain season in Jordan extends from around October to May of the next year and about 80% of the seasonal rainfall occurs through the months of December to March.

The annual total precipitation amounts vary sharply from one climatic region to another. In general the annual precipitation in the Ghore Region is less than that over mountainous region. The annual precipitation in the northern parts of the Ghore is the highest at the north, decreasing gradually southward. Figure 3 shows the spatial distribution of precipitation in the Ghore Region.

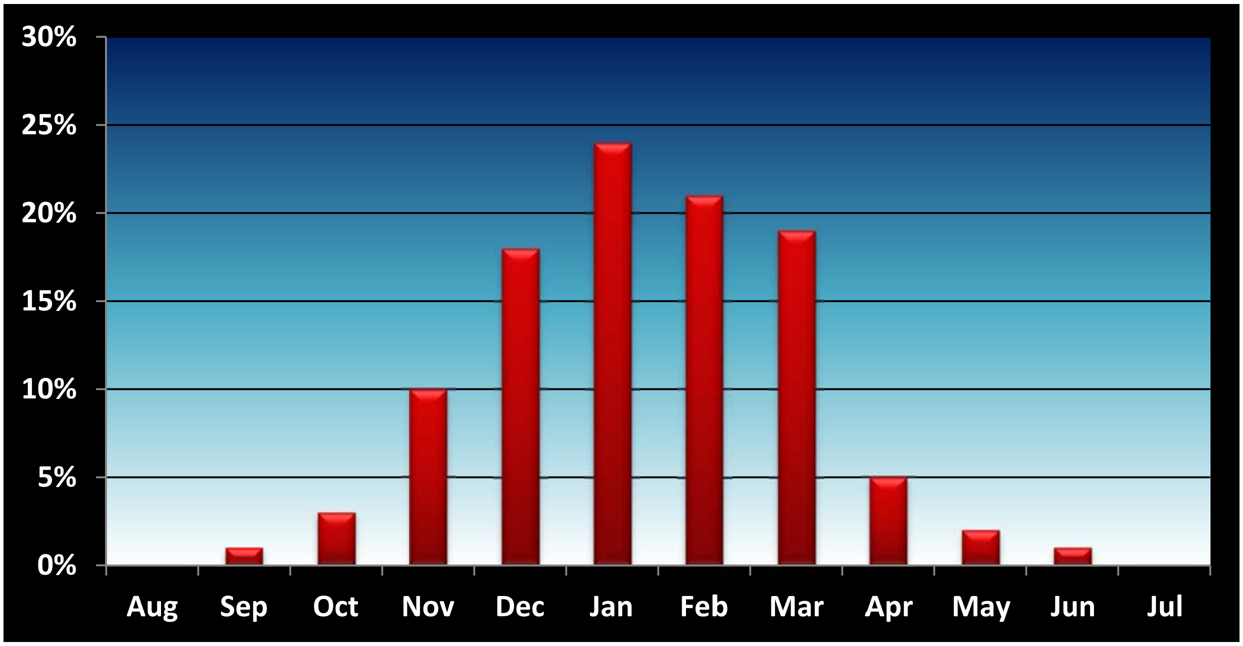


Figure (2): Temporal Distribution of the Rainfall over Jordan.

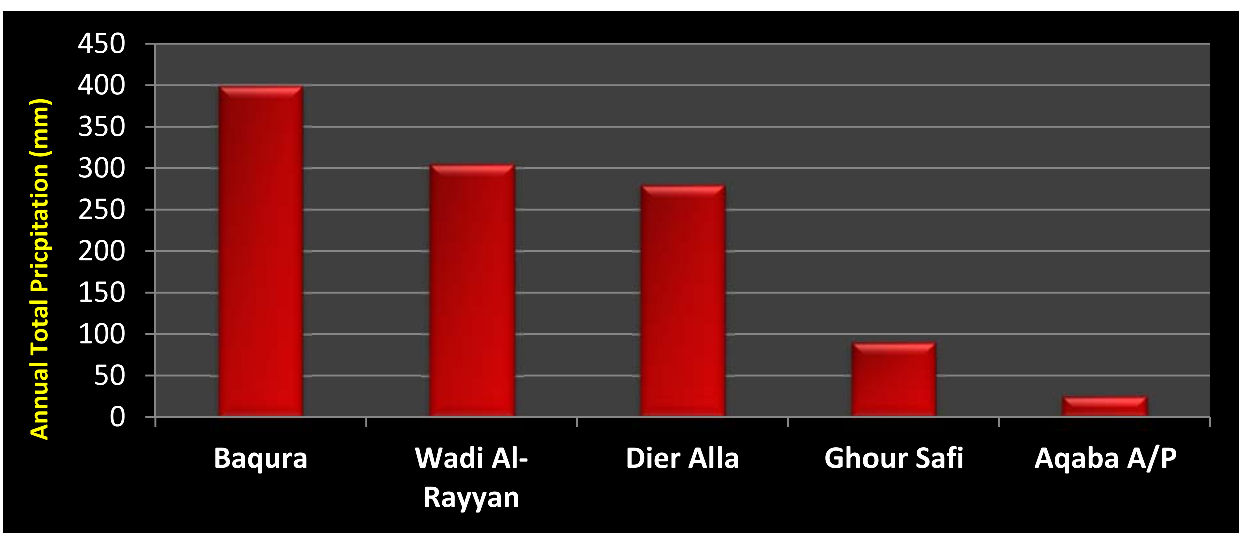


Figure (3): North – South spatial variation of precipitation in the Ghore region.

The amount of annual precipitation in mountainous region is the highest. It exceeds 550 mm in Ras Muneef (592 mm) and Bulqa mountains (557 mm), decreasing gradually southward to 349 mm in Madaba, 336 mm in Al-Rabba, 304 in Al–Shoubak and 229 mm in Tafeeleh. Figure 4 shows the north – south spatial distribution of precipitation in the Highlands Region.

In the Steeps Region, the amount of rainfall is about 100-200 mm. It is 150 mm in Mafraq and Wadi Dhulail. In the Badia, it is about 75-110 mm in the north decreasing to about 60 mm in the south. In the Jordanian Desert (south east of Jordan) the annual rainfall is less than 35 mm (31.7 mm in Al–Jafr). Figure 5 illustrates the west – east spatial distribution of precipitation over the kingdom.

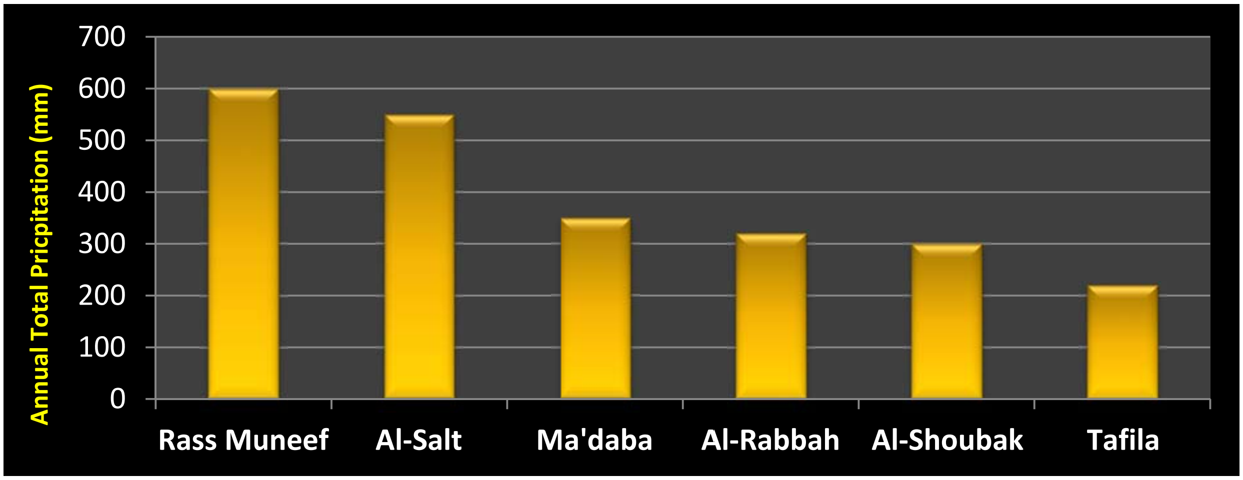


Figure (4): North – South spatial variation of precipitation in the Highlands region.

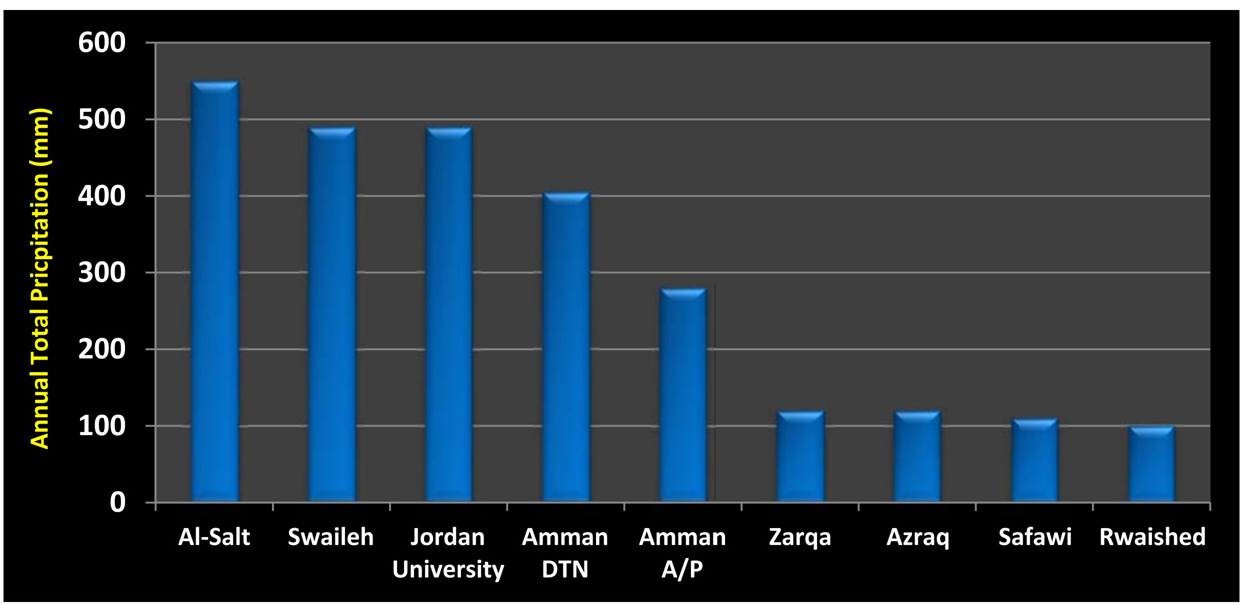


Figure (5): West – East spatial variation of precipitation over the kingdom.

3.5. Temperature characteristics over various climatic regions

The temperature in the Ghore is very high. It is very hot in summer and warm in winter. Therefore, the Ghore region is considered the main source of vegetables and fruits in Jordan during all seasons. Moreover, the Ghore is also considered the best winter resort. During summer the mean daily maximum temperature is around 39 °C. During winter the mean minimum temperature is about 9 °C, the temperature is pleasant and frost is rare.

In the mountainous region it is rather cold during winter. The mean daily minimum temperature is about 4 °C. During summer it is pleasant and the mean daily maximum temperature is between 26 – 30 °C.

In the Badia region (desert region) it is hot in summer and cold in winter the maximum temperature in summer varies between 36 °C and 38 °C and the minimum temperature in winter varies between 1 °C and 4 °C.

3.6. Trends of climatic elements

Several methods of estimating trend significance have been used in climatological studies. Probably the most common approach is to estimate trends by linear regression methods. Such parametric methods require the variable to be normally distributed and temporally and spatially independent. To avoid disadvantages of the parametric linear regression methods, nonparametric methods such as the sequential Mann-Kendall rank method is employed.

The climatic trend is defined as a monotonic increase or decrease in the average value between the beginning and the end of an available time series. Therefore, the linear trends are not the correct tool to detect the start of the trend. Among some nonparametric trend tests, the sequential version of the Mann-Kendall rank trend test has the ability to detect the beginning and/or the end of the trend. The Mann-Kendall test is widely used for trend testing, particularly when many time series needed to be analyzed at the same time (Sneyers, 1990; De Gaetano, 1996; Freiwan and Kadioglu, 2008-b; SNC, 2009).

In the SNC (2009) climate change study the monthly time series of precipitation, mean temperature, maximum temperature, minimum temperature, relative humidity, Class A-Pan evaporation, number of rainy days and sunshine duration are analyzed in order to identify meaningful long-term trends by making use of the Mann-Kendall statistics in addition to the linear trend statistics. For this purpose 19 meteorological observation stations that represent all the climatic regions of the country were selected and their longest available records of the above mentioned climatic elements were subject to trend analyses.

The SNC trend analyses show that the precipitation time series exhibit decreasing trends in the majority of the stations in the country. But it is significant only in Al–Shoubak and QAIA/P. While some other stations exhibit insignificant (slight) increasing precipitation trends such as: Ruwaished, Safawi, Deir Alla, Jordan University and Ras Muneef. Maximum, minimum and mean temperatures revealed significant warming trends at 99% confidence level in most of the stations. The significant warming trends of minimum temperature are too much greater than that of maximum temperature. As a result, the mean temperature shows significant warming trends in all stations which is in a great agreement with the findings of other studies conducted in the region such as: GCEP, 1999; Freiwan and Kadioglu, 2006; Freiwan and Kadioglu, 2008-b.

3.7. Trend Analysis in Zarqa River Basin (ZRB)

Six observation stations are used to investigate the trends of the observed time series of maximum, minimum, mean temperatures and precipitation amount in Zarqa River Basin (ZRB). These stations are: Amman Airport, Wadi Dhulail and Mafraq stations from the Jordanian Meteorological Department, and AL0035 K. H. Nursery Evap. station (BAQ'A), AL0059 Um El-Jmal Evap. station and AL0066 Khirbet Es Samra Evap. station from the Ministry of water and irrigation (Figure 6).

3.8. Precipitation trends

Figure A-1 shows that Wadi Dhuleil, Amman Airport, Mafraq, Umm El Jmal revealed an obvious decreasing trends in the precipitation time series. While Baq'a stations didn't show any significant tend. Khirbet Es Samra station exhibited an increasing trend in precipitation. The annual rainfall amount in the station is 120 mm. The station has started in 1986 with a record length of 23 years, which is very short period for trend and climate change studies. There are few low annual readings in the beginning of the record that corresponds to the decade 1980's. The 1970's and 1980's are the two decades where the precipitation starts to decrease in the most of locations in the country. In the mid of the time series 1994 and toward the end of the series 2003 the largest rainfall amounts were recorded, 217 mm and 194 mm consequently. This is why the precipitation in Khirbet Es Samra unlike all other stations showed an increasing trend. Accordingly the trend in this station cannot be considered as real increasing precipitation trend.

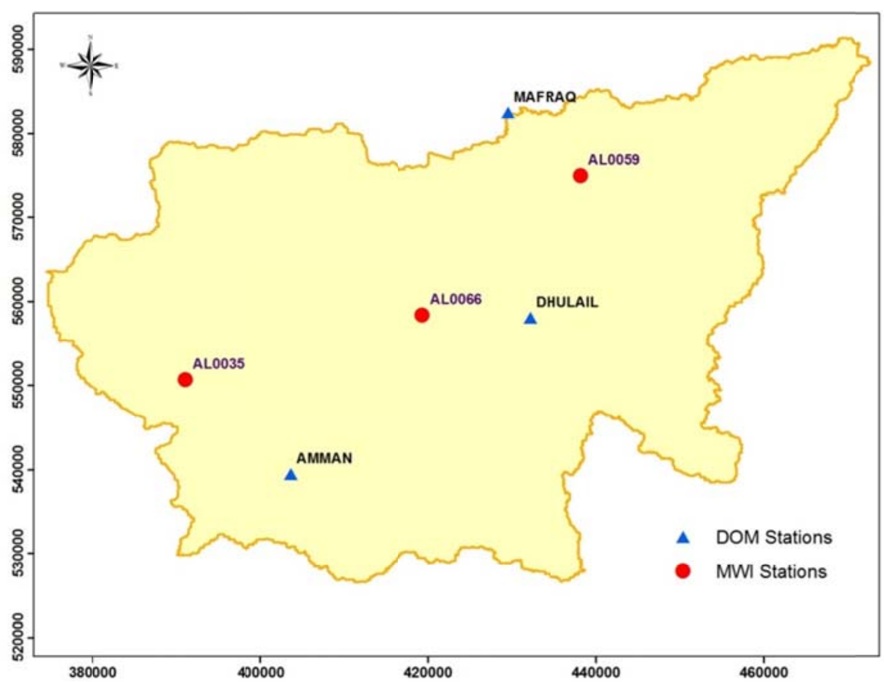


Figure (6): The climatic stations selected to investigate their trends and to generate climate change scenarios.

3.9. Temperature trends

Figure A2 Shows that the maximum temperature time series reveal obvious increasing trends in Wadi Dhulail, Mafraq, Baq'a, and Khirbet Es Samra. While Amman A/P station exhibits a slight insignificant decrease in the maximum temperature. Amman A/P maximum temperature time series shows that there is a jump in the data in the year 1967; there is a sudden decrease in the annual maximum temperature from 25.5 °C in 1966 to 22.4 °C in 1967, this abrupt jump is no not a real temperature variation, it is attributed to the transfer of the station location within the airport area that affects the homogeneity of the data. Khirbet Es Samra station the only station that reveals obvious significant decreasing trend.

All stations in the ZRB reveal increasing minimum temperature trends except Khirbet Es Samra and Umm El Jmal (Figure A3). The same figure obviously shows that the minimum temperature decrease is greater than the maximum temperature decrease.

The mean temperature increasing trends are also obvious and significant in all locations except Khirbet Es Samra which exhibits a decreasing trend and Umm El Jmal that doesn't show any trends in the mean temperature (Figure A4).

3.10. Climate change scenarios

Climate change impact assessment studies usually require characterization of future climate conditions, i.e., climate scenarios. Climate change studies indicate that the global climate is likely to warm. However, the direction and magnitude of regional climate changes over the next century are highly uncertain. Because of this significant uncertainty, scenarios are used as a tool to explore likely impacts of potential changes in regional climate.

3.11. Types of climate scenarios

3.12. Baseline scenarios (Business as Usual)

A baseline climate is the climatic conditions that are representative of present day or recent prevailing climatic trends for a given period of time in a specific geographic area. A baseline climate describes average conditions, spatial and temporal variability and anomalous events over the baseline period. The baseline climate should provide sufficient information on those present-day conditions that will be characterized in the scenarios under a changing climate at the appropriate temporal and spatial scales. It also provides a benchmark against which to measure future changes in climatic variables and to assess the impacts of future changes. In addition, impact assessors might use baseline climate data to calibrate and test impact models. Good quality observed climatological data are often required to define a baseline climate.

Business as usual climate studies uses the following sources of data for defining baseline climatologies:

- **i.** The national meteorological services and other agencies' archives, or
- **ii.** Supranational and global data sets which are prepared by Annex I countries to the UFCCC and international organizations, or
- **iii.** Weather generators which are statistical models that describe the properties of an observed climatic variable in a region using few parameters, or
- **iv.** Climate model outputs: two types of data from GCM simulations can be used for specifying climate baselines: (i) reanalysis data and (ii) outputs from the General Circulation Models (GCMs) control simulations.

The primary objective in applying baseline data in an impact assessment is to characterize the sensitivity of the exposure unit to present-day climate. A baseline climate scenario may be created to examine the behavior of each sector under the current climate. In addition, the baseline climate scenario may be compared with the outputs of the GCMs at the current condition to select the most appropriate GCMs to be used in the climate change studies.

In this study, the climate baselines are constructed to cover the 50 years period 1961 – 2010. The observed climatological data used to develop the baseline scenarios were obtained from the Jordanian Meteorological Department and the ministry of water and irrigation. The record lengths of the observed data used to generate the baseline scenarios are given in Table 2. Table 2 shows that the record lengths of the MWI stations (AL0035, AL0059 and AL0066) are consequently 46, 42 and 22 years for rainfall and 42, 40 and 23 years for temperature. While the record length of the Meteorological Department stations (Wadi Dhulail, Amman Airport and Mafraq) is 45 years for both rainfall and temperature. Thus none of the 6 stations has 50 years record to be used directly as a climate baseline scenario. Therefore we were forced to generate 50 years baseline scenarios of daily maximum temperature, minimum temperature, mean temperature and precipitation from the NCEP Reanalysis data using the Statistical Downscaling Model (SDSM) and Hadley General Circulation Model (HadCM3) outputs for the mentioned 6 locations (Figure 6). These 6 climatic stations are the available only stations that include proper temperature and rainfall data in the ZRB. There is no further single station has a complete 10 years temperature time series in the basin, neither Meteorological department nor MWI station. Moreover the downscaling procedure is done separately for each single station and it is not affected by other locations. Thus the number of stations is not important in such studies.

Table 2: The record length of the data used to generate the baseline scenarios.

	Station					
Climatic Element	**Wadi Dhalail**	**Amman Airport**	**Mafraq**	**Al0035 Baq'a**	**Al0059 Khirbet Es Samra**	**Al0066 Um El Jmal**
Rainfall	1968-2005	1961-2005	1961-2005	1964-2009	1968-2009	1986-2009
Temperature	1968-2005	1961-2005	1961-2005	1967-2008	1969-2008	1986-2008

3.13. Climate change scenarios

Climate change scenarios describe plausible future changes in climate variables and are usually measured with respect to baseline climate conditions. Although climate change scenarios can be applied directly to support risk analysis, most (biophysical) impact assessments require inputs of future climate *states*, rather than *changes*, with relation to the baseline reference period, in order to assess potential impacts of projected changes in climate. Climate scenarios usually (although not always) combine observed baseline climate with estimates of future climate changes. These possible changes are often (although not always) derived from climate model outputs.

The most common approach to deriving climate change scenarios is to make use of General Circulation Models, or Global Climate Models (GCMs).

The GCMs are mathematical representations of physical processes in the atmosphere, ocean, cryosphere and land surface. GCMs depict the climate using a three-dimensional grid over the globe, typically with a horizontal resolution between 150 and 450 km, 10 to 34 vertical layers in the atmosphere and as many as 30 ocean layers. The GCM's resolution is thus rather coarse relative to the scale of exposure units in most impact assessments. Thus, downscaling or regionalization techniques are required to "transfer" the coarse-resolution GCM outputs to the regional or local scales or even to a single site required for Climate Change Impacts assessments.

3.14. Statistical DownScaling Model (SDSM)

In previous climate change studies site-scale climate change scenarios of mean temperature and rainfall amount were constructed from the GCM's outputs using interpolation techniques to increase the number of grid points over the area and to generate average future scenarios in the study area (Climate change scenarios – Second National Communication Report to the UNFCCC – Vulnerability & Adaptation).

In this study the Statistical DownScaling Model (SDSM) version 4.2 developed by Wilby et al (2002) is employed to generate site-scale or station-scale future climate change scenarios of maximum temperature, minimum temperature, mean temperature and rainfall amount from the GCM's outputs at each of the selected six stations in ZRB.

General Circulation Models (GCMs) indicate that rising concentrations of greenhouse gases will have significant implications for climate at global and regional scales. Unfortunately, GCMs are restricted in their usefulness for local impact studies by their coarse spatial resolution and inability to resolve important sub–grid scale features such as topography and site climatic characteristics.

As a consequence, two sets of techniques have emerged as a means of deriving local–scale surface weather from regional–scale atmospheric predictor variables Firstly; statistical downscaling is analogous to the "model output statistics". Secondly, Regional Climate Models (RCMs) simulate sub–GCM grid scale climate features dynamically using time–varying atmospheric conditions supplied by a GCM bounding a specified domain. Both approaches will continue to play a significant role in the assessment of potential climate change impacts arising from future increases in greenhouse–gas concentrations.

Statistical downscaling methodology enables the construction Land Precipitation Topography Vegetation Soils Aggregation Downscaling RCM GCM SDS Climate Model Grid Scale of climate change scenarios for individual sites at daily time–scales, using coarse grid resolution GCM output (Figure 7).

Statistical downscaling methodologies have several practical advantages over dynamical downscaling approaches. In situations where low–cost, rapid assessments of localized climate change impacts are required, statistical downscaling (currently) represents the more promising option. In addition:

- Station–scale climate information from GCM–scale output
- Cheap, computationally undemanding and readily transferable

- Ensembles of climate scenarios permit risk /uncertainty analyses
- Applicable to 'exotic' predictands such as air quality and wave heights.

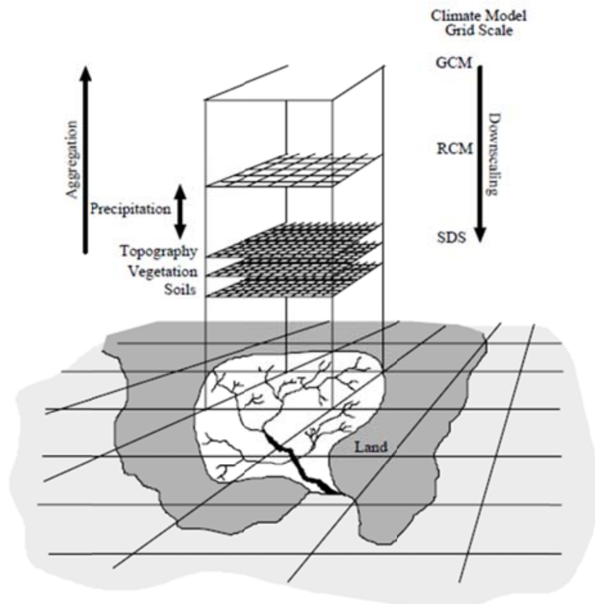


Figure (7): Schematic illustrating the general approach to downscaling

3.15. Construction of future climate scenarios

Because projections of climate change depend heavily upon future human activity, climate models are run against emissions scenarios. Within the SRES family, there are 40 different scenarios, each making different assumptions for future greenhouse gas pollution, land-use and other driving forces. Assumptions about future technological development as well as the future economic development are thus made for each scenario. Most include an increase in the consumption of fossil fuels. Peak Oil is for instance not discussed in the emission scenarios.

These emission scenarios are organized into families, which contain scenarios that are similar to each other in some respects. IPCC assessment report projections for the future are often made in the context of a specific scenario family.

Scenario families contain individual scenarios with common themes. The six families of scenarios discussed in the IPCC's Third Assessment Report (TAR) and Fourth Assessment Report (AR4) are A1FI, A1B, A1T, A2, B1, and B2.

In this study the A2 and B2 families of scenarios were selected to generate future projections of climate change scenarios.

The A2 scenarios are of a more divided world. The A2 family of scenarios is characterized by:

- A world of independently operating, self-reliant nations.
- Continuously increasing population.
- Regionally oriented economic development.
- Slower and more fragmented technological changes and improvements to per capita income.

The B2 scenarios are of a world more divided, but more ecologically friendly. The B2 scenarios are characterized by:

- Continuously increasing population, but at a slower rate than in A2.
- Emphasis on local rather than global solutions to economic, social and environmental stability.
- Intermediate levels of economic development.
- Less rapid and more fragmented technological change than in A1 and B1.

Few meteorological stations have 100% complete and/or fully accurate data sets. Handling of missing and imperfect data is necessary for most practical situations. The first step in the application of the SDSM is the Simple Quality Control check that enables the identification of gross data errors, specification of missing data codes and outliers prior to model calibration. The quality control applied to the 6 stations in the ZRB shows that the MWI climate stations' time series have outliers, missing and incorrect data more than the Meteorological observation stations. The outliers were omitted, the incorrect data were corrected and there was nothing to do with the large number of missing data that reach few years in some cases. However the missing data don't affect the statistical calculation processes of the model.

The second step in the model application is the screening of downscaling predictor variables. This option identifies empirical relationships between gridded predictors (such as NCEP 500 hPa geo-potential height) and single site predictands (such as observed mean temperature) is central to all statistical downscaling methods (Figure 8). The main purpose of the Screen Variables operation is to assist the user in the selection of appropriate downscaling predictor variables.

The third step is the Calibrate Model operation which takes a User–specified predictand (from the observed data such as maximum temperature) along with a set of predictor variables from the NCEP Reanalysis data, and computes the parameters of multiple regression equations via an optimisation algorithm (either dual simplex of ordinary least squares.

The fourth step is the Weather Generator operation generates ensembles of synthetic daily weather series given observed (or NCEP re–analysis) atmospheric predictor variables. The procedure enables the verification of calibrated models (using independent data) and the synthesis of artificial time series for present climate conditions. Figure 9 shows the Probability Density Function (PDF) and scatter plot of the maximum temperature and the 20 ensembles of the downscaled maximum temperature at Wadi Dhulail.

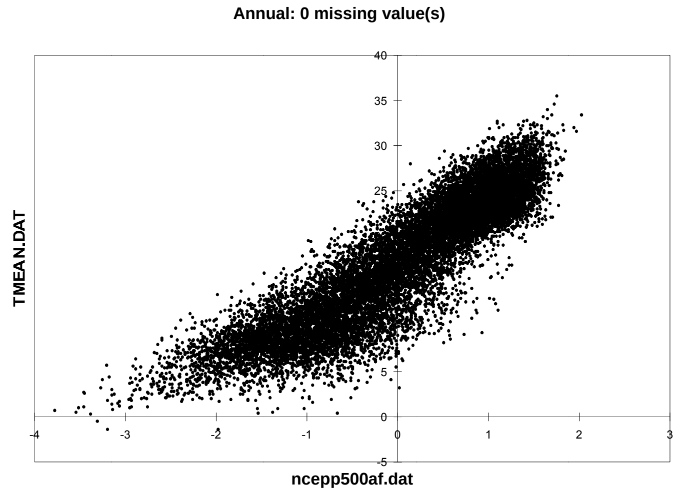


Figure (8): The relationship between gridded predictor (NCEP 500 hPa geo-potential height) and single site predictand (mean temperature).

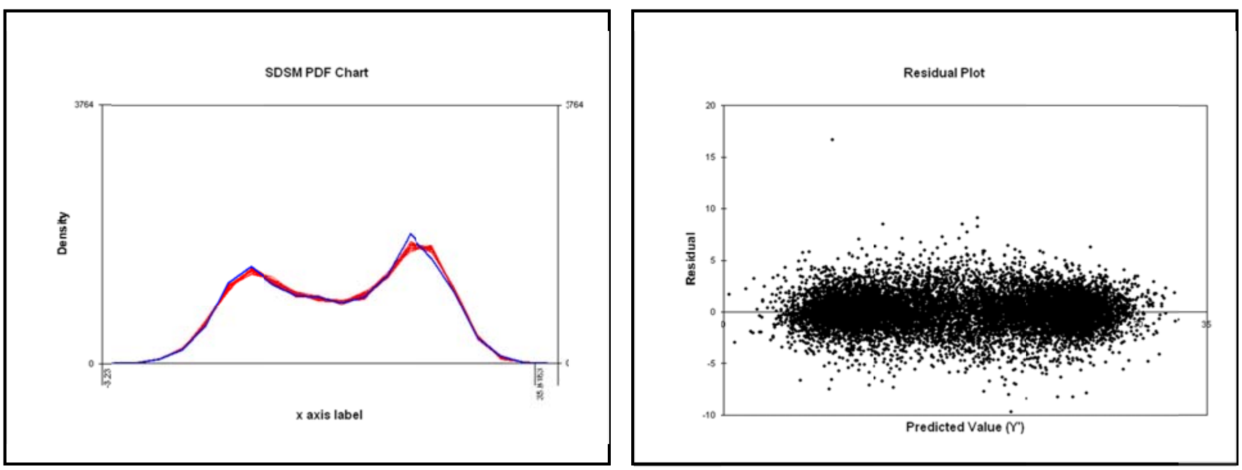


Figure (9): PDF Plot (left) and scatter plot (right) of the observed and downscaled maximum temperature at Wadi Dhulail.

The observed data time series are not required to have the same length as the NCEP Reanalysis data used to predict the downscaled baseline scenarios. The baseline scenarios of the rainfall amount, maximum, minimum, and mean temperatures are predicted to cover 50 years period 1961-2010 at all sites in the basin regardless the length of the observed time series at each station.

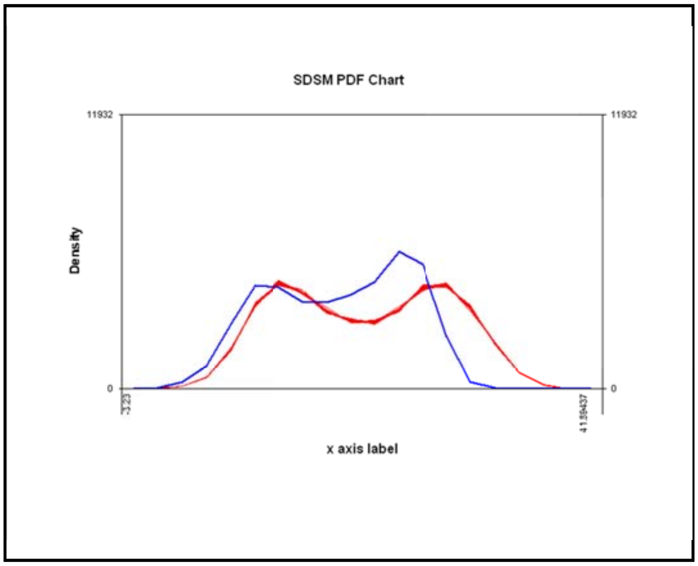


Figure (10): PDF Plot of the downscaled baseline scenario (blue) and generated future climate scenario (red) of maximum temperature at Wadi Dhulail.

The fifth and final step is the Scenario Generator operation which produces ensembles of synthetic daily weather series given atmospheric predictor variables supplied by a climate model (either for present or future climate experiments), rather than observed predictors (Figure 10).

The GCM model used to generate the baseline and future climate scenarios is HADCM3 (HADley Center Coupled Atmosphere Ocean Climate Model version 3, UK). The experiments of the two SRES scenarios A2 and B2 produced by greenhouse gas, sulphate aerosol, and solar forcing is used to generate climate scenarios for each of the 6 single sites in the ZRB. Two different scenarios (A2 and B2) of the maximum, minimum, mean temperatures and rainfall amount were generated for each of the station-scale sites in the ZRB over the period 1961 – 2099.

Comparison between the generated baseline scenarios and the observed data shows a great coincidence (Figure 9). The baseline scenarios of the four climatic elements at the six climatic stations were generated to the period 1961 – 2010 with very high accuracy. Then the future climate scenarios were separately generated to the end of the century along three periods:

50 years beyond the baseline period (2011 – 2060),

The remaining 40 years to the end of the century (2060 – 2099).

The whole 21st century between 2011 and 2099.

Figure 10 shows the Probability Density Function (PDF) of the SDMS model generated 20 ensembles of maximum temperature drawn against the baseline maximum temperature in Wadi Dhlail. The figure shows that the maximum temperature is predicted to be higher than the observed.

The deviation of the downscaled future scenarios from the baseline scenarios is found for the above three periods for each climatic element at each station and summarized in Annex B (Tables B1 to B6). The deviation of temperature is directly derived by calculating the difference between the predicted and the observed temperatures, while the change in rainfall amount is calculated as a percentage of the observed value as follows:

$$\textbf{The Deviation} = \frac{\textbf{Predicted} - \textbf{Observed}}{\textbf{Observed}} \times \textbf{100}\ \%$$

The following important points are derived from the future climate scenarios:

- Both scenario experiments A2 and B2 predicted temperature increase in all periods at all locations. But the increase in A2 is little bit greater in B2.
- The temperature increases at different rates during the three periods.
- The expected increase during the first period 2011 – 2060 is 1-3°C.
- The highest increase is expected to take place in the second period 2061 – 2099 with a rate of 2-4 °C.
- The expected increase during the period 2011 – 2090 is 2-3°C.
- The temperature increase over the winter months is greater than other months of the year.
- Rainfall scenarios show an obvious uncertainty at all sites.
- 30 - 60 % increase in the rainfall amounts is expected at Mafraq and Wadi Dhulail.
- 15 – 30 % decrease in Amman A/P future rainfall is predicted.
- 30 – 50 % decrease in rainfall at other locations is expected.
- The reduction in rainfall amounts is expected through the winter months from October to April, while the months from May to September are exposure to increase in rainfall amounts. This result is not unusual in GCM modeling because summer months rarely record rain in Jordan.
- Combination of temperature increase and rainfall reduction in the winter months will worsen the future climate and increase the negative impacts of climate change on water resources, agriculture, socio-economy and all other sectors.

3.16. Incremental scenarios

Developing incremental scenarios is the simplest way to obtain climate change scenarios. They provide a wide range of potential regional climate changes and help identify sensitivities to changes in temperature and precipitation. For each location in the study area, increases in temperature of +1°C, +2°C, +3°C and +4°C were combined with no change, and with –20%, –10%, +10%, and +20% changes in precipitation (Table 3). As a result, 20 incremental climate change scenarios were developed for each station.

The main disadvantage of using incremental scenarios is that they may not be physically plausible. Also, uniform climate changes throughout a year are not realistic. For instance, the estimated warming in summer should be much greater than in winter. Despite these concerns, incremental scenarios are feasible for Jordan, which has great spatial and temporal variability in precipitation; warm and rainy years as well as hot and dry years have occurred.

The twenty incremental scenarios have been constructed for each selected station in the study area as monthly scenarios. The incremental adjustments shown in Table 3 were combined with the available climatological time series of daily max, min and mean temperatures and daily precipitation amounts to construct the daily incremental scenarios for the period 2011 – 2060 in each of the 6 sites of the study area.

These incremental scenarios as well as the downscaled GCMs daily scenarios of the temperature and rainfall amount will be used in the climate change impacts assessment studies in various sectors such as water resources and quality sector and socio-economic sector in the ZRB.

Table 3: Increments used to construct the 20 incremental climatic change scenarios.

Dry Scenarios							
– 20%				– 10%			
+ 1 °C	2 °C	+ 3 °C	+ 4 °C	+ 1 °C	+ 2 °C	+ 3 °C	+ 4 °C
Normal Precipitation Scenarios							
0%							
+ 1 °C		+ 2 °C		+ 3 °C		+ 4 °C	
Wet Scenarios							
+ 20%				+ 10%			
+ 1 °C	+ 2 °C	+ 3 °C	+ 4 °C	+ 1 °C	+ 2 °C	+ 3 °C	+ 4 °C

3.17. Obstacles and constraints related to climate change scenarios

The natural variability of climate could be as large as the changes have been actually observed. In the case of ZRB the data time series in almost half the stations are too short to identify a definite long-term climatic trend. But it might be a good indication to a signal of the recent climate variability and to the series behaviors. Although the baseline period is selected to cover the period 1961 – 2010, the record length of the climatological data at most of the stations in the study area is shorter than the baseline period. The climatological data used to construct the baseline scenarios were obtained from the Jordanian Meteorological Department and the Ministry of Water and Irrigation. There are many outliers, incorrect and missing data in the daily and monthly climatological time series at the majority of the stations.

Several major constrains and gaps were identified during preparation of the thematic studies on climate change impact assessment. The most persisting one is a problem in data availability, consistency and transparency. Existing monitoring in climate and water resources conducted by Meteorology and hydrology Services in the country is facing permanent problems in operation, slow modernization of equipment, reducing of monitoring network. Therefore, improvement of the hydrological and meteorological monitoring stations, improvement of the data processing, implementation of the predictive models in real time and modernization of the equipment (in the field, in laboratory, software and hardware) are of highest importance in the near future. Soil monitoring does not exist, as well as ground water monitoring. Basic maps and data bases are hardly available. There is need for increasing technical capacities for monitoring and updating of basic data sets. Modern tools for impact assessment are needed. In the field of climate change and climate change scenarios there is a need to establish regional models.

3.18. Conclusions

In order to detect any trends in the climatological time series in Jordan the linear trend test has been applied to the available longest time series of precipitation, maximum temperature, minimum temperature and mean temperatures at 6 observation stations, 3 from the Met. Dept. and 3 from the MWI. Because of the short record of the daily observational data of temperature and precipitation, and the large number of missing and incorrect data at a part of 6 stations, the Statistical Downscaling Model (SDSM) was employed to develop baseline scenarios covering the period 1961–2010.

Since the typical grid resolution in these GCMs is still too coarse to examine effects of local topography and land use, and to assess climate change impacts in station-scale sites, it was necessary to apply a downscaling model to downscale the coarse resolution GCM projections to each single site in the study area. For this purpose HadCM3 General Circulation Model and Statistical Downscaling Model (SDSM4.2) and are employed to generate future temperature and rainfall scenarios at the 6 stations in the ZRB for the period from 2011 to 2099.

The daily baseline scenarios, the daily climate change future scenarios together with the daily and monthly incremental scenarios were distributed to the climate change impact assessment team members to study the impacts of climate change on the water resources, water quality and socio-economic sectors.

The most important conclusions summarized as follows:

- The maximum, minimum and mean temperatures reveal significant warming trends at in most of the stations. The warming trends of minimum temperature are greater than that of maximum temperature. As a result the mean temperature shows warming trends in all stations.
- The temperature increase ranges from 1-4 °C.
- The temperature increase is greater in the winter months.
- The temperature increase is greater in the period 2060 – 2099.
- The precipitation climate change scenarios are highly variable.
- The rainfall amount at Mafraq and Wadi Dhulail is expected to increase by 30 - 60 %.
- The future rainfall amount at Amman A/P is predicted decrease by 15 – 30 %.
- 30 – 50 % decrease in rainfall at other locations is expected.
- The reduction in rainfall amounts is expected through the winter months from October to April, while the months from May to September are exposure to increase in rainfall amounts. This result is not unusual in GCM modeling because summer months rarely record rain in Jordan.
- Combination of temperature increase and rainfall reduction in the winter months will worsen the future climate and increase the negative impacts of climate change on water resources, agriculture, socio-economy and all other sectors.

3.19. Recommendations

The time allocated for the climate change scenarios in this study and in other similar studies is too short. Longer time is needed to employ the most modern and new model applications. In future climate change studies it is recommended to employ the Dynamical Downscaling Modeling Technique and RCMs to produce high resolution climate scenarios for a domain of 10 – 50 km by nesting from the initial boundary conditions of the coarse GCMs outputs.

Due to the lack of the observation stations in specific regions of Jordan accompanied to the inadequate length of climatic time series, it is necessary to construct an atlas of climate change scenarios for all climatic elements that includes GIS maps of the whole country.

Cooperation among all concerned ministries, departments, scientific institutions, universities and research centers is highly recommended to facilitate accessibility and exchange of data and experience among researchers.

4. Impacts of climate change on surface water availability in ZRB

4.1. Introduction

According to IPCC Technical Report on Climate Change and Water Resources (2008), Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems. Furthermore, Climate change affects the function and operation of existing water infrastructure – including hydropower, structural flood defences, drainage and irrigation systems – as well as water management practices. Climate change is expected to increase the stresses on water resources in arid and semi-arid areas, and in areas with limited water resources like Jordan. The climate change will not affect only the quantities of available water resources but also their quality.

In this part of the report, the impact of climate change on the surface water availability of ZRB is addressed.

4.2. Adopted Methodology

The adopted methodology to assess the impacts of climate change on water availability and quality in ZRB is shown in Figure (11). The methodology can be divided into the following phases:

4.3. Selecting the appropriate hydrological model

A wide range of software and hydrological models are available in the market, however, not all of these products are suitable or even applicable to ZRB conditions. Therefore, in this phase, a set of hydrological models and software were tested and evaluated in terms of its suitability and applicability. Another important factor that was taken in consideration during the selection process is the support of climate change scenarios. The selected model or software should be able and facilitate the managing of incremental and GCM climatic scenarios and also should be able to provide a comparison between these scenarios and baseline scenario. Furthermore, the IPCC 2007 guideline regarding this issue was taken into account. Although there are a wide range of rainfall-models available, the selected model should be simple enough to use, as well as to understood. The selected model should also be representative. The minimum data required by the model is another reason for such selection.

4.4. Model data input preparation

In this phase, required data sets were collected from various sources, these data sets include: Metrological, Soil, Landuse, Topographic, Stream Flow data and any other sets that might be required to run this part. These data sets were prepared using Geographic Information Systems (GIS) and were integrated with the other phases of this activity. The output of this phase is a complete GIS based digital database that is integrated with other components. This database might be accessed and distributed using the internet (A WEB portal will be designed).

4.5. Calibration and validation of the selected Hydrological model

The required data sets and input parameters of the selected model were prepared in its readable format, and additional calculation like the potential evapotranspiration was made using the suitable software and tools. These input parameters were prepared using GIS as set of thematic layers. The selected model was calibrated and then validated using the hydrological and climatelogical baseline. As mentioned earlier long record of observed streamflow, rainfall, temperature, Pan A evaporation, relative humidity from 1960-2009 was used in this study. Such long period will be very helpful to investigate the potential impact of climate change on ZRB for the next 50 years.

4.6. Conduct climate change impact studies on water availability

The next step after creating the baseline scenario that describes the water availability and quality in ZRB, the realistic basin scale climate change scenarios was plugged into the implemented model to assess the impact of climate change on water availability and quality in ZRB. This will include the impacts on the amounts of surface runoff, water quality and groundwater resources.

In the following sub-sections, the application of this methodology on ZRB was described.

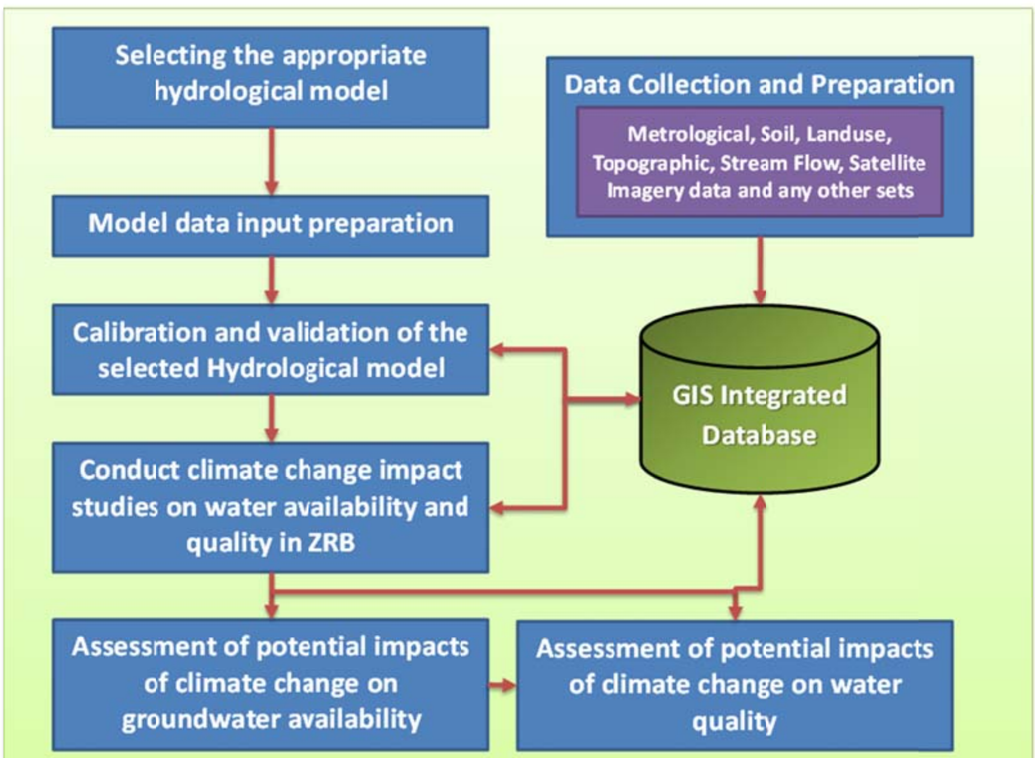


Figure (11): Adopted methodology to assess the impacts of climate change on water availability and quality in ZRB

4.7. Selecting the appropriate hydrological model

Models are needed to work on a spatial scale fine enough to allow assessment of the possible future impacts in a river basin. Such models need observation data on that scale to be able to calibrate and to run the models and to evaluate the results. The hydrologic assessment, the first step of water resources vulnerability and adaptation assessment, is the most developed methodology. To undertake this stage of the assessment, hydrologic models that estimate runoff are used. There many hydrological models available in the literature such as SFB, SWAT, HSPF, WMS, and Pitman models. All these models are tested for Jordan and especially for ZRB (Al-Omari et al., 2009, Abdulla et al., 2009, Abdulla and Al-Omari, 2008, Al-Abed et al., 2005, Gibb 1997) .

In this study, appropriate hydrological models to make predictions (stream flow, recharge, soil moisture, evaporation transpiration, water quality, etc) under preferred climate change scenarios was selected. To accomplish this activity, various hydrological rainfall-runoff model were screened based on the previous studies. For example Abdulla and Al-Omari (2008) used the Soil-inFiltration-Baseflow model to study the impact of climate change on the monthly runoff of ZRB, also Abdulla et al. (2009) used HSPF to simulate the water balance component of ZRB. These model as well as other models such as SWAT, WMS and other models recommended by the IPCC 2007 were screened. In the search procedure, the model that provides good calibration results was selected.

A wide range of software and hydrological models are available in the market, however, not all of these products are suitable or even applicable to ZRB conditions. Therefore, in this phase, a set of hydrological models and software were tested and evaluated in terms of its suitability and applicability. These models include:

- **SPATSIM** (Spatial and Time Series Information Modeling Software) developed by Rhodes University, South Africa. This software includes the PITMAN model which suitable for arid and semi-arid areas like ZRB.

- **SWAT (Soil and Water Assessment Tools)** which developed by Blackland Research Laboratory and USDA Agricultural Research Services.
- **WEAP** (Water Evaluation and Planning) developed by Stockholm Environment Institute Netherland.
- **WetSpass** (Steady state spatially distributed water balance model) developed by Dept of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Belgaum.
- **WetSpa** (Water and Energy Transfer between Soil, Plants and Atmosphere) developed by Dept of Hydrology and Hydraulic Engineering, Vrije Universiteit Brussel, Belgaum.
- **HEC-HMS** (The Hydrologic Modeling System) developed by US Army Corps and Engineers.
- **HPSF** (Hydrological Simulation Program - FORTRAN) developed by United States Environmental Protection Agency (EPA)

The selection of the suitable model, the following criteria were used:

a) The model should be recommended by IPCC 2007 guideline.
b) The model should facilitate and support the climate scenarios management.
c) The required data to implement, run and calibrate are available.
d) The model should consider both quality and quantity of water resources.
e) The calibration process should be available even manually or automatically.
f) Model assumptions should be matched with ZRB conditions.
g) It should support GIS data formats as most of ZRB available data are prepared using GIS.
h) The availability of model documentations and technical support.

Based on these issues and after contacting the hydrological modeling department at the Ministry of Water and Irrigation to have their feedback on this issue, three models were nominated, these are WEAP, HSPF and SWAT. However, after the discussion with the Surface Water Department at MWI, it was agreed to exclude the WEAP model because it is not recommended for surface modeling, it is highly recommended for water management as decision support system. It was agreed finally based on the discussions with the stakeholders at the Ministry of Water and Irrigation to select the SWAT model because the data required to calibrate the model is available for ZRB in terms of quantity and quality. **S**oil and **W**ater **A**ssessment **T**ools (SWAT) is a river basin scale hydrologic model developed to quantify the impact of land management practices in large, complex watersheds. It is a public domain model actively supported by the USDA Agricultural Research Service. SWAT is constantly being updated and the latest version named ArcSWAT is designed totally to run under ArcGIS environment. SWAT is a hydrological model with the following components: Weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading, water transfer. SWAT can be considered as a watershed hydrological transport model.

4.8. Description of SWAT

SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. To satisfy this objective, the model is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed (Neitsch et. al.,2005). The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc. are directly modeled by SWAT using this input data. SWAT is a continuous time model, i.e. a long-term yield model. The model is not designed to simulate detailed, single-event flood routing.

SWAT is constantly being updated and the latest version named ArcSWAT is designed to run under ArcGIS environment. The advantages of ArcSWAT can be summarized as follows:

- The simulation can be run on different time steps including daily time step.
- SWAT was developed to predict the effects of various management scenarios on water quality, sediment yields and pollutant loadings from different watersheds
- ArcSWAT is a totally ArcGIS based interface that can directly handle datasets that already stored within GIS database without the need for any conversion tools.
- SWAT facilitates manual and automated calibration for the simulated results which leads to more reliable simulation results.
- Recently, a lot of research and publications were conducted using SWAT model to assess the impacts of climate change on water resources quantity and quality.

The major disadvantages of SWAT model its data preparation and it needs more careful attention in its calibration.

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

where

SW_t : *final soil water content (mm H_2O),*

SW_0 : *initial soil water content on day i (mm H_2O),*

t : *time (days),*

R_{day} : *amount of precipitation on day i (mm H_2O),*

Q_{surf} : *amount of surface runoff on day i (mm H_2O),*

E_a : *amount of evapotranspiration on day i (mm H_2O),*

w_{seep} : *amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and*

Q_{gw} : *amount of return flow on day i (mm H_2O)*

The potential pathways of water movement simulated by SWAT in the hydrologic response unit (HRU) are illustrated in Figure (12).

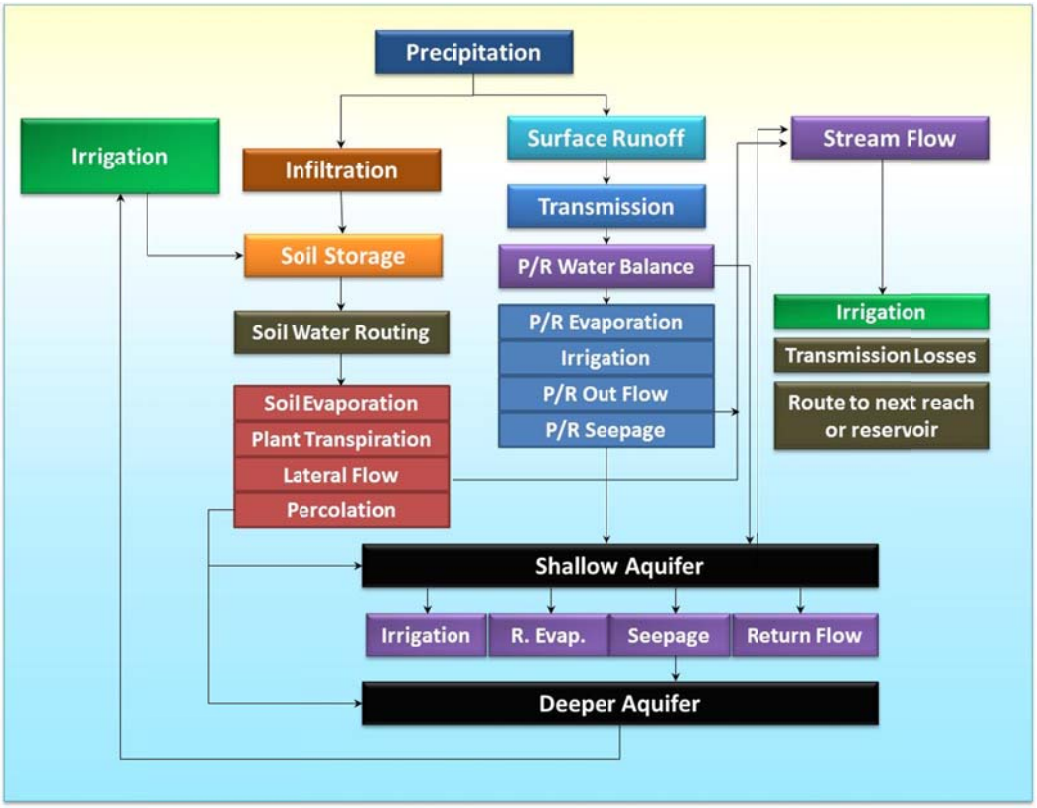


Figure (12): Schematic of pathways available for water movement in SWAT (Modified after Neitsch et. al.,2005)

SWAT provides two methods for estimating surface runoff: the SCS curve number procedure (SCS, 1972) and the Green and Ampt infiltration method (1911). Due to data availability constraints, SCS curve number is going to be using in this study.

The SCS runoff equation is an empirical model that came into common use in the 1950s. It was the product of more than 20 years of studies involving rainfall-runoff relationships from small rural watersheds across the U.S. The model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Rallison and Miller, 1981). The SCS curve number equation is (SCS, 1972):

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}$$

where

Q_{surf} *: accumulated runoff or rainfall excess (mm H2O),*

R_{day} *: rainfall depth for the day (mm H2O),*

I_a *: initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H2O), and*

S *: retention parameter (mm H2O).*

The retention parameter varies spatially due to changes in soils, land use, Management and slope and temporally due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

where

CN is the curve number for the day.

The initial abstractions, I_a, is commonly approximated as 0.2S.

The major factors that determine CN are the hydrologic soil group (HSG), cover type, treatment, hydrologic condition, and antecedent runoff condition (ARC). Another factor considered is whether impervious areas outlet directly to the drainage system (connected) or whether the flow spreads over pervious areas before entering the drainage system (unconnected).

CN's in table (4) represent average antecedent runoff condition for urban, cultivated agricultural, other agricultural, and arid and semiarid rangeland uses. This table assumes impervious areas are directly connected (USDA, 1986). The SCS curve number is a function of the soil's permeability, land use and antecedent soil water conditions. Sample of typical curve numbers for moisture condition II are listed in table (4) for various land covers and soil types (SCS Engineering Division, 1986).

Table(4): Runoff curve numbers for urban areas (USDA, 1986).

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area [2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.

2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

4.9. SWAT data preparation

SWAT 2009 was used in this study. The preparation of data was done using ArcSWAT which is an integrated GIS based interface that aid in this process. ArcSWAT is a graphical user interface that runs under ArcGIS environment to facilitate the preparation on input files for SWAT model (Figure 13). Further, it also aid in reading the SWAT outputs, and importing these outputs into project database.

The main components of ArcSWAT are explained in Figure (14) which includes:

a) Watershed Delineation.
b) HRU Analysis
c) Write Input Files
d) SWAT Simulation

Each of these components has its own data inputs and requirements, which will build up the project database. The required datasets are shown in table (5).

4.9.1. Watershed Delineation

Watershed delineation requires a Digital Elevation Model (DEM) to start. In this project, DEM was obtained and downloaded from Earth Remote Sensing Data Analysis Center (ERSDAC) website (http://www.gdem.aster.ersdac.or.jp/). The type of downloaded is ASTER GDEM with a spatial resolution of 30 m (Figure 15). The downloaded DEM covers the entire ZRB and the elevation values were ranged from -36m at the outlet of ZRB to 1229 at the western highlands.

The downloaded DEM covers the entire ZRB and the elevation values were ranged from -36m at the outlet of ZRB to 1229 at the western highlands. DEM is the first input to ArcSWAT, where stream flow, stream accumulation, stream network and sub catchments are delineated automatically by the ArcSWAT. Figure (16) shows the ArcSWAT built-in interface for automated watershed delineation.

Another important input at this stage is the pollution point sources, which will help in simulating not only the water quantity, but also the water quality.

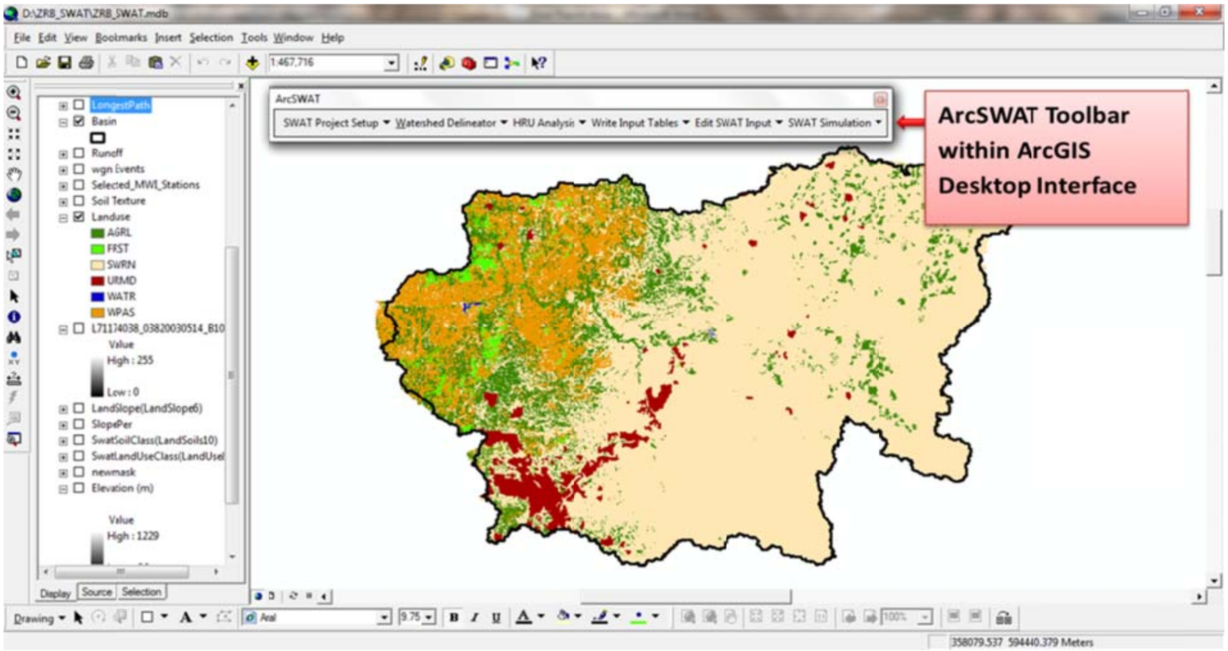


Figure (13): ArcSWAT interface within ArcGIS Desktop Environment.

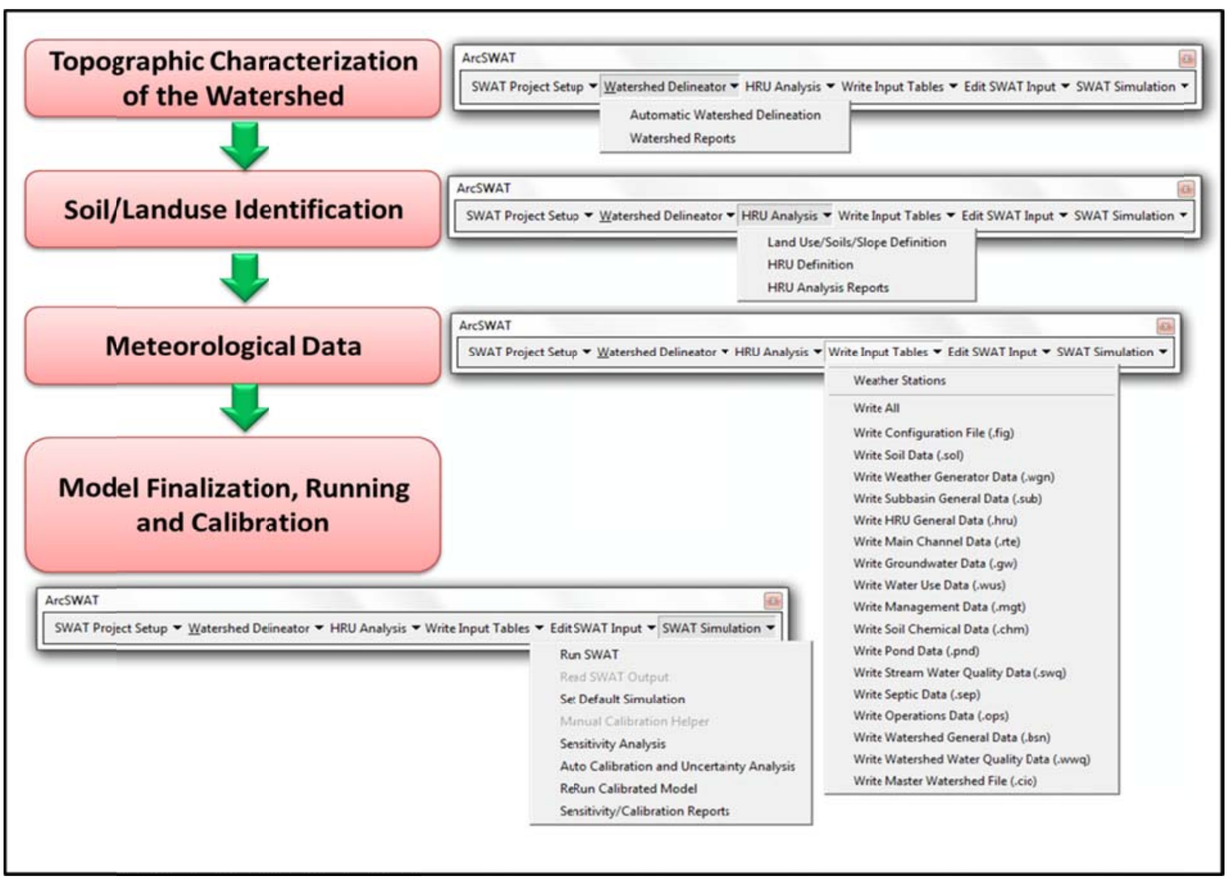


Figure (14): Major Components of ArcSWAT Toolbar.

Table (5): Required datasets used by ArcSWAT

	Data set	Resolution	Source
1	Digital Elevation Model	30m	The CGIAR Consortium for Spatial Information (CGAIR-CSI) website (http://srtm.csi.cgiar.org/).
2	Soil Data	1:50,000	Ministry of Agriculture
3	Landuse/cover	1:50,000	Ministry of Agriculture
4	Meteorological Data	Last 40 Years	Ministry of Water and Irrigation Department of Meteorology
5	Surface run gaging data	Last 40 Years	Ministry of Water and Irrigation

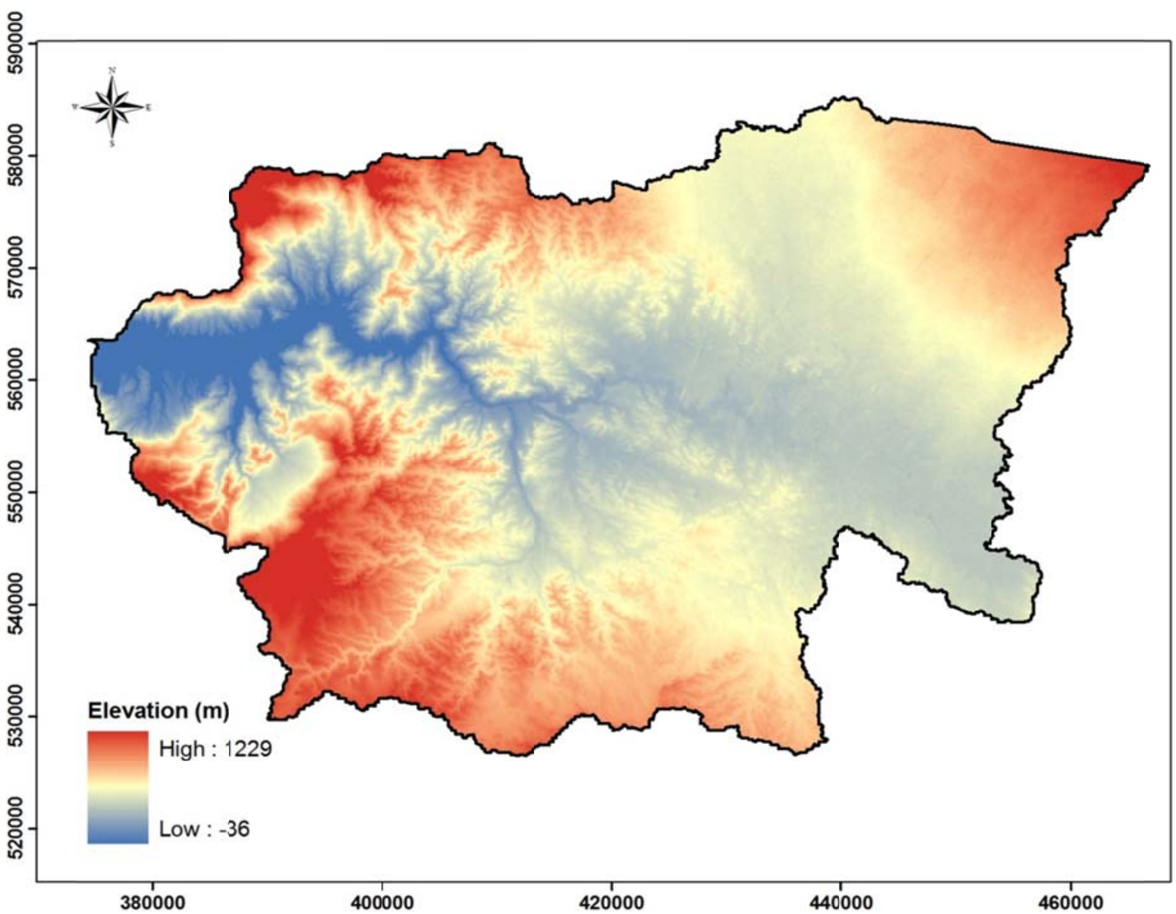


Figure (15): SRTM Digital Elevation Model (DEM) with 30 m Resolution

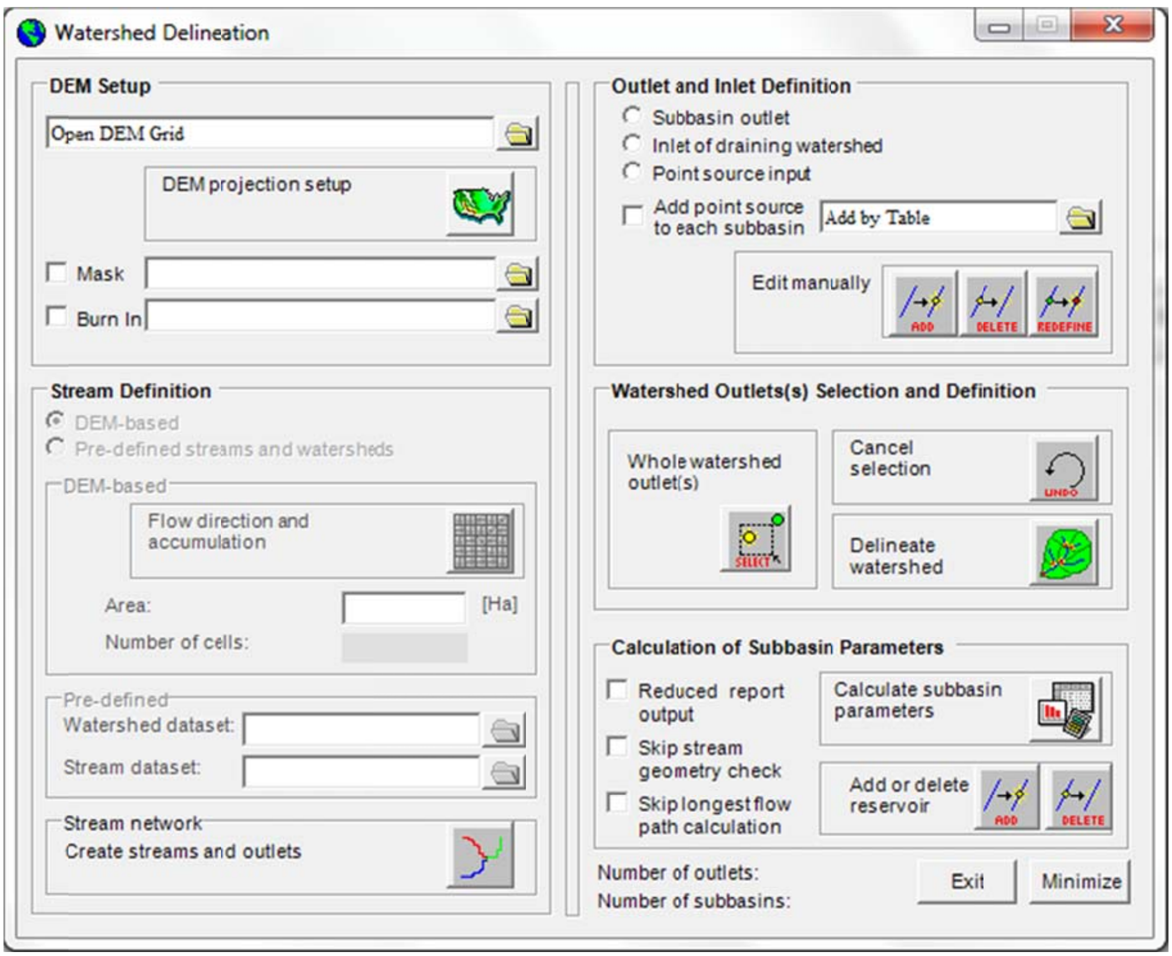


Figure (16): Watershed Delineation Interface within ArcSWAT Toolbar.

4.9.2. HRU Analysis

HRU which stands for Hydrological Response Units are distributed heterogeneously structured areas with common land use and pedo-topo-geological associations controlling their unique hydrological dynamics (Flugel, 1996). This definition implies that for each HRU, the variations of the hydrological dynamics within the same HRU are negligible if compared with the differences with the neighboring HRUs.

ArcSWAT enables the delineation of HRUs for the watershed based on Soil, Landuse and Slope Information.

i. **Soil Data**

Soil is the uppermost layer of the earth crust developing considerable slowly as a result of weathering process. Amount of water, wind, solar radiation, temperature, vegetation and landuse are important parameters besides the type of rock exposed determining the type of soil which develops at distinct sites. ZRB soil texture can be divided into five soil groups as shown in figure (17) depending on the soil texture. Also, table (6) shows the main soil properties for these groups.

ii. **Land use**

The land use in ZRB divided into four types. The first type is agricultural land which contains rain fed and irrigated agricultural land with deciduous and non-deciduous trees. Other types are forest, natural vegetation and urban lands as seen in Figure (18). The western and the northeastern parts of the study area contain more than 90 % of agricultural activities and vegetation. Agricultural land, forest land and pasture land are concentrating in the western part of Zarqa basin. Urban land presents in the southwestern part of Zarqa basin (the north part of Amman city and Zarqa city). Barren land presents in the eastern part of Zarqa basin. Generally the landuse types of ZRB contain the following: 65% as bare rock, thin soils and urbanization and 35% as natural vegetation, forest, irrigated agriculture (cereals, vegetables, fruit trees, olives, bananas and citrus) and rained agriculture (cereals, vegetables, fruit trees, olives, bananas and citrus).

iii. **Slope Percentage**

Slope information were extracted using DEM and ArcMAP Spatial Analyst Extension^{TM}, the generated slope map appears in Figure (19). The general slope in the basin changes from west to east where hilly areas comprise a large part of the western and surrounding areas along the boundary of the basin. Altitudes gradually decrease towards the center of the basin and towards the outlet of the catchment to Jordan Valley near Deir Alla in the west.

Table (6). The main soil texture parameter in Zarqa basin

TEXTURE	description	K_S mm/hr	n	S_{MAX}	SAND %	SILT %	CLAY %	K_{FF}
C	Clay	0.600	0.475	0.810	27.000	23.000	50.000	0.340
CL	Clay loam	2.300	0.464	0.840	32.000	34.000	34.000	0.390
SIC	Silty clay	0.900	0.479	0.880	9.000	45.000	46.000	0.310
SICL	Silt clay loam	1.500	0.471	0.920	12.000	54.000	34.000	0.400
SIL	Silty loam	6.800	0.501	0.970	23.000	61.000	16.000	0.490

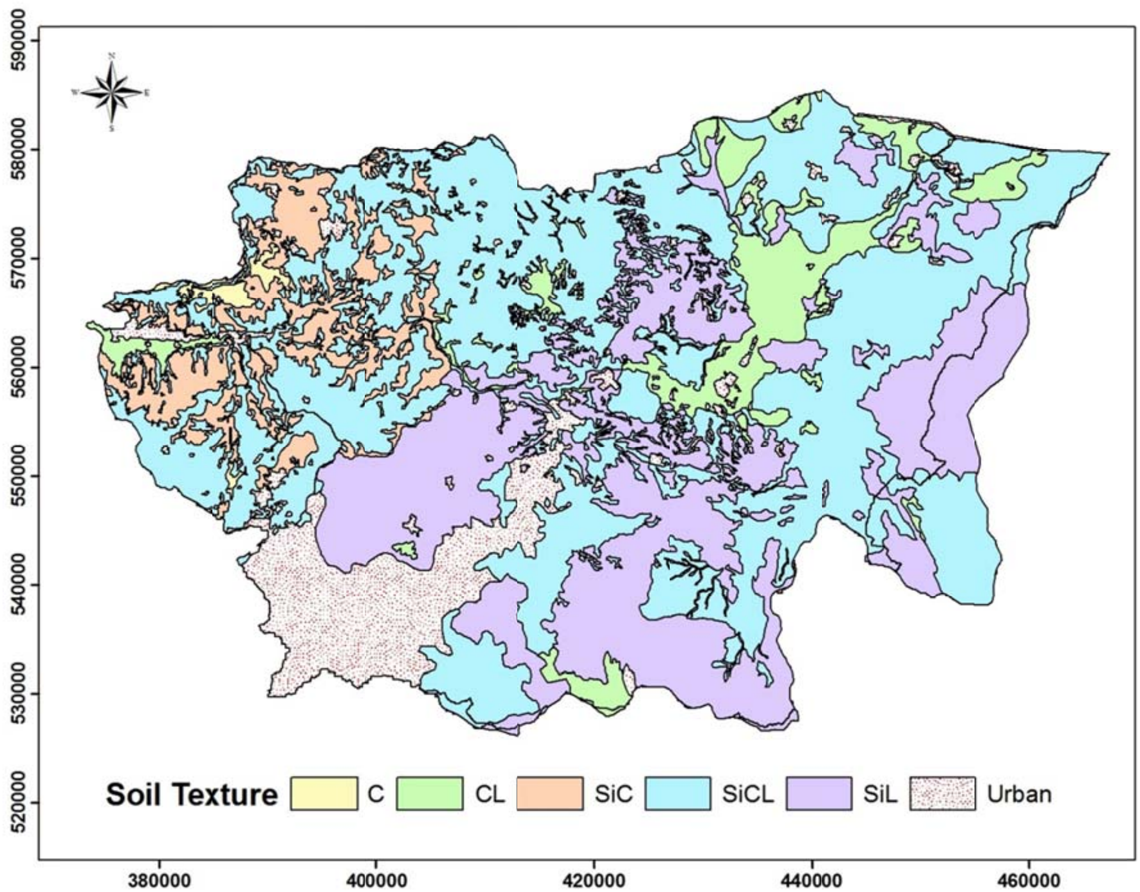


Figure (17): Spatial Distribution of Soil Texture Classes at ZRB.

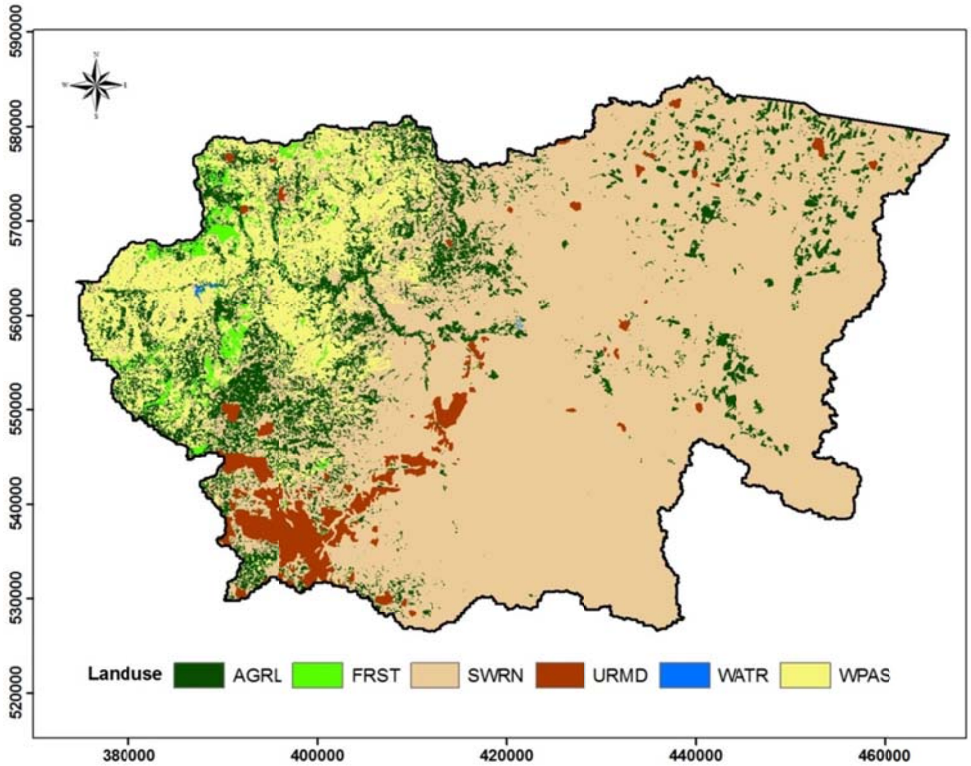


Figure (18): Spatial Distribution of Land uses Classes at ZRB.

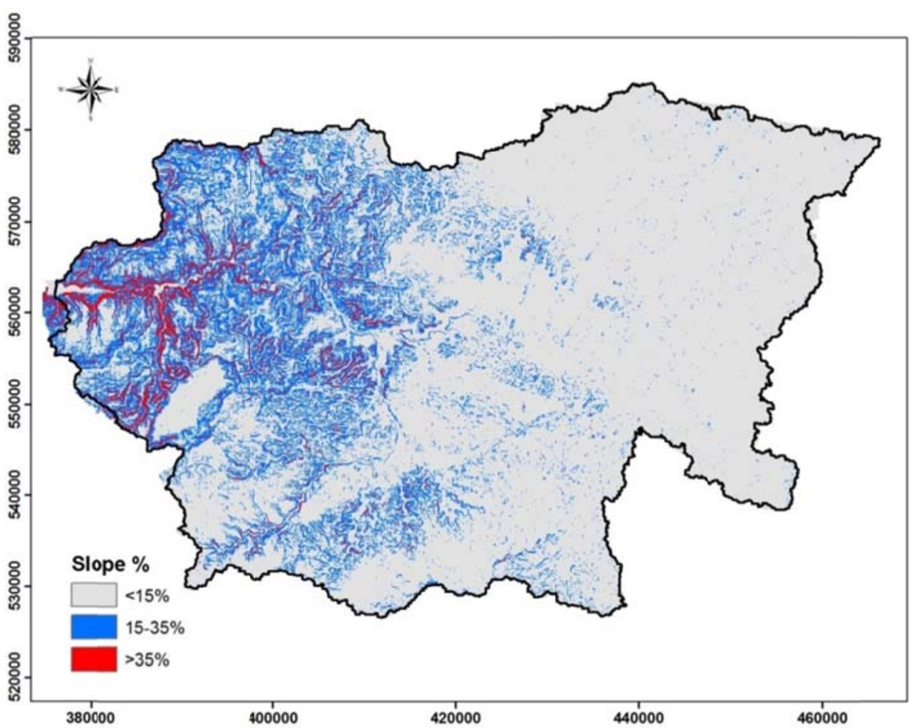


Figure (19): Spatial Distribution of Slope % at ZRB.

4.9.3. Write Input Files

This is the last step in preparing SWAT input files, where meteorological parameters is defined. As seen in figure (20), the interface face for this part allows the identification of the following parameters:

a) Weather Generator Data

b) Rainfall Data

c) Temperature Data

d) Relative Humidity Data

e) Solar Radiation Data

f) Wind Speed Data

Due to data availability, only the first three data sets were used in this study. Rainfall and temperature data were obtained from two main sources that produce climatic data in Jordan. These are Ministry of Water and Irrigation (MWI) and Department of Meteorology (DOM). Figure (21) shows the location of climate stations that used in this study. By completing this part, the ArcSWAT database which stored as Microsoft Access Database is complete and the last step is to convert all these datasets into a SWAT input files. A total number of 17 files are generated with different file extensions as shown in table (7).

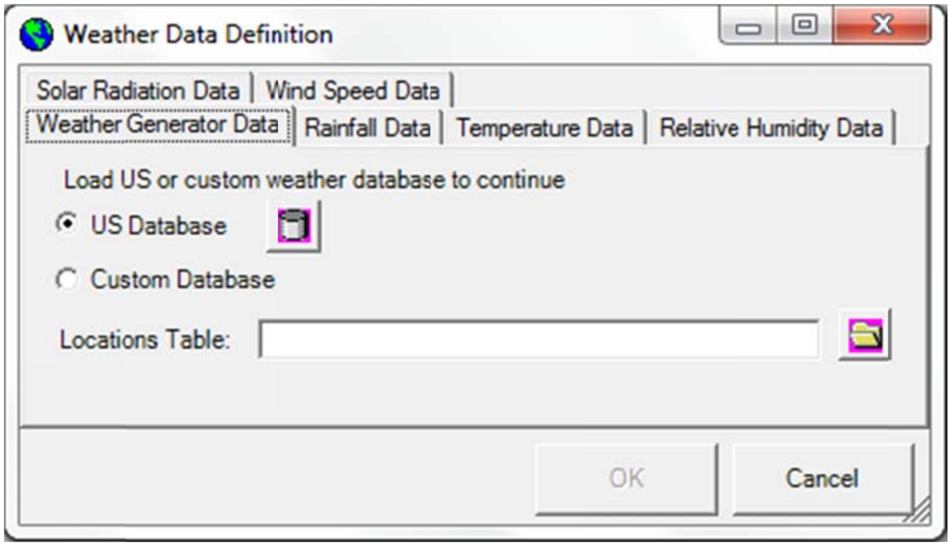


Figure (20): Weather Data Definition interface within ArcSWAT toolbar.

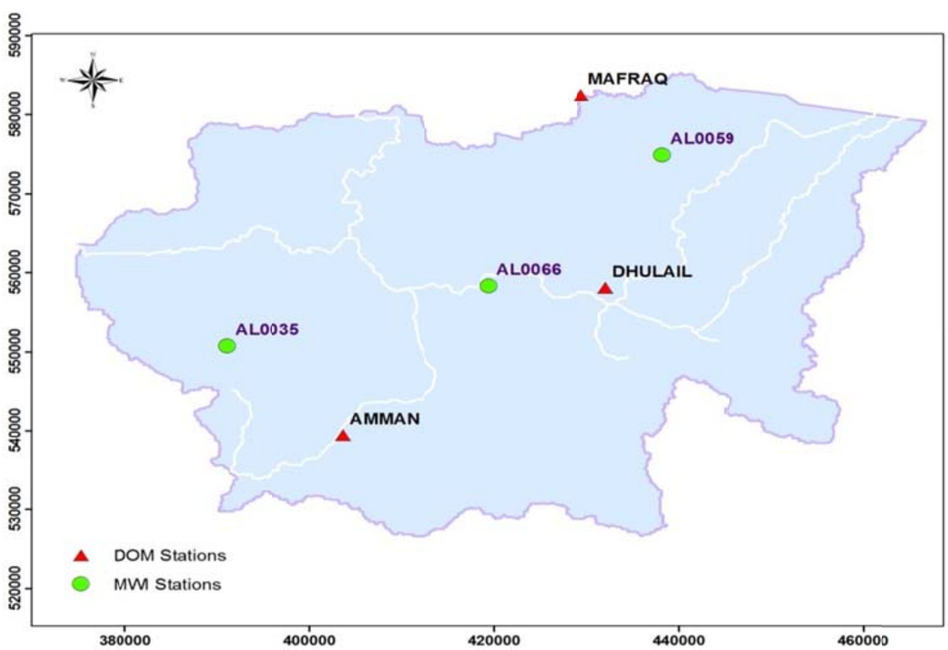


Figure (21): Location of the climate stations used in this study.

Table (7): SWAT input files (Neitsch et. al., 2009)

	File Name	Extension	Description
1	**Configuration File**	*.fig*	This required file defines the routing network in the watershed and lists input file names for the different objects in the watershed.
2	**Soil Data**	*.sol*	Describe different soil classes and their physical properties
3	**Weather Generator Data**	*.wgn*	General Statistics about climate parameters for the whole watershed
4	**Subbasin General Data**	*.sub*	This required file for each subbasin defines climatic inputs, tributary channel attributes, and the number and types of HRUs in the subbasin
5	**HRU General Data**	*.hru*	Required file for HRU level parameters. Catch-all file
6	**Main Channel Data**	*.rte*	This required file contains parameters governing water and sediment movement in the main channel of a subbasin.
7	**Groundwater Data**	*.gw*	This required file contains information about the shallow and deep aquifer in the subbasin.
8	**Water Use Data**	*.wus*	This optional file contains information for consumptive water use in a subbasin
9	**Management Data**	*.mgt*	This required file contains management scenarios and specifies the land cover simulated in the HRU.
10	**Soil Chemical Data**	*.chm*	This optional file contains information about initial nutrient and pesticide levels of the soil in the HRU.
11	**Pond Data**	*.pnd*	This optional file contains information for impoundments located within a subbasin.
12	**Septic Data**	*.sep*	This file contains information on septic systems.
13	**Operation Data**	*.ops*	An optional file which allows the simulation of non-reoccurring management related activities.
14	**Watershed General Data**	*.bsn*	This required file defines values or options used to model physical processes uniformly over the entire watershed.
15	**Master Watershed File**	*.cio*	This required file contains the names of watershed level files and parameters related to printing.
16	**Precipitation input file**	*.pcp*	This optional file contains daily measured precipitation for a measuring gage(s).
17	**Temperature input file**	*.tmp*	This optional file contains daily measured maximum and minimum temperatures for a measuring gage(s).

4.9.4. SWAT Simulation

The last menu of ArcSWAT is the simulation menu by which the SWAT model simulation can be run and calibrated. In the Run SWAT menu (Figure 22), period of simulation is identified beside the time steps for the simulation (Monthly or daily bases). The calibration process requires the preparation of observation file that contains measure stream flow data quantities and qualities. Running the simulation will open a DOS window that shows the progress of running SWAT 2009 simulation.

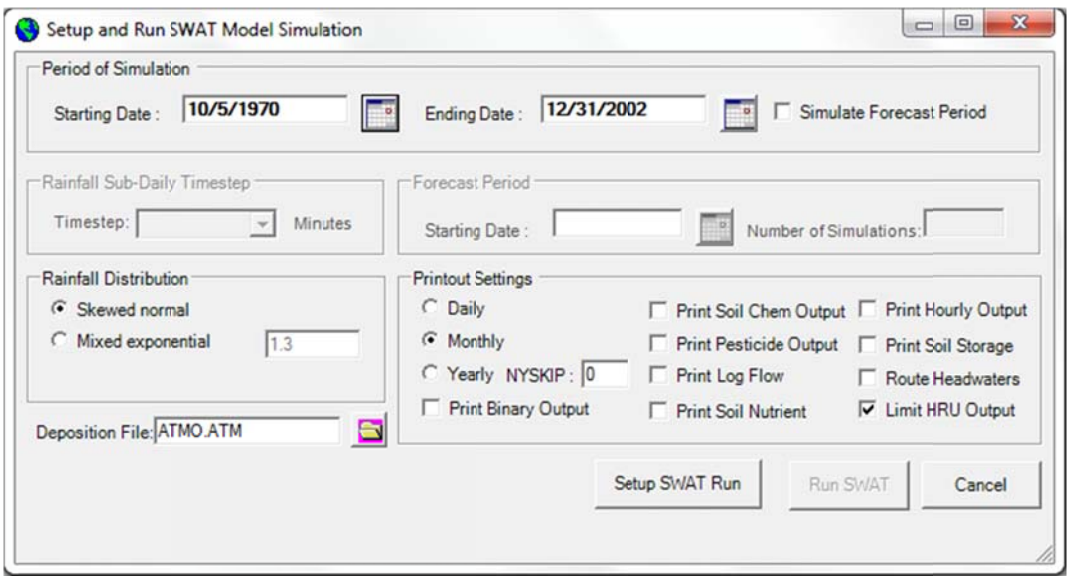


Figure (22): ArcSWAT Simulation Interface

4.10. SWAT calibration using for ZRB using baseline scenario data

ArcSWAT was used to build up the hydrological model for ZRB as described earlier. The model was used to simulate the surface runoff from the period of 1/1/1970 to 31/12/2009. For calibration purposes, the period from 1/1/1980 to 31/12/1995 was used. The calibration period contains dry, wet, and normal flood flow years. SWAT model contain a huge number of parameters, most of them are measured or estimated from ArcSWAT database. Before the calibration process sensitivity analysis had performed to consider the most sensitive parameters. Table (8) shows the sensitive parameters used in the calibration process.

Table (8): Parameters used in SWAT model Calibration for ZRB.

Name	Definition	Estimated value	Calibrated value	Units	Possible range	
					Min	Max
CN2	Curve number	80.1	82.6	None	0	100
SOIL_ALB	Moist soil albedo	0.21	0.81	None	0	1
EPCO	Plant uptake compensation factor	0.41	0.95	inches	0	1
ESCO	Soil evaporation compensation factor	0. 099	0. 1200	inches	0	1
SOIL_K	Saturated hydraulic conductivity	0.9100	0.9100	mm/hr	0	2000
CANMX	Maximum canopy storage (mm H_2O).	0.186	0.27	mm	0	2.5
REVAPMN	Threshold depth of water in the shallow aquifer	0.13	0.65	mm	-1	1

The calibration process was performed using daily observed flow data measured at station AL0060 (Jerash Bridge gaging station, Figure (23)). The result of the calibration process of SWAT for ZRB for the period 1980-1995 is shown in Figure (24). According to Figure 24, there is a good agreement between the simulated (calibrated) flow and the observed flow. The model gave higher peak than the observed flow in years 1985 and 1992. The mean monthly simulated stream flow for the calibration period (1980-1995) was 2.58 m^3/s, which is the same value for the observed mean stream flow in this period.

Figure (25) shows a scatter plot of observed and simulated monthly flow using SWAT model. The model simulated monthly stream flows satisfactorily as indicated by the high coefficient of determination (R^2 = 0.95) and the slope of the relationship between observed and simulated flow was nearly close to unity (0.92).

Figure (26) shows the simulation results of the calibrated model over the period from 1/1/1970 to 31/12/2009. Again, as can be noticed from this figure the calibrated monthly flows matched very well with the observed flow values. Figure (27) shows the annual mean flow results of the calibrated model compared with the mean annual observed flow.

Figure (23): Location map of Jerash Bridge gaging station.

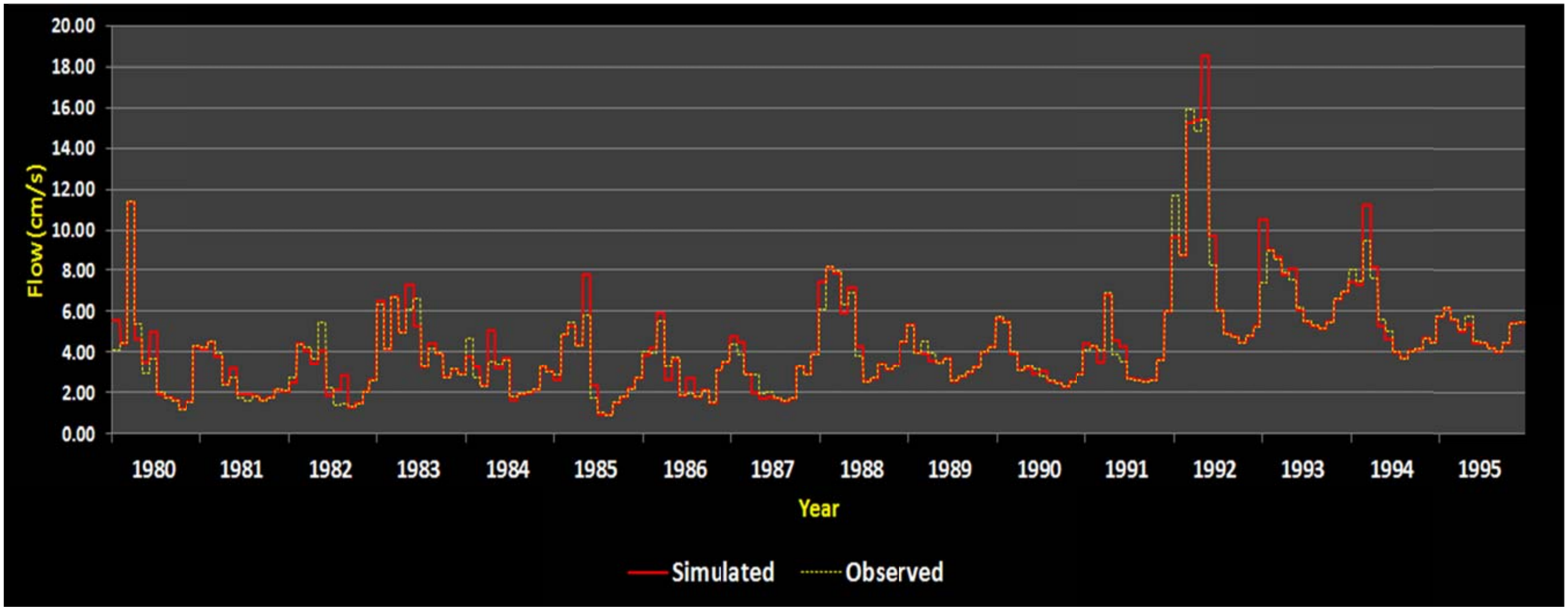


Figure (24): Comparison between observed and calibrated (simulated) mean monthly mean flow (m3/s) at AL0060 Station

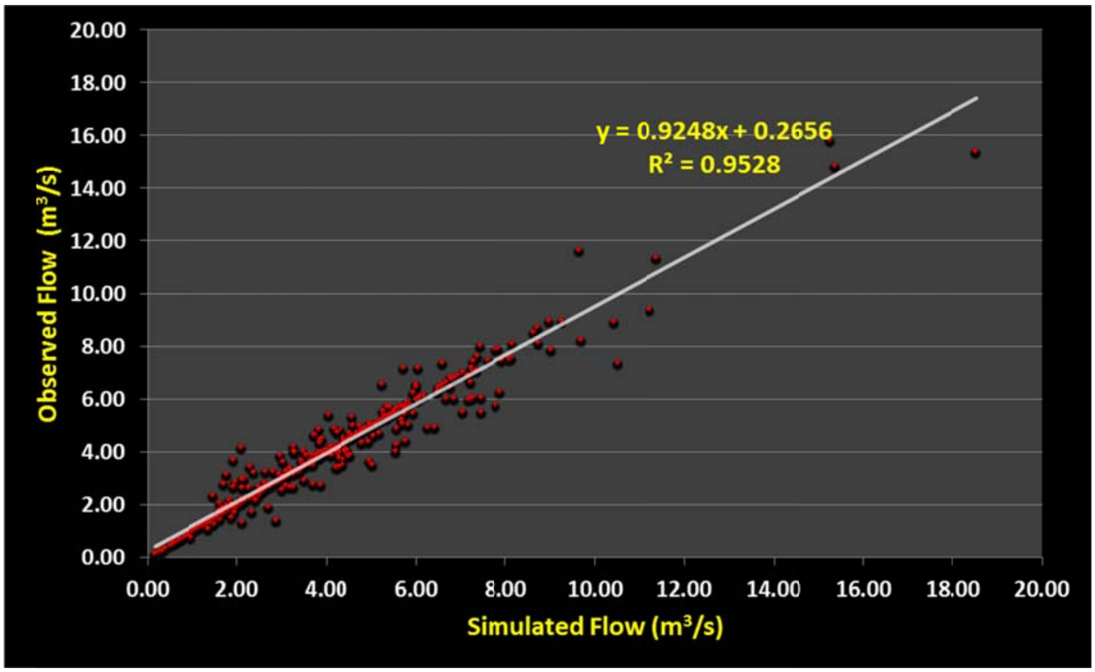


Figure (25): Scatter plot for the relationship between observed and simulated mean flow in m^3/s

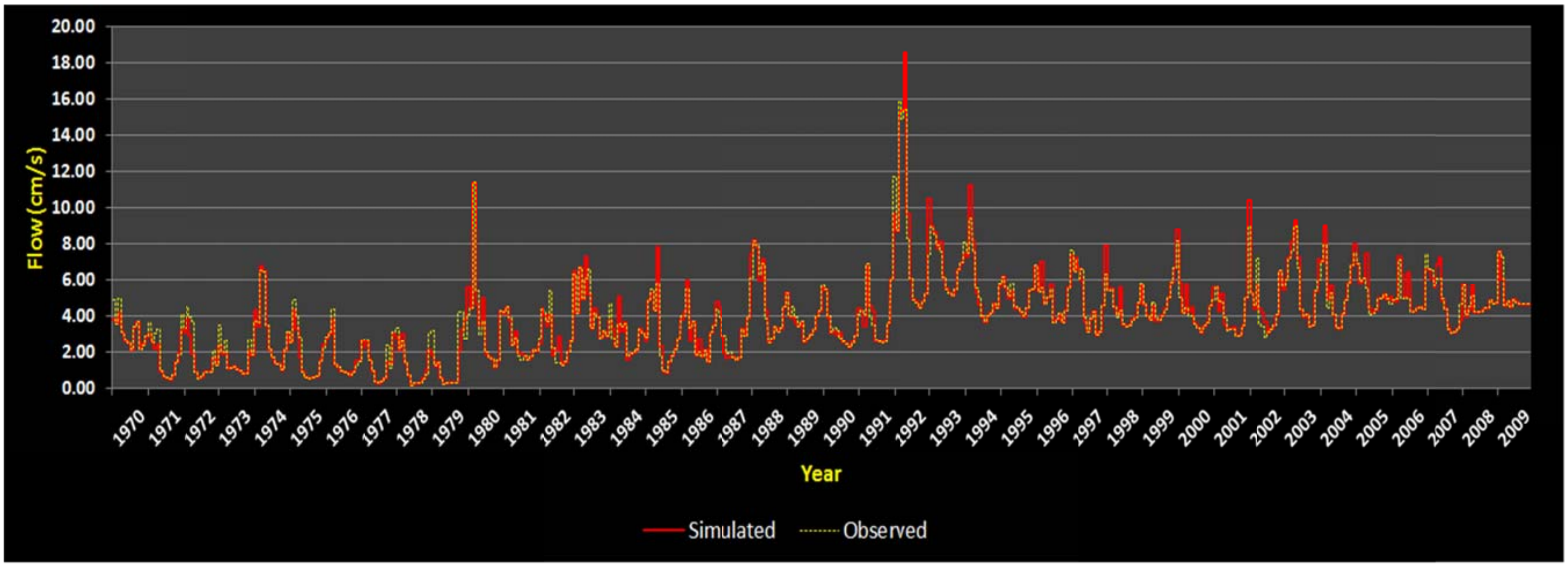


Figure (26): Simulated monthly flow as compared with the observed flow for the ZRB

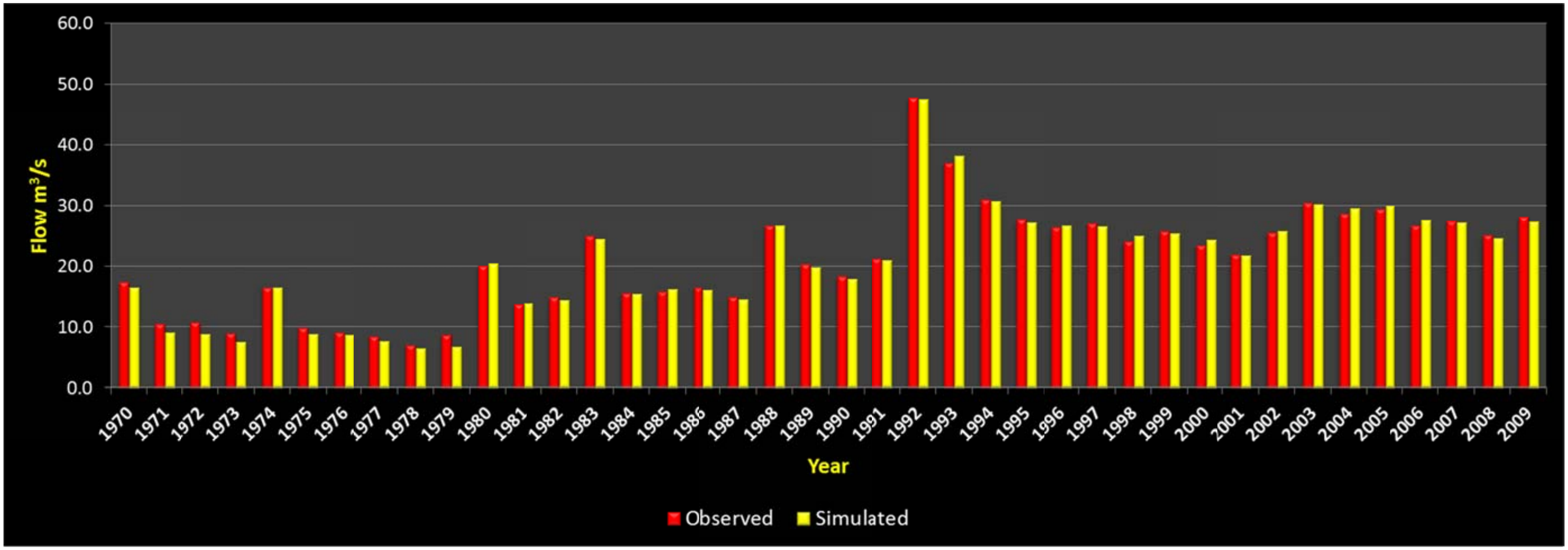


Figure (27): simulated annual flow as compared with the observed flow for the ZRB

4.11. Impacts of climate change on surface water quantities of ZRB.

According to the meteorological section of this study, two types of future climate change scenarios were adopted in this study, these are: the incremental scenarios and global climate models (GCM). Twenty incremental scenarios were created and two types of GCM models were created using downscaling techniques. The outputs of these models were used to assess the impacts of future climate models on water availability at ZRB.

4.11.1. Impact of climate change on surface runoff using the incremental climate change scenarios

The created incremental climate change scenarios have been classified into four main categories (Table 9); the first group assumes the mean annual temperature will be increased by one degree, the second by two degrees, the third group by three degrees and the fourth group by four degrees. Within each group, the precipitation was assumed to be changed by -20%, -10%, not changed, +10%, and +20%, these changes represents dry, normal and wet climatic conditions. The outputs of these scenarios were used in SWAT model to assess the impacts of these changes on the baseline monthly surface runoff. The simulation results of these 20 incremental scenarios are shown in figure (28).

Table (9): Incremental climate change scenarios

Scenario ID	Change in Temperature	Change in Precipitation
INC_SEN 1	Mean +1	-20%
INC_SEN 2		-10%
INC_SEN 3		No Change
INC_SEN 4		+10%
INC_SEN 5		+20%
INC_SEN 6	Mean +2	-20%
INC_SEN 7		-10%
INC_SEN 8		No Change
INC_SEN 9		+10%
INC_SEN 10		+20%
INC_SEN 11	Mean +3	-20%
INC_SEN 12		-10%
INC_SEN 13		No Change
INC_SEN 14		+10%
INC_SEN 15		+20%
INC_SEN 16	Mean +4	-20%
INC_SEN 17		-10%
INC_SEN 18		No Change
INC_SEN 19		+10%
INC_SEN 20		+20%

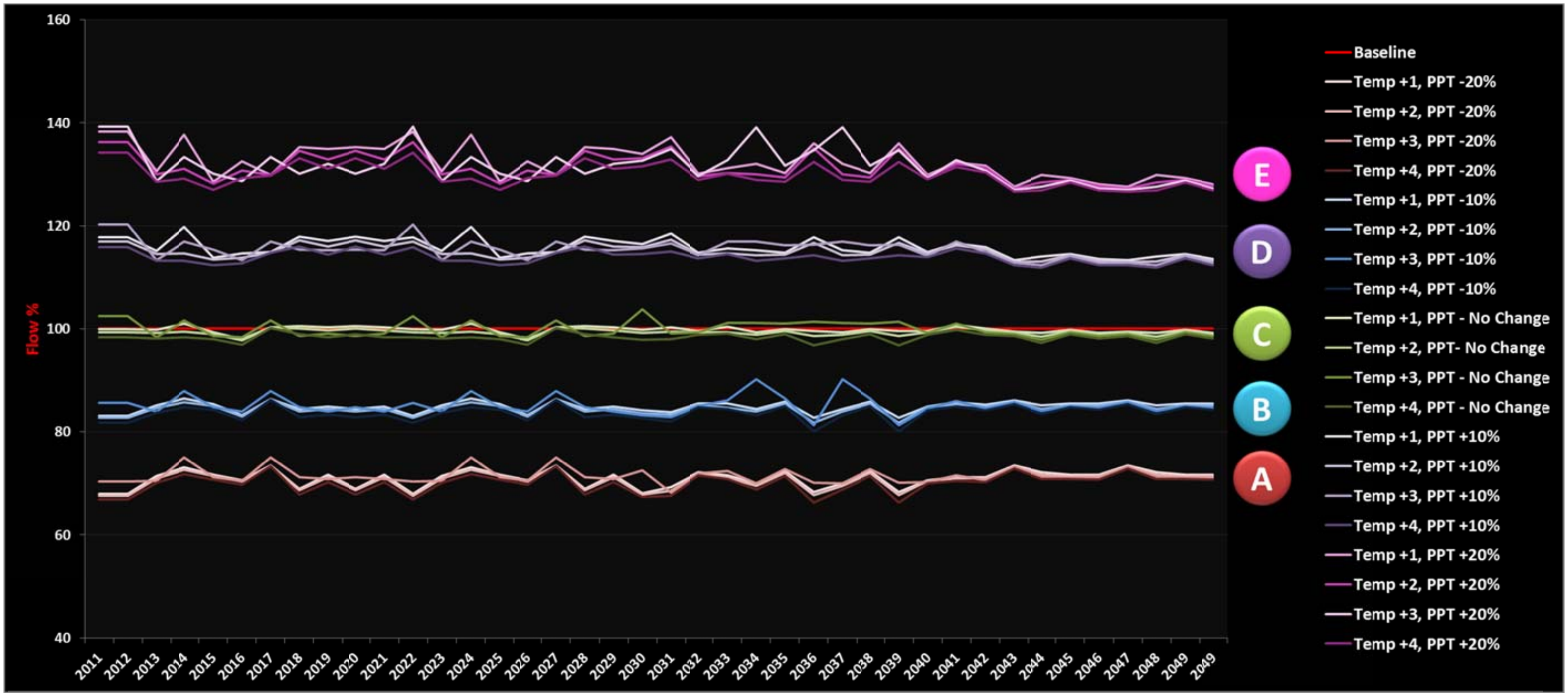


Figure (28): SWAT simulation results for the 20 Incremental Scenarios

As can be inferred from figure (28), the main factor that plays an important role in determining the behavior of the surface runoff amounts in the future is the precipitation. For example, The first group of curves represents (Group A) the incremental scenarios where precipitation is assumed to be decreased by 20% and the temperature is increased by 1,2,3 and 4 degrees. We can see temperature variation was has little contribution on the behavior of runoff curve. While decreasing the precipitation by 20%, affect the amounts of surface runoff to drop up to 50% of the baseline scenario. The same behavior of temperature can be noticed on the other groups of incremental scenarios. This remark can be easily noticed on group (C), where precipitation is not changed, and the four curves with different temperatures increases shows a similar simulation as the baseline scenario. On the other extreme, Group (E) of incremental scenarios showed that the amounts of surface runoff might increase up to 20% as a result of increasing precipitation with 20%. Incremental scenarios groups (A) and (B) represents dry years, while group (C) represents normal years and groups (E) and (F) represents wet years.

The advantage of such analysis is that, it provides a broad picture about the different possibilities that might happens on the future. However, we such analysis can't predict exactly, which of these 20 scenarios are the most probable scenario for the future, which considered as disadvantage for such analysis. Therefore, Global Climate Models were also incorporated in this study.

4.11.2. Impact of climate change on surface runoff using downscaled climate change scenarios

HadCM3 was selected in this study as future climate model. The outputs from downscaling analyses were in SWAT simulation to assess the impact of future climate changes on water arability at ZRB. Two type series of HadCM3 (A2 and B2) were used in this study. Figure (29) shows the simulation mean annual results for the types of GCM data. The simulation was run from year 2011 until 2096. By referring to this figure, the following can be inferred:

i) Both experiments (A2, B2) predict that the amounts of surface runoff are going to be decreased within the next 90 years.

ii) This decrease will be highly noticed after the year 2050

iii) The two experiments show similar behavior about the future amounts of surface runoff.

i) The maximum amount of surface runoff would be received in 2032 based on the two experiments.

ii) The maximum peak flow will drop from about 50 m^3/s recorded in the baseline scenario to less than 35 m^3/s in the future scenarios.

iii) By referring to the mean annual simulated values of surface runoff, it's expected that these values are going to be decreased for the next 50 years.

Figure (30)a shows the long term monthly average values for future scenarios and compares them with baseline scenario. Figure (30)b shows the future predicted change in monthly stream flow values in percent according to HadCM3 GCM model experiments A2 and B2. While figure (30)c shows the future predicted change in monthly stream flow values according to HadCM3 GCM model experiments A2 and B2. By referring to these two figures the following can be noticed:

1) Both future climate models predict that values of surface runoff amounts will be decreased for the rainy months at ZRB (Dec, Jan, Feb and Mar). This reduction may reach up 50% especially in February.
2) On the other hands, an increase in the surface runoff amounts will be noticed on other months were usually get no or very little amounts of surface runoff like October and December.
3) Another important notice about the results of HadCM3 simulation results is that, it is expected to have more precipitation at summer season, which will result in surface runoff amounts in these months, while in fact this is not common at ZRB as can be seen from the baseline scenario results.
4) The monthly peak flow values are expected to decrease 40% in Jan, Feb and Mar. On the other hand, there will be an increase on other months like Oct and Dec

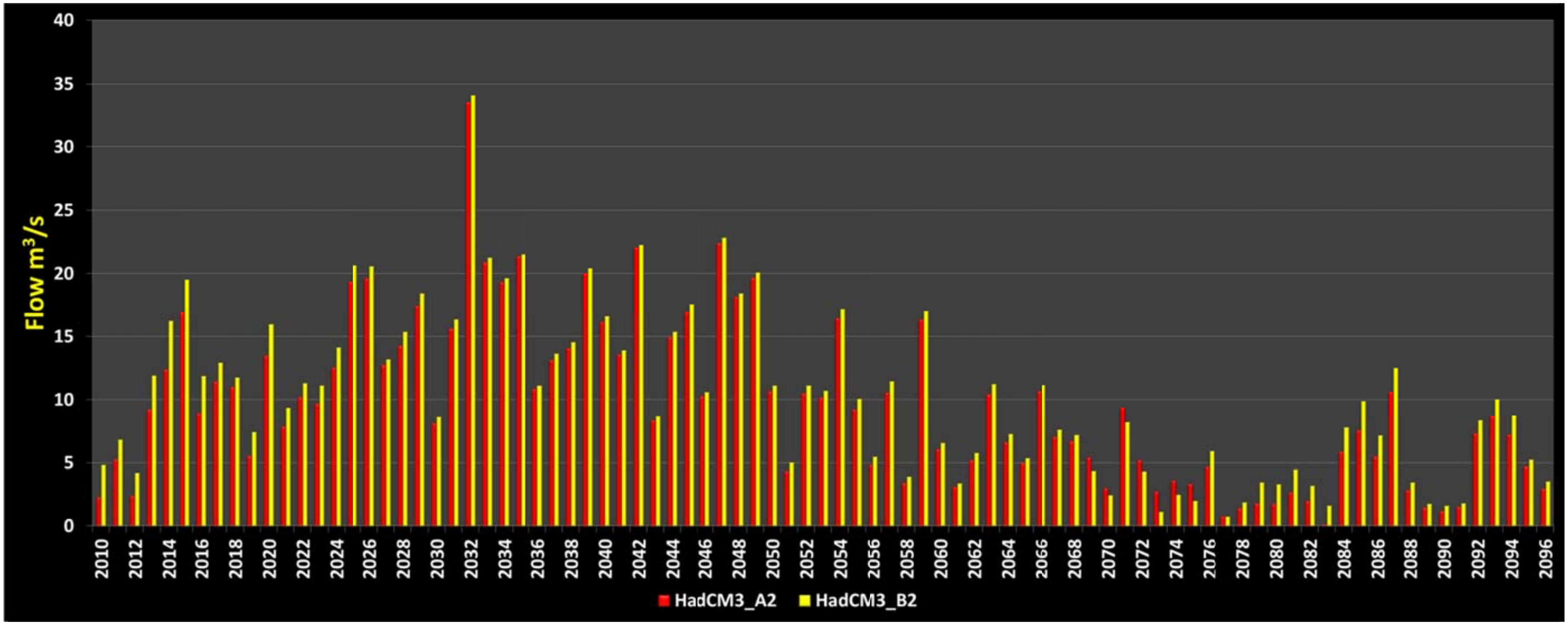


Figure (29): Simulated mean annual surface runoff amounts from 2011 - 2096

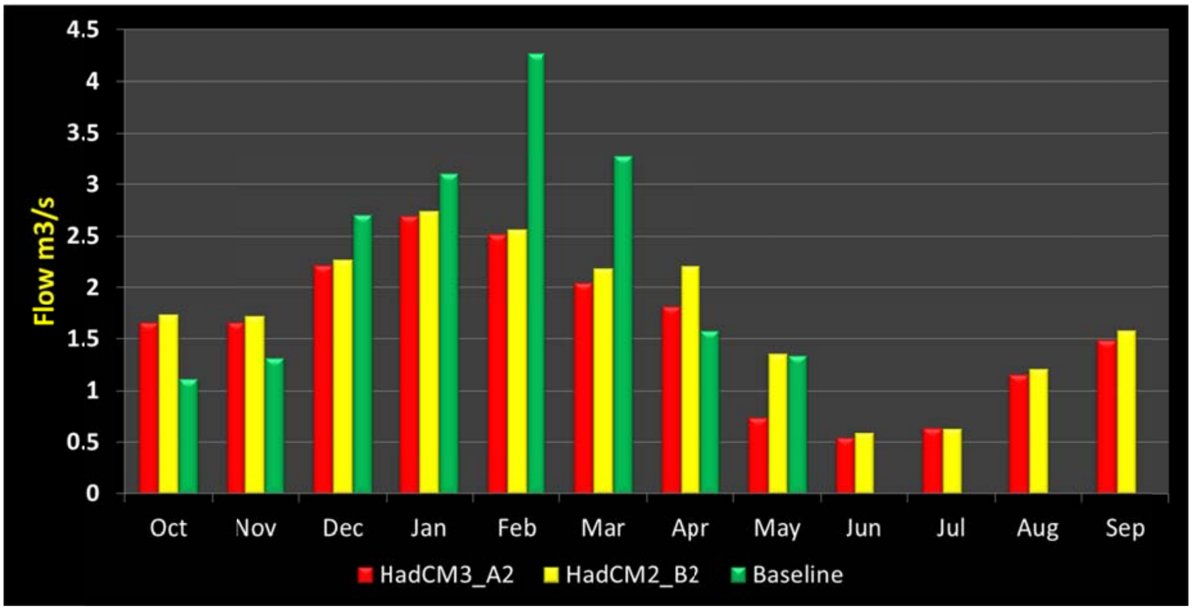


Figure (30)a: Long term monthly mean values from future climate modes (HadCM3 A2, B2) as compared with Baseline Scenario.

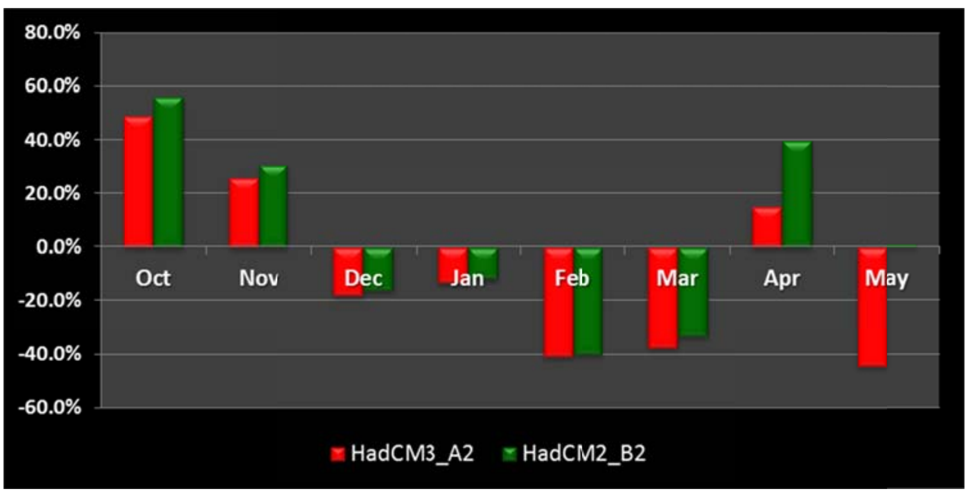


Figure (30)b: Future predicted change in monthly stream flow values according to HadCM3 GCM model experiments A2 and B2.

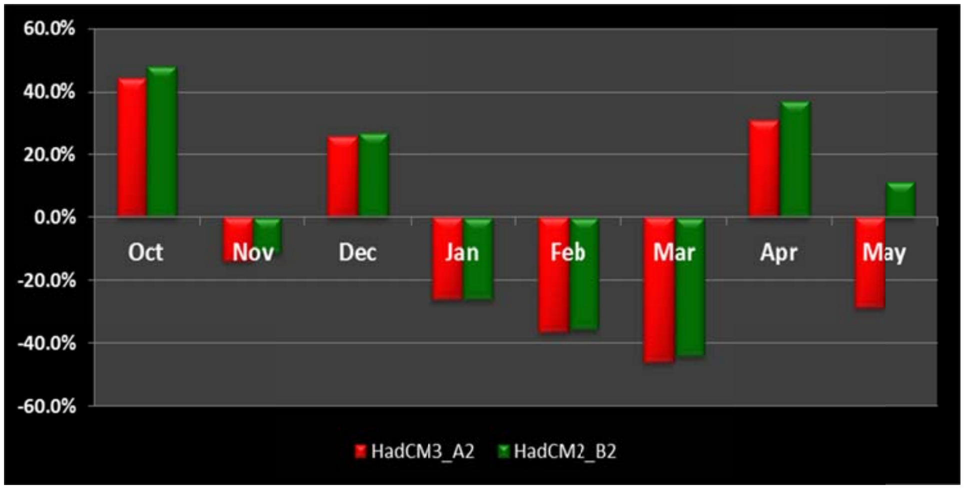


Figure (30)c: Future predicted change in monthly peak flow values according to HadCM3 GCM model experiments A2 and B2

4.12. Conclusion

In this section, a hydrological model was implemented using SWAT model through GIS environment. Various data sets were used in this process which include digital elevation model (DEM), Soil Data, Land use data, besides meteorological data which include daily precipitation and temperature. The implemented model was calibrated using observed flow values obtained from Jerash Bridge gauging station (AL0061). The correlation coefficient between the simulated values and the observed values (R^2) is 0.95 which indicates a high correlation. The calibrated model was used to assess the impacts of climate change on surface runoff availability. Two types of future climate data were used for this purpose. The first is the incremental future data and the other is the global climate models (GCM) data.

Results for the incremental data showed that the precipitation is the major factor that affects the availability of surface runoff water. In dry years, it's expected that these amount may decreased up to 35%, while in normal years it will be decrease only by 2% even if the temperature increase 4^{o}c. In the wet years these values my increase up to 40%.

Depending on the incremental scenarios for assessing the future impacts of climate change on surface water availability is not enough. Because it is not possible to determine which is the most probable scenario that might happens in the future. Therefore GCM data was used.

Based on the outputs from the metrological analyses, HadCM3 model with two experiments (A2 and B2) was used in this section. Based on simulated values for these two experiments, the mean annual surface runoff values are expected to decline for the next 80 years. For the mean monthly values, there will be a major decease in the surface runoff availability especially for the rainy months (Dec, Jan, Feb and Mar). While a slight increase was expected for other months like Oct, Nov, Apr and May. Similar results were also obtained for the maximum monthly peak flow values. The same results were obtained for both experiments A2 and B2.

4.13. Recommendations

The main recommendations arising from this study for future follow up are:

1) Extend the target area of the study to include more watersheds in Jordan Like Yarmouk Basin and Mujieb Basin.
2) This study was based on several data sets from different sources, and sometimes, obtaining such data is a time consuming process. It's important to hold a meeting with involved ministries and governorates to start thinking in building Jordan's national spatial network. MWI may initiate this process and may also hos the server and portals for data sharing and dissemination.
3) Based on the results obtained from this section, it was found generally that surface water availability are going to be affected by climate change and may drop in rainy months up to 40%, therefore, Jordan's Water National Strategy which starts in 2008 and will last until 2022 should be revised to take into consideration these figures.
4) To reduce the impacts of climate change on water resources of ZRB, a detail study is needed to select and priorities the most suitable climate change adaption strategies for ZRB.
5) It is important to start seeking for new non-conventional water resources project like water harvesting projects and use of gray water project.

5. Impacts of climate change on water quality of ZRB.

5.1. Introduction

The Impact of climate change on water quality is still considered a challenge for many researchers and investigators. Therefore, there are only limited number of studies that dealt with the impact of climate change on water quality (Jun Tu, 2009). The fresh water chapter of the IPCC fourth assessment report did not consider the impact of climate change on water quality in a detailed manner.

The main objective of this part of the study is to assess the direct and indirect impacts of the climate change on the water quality of the Zarqa River based on the climate change scenarios that developed by the project team. To achieve this objective, data on water quality of the Zarqa River were collected for the years 2005-2010 from various stations along the river as shown on Figure 31 The data included flow rate, chemical oxygen demand (COD), Turbidity, Dissolved oxygen (DO), electrical conductivity (EC), Total Phosphorus and Total Nitrogen.

To assess the impacts on various water quality parameters trend analysis of each parameter were carried out. For example, Figures 32, 33 and 34 showing the trend of water temperature, for the period 2005-2010 at the stations M-9, M-10 and M-11 along the Zarqa River. It can be observed that the water temperature is increasing with time. There was an increase of 1, 1.5 and 1.2 ◦C in the average water temperature at stations M-9, M-10 and M-11, respectively. This indicates that water temperature is increasing with time which is reflecting the impact of the ambient temperature.

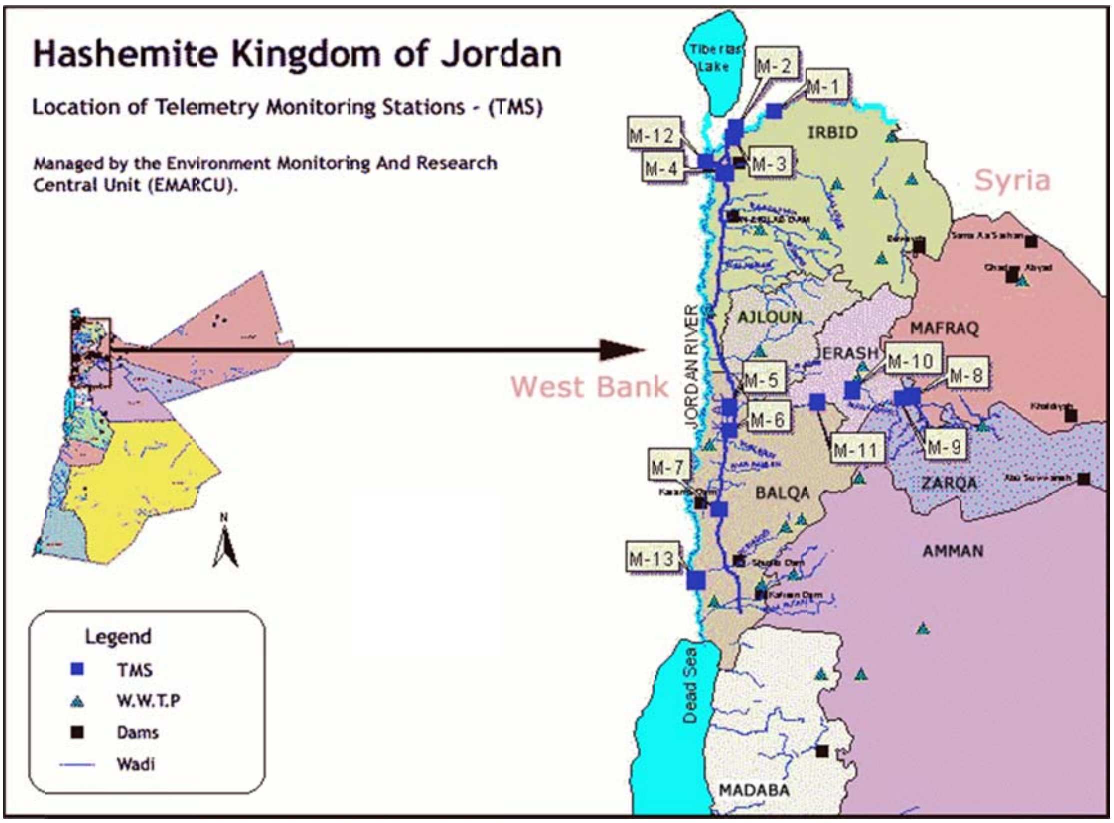


Figure (31) Location of the water quality monitoring stations within the Zarqa River basin

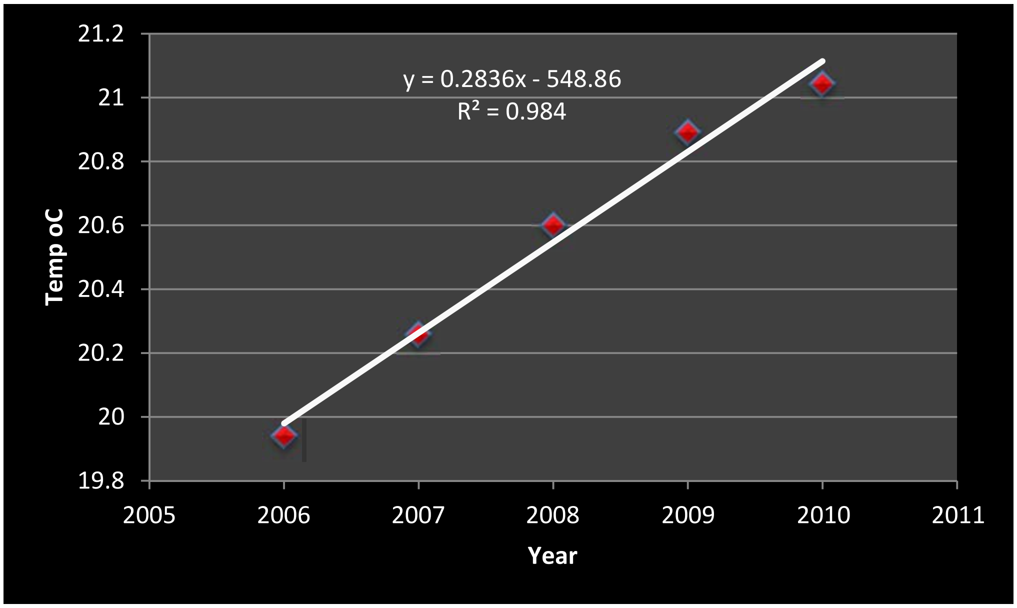


Figure (32) Change average temperature of the river water during the period 2006-2010 at station M-9

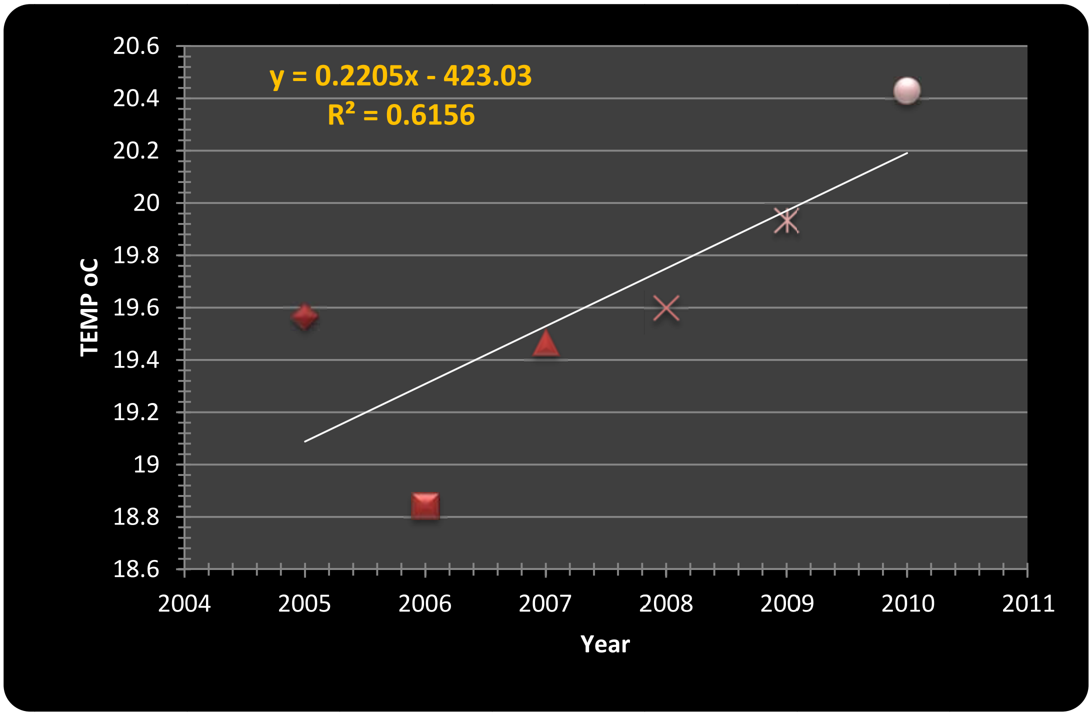


Figure (33) Change average temperature of the river water during the period 2006-2010 at station M-10

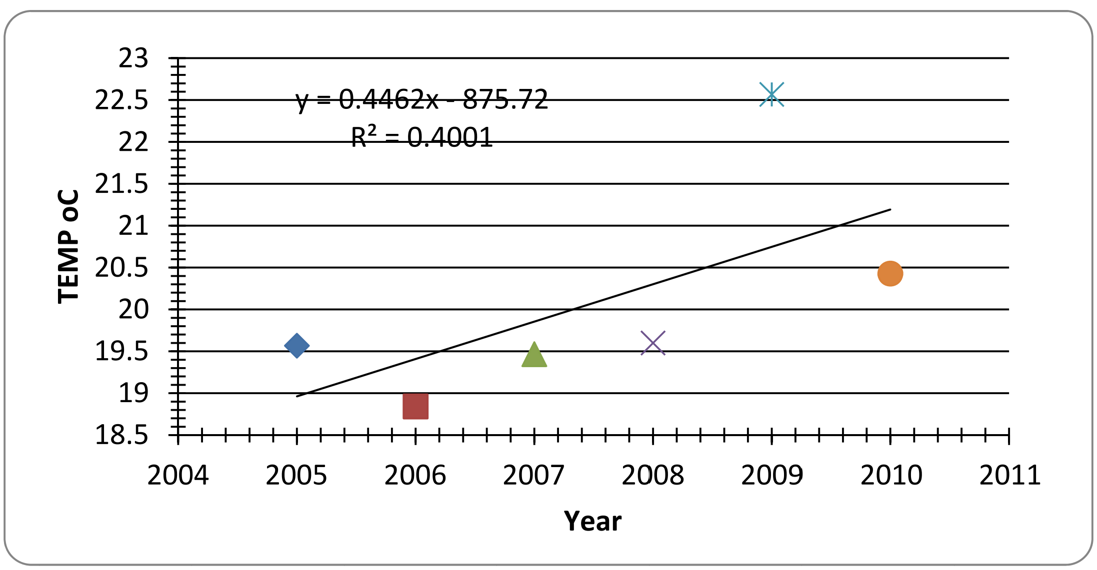


Figure (34) Change in average temperature of the river water during the period 2006-2010 at station M-11

It is well known that increase in the water temperature leading to decrease in dissolved oxygen and consequently deterioration in the quality of the water body. This is also reflected on the degradation kinetics of the organic pollutants. As it may be seen in Figures 35 there is a decreasing trend in the chemical oxygen demand (COD)of the river water. In addition to the impact of temperature on the degradation kinetics, the decrease in COD may be also attributed to the fact that the performance of Kherbit Al Samra treatment plant which was converted into mechanical plant and put into operation in 2006.

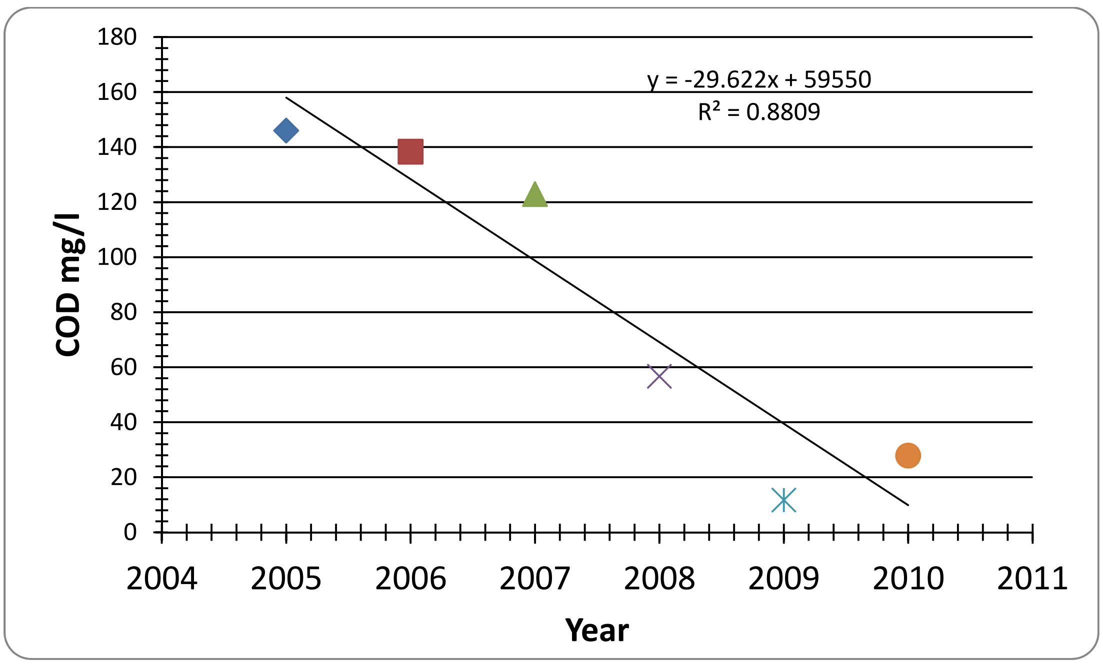


Figure (35): Change in average COD value of the river water for the period 2005-2009

After conducting the trend analysis, the value of each quality parameter was correlated to the temperature. Figure 36 and 37 show the correlation between COD and TDS respectively, with temperature for the year 2006 at station M-9. It can be seen that the COD value decreasing with increase in temperature as a result of organic matter degradation, while the TDS value is increasing. This is logical, as the solubility of solids is increasing with increase in temperature.

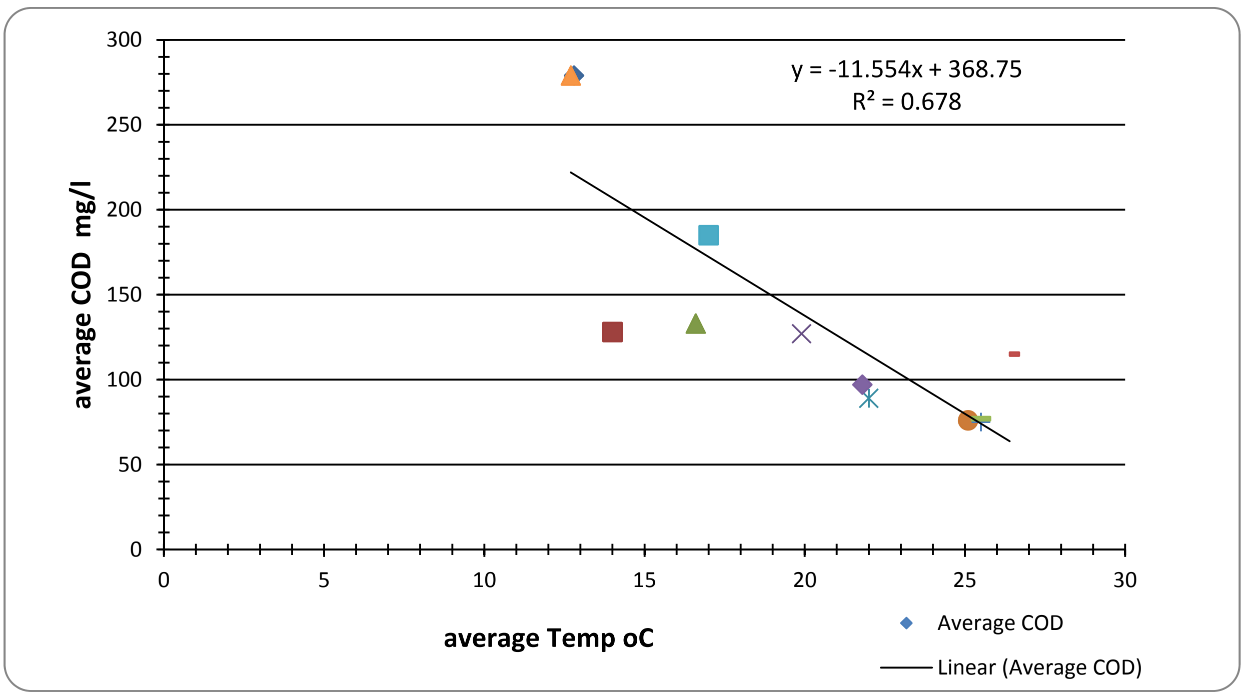


Figure (36) Change in average COD value of the river water with temperature during 2006 at station M-9

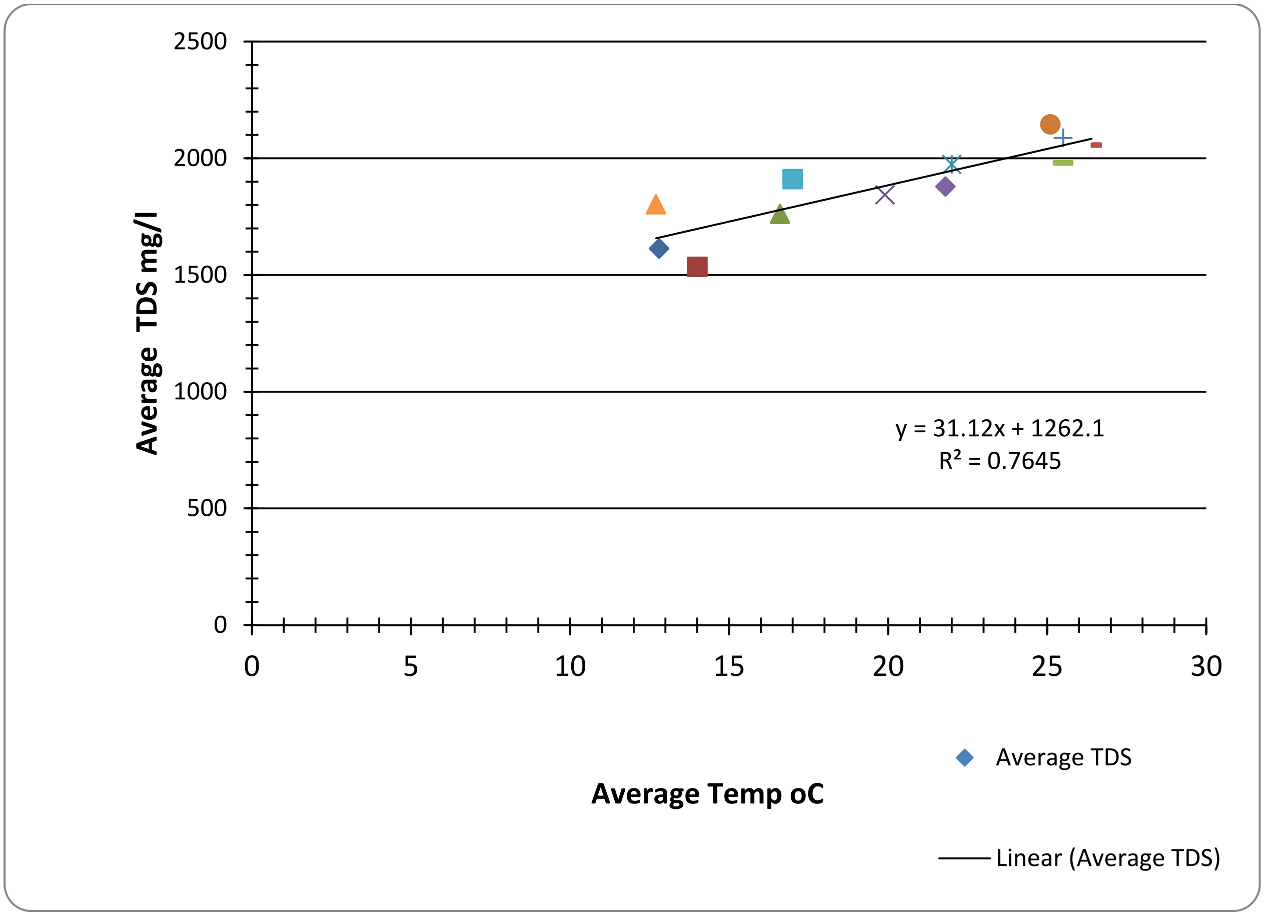


Figure (37): Change in average TDS value of the river water with temperature during 2006 at station M-9

Turbidity value was also observed to be decreasing with the increase in temperature as shown in figure 38. This is may be explained by the fact that most of the colloidal materials that are causing the turbidity, are of organic origin and consequently degrading with increase in temperature.

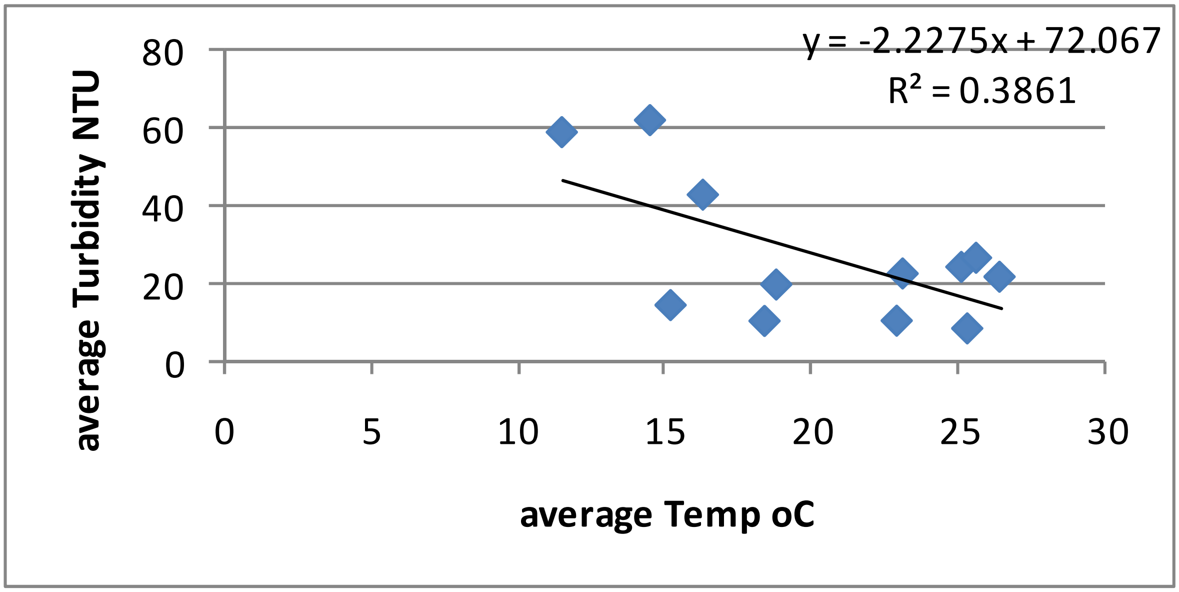


Figure (38): Change in average turbidity value of the river water with temperature during 2007at station M-9

5.2. Water quality for the baseline scenario.

In addition to its ability to simulate stream flow quantities in any given watershed, SWAT also has the capability to consider water quality through a set of parameters like: dissolved oxygen and carbonaceous biological oxygen demand (CBOD) entering the main channel with surface runoff, nitrates and other parameters. Loadings of these three parameters impact the quality of stream water.

Due to the limitation regarding the data availability for water quality at ZRB, the quality parameters that were considered in this study are Surface NO_3, Organic N and Organic P.

5.2.1. Surface Runoff Nitrate

According Neitsch, et, al 2005 (SWAT 2005 Theoretical Manual), Nitrate may be transported with surface runoff, lateral flow or percolation. To calculate the amount of nitrate moved with the water, the concentration of nitrate in the mobile water is calculated. This concentration is then multiplied by the volume of water moving in each pathway to obtain the mass of nitrate lost from the soil layer. The concentration of nitrate in the mobile water fraction is calculated:

$$conc_{NO3,mobile} = \frac{NO3_{ly} \cdot \left(1 - \exp\left[\frac{-w_{mobile}}{(1-\theta_e) \cdot SAT_{ly}}\right]\right)}{w_{mobile}}$$

Where:

$\boldsymbol{conc}_{NO3,mobile}$	is the concentration of nitrate in the mobile water for a given layer (kg N/mm H2O),
$\boldsymbol{NO3}_{ly}$	is the amount of nitrate in the layer (kg N/ha),
$\mathbf{w}_{mobile}$	is the amount of mobile water in the layer (mm H_2O),
$\boldsymbol{\theta}_e$	is the fraction of porosity from which anions are excluded, and
$\boldsymbol{SAT}_{ly}$	is the saturated water content of the soil layer (mm H_2O).

The amount of mobile water in the layer is the amount of water lost by surface runoff, lateral flow or percolation:

$$w_{mobile} = Q_{surf} + Q_{lat,ly} + w_{perc,ly} \qquad \text{for top 10 mm}$$

$$w_{mobile} = Q_{lat,ly} + w_{perc,ly} \qquad \text{for lower soil layers}$$

where

$\boldsymbol{w}_{mobile}$ is the amount of mobile water in the layer (mm H_2O),

$\boldsymbol{Q}_{surf}$ is the surface runoff generated on a given day (mm H_2O),

$\boldsymbol{Q}_{lat,ly}$ is the water discharged from the layer by lateral flow (mm H_2O), and

$\boldsymbol{w}_{perc,ly}$ is the amount of water percolating to the underlying soil layer on a given day (mm H_2O). Surface runoff is allowed to interact with and transport nutrients from the top 10 mm of soil.

Nitrate removed in surface runoff is calculated:

$$NO3_{surf} = \beta_{NO3} \cdot conc_{NO3,mobile} \cdot Q_{surf}$$

where

$\boldsymbol{NO3}_{surf}$ is the nitrate removed in surface runoff (kg N/ha),

$\boldsymbol{\beta}_{NO3}$ is the nitrate percolation coefficient,

$\boldsymbol{conc}_{NO3,mobile}$ is the concentration of nitrate in the mobile water for the top 10 mm of soil (kg N/mm H_2O), and

$\boldsymbol{Q}_{surf}$ is the surface runoff generated on a given day (mm H_2O).

In large sub basins with a time of concentration greater than 1 day, only a portion of the surface runoff and lateral flow will reach the main channel on the day it is generated.

SWAT incorporates a storage feature to lag a portion of the surface runoff and lateral flow release to the main channel. Nutrients in the surface runoff and lateral flow are lagged as well. Once the nutrient load in surface runoff and lateral flow is determined, the amount of nutrients released to the main channel is calculated:

$$NO3_{surf} = \left(NO3'_{surf} + NO3_{surstor,i-1}\right)\cdot\left(1-\exp\left[\frac{-surlag}{t_{conc}}\right]\right)$$

where

$NO3_{surf}$	is the amount of nitrate discharged to the main channel in surface runoff on a given day (kg N/ha),
$NO3'_{surf}$	is the amount of surface runoff nitrate generated in the HRU on a given day (kg N/ha),
$NO3_{surstor,i-1}$	is the surface runoff nitrate stored or lagged from the previous day (kg N/ha),
surlag	is the surface runoff lag coefficient, and
t_{conc}	is the time of concentration for the HRU (hrs)

Surface NO_3 was computed by SWAT using the above mentioned method. Figure (39) shows the mean annual concentrations of surface NO_3 for the baseline scenario.

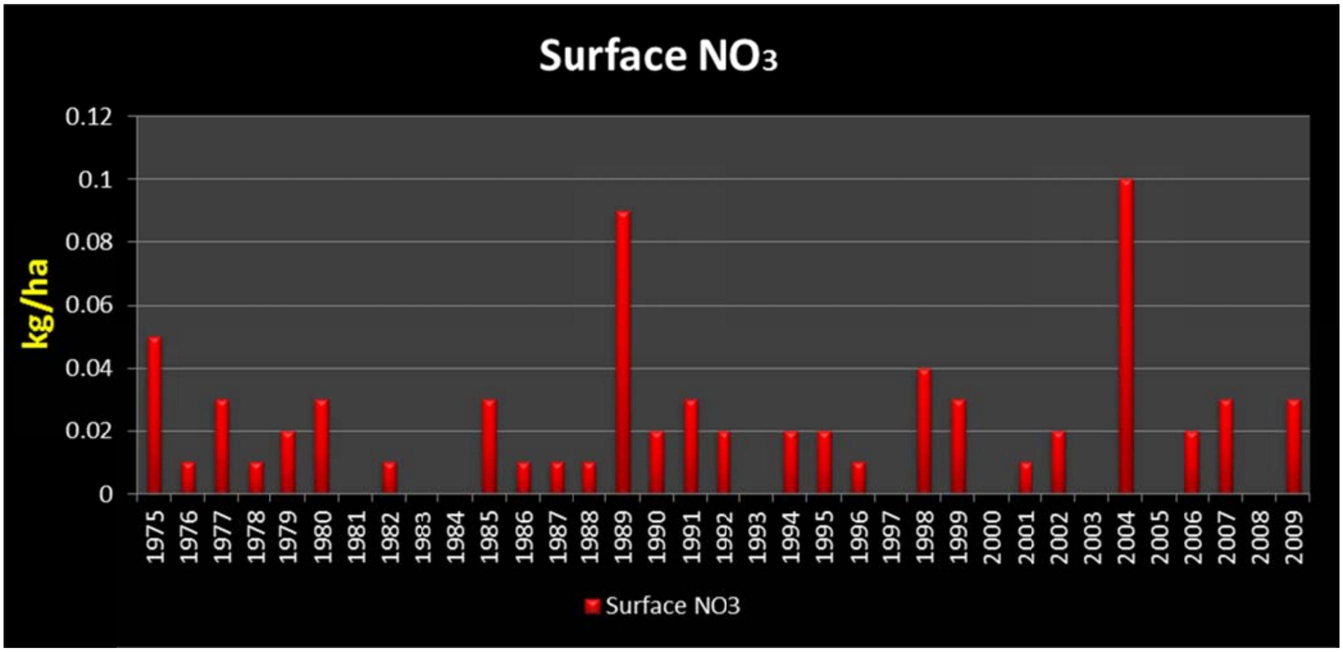


Figure (39): Surface NO3 values for the baseline scenario (1975-2009).

5.2.2. Organic N in Surface Runoff

According to SWAT2005 theoretical manual by Neitsch, et, al, Organic N attached to soil particles may be transported by surface runoff to the main channel. This form of nitrogen is associated with the sediment loading from the HRU and changes in sediment loading will be reflected in the organic nitrogen loading. The amount of organic nitrogen transported with sediment to the stream is calculated with a loading function developed by McElroy et al. (1976) and modified by Williams and Hann (1978):

$$orgN_{surf} = 0.001 \cdot conc_{orgN} \cdot \frac{sed}{area_{hru}} \cdot \varepsilon_{N:sed}$$

where

***orgN**$_{surf}$* : is the amount of organic nitrogen transported to the main channel in surface runoff (kg N/ha),

$conc_{orgN}$:is the concentration of organic nitrogen in the top 10 mm (g N/ metric ton soil),

sed : is the sediment yield on a given day (metric tons),

$area_{hru}$: is the HRU area (ha), and

$\varepsilon_{N:sed}$: is the nitrogen enrichment ratio, which given by:

$$conc_{orgN} = 100 \cdot \frac{\left(orgN_{frsh,surf} + orgN_{sta,surf} + orgN_{act,surf}\right)}{\rho_b \cdot depth_{surf}}$$

where

$orgN_{frsh,surf}$: is nitrogen in the fresh organic pool in the top 10mm (kg N/ha),

$orgN_{sta,surf}$: is nitrogen in the stable organic pool (kg N/ha),

$orgN_{act,surf}$: is nitrogen in the active organic pool in the top 10 mm (kg N/ha),

ρ_b : is the bulk density of the first soil layer (Mg/m3), and

$depth_{surf}$: is the depth of the soil surface layer (10 mm).

Organic N was simulated using SWAT based on HUR information which based on land use, soil and slope information. Table (9a) shows the Land use, Soil and slope classes at ZRB, and table (9b) shows the distribution of these classes within each sub catchment forming the unique HRUs of ZRB. Based on these HRUs, the organic N was computed for the base line scenario as shown in Figure (40).

Table (10*a*): Land use, Soil and Slope classes of ZRB.

		Area [km]	Area %
Landuse Class	**SWAT Class**		
Agricultural Land-Generic	AGRL	446.51	12.96
Southwestern US (Arid) Range	SWRN	2375.73	68.94
Water	WATR	1.21	0.03
Forest-Mixed	FRST	47.12	1.37
Winter Pasture	WPAS	447.83	13
Residential-Medium Density	URMD	127.75	3.71
Soil Class	**SWAT Class**		
SiL	AL0026	20.08	0.58
SiCL	AL0057	1601.63	46.48
CL	AL0121	274.59	7.97
SiC	AR0013	273.77	7.94
Urban	GA0014	1276.07	37.03
Slope Range	**Slope Class**		
<20	1	2962.58	85.97
20-40	2	409.25	11.88
>40	3	74.31	2.16

Table (10*b)*: HRUs of ZRB based on land use, soil and slope classes.

Subbasin #		Area [Km]	Area %											
1		918.21	26.64											
	Landuse						Soil					Slope		
	AGRL	SWRN	WATR	FRST	WPAS	URMD	AL0026	AL0057	AL0121	AR0013	GA0014	<20%	20-40	>40%
Area [Km]	251.36	178.64	0.93	45.88	430.74	10.39	20.08	525.62	30.66	273.77	67.80	572.32	281.07	64.55
Subbasin Area %	7.29	5.18	0.03	1.33	12.5	0.3	0.58	15.25	0.89	7.94	1.97	16.61	8.16	1.87
Watershed Area %	27.37	19.45	0.1	5	46.91	1.13	2.19	57.24	3.34	29.82	7.38	62.33	30.61	7.03
2		499.85	14.5											
Area [Km]	45.01	447.23	-	-	0.04	7.51	-	259.62	154.55	-	85.63	497.63	2.12	0.05
Subbasin Area %	1.31	12.98	-	-	0	0.22	-	7.53	4.48	-	2.48	14.44	0.06	0
Watershed Area %	9	89.47	-	-	0.01	1.5	-	51.94	30.92	-	17.13	99.55	0.42	0.01
3		592.74	17.2											
Area [Km]	49.52	531.99	0.27	0.08	0.49	10.93	-	266.38	50.19	-	276.73	554.50	37.13	1.66
Subbasin Area %	1.44	15.44	0.01	0	0.01	0.32	-	7.73	1.46	-	8.03	16.09	1.08	0.05
Watershed Area %	8.36	89.75	0.05	0.01	0.08	1.84	-	44.94	8.47	-	46.69	93.55	6.26	0.28
4		793.24	23.02											
Area [Km]	37.73	754.09	-	-	0.01	1.43	-	432.04	19.85	-	341.36	785.88	7.22	0.15
Subbasin Area %	1.09	21.88	-	-	0	0.04	-	12.54	0.58	-	9.91	22.8	0.21	0
Watershed Area %	4.76	95.06	-	-	0	0.18	-	54.47	2.5	-	43.03	99.07	0.91	0.02
5		642.10	18.63											
Area [Km]	62.89	463.78	-	1.16	16.54	97.49		117.97	19.35		504.55	552.25	81.71	7.90
Subbasin Area %	1.82	13.46	-	0.03	0.48	2.83		3.42	0.56		14.64	16.03	2.37	0.23
Watershed Area %	9.79	72.23	-	0.18	2.58	15.18		18.37	3.01		78.58	86.01	12.72	1.23

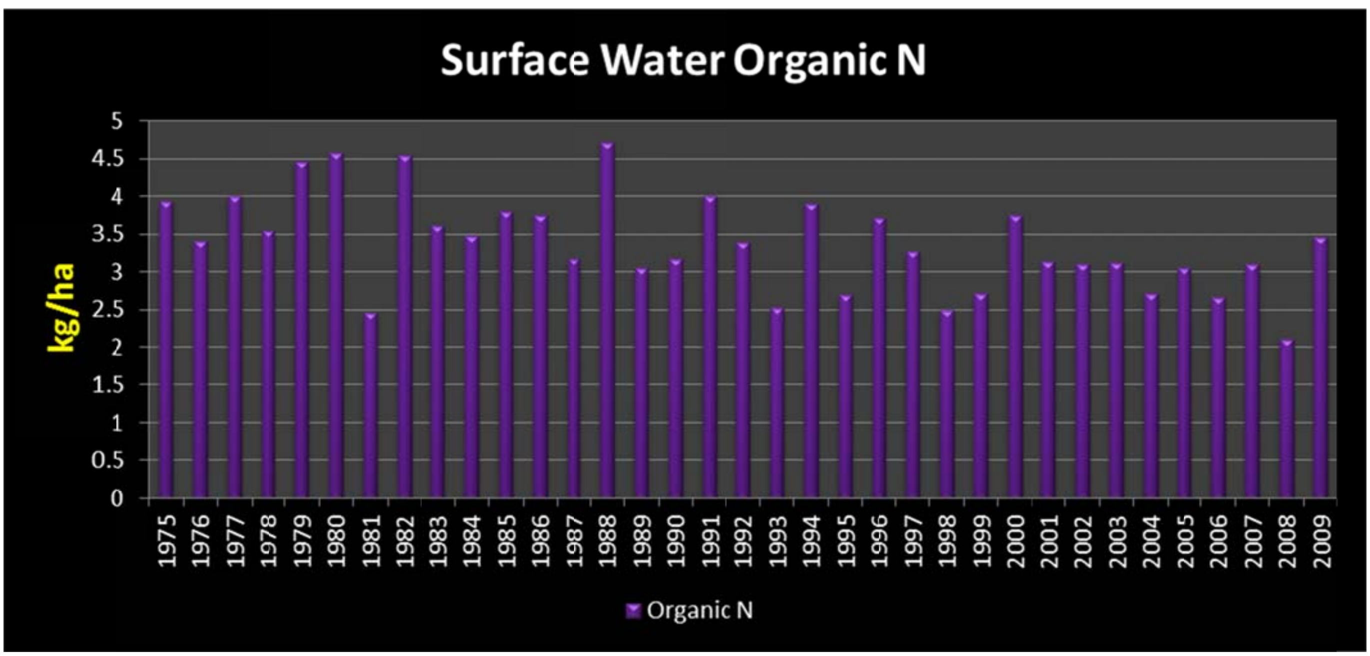


Figure (40): Simulated surface water organic N for base line scenario.

5.2.3. Organic P

Many studies have shown that after an application of soluble P fertilizer, solution P concentration decreases rapidly with time due to reaction with the soil. This initial "fast" reaction is followed by a much slower decrease in solution P that may continue for several years (Barrow and Shaw, 1975; Munns and Fox, 1976; Rajan and Fox, 1972; Sharpley, 1982). In order to account for the initial rapid decrease in solution P, SWAT assumes a rapid equilibrium exists between solution P and an "active" mineral pool. The subsequent slow reaction is simulated by the slow equilibrium assumed to exist between the "active" and "stable" mineral pools. The algorithms governing movement of inorganic phosphorus between these three pools are taken from Jones et al. (1984). Organic P was computed by SWAT for the baseline scenario as appears in figure (41).

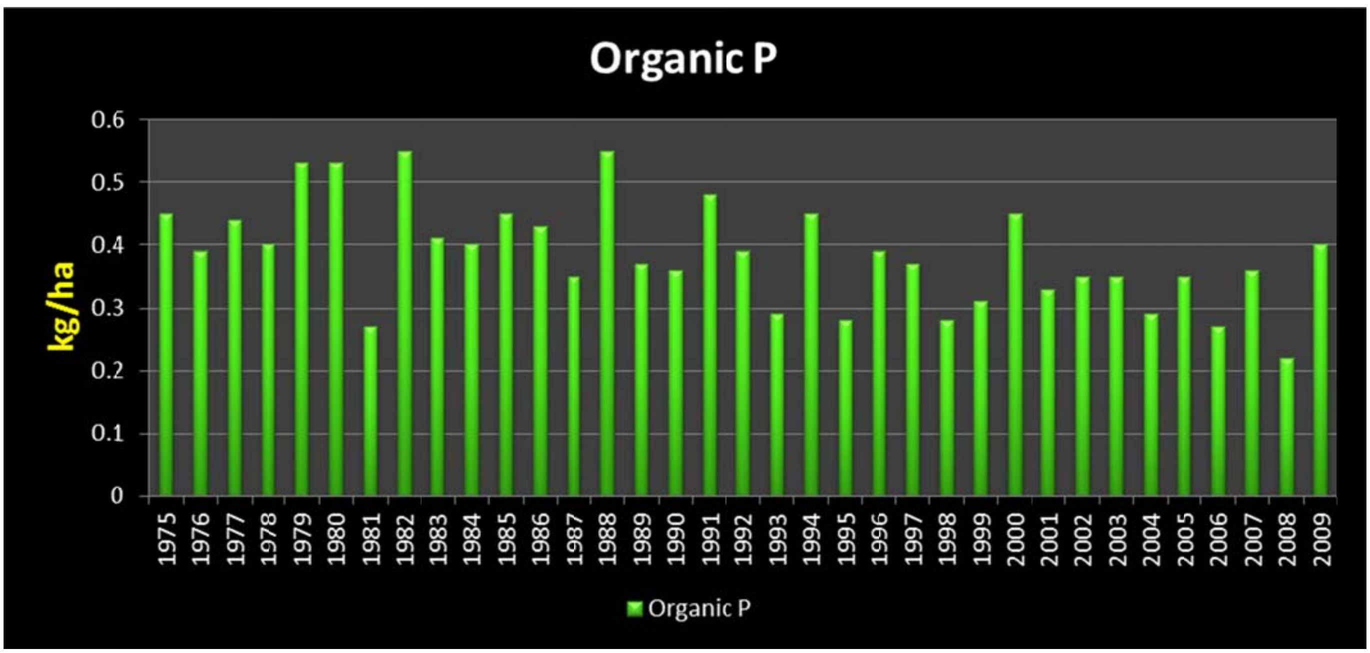


Figure (41): Simulated surface water organic P for base line scenario.

5.2.4. Climate change Impacts Assessment on water quality using Incremental Scenarios

In order to assess the impact of climate change on the water quality of the Zarqa River under incremental scenarios of climate change, the 20 incremental scenarios that developed earlier (Table 19) were applied. The impact on water quality parameters like nitrate, organic nitrogen and organic phosphorus were assessed and compared with the baseline scenarios for the period 2015-2049, as shown in figures 43, 44 and 45. From figure 43 it can be observed that the highest amount of nitrates will occur in the year 2044 under all incremental scenarios. This amount is reaching 0.1 kg/ha of nitrate. On the other hand, the amount of organic nitrogen is predicted to be higher than the nitrates under all scenarios of climate change. As shown in Figure 43, the organic nitrogen value ranges from 3- 12 kg/ha during the period 2015-2049. Figure 44 depicts the amount of predicted organic phosphorus that will be generated during the period 2015-2049. It can be seen that the value ranges from 0.2 -1.4 kg/ha under various incremental scenarios.

5.2.5. Climate change impacts assessment on water quality using GCM Scenarios

The GCM scenarios that developed earlier in the study were used to predict the water quality of the zarqa river by assessing the pollutional loads of nitrate, organic nitrogen and organic phosphorus. Figure 45 shows the predicted loads of pollutants for the period 2015-2049. As it can be seen from the figure, the GCM models used (HadCM3-A2 and Had CM3-B2) are predicting the same amounts of nitrate as compared to the baseline scenarios. However, in most of the cases, the GCMs are predicting lower amounts of organic nitrogen and organic phosphorus, as compared to the baseline scenarios.

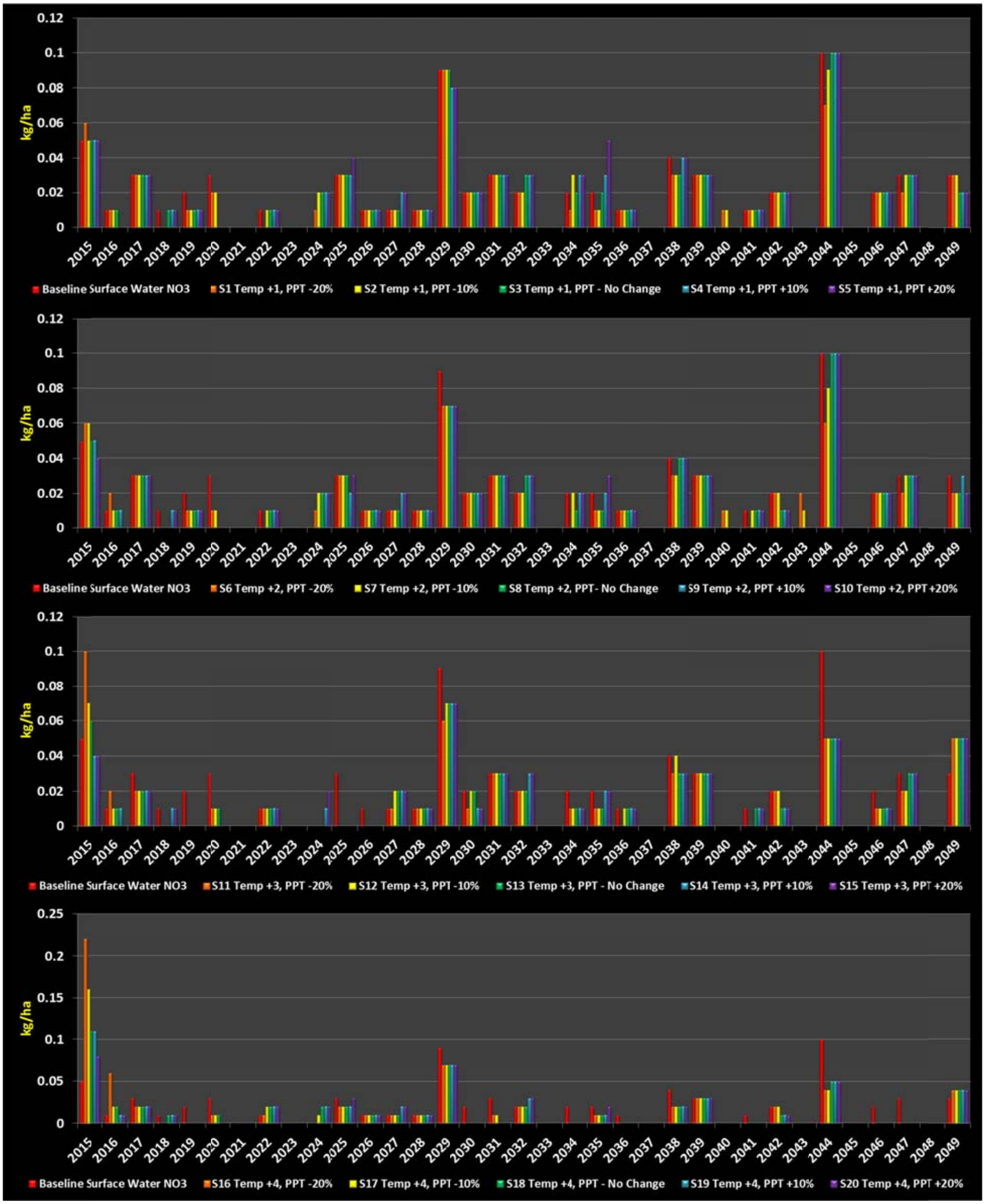


Figure (42): Surface NO_3 simulation using 20 incremental Scenarios.

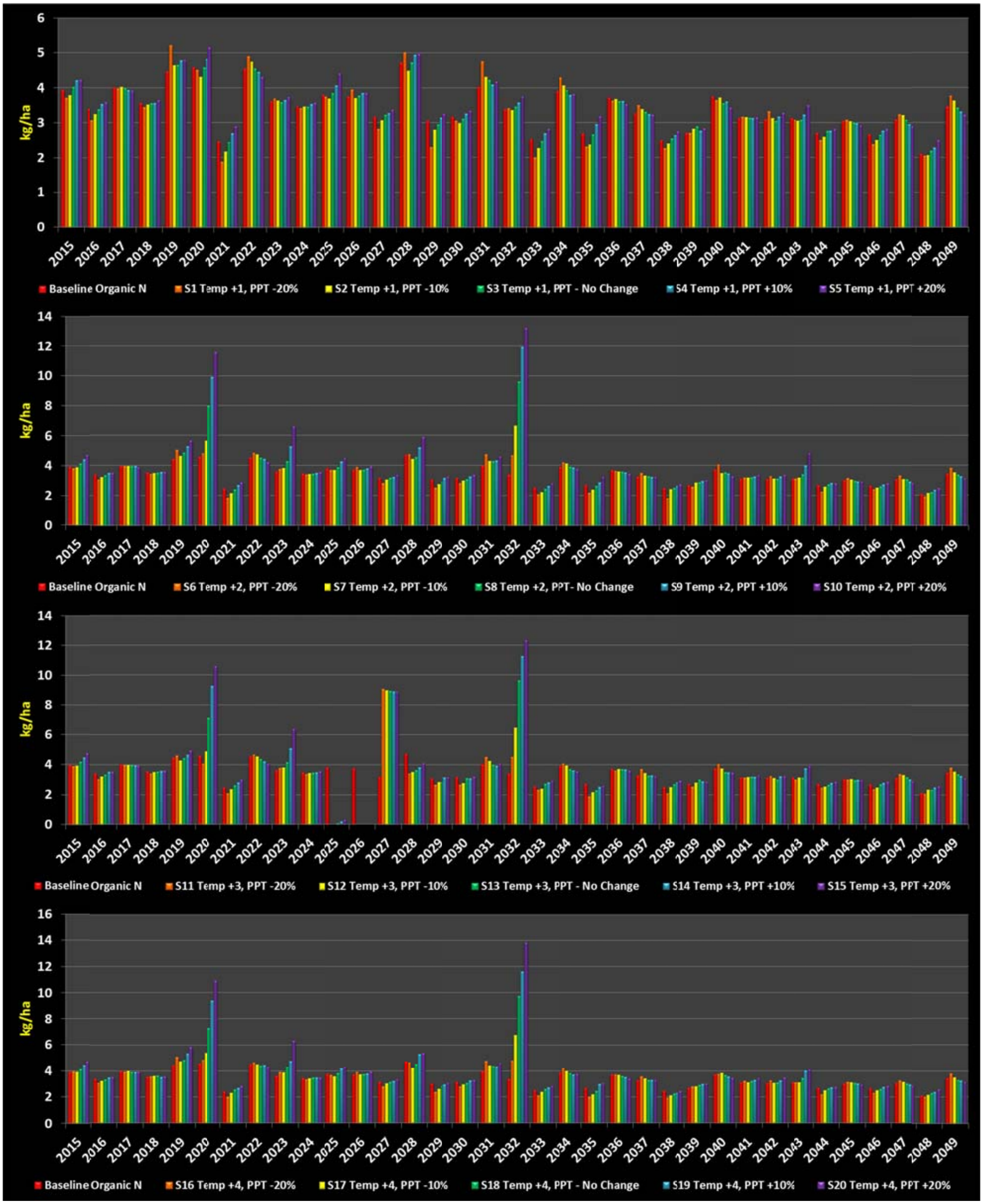


Figure (43): Organic N simulation using 20 incremental Scenarios.

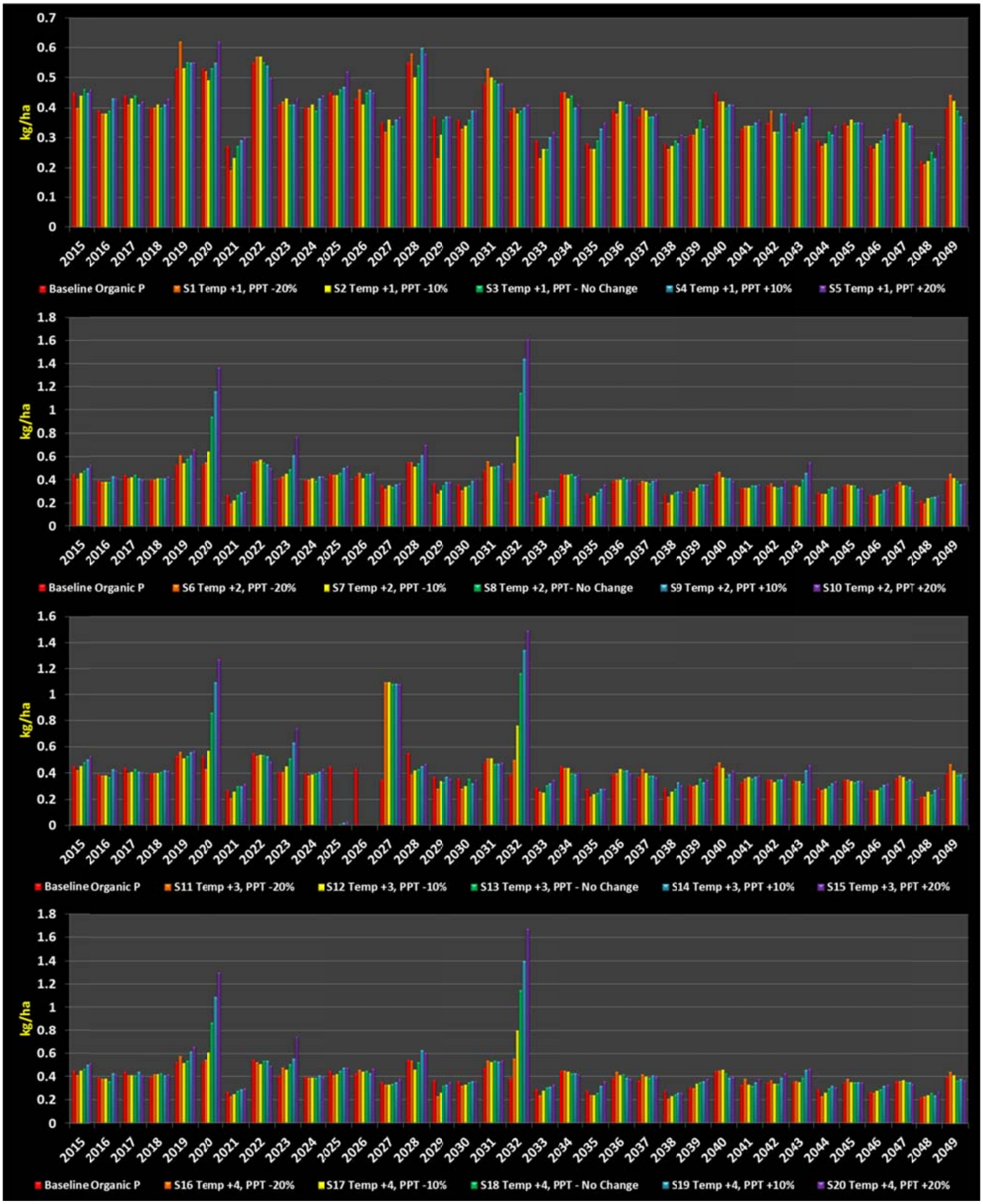


Figure (44): Organic P simulation using 20 incremental Scenarios.

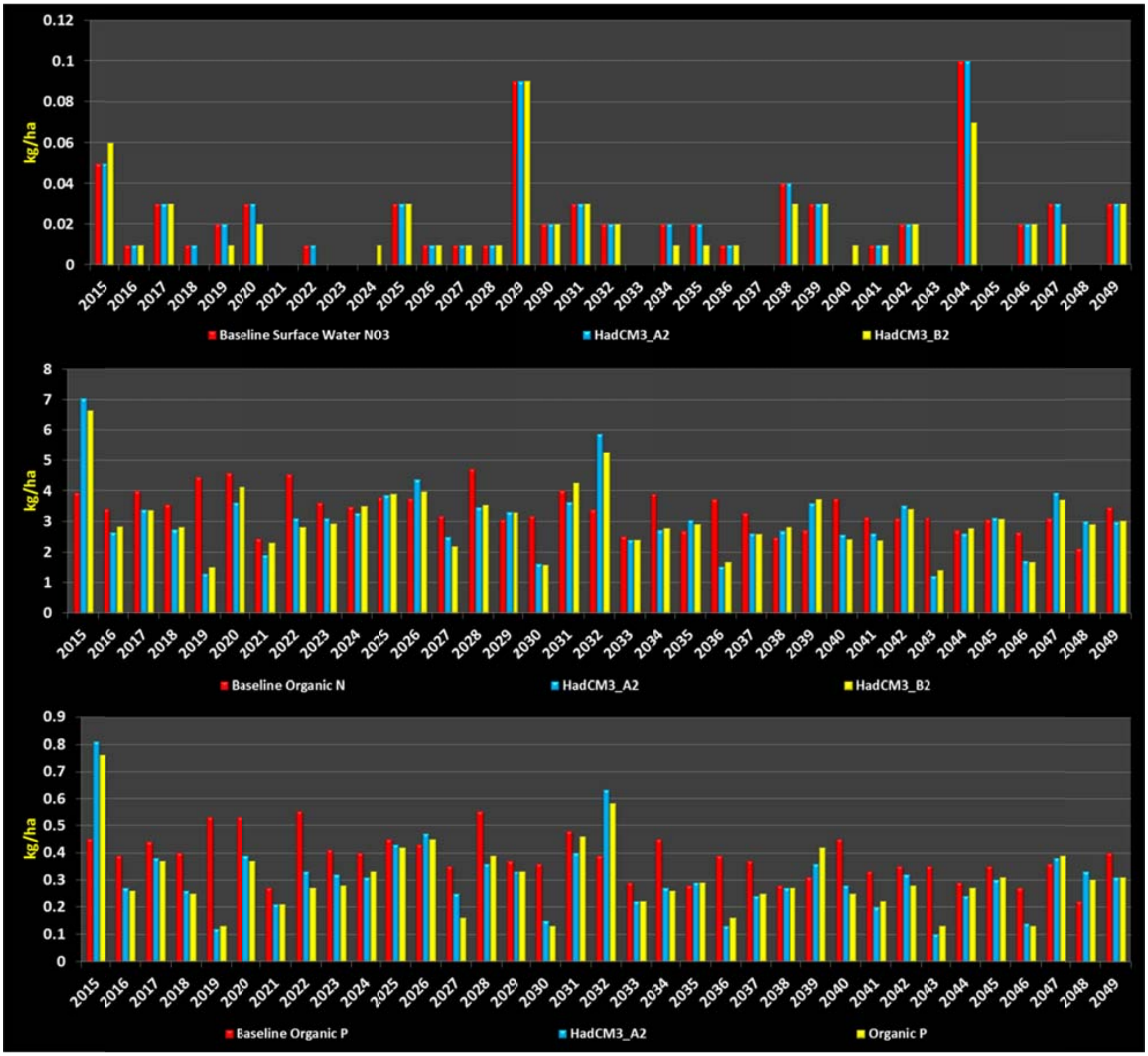


Figure (45): Simulation of Surface water NO3, Organic N and Organic P using GCM scenarios.

5.3. Conclusions

The impact of climate change on water quality is still a relatively new area of research, which is considered a serious challenge for investigators. In this study, the impact of climate change on the water quality of Zarqa river was assessed under both incremental and GCM scenarios that were developed in the course of the study using SWAT model. The impact on water quality parameters like nitrate, organic nitrogen and organic phosphorus were assessed and compared with the baseline scenarios for the period 2015-2049. It was concluded that under incremental scenarios the highest amount of nitrates will occur in the year 2044 under all incremental scenarios. While, the phosphorus amount found to range between 0.2 -1.4 kg/ha under various incremental scenarios.

The predicted loads of pollutants for the period of 2015-2049 under GCM models (HadCM3-A2 and Had CM3-B2) was found to be of the same values of nitrate as compared with the baseline scenario. However, in most of the cases, the GCMs are predicting lower amounts of organic nitrogen and organic phosphorous.

6. Impact of climate change on Groundwater of ZRB

6.1. Hydrogeology of Zarqa River Basin

6.1.1. Geology

The outcropping of ZRB extends from Lower Cretaceous (except for the wadi fill deposits which are of Quaternary) to recent age, which is belonging to the Ajlun and Belqa Groups according to Jordanian classification. However, the Kurnub Group (Lower Cretaceous) is usually found at certain depths except outcrops at the western parts of the study area (Baq'a Valley) along the axis of Suweileh anticline. The surface distribution of the major hydrological units is shown in Figure 46. Lithologically in ZRB includes from old to young the following (Al-Mahamid, 2005):

i. Zarqa Group: this group consists of sandstone, shale, dolomite and dolomitic limestone, marl, gypsum and intercalation of volcanic ash. Its thickness reached up to 1000 meters as encountered at Wadi Rimam (south of Amman).
ii. Kurnub Group: this group is exposed in the western parts of ZRB at Baq'a Valley. It mainly consists of white, gray and multicolored sandstone (weakly cemented fine-medium and coarse grained) with red silts, shales and dolomite streaks. The top of this group is known as the Subeihi Formation, which mainly consists of red-brown

varicolored sandstone with a large portion of marl, clay and siltstone. On the other hand, the lower part of this group is known as Aarda Formation which consists of yellow-white sandstone with shale partings and dolomite streaks.

iii. The Ajlun Group overlays the Kurnub Group and consist of five formations, namely: the Naur (A1-2); the Fuheis (A3); the Hummar (A4); the Shuayb (A5-6) and the Wadi as Sir (A7).

iv. The Belqa Group overlays the Ajlun Group and consists of five formations, namely: Wadi Umm Ghudran (B1); Amman-Al Hisa (B2); Muwaqqar (B3); Umm Rijam (B4) and Wadi Shallala (B5). However, Wadi Shallala formation is not represented in the geological of Amman-Zarqa Basin.

v. Basalt outcrops in the eastern and north eastern parts of ZRB. Its age is ranging from Miocene to Pleistocene. It consists of black olivines, basalt interbedded with clay beds and volcanic ashes. Most of basalt flow surface is mantled by sub-rounded boulders of basalt and in other places by local alluvium (USAID and WAJ 1989). The thickness of basalt ranges from 30 meters to 100 meters in Wadi Dhuleil and generally becomes thicker to north and northeast of Amman-Zarqa Basin to reach 400 meters thickness in Wadi Al Agib area.

vi. The Wadi Fill Deposits form the bed and terraces of the Seil el Zarqa. They consist of sands and gravels with clays and have a variable thickness up to 20 meters at different places of ZRB.

vii. As a demonstration, Figure 47 illustrates the geological cross section A-A' (shown in Figure 46) for AZB. The figure presents the sequence of the geological strata described above.

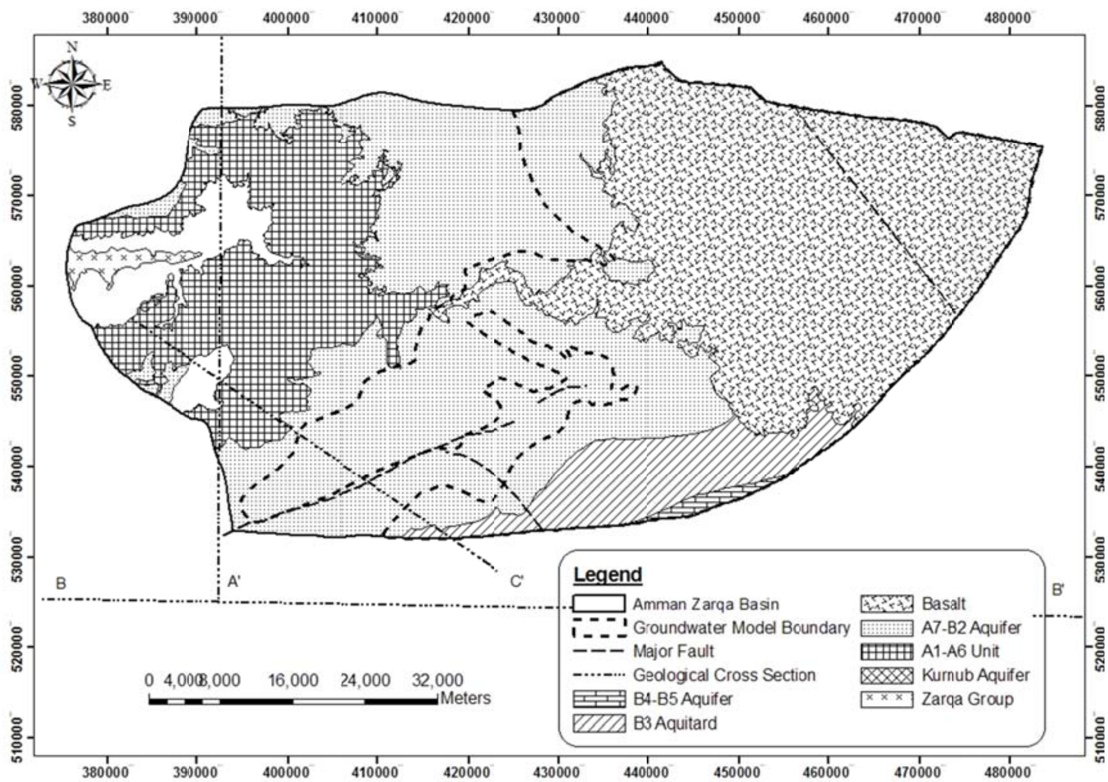


Figure (46): Surface Distribution of Major Hydrological Units in Amman Zarqa Basin.

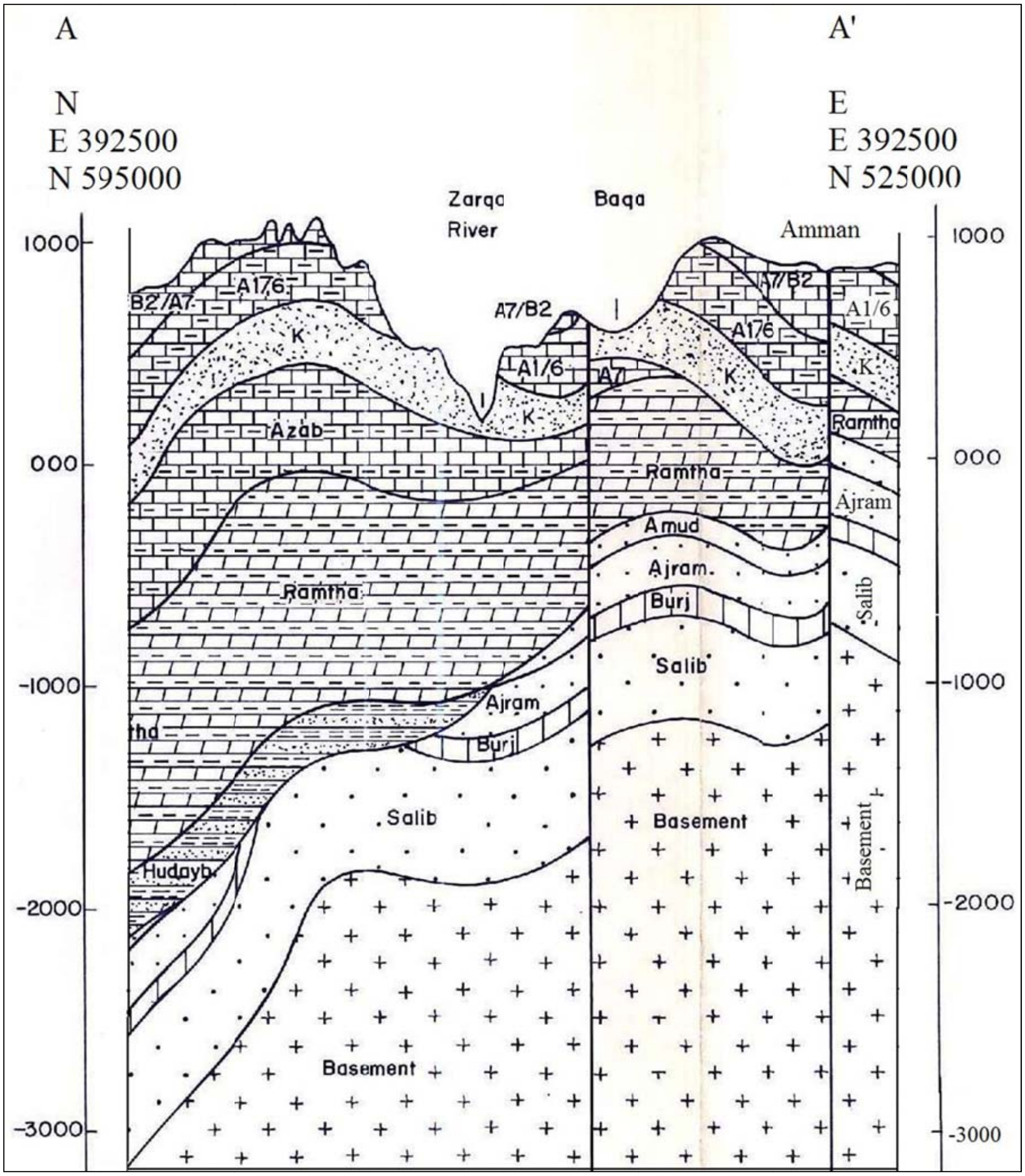


Figure (47): Geological Cross Section A-A' for Amman Zarqa Basin (after BGR/WAJ, 1994)

6.1.2. Groundwater Aquifers

Amman-Zarqa aquifers system is considered one of the most important groundwater basins in Jordan with respect to its groundwater resources (there are 12 basins constituting the Jordan aquifers). The aquifers distribution of ZRB are summarised in Table 11.

A significant part of the recharge is groundwater inflow from Syria, with the remainder from local rainfall and intermittent runoff. The total renewable groundwater safe yield of ZRB amounts 87.5 MCM/yr. Around 80% of the total area in the Basalt and the B2/A7 aquifers (Amman-wadi sir system), which are located in the north-eastern highlands extending north to the Syrian border and southwest to the outskirts of Amman over approximately 2,420 km2 (Al-Mahamid, 2005).

The measured transmissivity values for the B2/A7 formation in Amman Zarqa Basin vary between 2.6 m^2/day to 2.6e+4 m^2/day. The specific yield values ranges between 12 and 22% as reported by Al-Mahamid (2005).

Table 11: Aquifers distribution in ZRB

Aquifer system	Geological formation
Upper aquifers	Alluvial
	Alluvial + B2/A7 (Amman-Wadi Sir Formation Deposits)
	Alluvial + A4
Intermediate aquifers	A1-2 + A4 (Fuhais Formation Deposits of Ajlun Group)
Deep aquifers	Kurnub + Rum + Triassic-Jurassic
	Kurnub + Rum

6.1.3. Groundwater Abstraction

Groundwater is considered to be the major source of water in ZRB. The safe yield of ZRB aquifer is about 87.5 MCM which makes about 32% of the country's renewable groundwater resources (USAID/*ARD, 2001*).

The aquifer is presently exploited to its maximum capacity and in some cases beyond the annual potential recharges quantities. The over abstraction in 1989 in respect to the self-yield of the basin was about 55% which increased to 70% in 2000. Thus, the aquifer overexploitation has contributed to the degradation of groundwater quality, impacting the sustainability of this resource for future use.

The majority of the groundwater abstraction occurs in the highlands (121 MCM) 46% of which was used for irrigation, 48% for domestic, 4.1% for industrial and 1.4% for pastoral use as occurred in 1998 (Table 12). In 2008, there were over 800 wells in ZRB used for different purposes of domestic, agricultural, tourist and industrial uses. Large number of which are privately owned. The overall groundwater abstraction slightly increased to around 155 MCM formulating around 177% of the safe yield (see Table 13). Groundwater wells are distributed in most parts of the ZRB as shown in Figure 48.

Other groundwater resources in the ZRB include the springs and the brackish water. There are about 150 springs in ZRB, the flow of which ranges between 0.1 MCM to larger than 1 MCM. Desalination plants are constructed at some of these springs, the effluent of which is used for domestic purposes such as Kayrawan spring which supplies part of Jarash. The main springs within ZRB that have considerable flow are: Kayrawan; Hazzir; Wadi Sir.

Table 12. Groundwater abstraction in the ZRB – 1998

Area in ZRB	Irrigation (MCM/yr)	Domestic (MCM/yr)	Industrial (MCM/yr)	Pastoral (MCM/yr)	Total (MCM/yr)	%
Highlands	60.00	53.50	5.70	2.00	121.20	81%
Rest of Basin	9.25	18.68	0.37	0.13	28.43	19%
Whole Basin	69.25	72.18	6.07	2.13	149.63	100%
% of use	46.28%	48.24%	4.06%	1.42%	100%	

Source: USAID/ARD, 2001

Table 13. Groundwater abstraction in the ZRB – 2008

	Safe yield	Drinking-Private	Drinking-Government	Industry	Agriculture	Total
Working wells		31	192	80	520	823
Quantity (MCM)	87.5	4.01	83.42	6.824	60.824	155.078
% From the safe yield		4.6%	95.3%	7.8%	69.5%	177.2%
% of use		2.6%	53.8%	4.4%	39.2%	100.0%

Source: WAJ, 2010

Historically, groundwater abstraction data for years before 1995 are considered not reliable to provide a clear picture of the overall abstraction rates since groundwater withdrawal from the irrigation wells was not included in the database of the Water Information System (WIS). Figure 49 illustrates that there is a large sudden jump in the abstraction rates from around 67 MCM in 1994 to around 145 MCM in 1995 according to the historical groundwater data records of MWI. Start including the groundwater abstraction rates of the irrigation wells an increase of more than double in groundwater abstraction quantities in one year. Thus those records belong to the years before 1995 could not be used for assessing the impact of climate change on groundwater.

In 1993, the Water Basin Project has been created in WAJ to collect the field data on groundwater abstraction from private wells by questioning of the farmers, and then WAJ decided that all private wells should be equipped with w meters to control the abstraction from these wells (Al-Mahamid, 2005). Thus since 1995, the fluctuation in groundwater abstraction quantities looks reasonable and thereby the groundwater abstraction records belong to this period are considered reliable to be used in the analysis.

The main brackish water aquifers within ZRB are those found in the lower sandstone hydraulic complex (deep aquifers system). According to USAID/ARD (2001) report, brackish water from the combined Kurnub/Zarqa and Rum aquifers total is estimated to about 151 MCM.

Figure 50 and Figure 51 present the historical number of working wells and abstraction rates in ZRB per use. Domestic and irrigation water use are dominant and both formulate around 95% of the total groundwater use. Half of the groundwater abstracted in ZRB is used for the domestic purpose, which is the highest ratio in comparison to the other basins in Jordan.

Around 75% of the groundwater is abstracted from the upper aquifers. The distribution of the groundwater abstraction quantities per aquifer in ZRB is presented in Figure 52 and Table 14 summarizes the groundwater abstraction quantities per aquifer in ZRB for the year 2009.

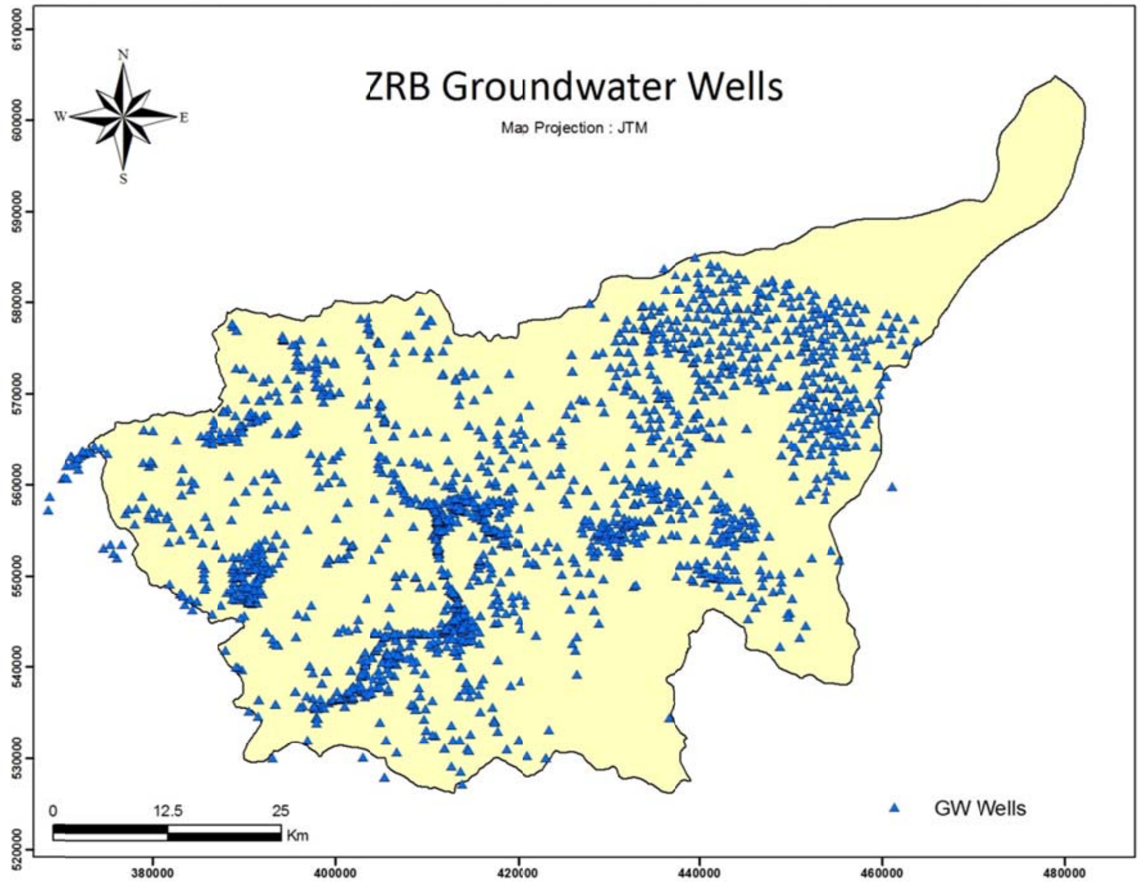


Figure (48): Distribution of groundwater wells in ZRB

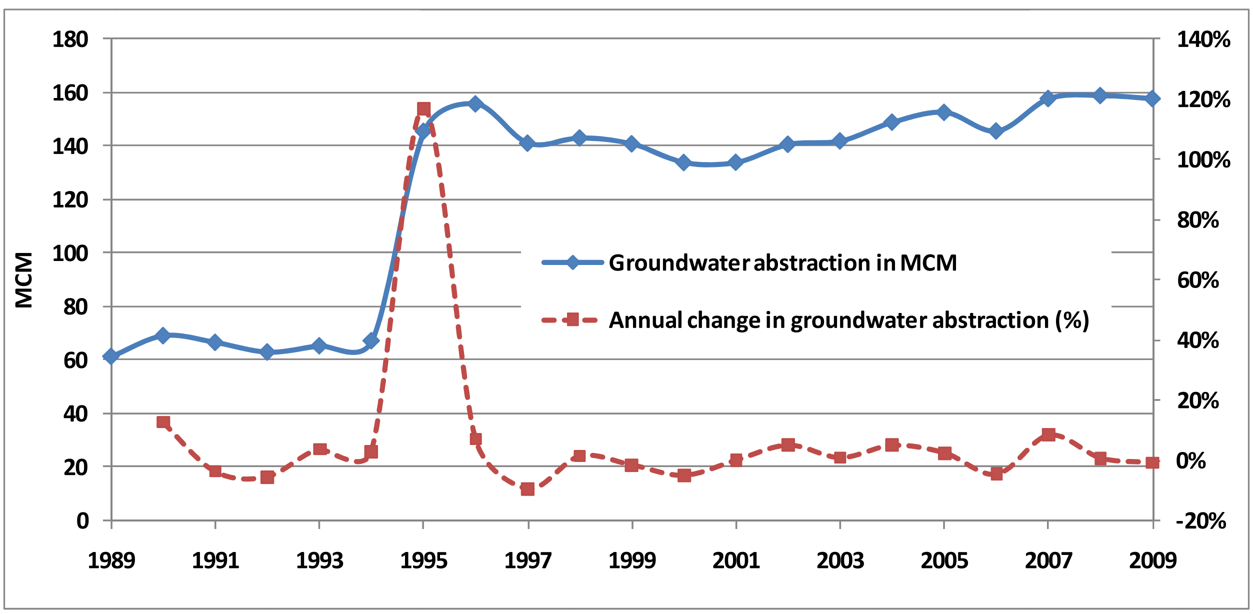


Figure 49: Historical trend of groundwater abstraction in ZRB (MIS, 2010)

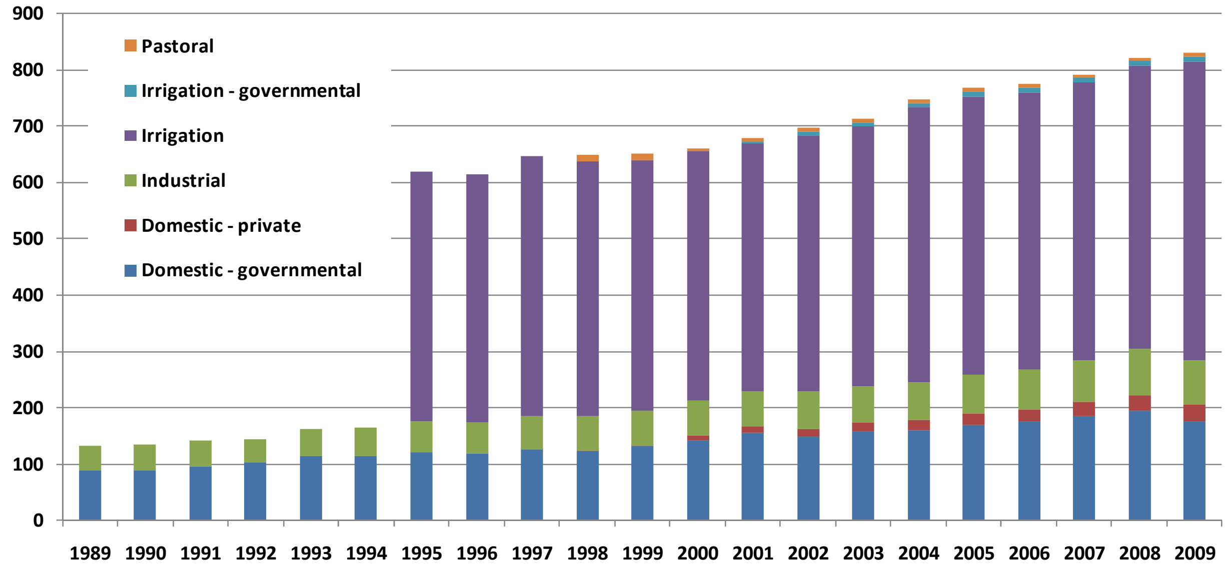


Figure 50: Historical number of working wells in ZRB per use

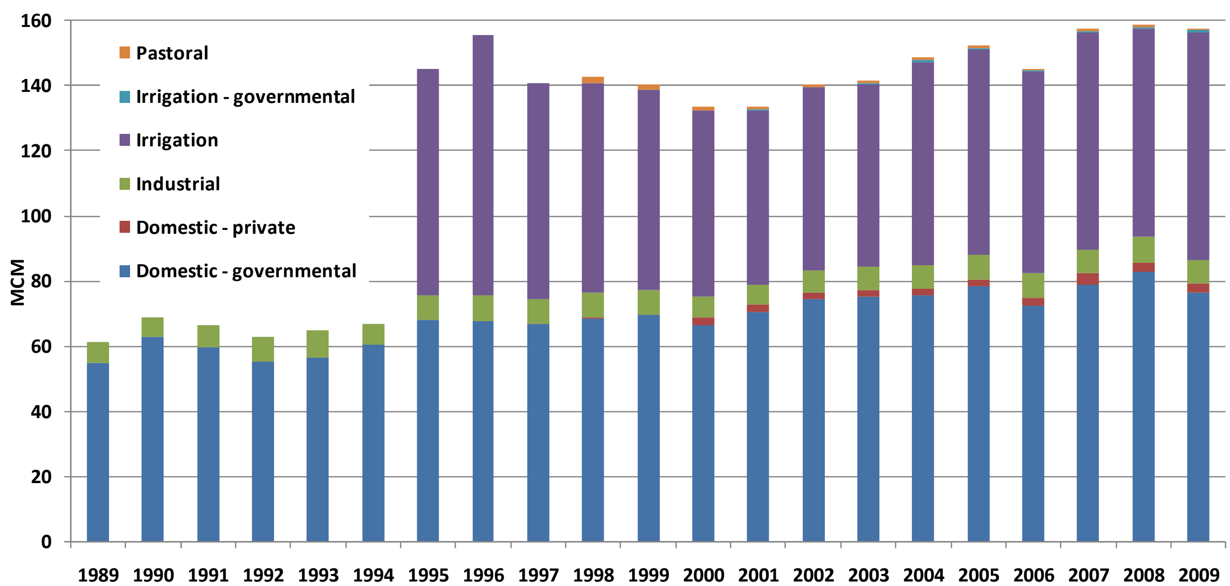


Figure 51: Historical groundwater abstraction rates in ZRB per use

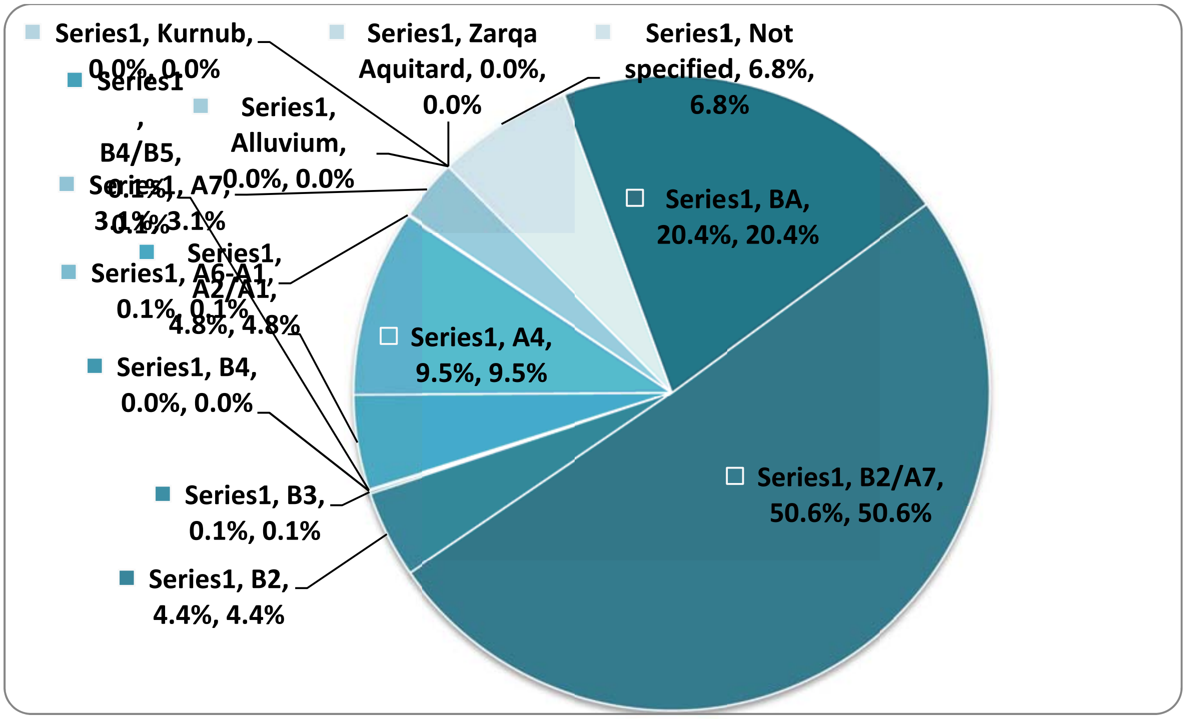


Figure 52: Distribution of groundwater abstraction quantities per aquifer in ZRB for 2009

Table 14: Groundwater abstraction quantities per aquifer in ZRB for 2009

Aquifer	Production (m^3)
BA	28,941,665
B2/A7	68,151,647
B2	4,428,158
B3	286,864
B4	33,288
B4/B5	129,012
A2/A1	6,156,528
A4	11,166,948
A6-A1	212,748
A7	4,457,564
Alluvium	4,642,623
Kurnub	14,430,230
Zarqa Aquitard	1,899,539
Not specified	12,423,738
Total	**157,360,552**

6.1.4. Groundwater level

There are 81 observation wells distributed in ZRB as shown in Figure 53. Some wells have been closed down or worked for a short time only because of technical problems or completed technical project. These observation wells are distributed on the different groundwater aquifers in ZRB to monitor them. The number of the observation wells for each aquifer is summarized in Figure 54Figure . It can be seen that most of the observation wells are located in the upper aquifer (BA, B2/A7, B2, A4 and Alluvium).

Due to the successive and over abstraction during the last years, groundwater levels dropped significantly in all the aquifers of ZRB. Figure 55 illustrates the historical groundwater level change in different observation wells representing all the groundwater aquifers in ZRB.

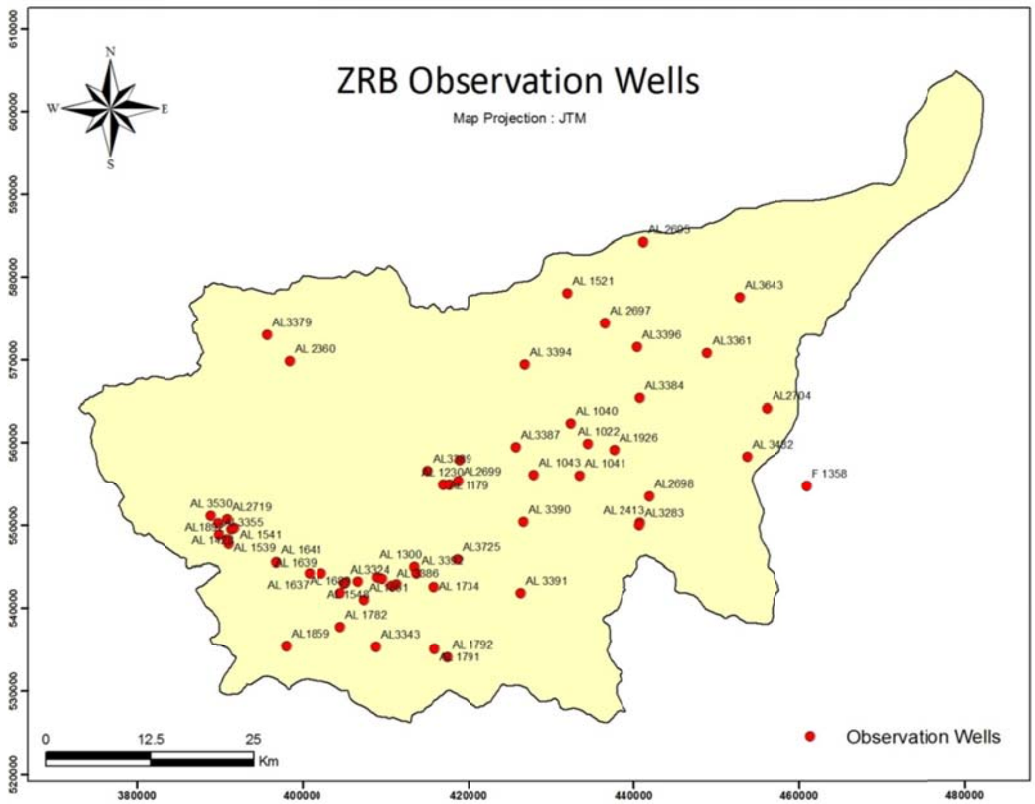


Figure (53): Distribution of groundwater observation wells in ZRB

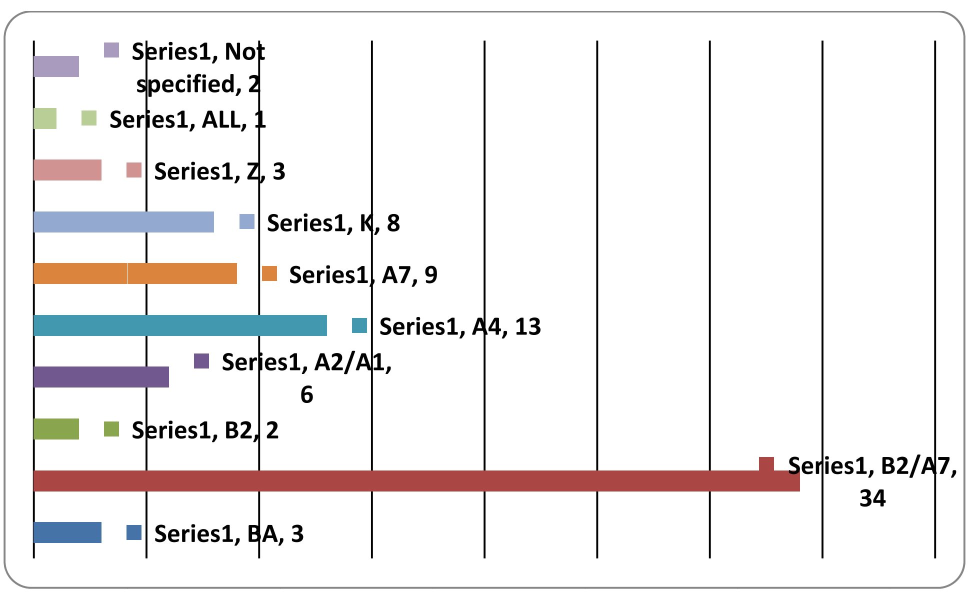


Figure (54): Number of observation wells in each groundwater aquifer in ZRB

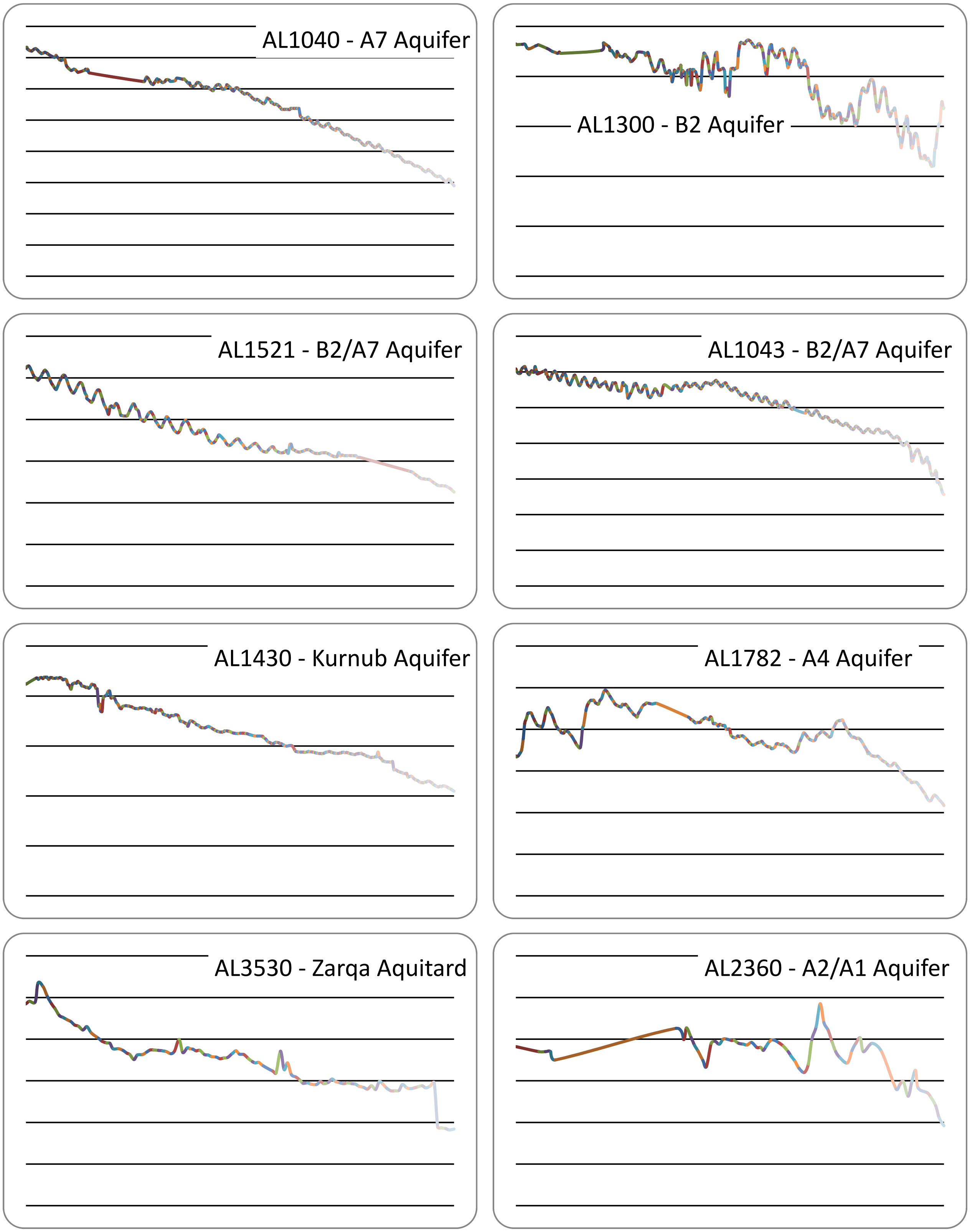


Figure 55: Historical groundwater table level in the different aquifers of ZRB (MWI, 2010)

6.2. Methodology

Impact of climate change on groundwater resources was not addressed in the SNC but it was addressed in the First National communication for Azraq basin only. The availability of groundwater is measured by the safe yield of groundwater abstraction. The amount of the safe yield depends on the direct groundwater recharge (natural and artificial) and net of underground inflow-outflow of water. Both are highly dependent on the amount and intensity (or duration) of the rainfall. However, there are other factors affecting them including land cover change and groundwater abstraction rates in the surrounding basins, which affect the quantity of net underground inflow-outflow of water. The impact of those factors is hard to isolate. Trend analyses were carried out to assess the climate change impact on groundwater resources availability but were not useful. Therefore, the water balance approach accompanied with regression analysis is used to create a relationship between the rainfall amount and recharge.

6.2.1. Water Balance Approach

The water balance approach is used to estimate the change in groundwater recharge. This model based on a simple water budget (hydrological balance) for the basin. Soil Conservation Services (SCS) methodology is used to estimate the recharge. Figure 56 illustrates the steps of the water balance approach using SCS methodology that are followed to estimate the natural recharge in ZRB for each representative rainfall station. A computer model using excel is developed to do this analysis. The daily rainfall data is the input for the model. Recharge is estimated storm by storm. The estimated is automated where the model first create the rainfall storms based on the daily rainfall data then applies the SCS approach to estimate the groundwater recharge quantity. The study area is divided into different zones based on the rainfall stations. Within each zone of the rainfall station, the CN value is estimated. A spatial curve number map is developed for the entire ZRB based on soil texture and land use digital maps at sub -catchment level. The weighted average curve number for the whole basin was not used as each zone has its specific CN value. The model produces two levels of outputs; output I is the monthly natural recharge for each year, and output II is average monthly and annual natural recharge. The following subsection describes the SCS approach.

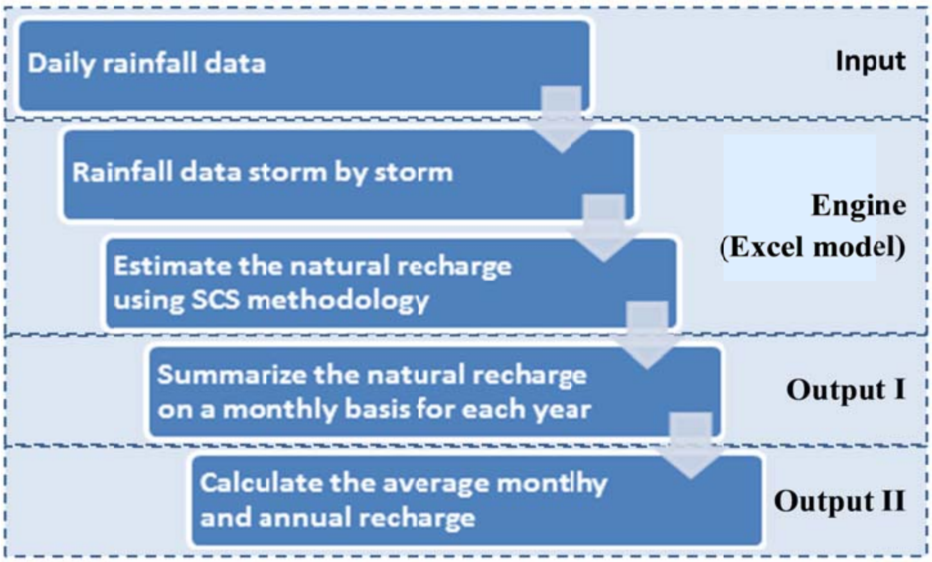


Figure (56): Step of water balance approach using SCS methodology

6.2.1.1. SCS methodology

Infiltration is the process in which water penetrating from the ground surface into the soil. The condition of the soil surface and its vegetation cover, the properties of the soil, such as its porosity and hydraulic conductivity, and the current soil moisture content and other factors influence the infiltration rate. Infiltration is a very complex process that can be described only approximately with mathematical equations (Chow et al. 1988).

Several equations and methods were developed to quantify and simulate the infiltration process. For example, Horton's equation, Philip's equation, Φ index method, Green and Ampt method and Stanford watershed model of infiltration. Choosing an equation or a method to estimate the infiltration quantities is dependent on the data availability and the required parameters for the equation or the method to be used.

SCS method is developed by the Soil Conservation Services to study the rainfall-runoff process. The method developed from a large number of unit hydrograph ranging in size and geographic location. SCS method assumes a relationship between accumulated total storm rainfall P, runoff Q, and infiltration plus initial abstraction ($F+I_a$) (Bedient and Huber, 1989).

$$F/S = Q/P_e \qquad \text{Equation 1}$$

where,

F :	Infiltration occurring after runoff begins (mm).
S :	Potential abstraction (mm).
Q :	Direct runoff (mm).
P_e :	Effective storm runoff (mm).

$$F = (P_e - Q) \qquad \text{Equation 2}$$

$$P_e = (P - I_a) = (P - 0.2S) \qquad \text{Equation 3}$$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad \text{Equation 4}$$

The SCS method uses the Runoff Curve Number CN, which is related to storage by

$$CN = 25400/(S + 254) \qquad \text{Equation 5}$$

where potential abstraction S (mm) becomes

$$S = (25400/CN) - 254 \qquad \text{Equation 6}$$

Using SCS approach, the initial abstraction by the soil is firstly estimated then the surface runoff. The remaining amount of the rainfall after subtracting the initial abstraction and surface runoff is the infiltrated amount that is considered to be the groundwater recharge amount.

6.2.1.2. Regression Analysis

In this study impact of climate change on groundwater of ZRB will be addressed using two approaches of regression analysis as illustrated in Figure 57 and Figure 58. Both approaches used the water balance approach to estimate the recharge amounts used to create the relationship.

Approach I of regression analysis (monthly rainfall – monthly recharge relationship) is based on creating relationship between the monthly rainfall and the estimated monthly recharge for each rainfall station using the available historical rainfall data set. The developed relationship is then used to estimate the recharge amount as a result of changing the rainfall amount, and then estimate the impact of rainfall change on the recharge.

Approach II of regression analysis (average monthly rainfall – average monthly recharge relationship) is based on estimating the average monthly recharge for each rainfall scenario in which the daily rainfall data is adjusted by the scenario factor. Then a relationship is created between the average rainfall and the estimated average recharge for all rainfall scenarios.

The incremental scenarios that were developed in this study are the input of the groundwater recharge model, where rainfall amounts were changed by -30%, –20%, –10%, +10%, +20%, and +30%. Temperature changes were not considered in development of the groundwater recharge scenarios since the preliminary trend analysis made on the temperature and recharge estimation did not show any correlation between those two parameters. Future potential impacts of climate change on groundwater recharge is quantified in section 6.4.

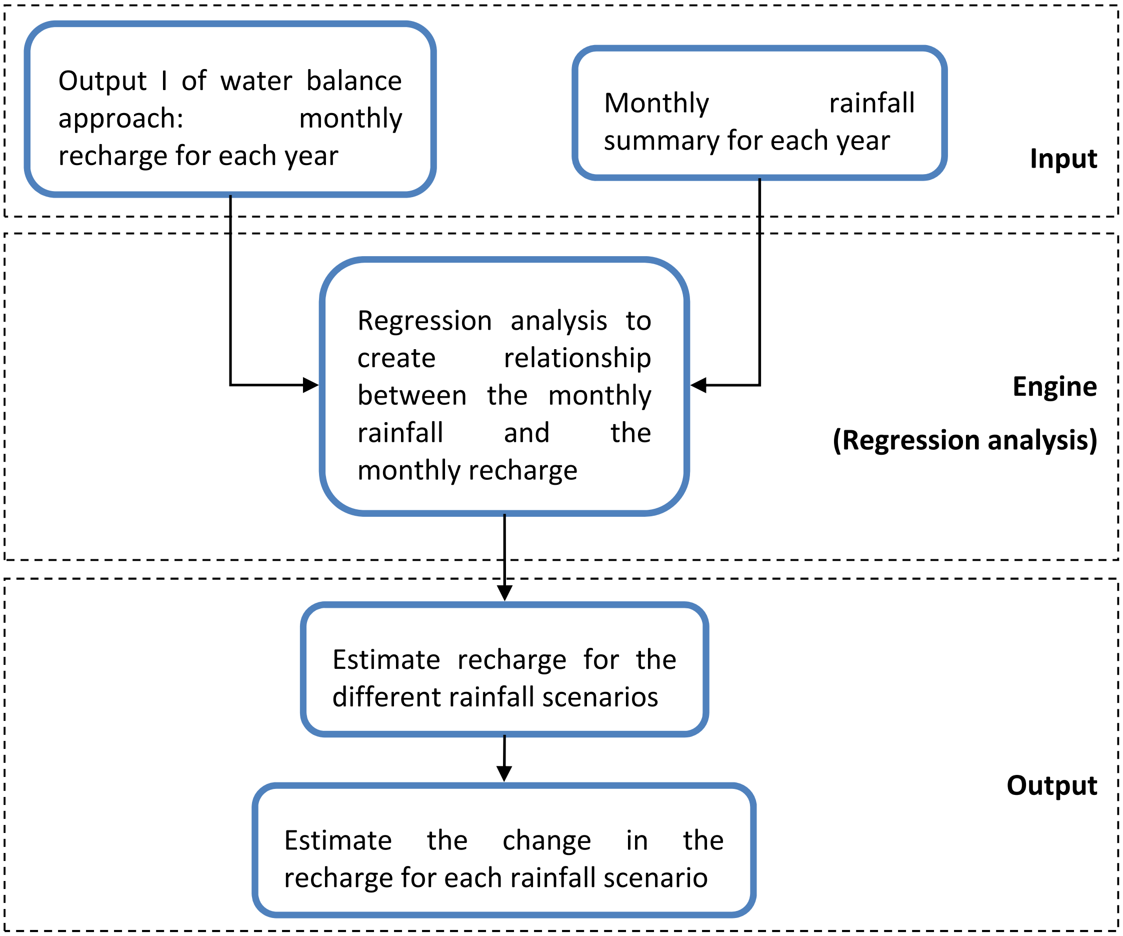


Figure (57): Approach I of regression analysis (monthly rainfall – monthly recharge relationship)

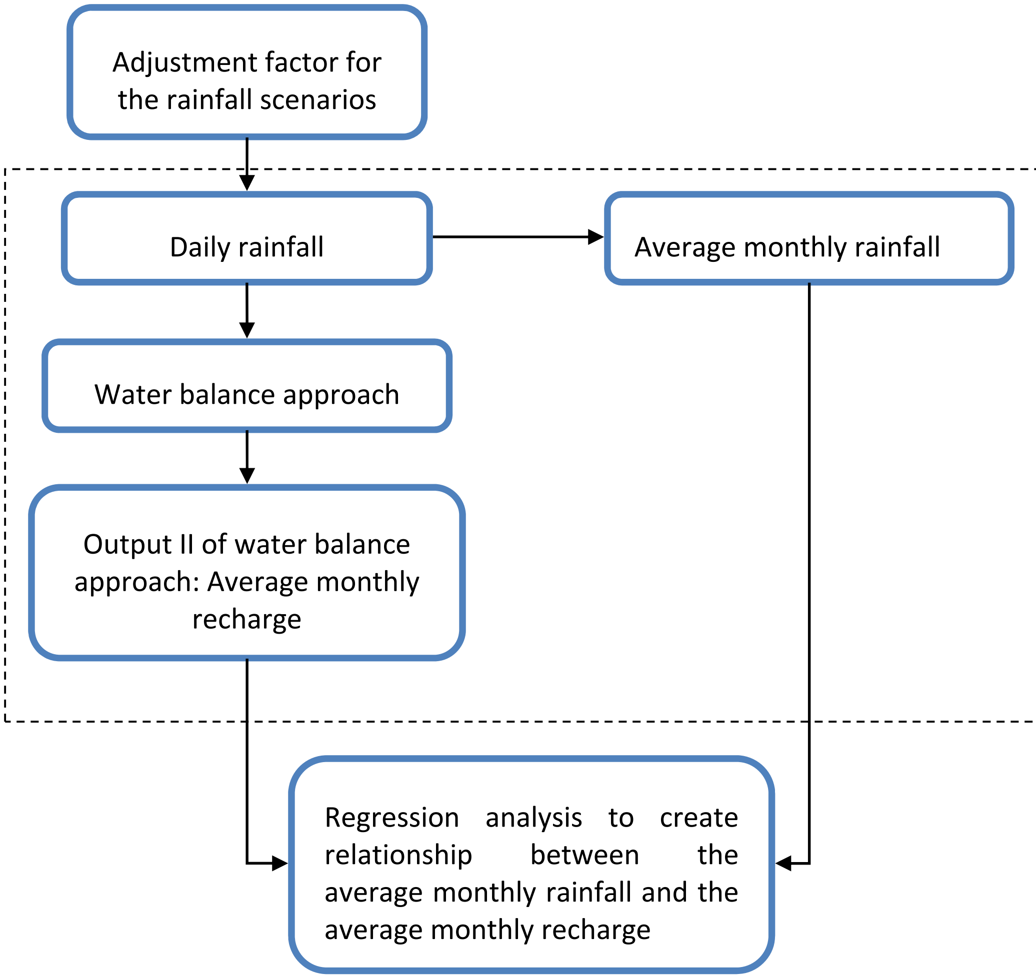


Figure (58): Approach II of regression analysis (average monthly rainfall – average monthly recharge relationship)

6.3. Groundwater Recharge

Nine rainfall stations and five climatological stations were selected to represent the rainfall quantities and climatic parameters of ZRB. The name, location and recording periods are summarized in Table 15 for the rainfall stations and in Table 16 for the climatological stations. Table 17 summarizes the monthly rainfall quantities for the representative rainfall stations. Table 18 summarizes the monthly average evaporation in mm per day for each climatological station. Using SCS methodology, the natural groundwater recharge is estimated. Since rainfall quantities and evaporation rates vary over ZRB, Thiessen polygon method was used to average the depth of precipitation and evaporation. The location and Thiessen polygons for the representative rainfall stations are presented in Figure 59. The location and Thiessen polygons for the rainfall and climatological stations used to estimate groundwater recharge are shown in Figure 60.

By using the Geographical Information System (ArcGIS 9.0) the Thiessen polygon map was overlaid the CN map (Figure 61). The CN values shown in Figure 61 are obtained by Shtewe (2006), who used the historical runoff and rainfall data to calibrate a hydrological model developed for ZRB. Therefore, these CN are representing to some extent the actual conditions in ZRB. Then the CN value is calculated for each polygon by averaging the different CN values within it. Relative weights are given for each different CN value within the same polygon corresponding to its areas. Table 19 presents the contributing area and CN values for each for the rainfall station used to predict the recharge quantities in ZRB.

Table 20 shows the results of application SCS method for determining recharge values in ZRB. The percent of the mean annual recharge from the mean annual precipitation ranges from 2% (2.7 mm/Year) in the northeastern side of the basin to 17% (82.9 mm/Year) in the southwestern side of the basin.

Table 15: List of representative rainfall stations in ZRB

Station ID	Station name	PGN	PGE	Recording period
AL0019	DEIR ALLA (NRA)	1178500	209500	1960-2009
AL0035	K.H.NURSERY EVAP.ST(BAQ'A)	1165400	230000	1964-2009
AL0036	PRINCE FEISAL NURSERY	1180500	234500	1964-2009
AL0047	SIHAN	1171800	221600	1967-2009
AL0054	HASHIMIYA	1171700	255200	1968-2009
AL0055	WADI DHULEIL NURSERY	1174000	271000	1973-2009
AL0057	WADI ES-SIR (NRA)YARD	1151600	230200	1979-2009
AL0059	UM EL-JUMAL EVAP .ST	1190400	276800	1968-2009
-	Mafraq	1195000	264000	1961-2005

Table 16: List of representative climatological stations in ZRB

Station Name	Station ID	PGN	PGE	Altitude (m asl)	Recording period	Missing records
Amman Airport	AL0019	538982	404359	790	1970-2002	1975-1979, 1983-1987
K.H. Nursery (Baq'a)	AL0035	550802	391055	700	1971-2003	1985-1986
King Talal Dam	AL0053	563423	389864	218	1972-1997	1977, 1989-1994
Um El-Jumal	AL0059	575016	438254	650	1970-2003	
Khirebit Es-Samra	AL0066	558431	419431	540	1985-2003	

Table 17: Average monthly rainfall for the representative rainfall stations in mm

Station	Jan	Feb	March	April	May	Oct	Nov	Dec	Annual
AL0019	63.4	56.1	43.3	15.4	4.6	10.0	24.3	49.3	253.2
AL0035	77.2	72.5	64.2	14.5	5.8	12.0	36.1	63.0	324.1
AL0036	81.3	74.6	66.4	18.3	6.2	12.0	34.2	67.1	343.8
AL0047	91.0	80.3	75.6	24.2	6.6	11.6	42.4	69.9	374.6
AL0054	29.5	28.7	22.2	8.0	8.0	7.4	15.0	22.2	116.4
AL0055	32.3	29.8	21.1	7.5	3.0	8.9	18.1	24.5	132.7
AL0057	126.3	116.7	91.2	20.9	8.6	16.3	53.0	101.7	475.9
AL0059	32.3	29.8	21.1	7.5	3.0	8.9	18.1	24.5	132.7
Mafraq	36.0	30.6	27.8	8.6	4.5	7.5	19.5	29.4	158.7
Total	50.0	45.4	37.1	11.9	5.0	9.4	23.7	39.2	204.4

Table 18: Monthly average evaporation in mm per day

Station ID	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
AL0019	5.9	3.4	2.5	2.2	2.9	4.2	6.5	9.3	11	11.4	10.3	8
AL0035	6.7	4.5	2.6	2.3	3.2	4.4	6.9	9.4	11.8	12.4	11	9.2
AL0053	7.3	5.1	3	3	3.3	4.2	6.4	9.2	11	11.7	10.2	9.6
AL0059	8.1	5.8	3.6	3.6	4.2	5.8	9.3	12	13.1	13.8	12.1	10.2
AL0066	5.1	3	1.7	1.7	2.1	3.5	5.5	8.3	10.4	10	9.1	8

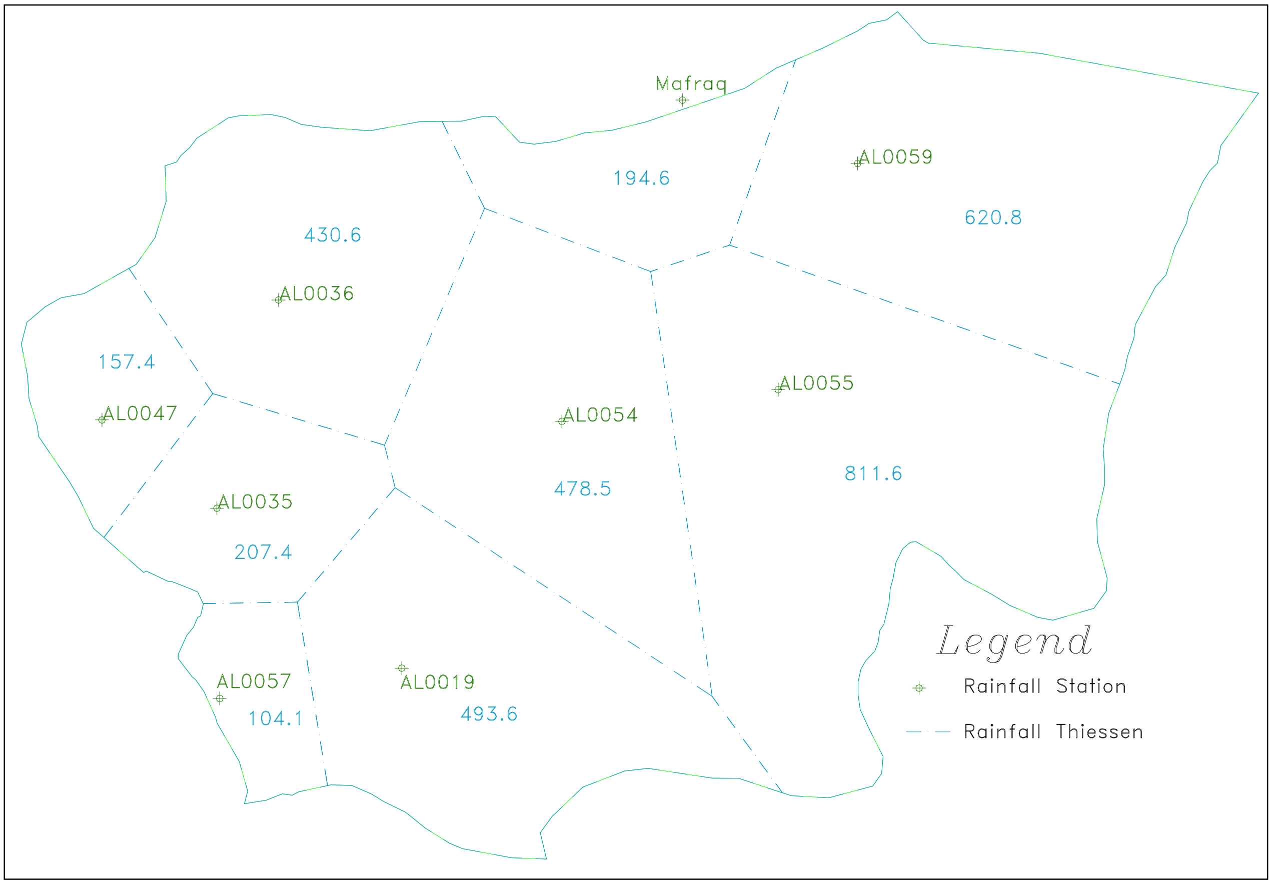


Figure (59): Thiessen polygons for the representative rainfall stations

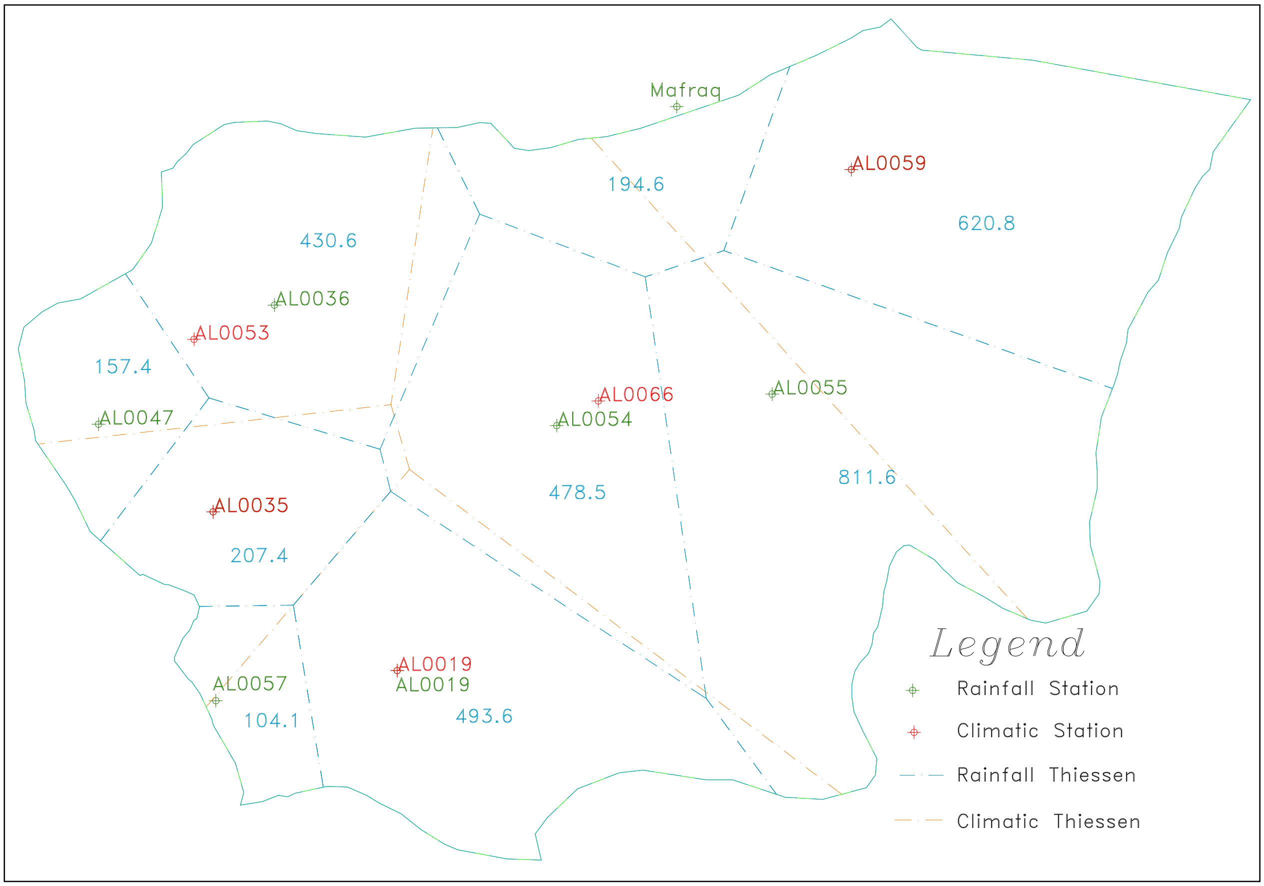


Figure (60): Thiessen polygons for the rainfall and climatological stations used to estimate groundwater recharge

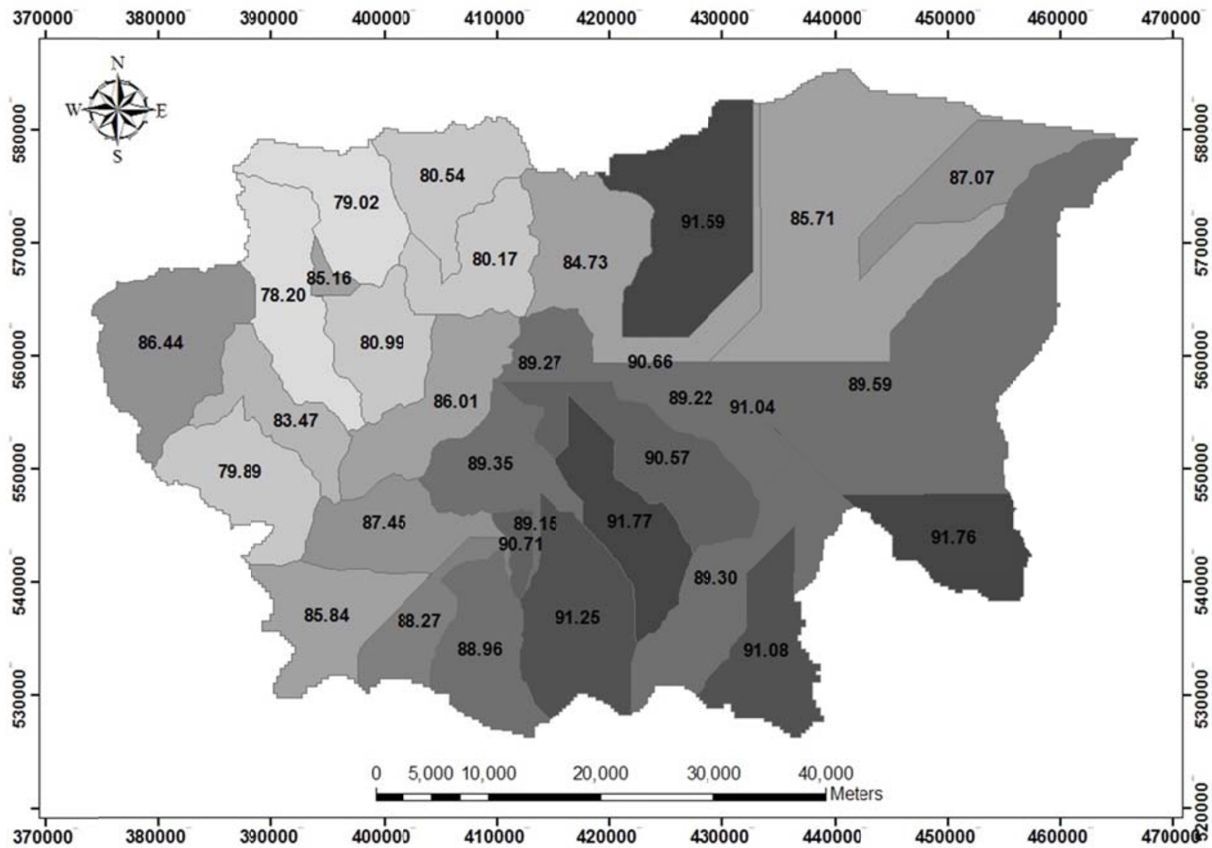


Figure (61): Curve Number Values for Amman Zarqa Basin (Shtewe, 2006)

Table 19 : List of rainfall stations used to predict the recharge quantities in ZRB and their contributing area and CN values

Station	Area (km2)	CN
AL0019	493.6	88.5
AL0035	207.4	83
AL0036	430.6	80
AL0047	157.4	86
AL0054	478.5	88
AL0055	811.6	90
AL0057	104.1	85.8
AL0059	620.8	87
Mafraq	194.6	87

Table 20: Average monthly groundwater recharge

Station	Jan	Feb	March	April	May	Oct	Nov	Dec	Annual	Annual	
	Mm									MCM	% of contribution
AL0019	9.1	4.3	1.1	0.1	0.0	0.2	1.8	6.0	22.5	11.1	13%
AL0035	16.5	9.9	5.2	0.3	0.0	0.1	4.0	12.1	47.2	9.8	12%
AL0036	15.0	9.6	8.4	0.2	0.0	0.0	2.4	12.2	47.3	20.4	24%
AL0047	15.5	10.5	8.6	0.3	0.0	0.0	4.4	11.3	49.0	7.7	9%
AL0054	4.9	2.8	1.5	0.1	0.0	0.0	1.6	2.6	13.3	6.4	8%
AL0055	4.3	2.9	0.9	0.0	0.0	0.0	1.0	3.9	12.9	10.5	13%
AL0057	27.8	15.8	10.7	0.6	0.0	0.7	7.9	20.3	82.9	8.6	10%
AL0059	4.3	2.9	0.9	0.0	0.0	0.0	1.0	3.9	12.9	8.0	10%
Mafraq	0.0	0.1	1.0	1.4	0.5	0.1	0.1	0.0	3.3	0.6	1%
Total	7.6	4.5	2.7	0.1	0.0	0.1	1.7	5.6	21.9	**83.1**	
	% of rainfall										
AL0019	14%	8%	3%	1%	0%	2%	7%	12%	9%		
AL0035	21%	14%	8%	2%	0%	1%	11%	19%	15%		
AL0036	18%	13%	13%	1%	0%	0%	7%	18%	14%		
AL0047	17%	13%	11%	1%	0%	0%	10%	16%	13%		
AL0054	16%	10%	7%	1%	0%	0%	11%	12%	11%		
AL0055	13%	10%	4%	0%	0%	0%	6%	16%	10%		
AL0057	22%	14%	12%	3%	0%	4%	15%	20%	17%		
AL0059	4%	2%	1%	0%	0%	3%	1%	3%	2%		
Mafraq	4%	2%	0%	1%	0%	0%	0%	4%	2%		
Total	15%	10%	7%	1%	0%	1%	7%	14%	11%		

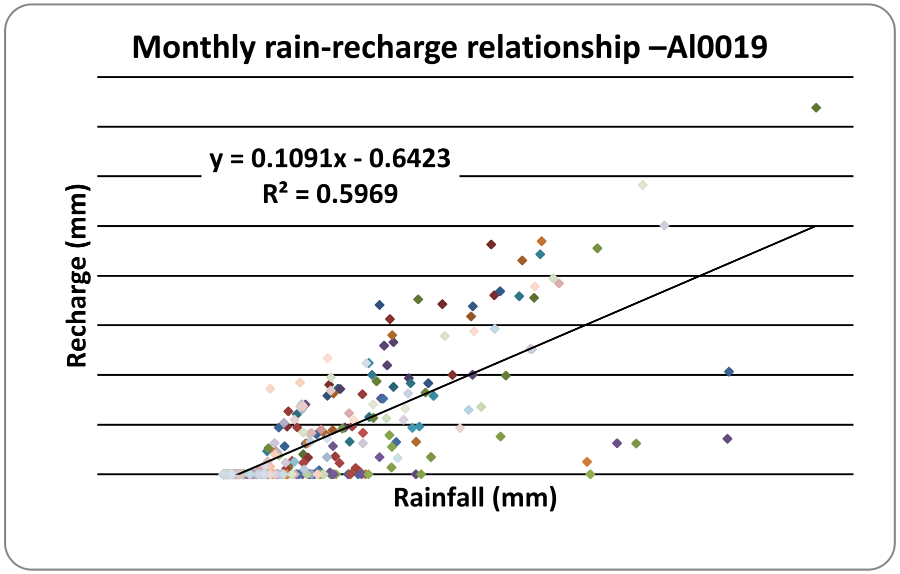
6.4. Climate Change Impact on Groundwater Recharge

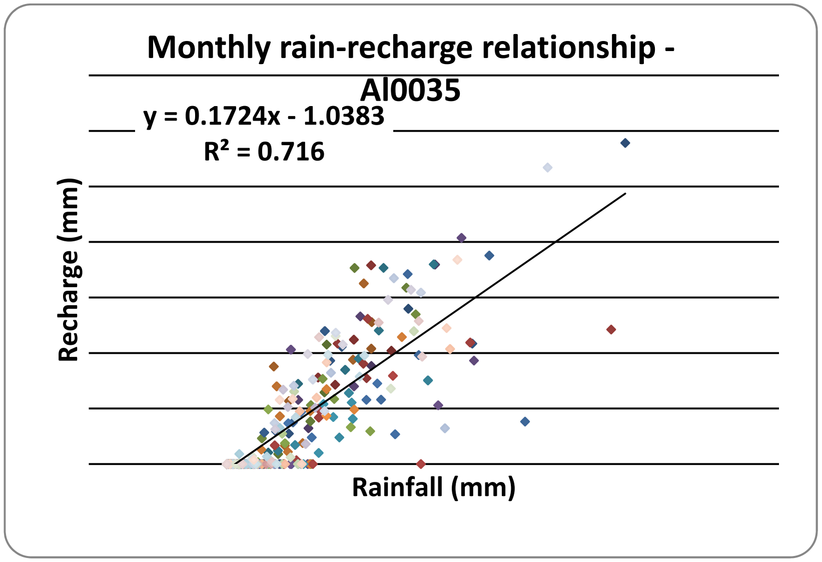
As explained in section 6.2, the impact of the climate change on the groundwater is a factor of the rainfall. A relation between the rainfall quantity and recharge is developed based on two approaches of regression analysis and both based on using SCS methodology to estimate the groundwater recharge. The analysis and the results of the climate change impact on groundwater recharge are discussed in the following sections.

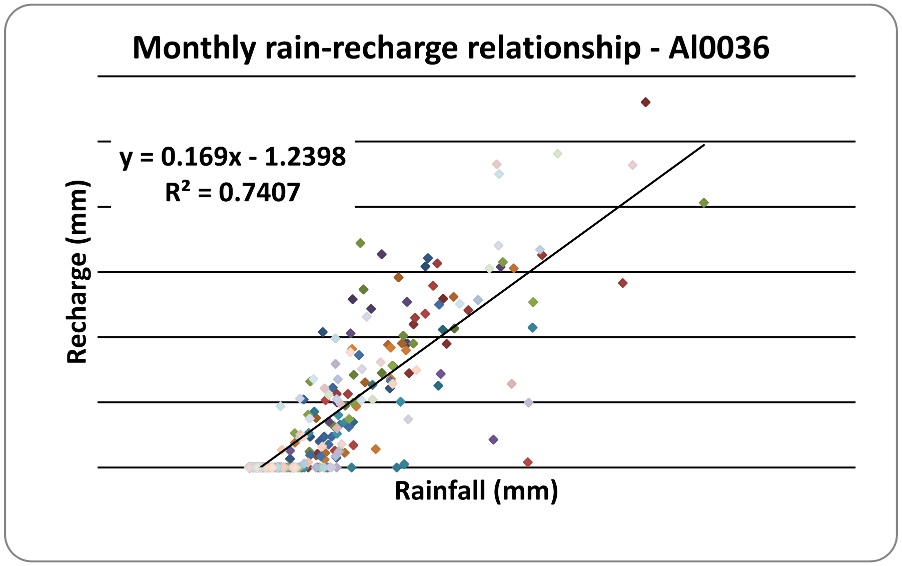
An important factor reducing the correlation factor is that the recharge is estimated based on storm interval where in many cases the rainfall storm starts in a certain month and ends in the following month and thereby the recharge amount is considered to happen in the first month while the rainfall is distributed on the two months which causes at the end some discrepancy.

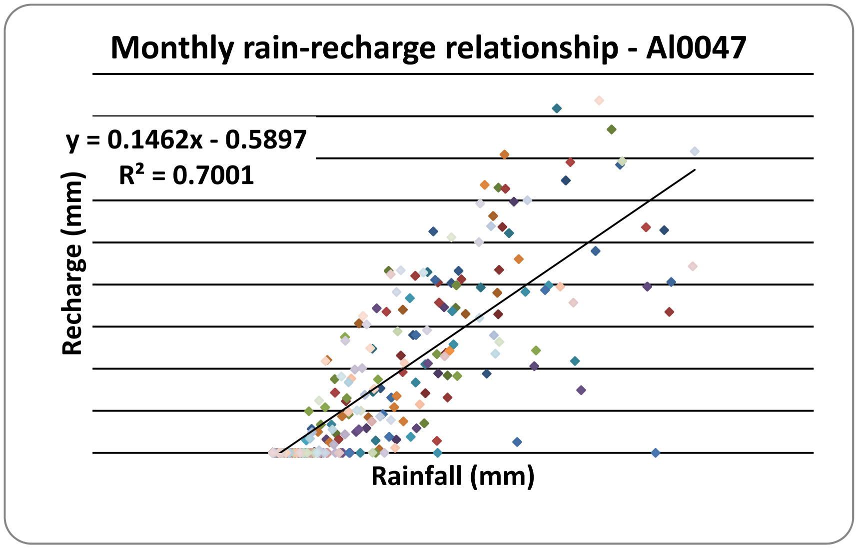
6.4.1. Approach I of regression analysis (monthly rainfall – monthly recharge relationship)

In this approach the historical daily rainfall data for the representative rainfall stations is used to firstly calculate the monthly rainfall for all years. The monthly recharge is also estimated using SCS methodology and based on storm by storm data. A data set from the monthly rainfall and monthly recharge quantities for each rainfall station is used to assess the relationship using linear regression analysis. Figure 62 illustrates the results of the regression analysis for the representative rainfall stations except for Mafraq rainfall station where there is no correlation. Table 21 presents the summary of regression analysis results and the correlation parameters which show good level of goodness-of-fit.


Monthly rain-recharge relationship –Al0019
y = 0.1091x - 0.6423
R² = 0.5969
Recharge (mm)
Rainfall (mm)


Monthly rain-recharge relationship - Al0035
y = 0.1724x - 1.0383
R² = 0.716
Recharge (mm)
Rainfall (mm)


Monthly rain-recharge relationship - Al0036
y = 0.169x - 1.2398
R² = 0.7407
Recharge (mm)
Rainfall (mm)


Monthly rain-recharge relationship - Al0047
y = 0.1462x - 0.5897
R² = 0.7001
Recharge (mm)
Rainfall (mm)

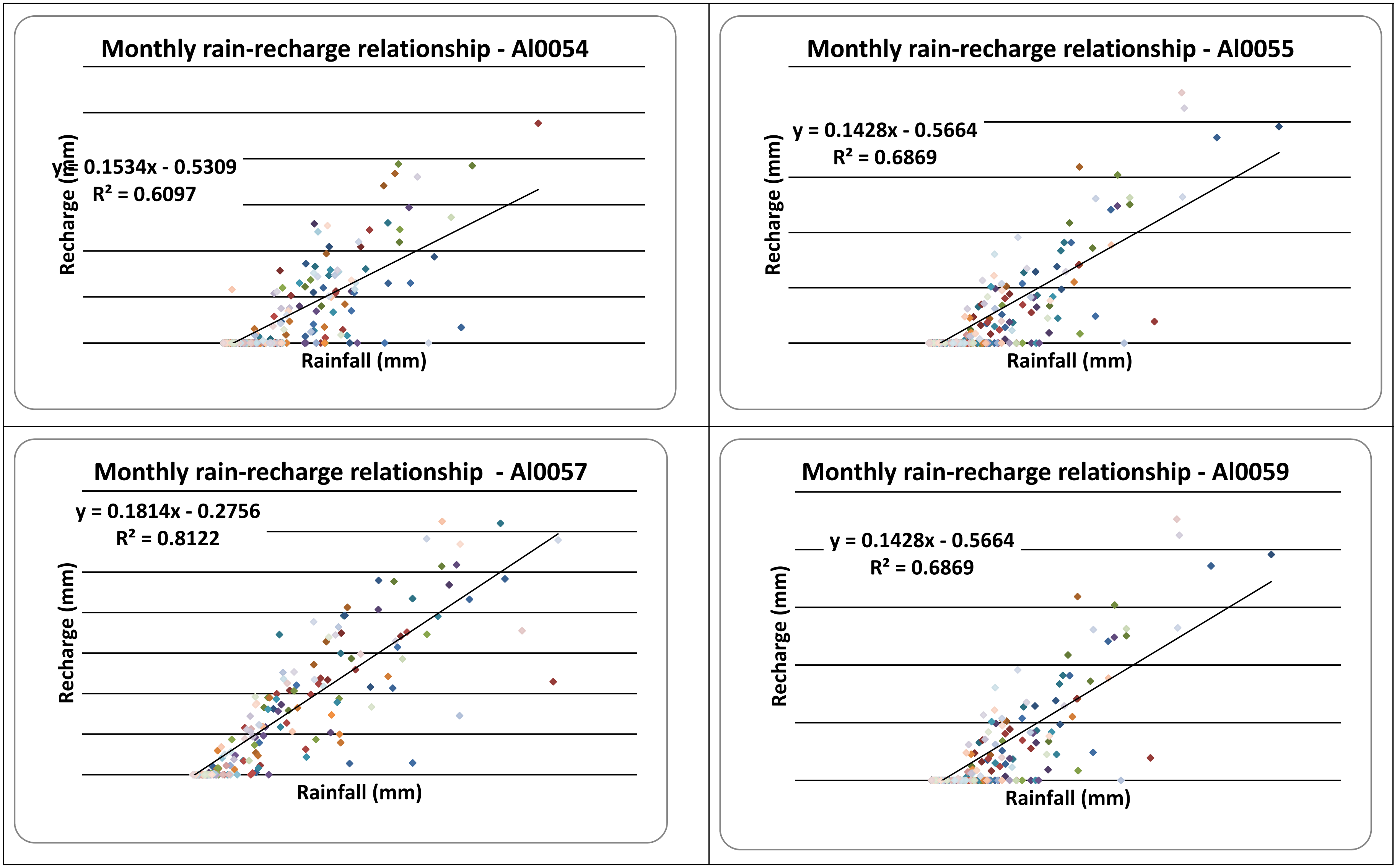


Figure (62): Monthly rainfall – monthly recharge relationship for each rainfall station

Table 21: Summary of regression analysis of monthly rainfall – recharge relationship

Station	Equation	R2	t Stat	P-value
AL0019	y = 0.1091x - 0.6423	0.5969	24.03178	5.9E-79
AL0035	y = 0.1724x - 1.0383	0.716	31.34514	1.3E-108
AL0036	y = 0.169x - 1.2398	0.7407	33.39671	1.9E-116
AL0047	y = 0.1462x - 0.5897	0.7001	30.17281	5E-104
AL0054	y = 0.1534x - 0.5309	0.6097	24.68378	1.07E-81
AL0055	y = 0.1428x - 0.5664	0.6869	29.25301	2.2E-100
AL0057	y = 0.1814x - 0.2756	0.8122	41.07466	1E-143
AL0059	y = 0.1428x - 0.5664	0.6869	29.25301	2.2E-100
Mafraq	No correlation found. As it has minor impact on the results, it also excluded from the analysis			

Y = recharge in mm, x = rainfall in mm

The regression equation between the monthly rainfall and the monthly recharge developed for each rainfall station (Table 21) are then used to estimate the recharge for different rainfall scenarios. Table 22 lists the 6 scenarios of rainfall that were carried out to assess the impact of rainfall change on the groundwater recharge. The detailed results of the impact of the rainfall change on the groundwater recharge change based on Approach I of the regression analysis are presented in Annex C1. The results show that there are large variations in the level of the climate change impact on the groundwater recharge among rainfall stations and among the months. Table 23 presents the summary results of the climate change impact overall ZRB. The reduction in the rainfall amount by 30% resulted in reducing the safe yield by around 35%.

Table 22: List of rainfall scenarios (climate change) used to estimate groundwater recharge

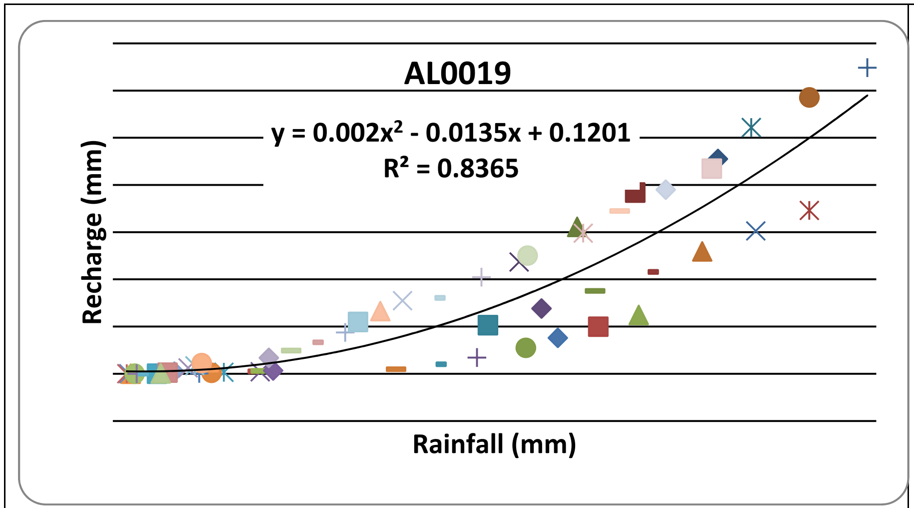
Scenario Name	Average	S1	S2	S3	S4	S5	S6
Rainfall Change (%)	**0%**	**-10%**	**-20%**	**-30%**	**10%**	**20%**	**30%**

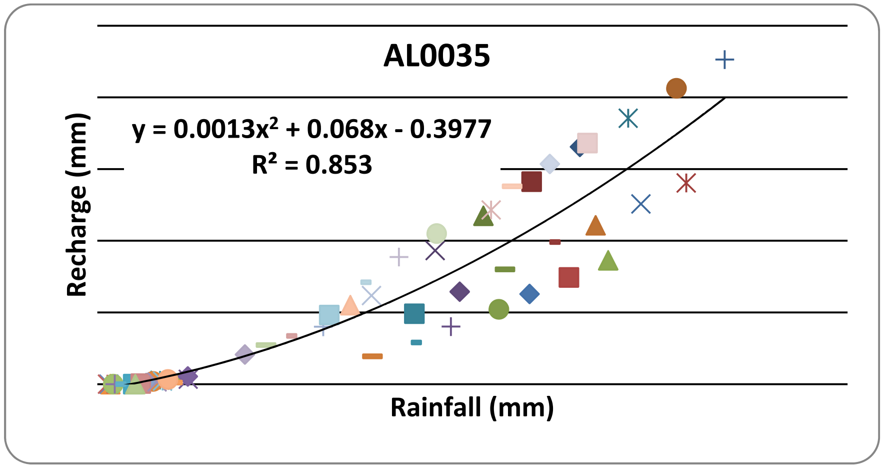
Table 23: summary results of climate change impact on groundwater – Approach I of regression analysis

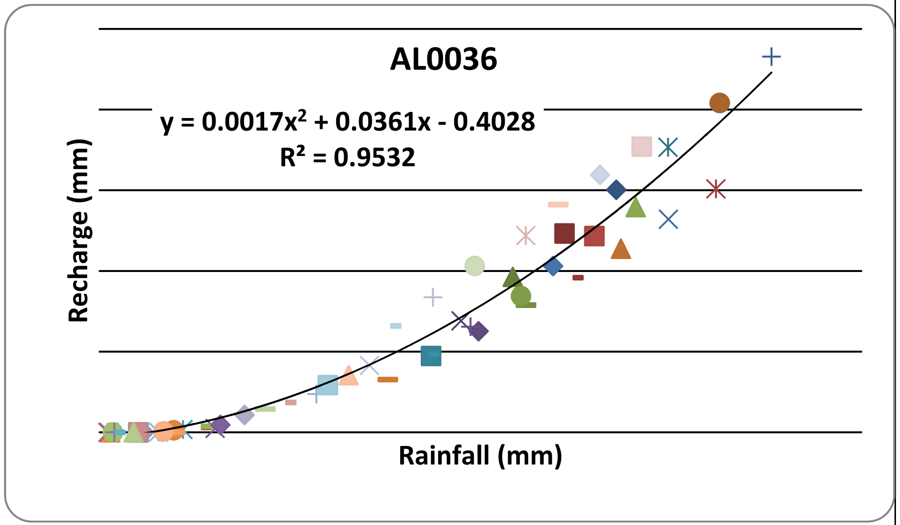
Scenario	No. 1	No. 2	No. 3	No change	No. 4	No. 5	No. 6
Rainfall change	-10%	-20%	-30%	0%	+10%	+20%	+30%
Groundwater recharge change	-11.9%	-23.5 %	-35.2%	0%	11.8%	23.6%	35.4%
Safe yield (MCM)	77.5	67.3	57.0	88	98.4	108.8	119.2
Current Abstraction (MCM)	157	157	157	157	157	157	157
% of abstraction to safe yield	203%	233%	275%	178%	160%	144%	132%

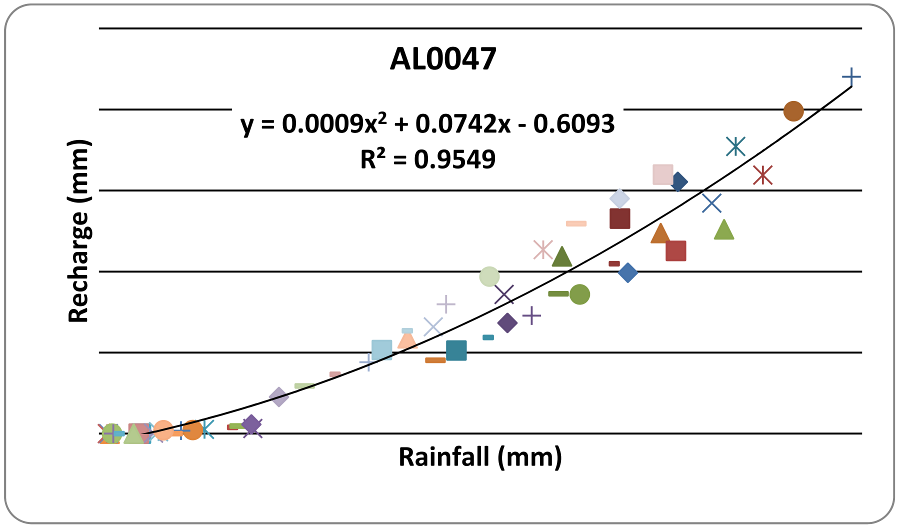
6.4.2. Approach II of regression analysis (average monthly rainfall – average monthly recharge relationship)

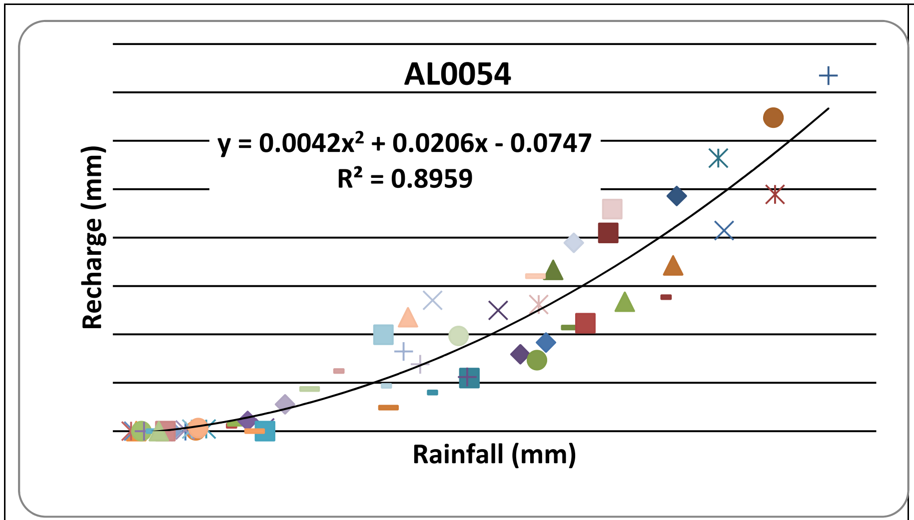
In this approach the historical daily rainfall data for the representative rainfall stations is adjusted by the rainfall scenario factors listed in Table 22 then the average monthly rainfall for each rainfall station is calculated. The average monthly recharge is also estimated using SCS methodology and based on storm by storm data. A data set from the average monthly rainfall and average monthly recharge quantities for each rainfall station is used to assess the relationship using quadratic regression analysis. Figure 63 illustrates the results of the regression analysis for the representative rainfall stations. Table 24 presents the summary results of the climate change impact overall ZRB using approach II of the regression analysis. The reduction in the rainfall amount by 30% resulted in reducing the safe yield by around 48%. On the other hand, the increase of the rainfall by 30% led to an increase in the safe yield by 62%.

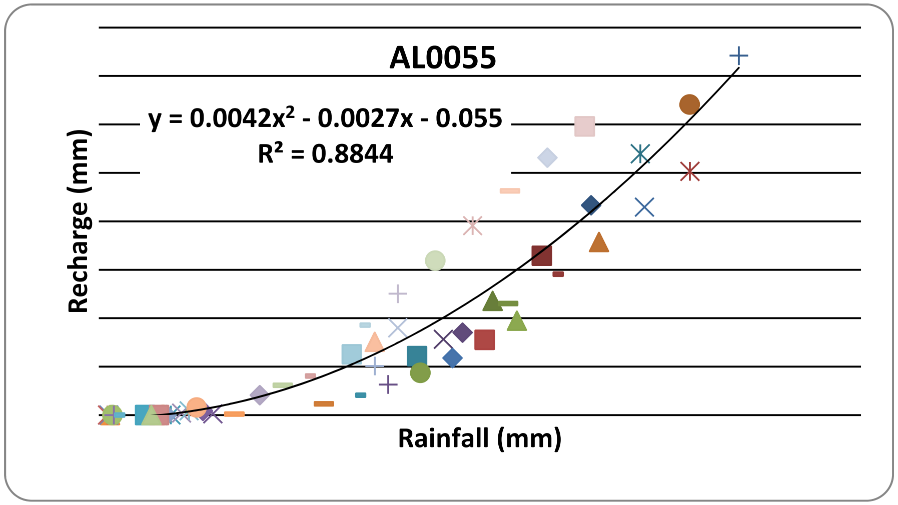

AL0019
$y = 0.002x^2 - 0.0135x + 0.1201$
$R^2 = 0.8365$
Recharge (mm)
Rainfall (mm)

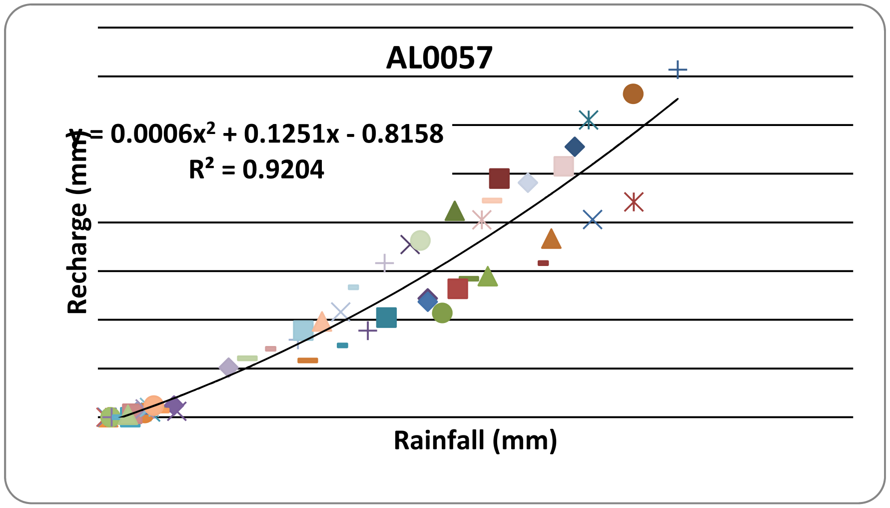

AL0035
$y = 0.0013x^2 + 0.068x - 0.3977$
$R^2 = 0.853$
Recharge (mm)
Rainfall (mm)

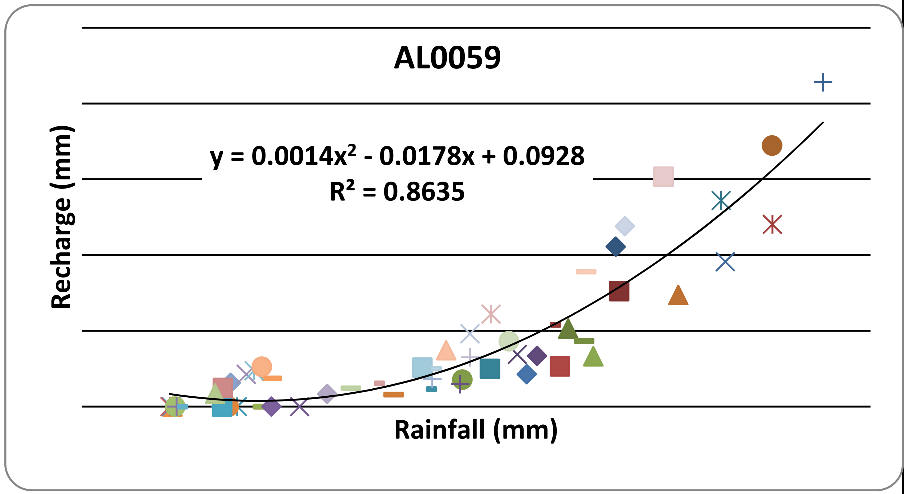

AL0036
$y = 0.0017x^2 + 0.0361x - 0.4028$
$R^2 = 0.9532$
Recharge (mm)
Rainfall (mm)


AL0047
$y = 0.0009x^2 + 0.0742x - 0.6093$
$R^2 = 0.9549$
Recharge (mm)
Rainfall (mm)


AL0054
y = 0.0042x² + 0.0206x - 0.0747
R² = 0.8959
Recharge (mm)
Rainfall (mm)


AL0055
y = 0.0042x² - 0.0027x - 0.055
R² = 0.8844
Recharge (mm)
Rainfall (mm)


AL0057
y = 0.0006x² + 0.1251x - 0.8158
R² = 0.9204
Recharge (mm)
Rainfall (mm)


AL0059
y = 0.0014x² - 0.0178x + 0.0928
R² = 0.8635
Recharge (mm)
Rainfall (mm)

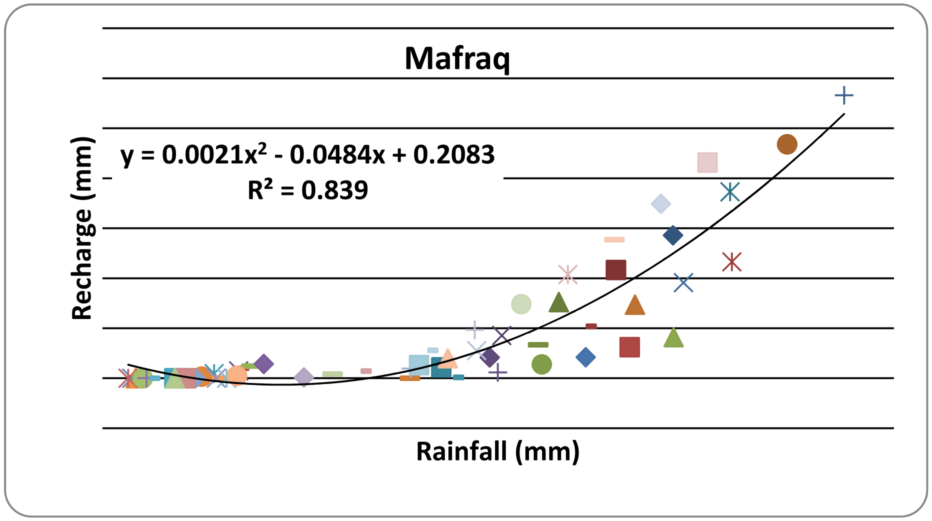


Figure (63): Average monthly rainfall – average monthly recharge relationship for each rainfall station

Table 24: summary results of climate change impact on groundwater – Approach II of regression analysis

Scenario	No. 1	No. 2	No. 3	No change	No. 4	No. 5	No. 6
Rainfall change	-10%	-20%	-30%	0%	+10%	+20%	+30%
Groundwater recharge change	-17.5%	-33.5%	-47.8%	0.0%	19.2%	39.9%	62.3%
Safe yield (MCM)	72.6	58.5	45.9	88	104.9	123.1	142.8
Current Abstraction (MCM)	157	157	157	157	157	157	157
% of abstraction to safe yield	216%	268%	342%	178%	150%	128%	110%

Figure 64 presents the developed relationship between the rainfall change and the groundwater change using both approaches of regression analysis. The second approach predicts a large impact of climate change on groundwater in comparison to the first approach. Additionally, the impact level of the rainfall change investigated using the first approach of the regression analysis is similar in both ways (increase or decrease), while the impact level of rainfall increase is high then the impact level of rainfall decrease in the second approach.

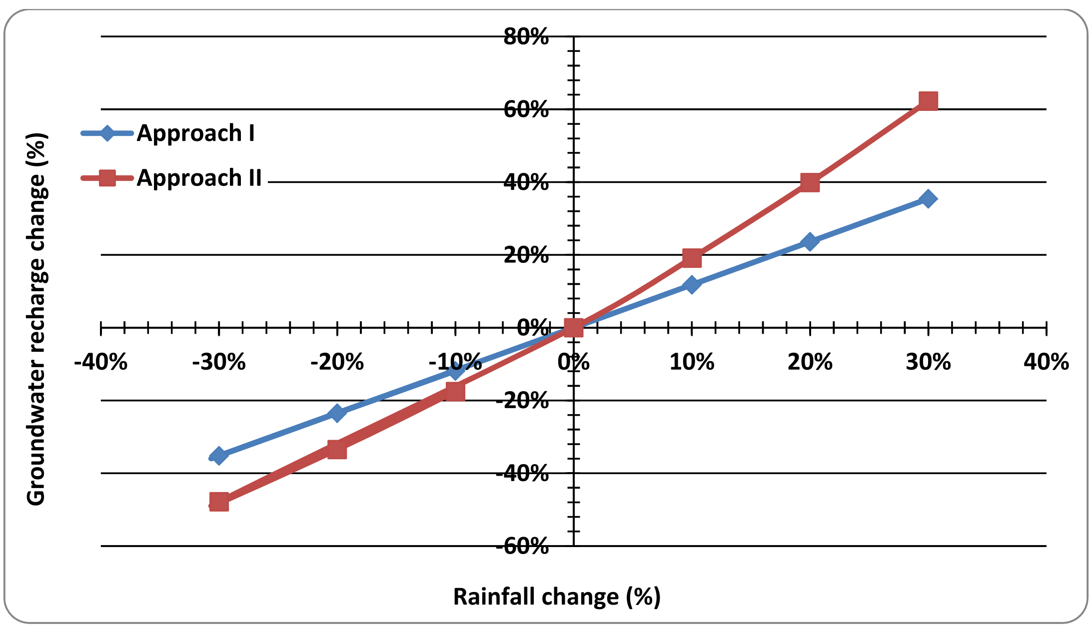


Figure (64): Relationship between rainfall change and groundwater change

6.5. Methodology Limitations

The methodology used to estimate the impact of the climate change on groundwater resources has different limitations that can be summarized in the following points:

- The interfaces with other groundwater basins were not considered in the assessment. Considering such factor would require assessing the impact of climate change on those basins first and then use groundwater model to assess the impact on the ZRB or to use a holistic groundwater model for the whole basins and then assess the impact of the rainfall reduction on the groundwater availability. Using one of these approaches would require large efforts, time and data.
- The change in the rainfall intensity or duration is not fully captured in the assessment of the future change. Daily rainfall data is most detailed data used to estimate the groundwater recharge, which does not fully capture the impact of the rainfall intensity factor on the groundwater recharge quantity although estimation is done storm by storm. Additionally, the forecast of the future groundwater recharge quantities is only based on the rainfall quantity as there is no reliable way to estimate the change of rainfall intensity.
- The approach of estimating the groundwater recharge was based on rainfall amount of each storm. The storm was creating by summing up all sequential days that have rainfall. Thus, the distribution of rainfall within the storm could not be addressed where some rainy days might have very little rainfall compared to the other days but they are still considered to be part of the rainfall storm.
- The groundwater characteristics were not fully address to estimate the groundwater recharge since the SCS approach is applied to estimate the groundwater recharge based on the infiltration rates which was assumed to be equal to the recharge amount. The impact of such factor is considered limited as the study interest was to assess the change in the recharge not the amount itself.

- Other factors such as urbanization and land use change could not b address since there is not enough historical data that could be used to assess these factors and then incorporate them in the groundwater recharge estimation.

- The groundwater resources availability is assessed based on the change of the safe yield that was assumed to be change proportionally with the change of the groundwater recharge quantities which might not be that accurate. A proper way to handle such issue is to use a groundwater model and then apply the change in the recharge amount to investigate the change on the safe yield.

- The assessment of the climate change impact is focused on estimating the impact of climate change on the groundwater availability through assessing change on the safe yield without assessing the impact on the groundwater movement that might effect on the regional safe yield within the aquifer zones. Again, using a groundwater model would allow to overcome such issue.

6.6. Conclusions

- The impact of climate change on groundwater of ZRB is addressed using two approaches of regression analysis. Both approaches used the water balance approach to estimate the recharge amounts used to create the relationship. The incremental scenarios that were developed in this study are the input of the groundwater recharge model, where rainfall amounts were changed by -30%, –20%, –10%, +10%, +20%, and +30%.

- Temperature changes were not considered in development of the groundwater recharge scenarios since the preliminary trend analysis made on the temperature and recharge estimation did not show any correlation between those two parameters.

- In the first approach the historical daily rainfall data for the representative rainfall stations is used to firstly calculate the monthly rainfall for all years. The monthly recharge is also estimated using SCS methodology and based on storm by storm data. The regression equation between the monthly rainfall and the monthly recharge developed for each rainfall station are then used to estimate the recharge for different climate change scenarios. The results show that there are large variations in the level of the climate change impact on the groundwater recharge among rainfall stations and among the months. The results indicated that a reduction in the rainfall amount by 30% resulted in reducing the safe yield by around 35%, while 10% reduction in the rainfall resulted in about 12% reduction in the safe yield.

- In the second approach the average monthly rainfall and average monthly recharge quantities for each rainfall station is used to assess the relationship using quadratic regression analysis. The reduction in the rainfall amount by 30% resulted in reducing the safe yield by around 48%, while 10% reduction in rainfall resulted in about 17.5% reduction in the safe yield. On the other hand, the increase of the rainfall by 30% led to an increase in the safe yield by 62%.
- The second approach predicts a large impact of climate change on groundwater in comparison to the first approach. Additionally, the impact level of the rainfall change investigated using the first approach of the regression analysis is similar in both ways (increase or decrease), while the impact level of rainfall increase is high then the impact level of rainfall decrease in the second approach.

6.7. Recommendations

- The ability to forecast the future availability of the groundwater resources is important for better water resources management and to allow decision makers to optimize the use of the future available water and to investigate other water resources to fulfill the deficit increased as a result of the decreased water resources.

- The change in the available groundwater resources will affect the daily operations of water utilizes with AZB particularly Miyahuna Company, Zarqa and Balqa Water Authorities which are highly dependent on the groundwater resources in AZB to supply the largest concentration of people in Jordan with drinking water. This future variability and uncertainty of AZB water increases the stresses on those utilities to find other alternative to supply drinking water particularly in summer season.

- The reduction in the groundwater availability in AZB will result in accelerated decrease in the groundwater levels and groundwater degradation. This means lower productivity of water and thereby increased cost of water production. The drawdown in groundwater table will also reduce the production efficiency and increase the energy consumption of pumping. All this will result in increasing the cost on the Water Authority of Jordan and thereby increase the financial stress.

- The water sector's organization should increase the awareness of public about the future changes in the water availability and the stakeholder participation in all steps of the development and implementation of adaptation strategies and measures.

- Climate change should increase the urgency for more sustainable water policy and investment choices. Urgent steps are needed towards developing a regional preparedness policy to adapt to extremes water events.

- For future assessment, it is recommended to use a mathematical groundwater model that will allow overcoming some of the limitation presented above. The model simulates the groundwater movement and estimate more accurately the safe yield that result in better assessment of the climate change impact on the groundwater resources availability. Such model will allow assessing the impact of the groundwater recharge quantity estimated by the SCS approach on the groundwater availability within the aquifer including springs and on the groundwater movement.

- Although, there is some uncertainty in assessing the impact of climate change on groundwater resources in AZB, this should never be a reason for inaction. Action and research on adaptation should be pursued simultaneously in order to minimize the climate change impact.

- Ensuring that data and information are readily available is crucial for making climate projections, assessing the climate change impact and identifying vulnerable groups and regions. So sharing information between the different concerned organizations in Jordan as well as in countries that share with Jordan its water resources is essential for effective and efficient climate change adaptation.

- Water supply and sanitation, especially during extreme weather events, require special attention in adaptation policy, as they are essential for good health. Increasing water scarcity and temperature may limit access to water for sanitation, reduce the self-cleaning capacity of sewers and limit the ability of natural ecosystems to assimilate wastes.

- It is important to start acting now even if the cost looks high since any delay in applying adaptation measures will be much higher once the effects of climate change are irreversible.

7. Conclusions and Recommendations

7.1. Conclusions

Climate change in Jordan is real, in particular in relation to temperature increase. However, there is still a high degree of uncertainty when it comes to knowledge about specific changes and impacts, as well as the relative weight of global warming compared to other changes in the physical environment with potential implications for local climate, e.g. in local land use. This report aims to assess the direct and indirect impacts of Climate Change on water availability and quality in the Zarqa River Basin".

7.1.1. Observed Trends and climate change scenarios

In order to detect any trends in the climatological time series in Jordan the linear trend test has been applied to the available longest time series of precipitation, maximum temperature, minimum temperature and mean temperatures at 6 observation stations, 3 from the Met. Dept. and 3 from the MWI. Because of the short record of the daily observational data of temperature and precipitation, and the large number of missing and incorrect data at a part of 6 stations, the Statistical Downscaling Model (SDSM) was employed to develop baseline scenarios covering the period 1961–2010.

Since the typical grid resolution in these GCMs is still too coarse to examine effects of local topography and land use, and to assess climate change impacts in station-scale sites, it was necessary to apply a downscaling model to downscale the coarse resolution GCM projections to each single site in the study area. For this purpose HadCM3 General Circulation Model and Statistical Downscaling Model (SDSM4.2) and are employed to generate future temperature and rainfall scenarios at the 6 stations in the ZRB for the period from 2011 to 2099.

The daily baseline scenarios, the daily climate change future scenarios together with the daily and monthly incremental scenarios were distributed to the climate change impact assessment team members to study the impacts of climate change on the water resources, water quality and socio-economic sectors.

The most important conclusions summarized as follows:

- The maximum, minimum and mean temperatures reveal significant warming trends at in most of the stations. The warming trends of minimum temperature are greater than that of maximum temperature. As a result the mean temperature shows warming trends in all stations.
- The temperature increase ranges from 1-4 °C.
- The temperature increase is greater in the winter months.
- The temperature increase is greater in the period 2060 – 2099.
- The precipitation climate change scenarios are highly variable.
- The rainfall amount at Mafraq and Wadi Dhulail is expected to increase by 30-60%.
- The future rainfall amount at Amman A/P is predicted decrease by 15 – 30 %.
- 30 – 50 % decrease in rainfall at other locations is expected.
- The reduction in rainfall amounts is expected through the winter months from October to April, while the months from May to September are exposure to increase in rainfall amounts. This result is not unusual in GCM modeling because summer months rarely record rain in Jordan.
- Combination of temperature increase and rainfall reduction in the winter months will worsen the future climate and increase the negative impacts of climate change on water resources, agriculture, socio-economy and all other sectors.

7.1.2. Impact of climate change on surface water availability

A hydrological model was implemented using SWAT model through GIS environment. Various data sets were used in this process which include digital elevation model (DEM), Soil Data, Land use data, besides meteorological data which include daily precipitation and temperature. The implemented model was calibrated using observed flow values obtained from Jerash Bridge gauging station (AL0061). The correlation coefficient between the simulated values and the observed values (R^2) is 0.95 which indicates a high correlation. The calibrated model was used to assess the impacts of climate change on surface runoff availability. Two types of future climate data were used for this purpose. The first is the incremental future data and the other is the global climate models (GCM) data.

Results for the incremental data showed that the precipitation is the major factor that affects the availability of surface runoff water. In dry years, it's expected that these amount may decreased up to 35%, while in normal years it will be decrease only by 2% even if the temperature increase 4^{o}c. In the wet years these values my increase up to 40%.

Depending on the incremental scenarios for assessing the future impacts of climate change on surface water availability is not enough. Because it is not possible to determine which is the most probable scenario that might happens in the future. Therefore GCM data was used.

Based on the outputs from the metrological analyses, HadCM3 model with two experiments (A2 and B2) was used in this section. Based on simulated values for these two experiments, the mean annual surface runoff values are expected to decline for the next 80 years. For the mean monthly values, there will be a major decease in the surface runoff availability especially for the rainy months (Dec, Jan, Feb and Mar). While a slight increase was expected for other months like Oct, Nov, Apr and May. Similar results were also obtained for the maximum monthly peak flow values. The same results were obtained for both experiments A2 and B2.

7.1.3. Impact of climate change on water quality

The impact of climate change on water quality is still a relatively new area of research, which is considered a serious challenge for investigators. In this study, the impact of climate change on the water quality of Zarqa river was assessed under both incremental and GCM scenarios that were developed in the course of the study using SWAT model. The impact on water quality parameters like nitrate, organic nitrogen and organic phosphorus were assessed and compared with the baseline scenarios for the period 2015-2049. It was concluded that under incremental scenarios the highest amount of nitrates will occur in the year 2044 under all incremental scenarios. While, the phosphorus amount found to range between 0.2 -1.4 kg/ha under various incremental scenarios.

The predicted loads of pollutants for the period of 2015-2049 under GCM models (HadCM3-A2 and Had CM3-B2) was found to be of the same values of nitrate as compared with the baseline scenario. However, in most of the cases, the GCMs are predicting lower amounts of organic nitrogen and organic phosphorous.

7.1.4. Impact of climate change on groundwater

The impact of climate change on groundwater of ZRB is addressed using two approaches of regression analysis. Both approaches used the water balance approach to estimate the recharge amounts used to create the relationship. The incremental scenarios that were developed in this study are the input of the groundwater recharge model, where rainfall amounts were changed by -30%, –20%, –10%, +10%, +20%, and +30%.

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7.2. Recommendations

- The time allocated for the climate change scenarios in this study and in other similar studies is too short. Longer time is needed to employ the most modern and new model applications. In future climate change studies it is recommended to employ the Dynamical Downscaling Modeling Technique and RCMs to produce high resolution climate scenarios for a domain of 10 – 50 km by nesting from the initial boundary conditions of the coarse GCMs outputs.

- Due to the lack of the observation stations in specific regions of Jordan accompanied to the inadequate length of climatic time series, it is necessary to construct an atlas of climate change scenarios for all climatic elements that includes GIS maps of the whole country.

- Cooperation among all concerned ministries, departments, scientific institutions, universities and research centers is highly recommended to facilitate accessibility and exchange of data and experience among researchers.
- Extend the target area of the study to include more watersheds in Jordan Like Yarmouk Basin and Mujieb Basin.
- This study was based on several data sets from different sources, and sometimes, obtaining such data is a time consuming process. It's important to hold a meeting with involved ministries and governorates to start thinking in building Jordan's national spatial network. MWI may initiate this process and may also hos the server and portals for data sharing and dissemination.
- Based on the results obtained from this section, it was found generally that surface water availability are going to be affected by climate change and may drop in rainy months up to 40%, therefore, Jordan's Water National Strategy which starts in 2008 and will last until 2022 should be revised to take into consideration these figures.
- To reduce the impacts of climate change on water resources of ZRB, a detail study is needed to select and priorities the most suitable climate change adaption strategies for ZRB.
- It is important to start seeking for new non-conventional water resources project like water harvesting projects and use of gray water project.
- The ability to forecast the future availability of the groundwater resources is important for better water resources management and to allow decision makers to optimize the use of the future available water and to investigate other water resources to fulfill the deficit increased as a result of the decreased water resources.
- The change in the available groundwater resources will affect the daily operations of water utilizes with AZB particularly Miyahuna Company, Zarqa and Balqa Water

Authorities which are highly dependent on the groundwater resources in AZB to supply the largest concentration of people in Jordan with drinking water. This future variability and uncertainty of AZB water increases the stresses on those utilities to find other alternative to supply drinking water particularly in summer season.

- The reduction in the groundwater availability in AZB will result in accelerated decrease in the groundwater levels and groundwater degradation. This means lower productivity of water and thereby increased cost of water production. The drawdown in groundwater table will also reduce the production efficiency and increase the energy consumption of pumping. All this will result in increasing the cost on the Water Authority of Jordan and thereby increase the financial stress.

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- It is important to start acting now even if the cost looks high since any delay in applying adaptation measures will be much higher once the effects of climate change are irreversible.

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9. ANNEXEX

Annex A) Time Series Trend Analysis Figures

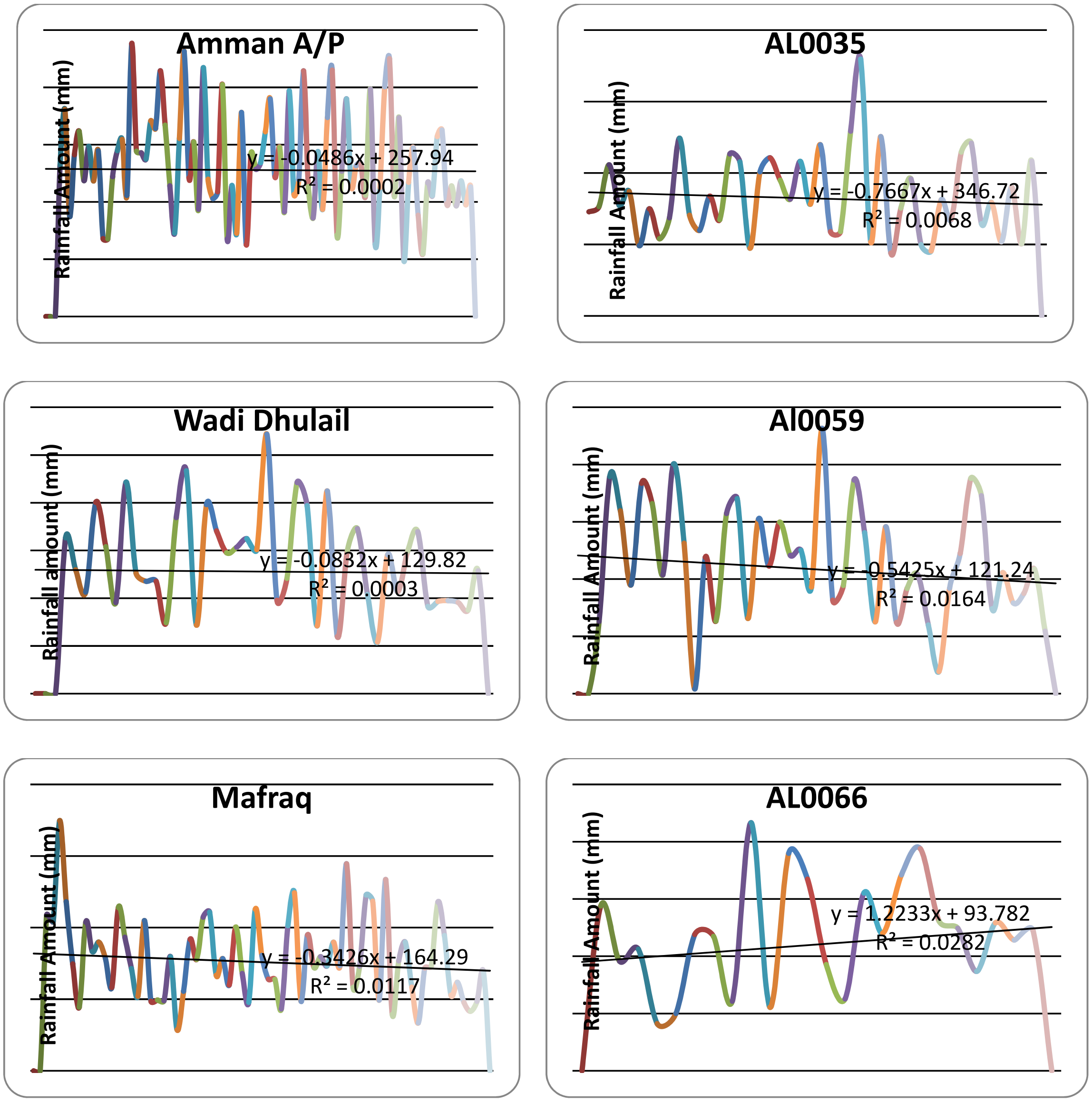

Figure A1: Trends of the rainfall amount time series.

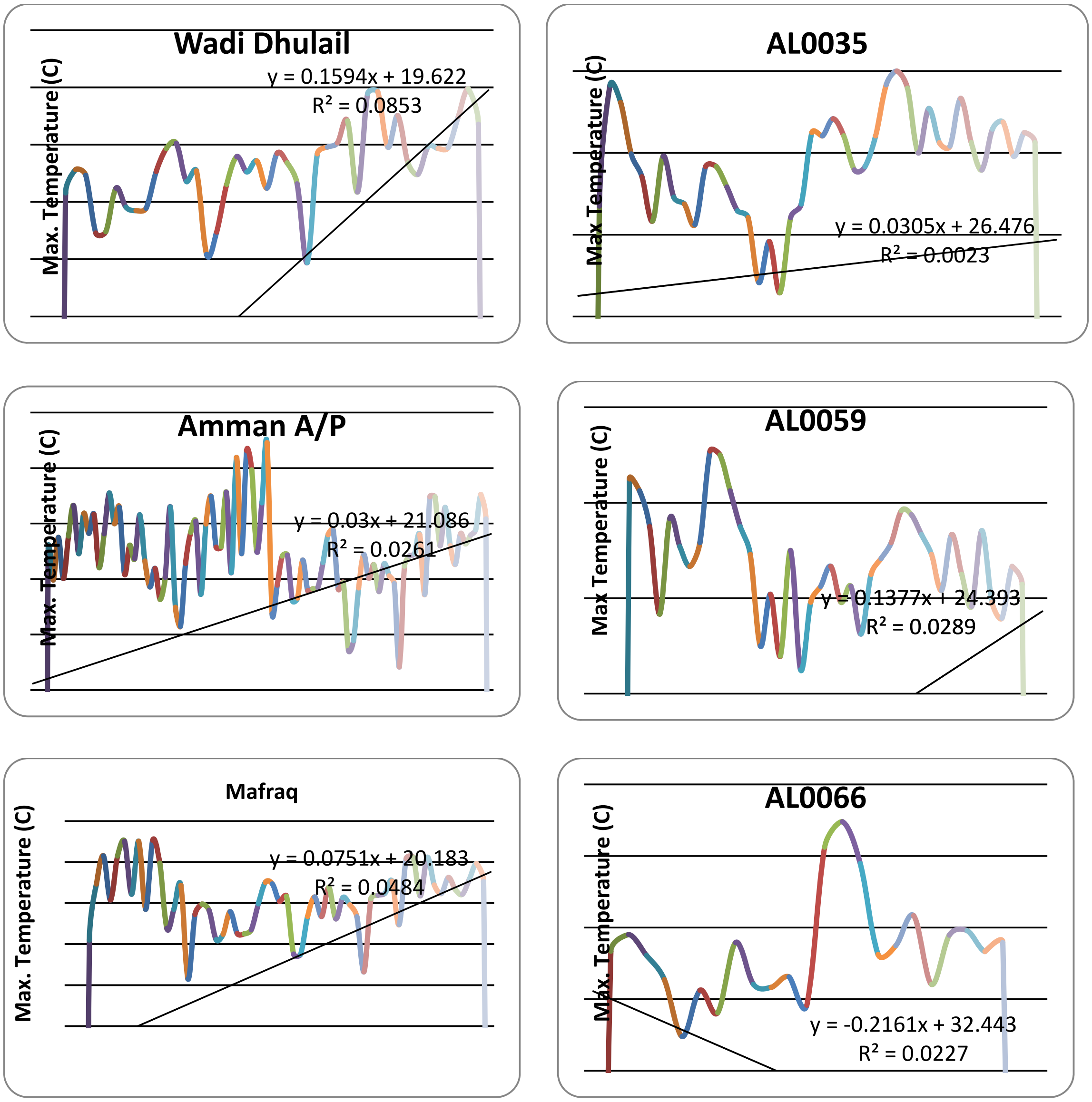

Figure A2: Trends of the maximum temperature time series.

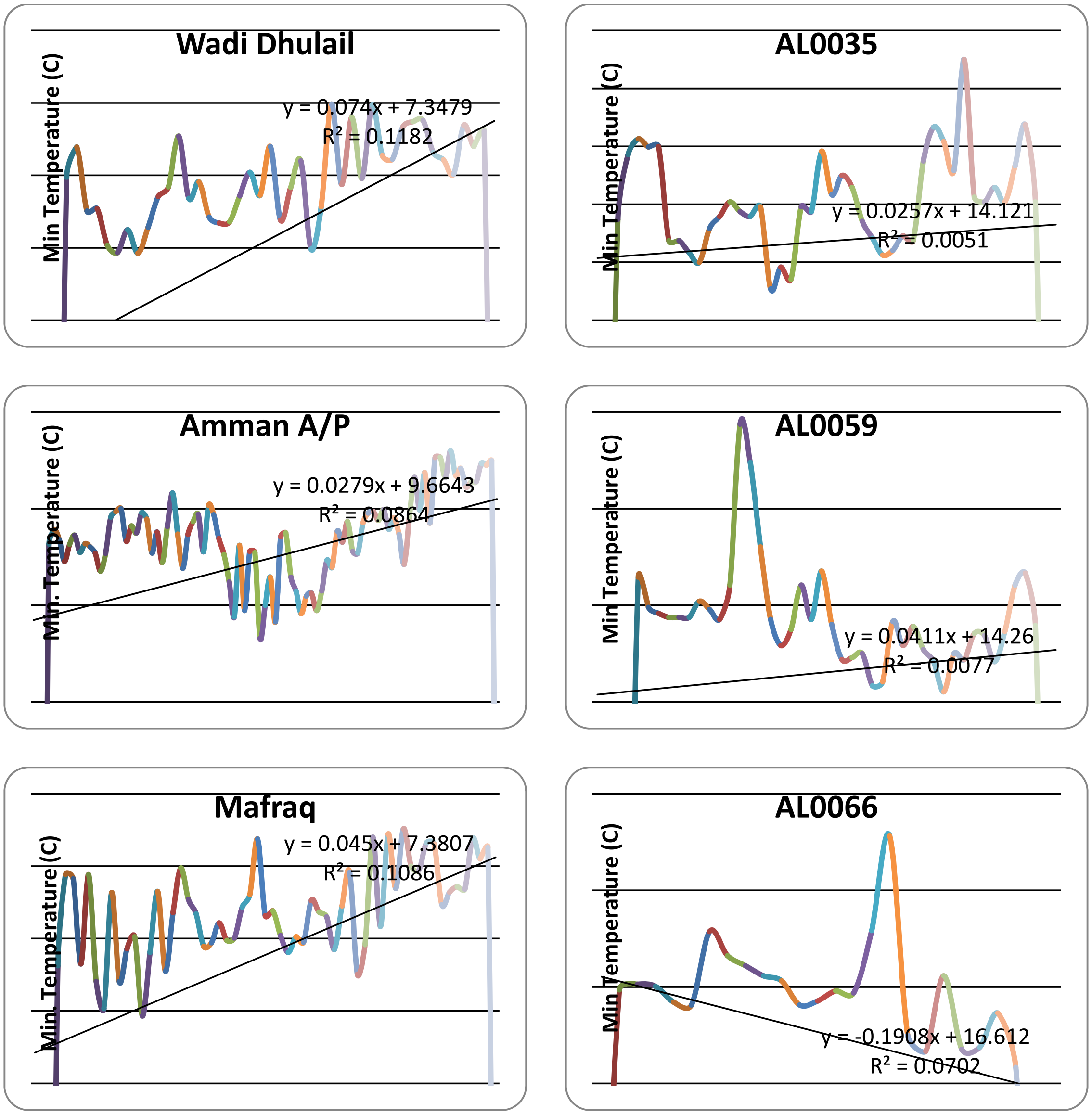

Figure A3: Trends of the minimum temperature time series.

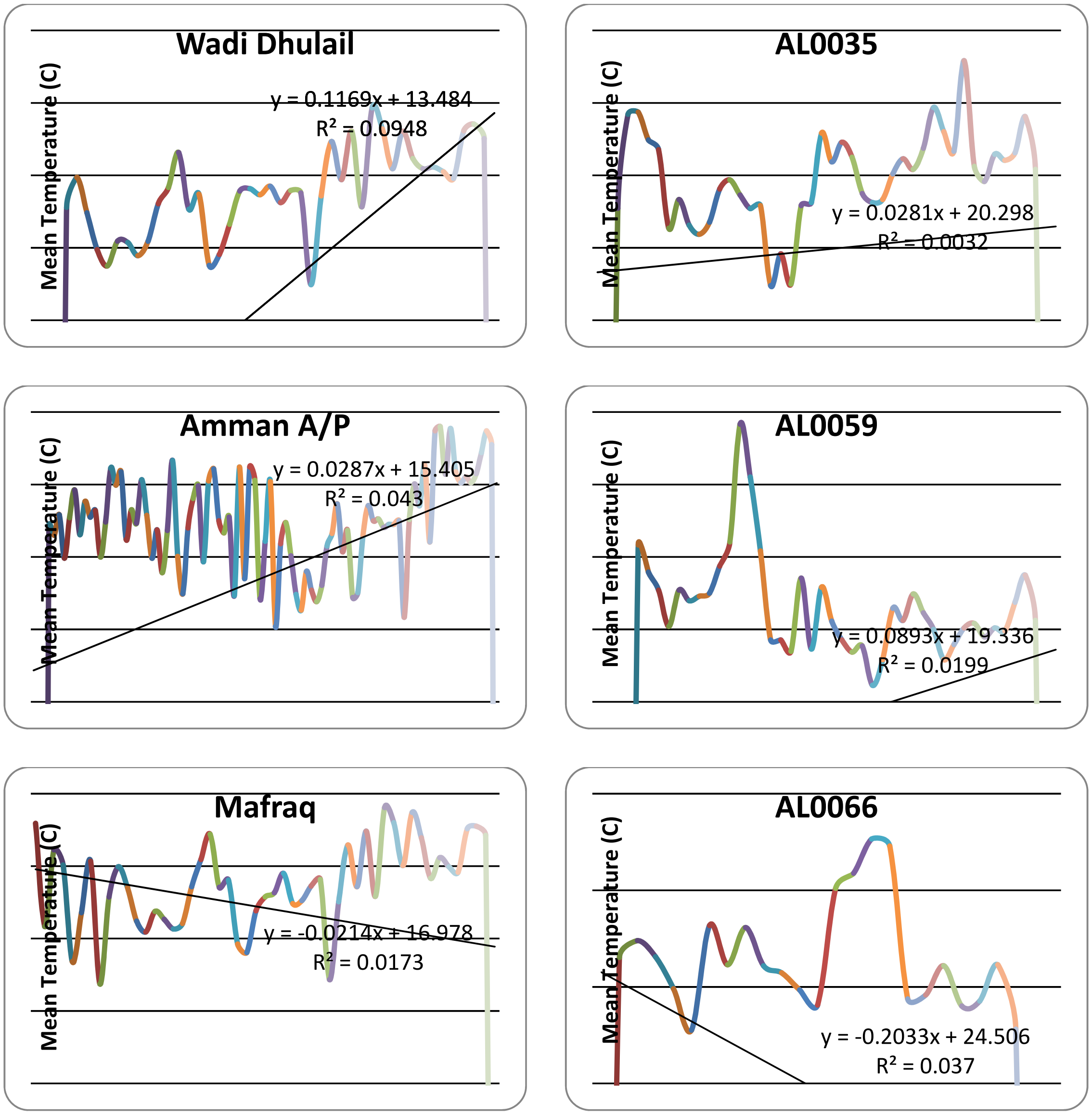

Figure A4: Trends of the mean temperature time series.

Annex B) GCM Downscaling results

Table B1: Downscaled Climate scenarios statistics for Amman Airport generated using SDSM4.2 and HadCM3 Global Circulation Model.

	HadCM3 – A2			HadCM3 – B2		
Minimum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 – 2010	11.5	11.2	- 0.3	11.5	11.2	- 0.3
2010 – 2060		11.8	+ 0.3		11.8	+ 0.3
2061 - 2099		12.8	+ 1.3		12.4	+ 0.9
2011 - 1099		12.2	+ 0.7		12.1	+ 0.6
Maximum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	24	23.5	- 0.5	24	23.6	- 0.4
2010 – 2060		25.3	+ 1.3		25.4	+ 1.4
2061 - 2099		28.2	+ 4.2		26.9	+ 2.9
2011 - 1099		26.5	+ 2.2		26.1	+2.1
Mean Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	17.5	17.5	0.0	17.5	17.6	+ 0.1
2010 – 2060		19	+ 1.5		19.1	+ 1.6
2061 - 2099		21.5	+ 4.0		20.4	+ 2.9
2011 - 1099		20.1	+ 2.6		19.7	+ 2.2
Rainfall Amount (mm/day)	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**
1961 - 2010	0.72	0.71	- 1	0.72	0.73	+ 1
2010 – 2060		0.64	- 12		0.62	- 14
2061 - 2099		0.48	- 33		0.54	- 25
2011 - 1099		0.57	-21		0.59	- 19

Table B2: Downscaled Climate scenarios statistics for Wadi Dhulail generated using SDSM4.2 and HadCM3 Global Circulation Model.

	HadCM3 – A2			HadCM3 – B2		
Minimum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 – 2010	10	10.2	+ 0.2	10	9.9	- 0.1
2010 – 2060		11.8	+1.8		11.8	+ 1.8
2061 - 2099		12.9	+ 2.9		12.4	+ 2.4
2011 - 1099		12.2	+ 2.3		12.1	+ 2.1
Maximum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	25.6	23.5	- 2.1	25.6	25.8	+ 0.2
2010 – 2060		25.3	- 0. 3		26.4	+ 0.8
2061 - 2099		28.2	+ 2.6		26.9	1.3
2011 - 1099		26.5	+ 0.9		26.1	+ 0.5
Mean Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	17.8	17.5	- 0.3	17.8	17.6	- 0.2
2010 – 2060		19.0	+ 1.2		19.1	+ 1.3
2061 - 2099		21.5	+ 3.7		20.4	+ 2.6
2011 - 1099		20.1	+ 2.3		19.7	+ 1.9
Rainfall Amount (mm/day)	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**
1961 - 2010	0.39	0.36	- 5	0.39	0.46	+ 2
2010 – 2060		0.64	+ 65		0.62	+ 61
2061 - 2099		0.48	+ 24		0.54	+ 41
2011 - 1099		0.57	+ 48		0.59	+ 52

Table B3: Downscaled Climate scenarios statistics for Mafraq generated using SDSM4.2 and HadCM3 Global Circulation Model.

	HadCM3 – A2			HadCM3 – B2		
Minimum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 – 2010	9.4	11.2	+ 1.8	9.4	11.2	+ 1.8
2010 – 2060		11.8	+ 2.4		11.8	+ 2.4
2061 - 2099		12.8	+ 3.4		12.4	+ 3.0
2011 - 1099		12.2	+ 2.8		12.1	2.7
Maximum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	24	23.5	- 0.5	24	23.6	- 0.4
2010 – 2060		25.3	+ 1.3		25.4	+ 1.4
2061 - 2099		28.2	+ 4.2		26.9	+2.9
2011 - 1099		26.5	+ 2.5		26.1	+ 2.1
Mean Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	16.7	17.5	+ 0.8	16.7	17.6	+ 0.9
2010 – 2060		19.0	+ 2.3		19.1	+ 2.4
2061 - 2099		21.5	+ 4.7		20.4	+ 3.7
2011 - 1099		20.1	+ 3.4		19.7	+ 3.0
Rainfall Amount (mm/day)	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**
1961 - 2010	0.42	0.41	- 4	0.42	0.41	- 4
2010 – 2060		0.64	+ 51		0.62	+ 46
2061 - 2099		0.48	+15		0.54	+ 28
2011 - 1099		0.57	+ 36		0.59	+ 38

Table B4: Downscaled Climate scenarios statistics for AL0035 Baq'a generated using SDSM4.2 and HadCM3 Global Circulation Model.

	HadCM3 – A2			HadCM3 – B2		
Minimum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 – 2010	16.1	15.4	- 0.7	16.1	15	-1.1
2010 – 2060		18.4	+ 2.3		17.6	+ 1.5
2061 - 2099		19	+ 2.9		18.2	+ 2.1
2011 - 1099		17.9	+ 1.8		18	+ 1.9
Maximum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	29.8	29.7	- 0.1	29.8	29.8	0.0
2010 – 2060		32	+ 2.2		31.6	+ 1.8
2061 - 2099		32.7	+ 2.9		31.7	+ 1.9
2011 - 1099		31.8	+ 2		31.4	+ 1.6
Mean Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	23.0	23.4	+ 0.4	23.0	23.7	-0.7
2010 – 2060		25.1	+ 2.1		25.5	+ 1.8
2061 - 2099		25.9	+2.9		25.1	+1.4
2011 - 1099		25.2	+ 1.8		25.3	+1.6
Rainfall Amount (mm/day)	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**
1961 - 2010	0.95	0.84	- 12	0.95	0.88	- 8
2010 – 2060		0.6	- 33		0.69	- 28
2061 - 2099		0.5	- 50		0.56	- 41
2011 - 1099		0.57	- 40		0.61	- 36

Table B5: Downscaled Climate scenarios statistics for AL0059 Um El Jmal generated using SDSM4.2 and HadCM3 Global Circulation Model.

	HadCM3 – A2			HadCM3 – B2		
Minimum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 – 2010	17.5	18.4	+ 0.9	17.5	17.8	+ 0.3
2010 – 2060		21.2	+ 3.7		20.6	+ 3.1
2061 - 2099		21.7	+ 4.2		21.2	+ 3.7
2011 - 1099		21.0	+ 3.5		19.9	+ 2.4
Maximum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	31.8	32.1	+ 0.3	31.8	32.4	0.6
2010 – 2060		34.7	+ 2.9		34.5	2.7
2061 - 2099		35.2	+ 3.4		34.9	3.1
2011 - 1099		34.6	+ 2.8		34.6	2.8
Mean Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	24.6	24.8	+ 1.2	24.6	24.8	+ 0.2
2010 – 2060		28.1	+ 3.5		27.5	+ 2.9
2061 - 2099		29.0	+ 4.4		28.4	+ 3.8
2011 - 1099		27.8	+ 3.2		27.1	+ 2.3
Rainfall Amount (mm/day)	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**
1961 - 2010	0.36	0.31	- 11	0.36	0.32	- 12
2010 – 2060		0.25	- 29		0.24	- 31
2061 - 2099		0.17	- 51		0.20	- 45
2011 - 1099		0.22	- 39		0.23	- 37

Table B6: Downscaled Climate scenarios statistics for AL0066 Khirbet Es Samra generated using SDSM4.2 and HadCM3 Global Circulation Model.

	HadCM3 – A2			HadCM3 – B2		
Minimum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 – 2010	15.9	17.0	+ 1.1	15.9		+ 0.6
2010 – 2060		19.6	+ 3.7		18.8	+ 2.9
2061 - 2099		19.8	+ 3.9		19.3	+ 3.4
2011 - 1099		18.8	+ 2.9		18.4	+ 2.5
Maximum Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	33.4	34.3	+ 0.9	33.4	33.5	+ 0.1
2010 – 2060		36.3	+ 2.9		35.2	+ 1.8
2061 - 2099		36.5	+ 3.1		36.1	+ 2.7
2011 - 1099		36.1	+ 2.7		35.6	+ 2.2
Mean Temperature (°C)	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**	**Observed (°C)**	**Modeled (°C)**	**Anomaly (°C)**
1961 - 2010	24.6	25.1	+ 0.5	24.6	24.3	- 0.3
2010 – 2060		27.2	+ 2.6		26.2	+ 1.6
2061 - 2099		27.7	+ 3.1		26.7	+ 2.1
2011 - 1099		26.8	+2.2		26.6	+ 2.0
Rainfall Amount (mm/day)	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**	**Observed (mm/day)**	**Modeled (mm/day)**	**Anomaly % of the Observed**
1961 - 2010	0.33	0.2	- 12	0.33	0.3	-9
2010 – 2060		0.15	- 54		0.23	- 31
2061 - 2099		0.08	- 76		0.18	- 44
2011 - 1099		0.12	- 64		0.19	-52

Annex C) Detailed results of the impact of the rainfall change on the groundwater recharge change based on Approach I of the regression analysis

Table C1: Rainfall station AL0019

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	-15%	-11%	-14%	-40%	No recharge	-86%	-18%	-13%	-10%
S2	-26%	-22%	-25%	-53%	No recharge	-100%	-31%	-25%	-20%
S3	-36%	-34%	-36%	-67%	No recharge	-100%	-43%	-36%	-31%
S4	6%	11%	9%	-13%	No recharge	-52%	7%	9%	10%
S5	17%	22%	20%	1%	No recharge	-35%	20%	20%	20%
S6	27%	34%	32%	14%	No recharge	-17%	33%	31%	31%

Table C2: Rainfall station AL0035

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	-11%	-11%	-13%	-53%	No recharge	-70%	-19%	-15%	-9%
S2	-22%	-22%	-24%	-66%	No recharge	-84%	-30%	-26%	-19%
S3	-33%	-33%	-35%	-79%	No recharge	-99%	-42%	-36%	-30%
S4	11%	11%	8%	-27%	No recharge	-41%	3%	6%	12%
S5	22%	22%	19%	-14%	No recharge	-26%	14%	16%	22%
S6	33%	33%	30%	-1%	No recharge	-12%	26%	27%	32%

Table C3) Rainfall station AL0036

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	-11%	-11%	-13%	-46%	No recharge	-100%	-18%	-13%	-10%
S2	-22%	-22%	-24%	-60%	No recharge	-100%	-30%	-24%	-20%
S3	-33%	-33%	-35%	-73%	No recharge	-100%	-42%	-35%	-31%
S4	11%	11%	9%	-19%	No recharge	-73%	7%	9%	10%
S5	22%	22%	20%	-6%	No recharge	-56%	19%	20%	20%
S6	33%	33%	31%	8%	No recharge	-39%	31%	31%	31%

Table C5: Rainfall station AL0047

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	0%	0%	0%	0%	0%
S1	-10%	-11%	-11%	-38%	-100%	-60%	-16%	-13%	-10%
S2	-21%	-21%	-21%	-47%	-100%	-71%	-26%	-23%	-20%
S3	-31%	-32%	-32%	-56%	-100%	-81%	-37%	-34%	-30%
S4	10%	11%	11%	-19%	-100%	-40%	5%	8%	10%
S5	21%	21%	21%	-10%	-100%	-29%	16%	18%	20%
S6	31%	32%	32%	-1%	-100%	-19%	26%	29%	30%

Table C6: Rainfall station AL0054

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	0%	0%	0%	0%	0%
S1	-14%	-19%	-19%	-68%	-100%	-100%	-31%	-22%	-12%
S2	-25%	-29%	-30%	-80%	-100%	-100%	-42%	-33%	-22%
S3	-36%	-40%	-41%	-92%	-100%	-100%	-53%	-44%	-32%
S4	8%	2%	3%	-44%	-100%	-92%	-9%	-1%	8%
S5	19%	13%	14%	-32%	-100%	-83%	2%	10%	18%
S6	30%	24%	25%	-20%	-100%	-74%	13%	20%	29%

Table C7: Rainfall station AL0055

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	-11%	-12%	-12%	-78%	No recharge	-90%	-32%	-12%	-10%
S2	-23%	-23%	-25%	-93%	No recharge	-100%	-43%	-24%	-21%
S3	-34%	-35%	-37%	-100%	No recharge	-100%	-53%	-36%	-31%
S4	11%	12%	12%	-48%	No recharge	-70%	-11%	12%	10%
S5	23%	23%	25%	-33%	No recharge	-60%	0%	24%	21%
S6	34%	35%	37%	-18%	No recharge	-50%	11%	36%	31%

Table C8: Rainfall station AL0057

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	0%	0%	0%	0%	0%
S1	-16%	-16%	-22%	-36%	-83%	-41%	-16%	-16%	-10%
S2	-25%	-25%	-31%	-44%	-87%	-49%	-26%	-26%	-20%
S3	-35%	-35%	-40%	-52%	-91%	-56%	-36%	-35%	-30%
S4	3%	3%	-4%	-20%	-74%	-25%	3%	3%	10%
S5	12%	12%	5%	-12%	-70%	-18%	12%	12%	20%
S6	22%	22%	13%	-4%	-65%	-10%	22%	22%	30%

Table C9: Rainfall station AL0059

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	1%	10%	-1%	-81%	No recharge	-84%	-27%	7%	3%
S2	-12%	-4%	-15%	-93%	No recharge	-100%	-39%	-8%	-9%
S3	-25%	-19%	-29%	-100%	No recharge	-100%	-50%	-22%	-21%
S4	27%	39%	27%	-59%	No recharge	-53%	-5%	35%	27%
S5	40%	53%	41%	-48%	No recharge	-37%	7%	50%	38%
S6	53%	68%	55%	-37%	No recharge	-21%	18%	64%	50%

Annex D) Results of the impact of the rainfall change on the groundwater recharge change based on Approach II of the regression analysis

Table D1: Rainfall station AL0019

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	-16%	-19%	-37%	-25%	No recharge	-47%	-24%	-16%	-18%
S2	-32%	-36%	-63%	-53%	No recharge	-73%	-44%	-31%	-35%
S3	-48%	-52%	-83%	-86%	No recharge	-90%	-61%	-46%	-51%
S4	15%	20%	38%	22%	No recharge	45%	25%	16%	18%
S5	29%	40%	82%	42%	No recharge	96%	52%	31%	36%
S6	42%	60%	127%	59%	No recharge	161%	77%	46%	55%

Table D2: Rainfall station AL0035

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	-15%	-19%	-23%	-19%	No recharge	-30%	-16%	-14%	-14%
S2	-29%	-35%	-44%	-43%	No recharge	-65%	-32%	-27%	-30%
S3	-44%	-50%	-63%	-69%	No recharge	-100%	-48%	-41%	-46%
S4	12%	12%	21%	22%	No recharge	31%	20%	14%	17%
S5	25%	27%	43%	39%	No recharge	84%	38%	26%	32%
S6	37%	42%	66%	58%	No recharge	179%	54%	38%	47%

Table D3: Rainfall station AL0036

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	No recharge	0%	0%	0%
S1	-18%	-18%	-22%	-26%	No recharge	No recharge	-22%	-15%	-18%
S2	-36%	-35%	-43%	-47%	No recharge	No recharge	-39%	-31%	-36%
S3	-54%	-51%	-61%	-70%	No recharge	No recharge	-55%	-46%	-52%
S4	18%	19%	22%	28%	No recharge	No recharge	24%	16%	19%
S5	36%	38%	44%	54%	No recharge	No recharge	50%	31%	38%
S6	55%	57%	65%	90%	No recharge	No recharge	75%	45%	57%

Table D5: Rainfall station AL0047

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	No recharge	0%	0%	0%
S1	-15%	-18%	-15%	-18%	No recharge	No recharge	-17%	-15%	-13%
S2	-30%	-35%	-31%	-30%	No recharge	No recharge	-33%	-30%	-29%
S3	-45%	-51%	-47%	-42%	No recharge	No recharge	-49%	-44%	-45%
S4	14%	18%	16%	23%	No recharge	No recharge	17%	14%	19%
S5	28%	36%	31%	47%	No recharge	No recharge	33%	28%	35%
S6	42%	52%	47%	79%	No recharge	No recharge	49%	41%	51%

Table D6: Rainfall station AL0054

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	-16%	-23%	-24%	-37%	No recharge	-100%	-25%	-25%	-21%
S2	-31%	-43%	-46%	-78%	No recharge	-100%	-47%	-47%	-40%
S3	-49%	-60%	-67%	-100%	No recharge	-100%	-66%	-64%	-58%
S4	16%	24%	25%	62%	No recharge	1330%	21%	22%	22%
S5	33%	50%	52%	124%	No recharge	2582%	43%	49%	45%
S6	51%	77%	82%	207%	No recharge	3761%	64%	75%	69%

Table D7: Rainfall station AL0055

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	-24%	-21%	-28%	-92%	No recharge	-100%	-20%	-18%	-22%
S2	-46%	-41%	-53%	-100%	No recharge	-100%	-39%	-36%	-42%
S3	-64%	-58%	-73%	-100%	No recharge	-100%	-59%	-53%	-60%
S4	25%	23%	35%	85%	No recharge	107%	24%	18%	23%
S5	48%	48%	78%	164%	No recharge	334%	49%	36%	47%
S6	71%	73%	123%	237%	No recharge	674%	78%	52%	71%

Table D8: Rainfall station AL0057

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	0%	No recharge	0%	0%	0%	0%
S1	-12%	-10%	-17%	-14%	No recharge	-25%	-12%	-10%	-11%
S2	-24%	-23%	-31%	-30%	No recharge	-49%	-24%	-22%	-23%
S3	-36%	-35%	-46%	-41%	No recharge	-64%	-36%	-34%	-36%
S4	10%	16%	11%	29%	No recharge	23%	12%	10%	13%
S5	20%	28%	23%	60%	No recharge	47%	24%	19%	24%
S6	29%	40%	35%	98%	No recharge	74%	36%	27%	34%

Table D9: Rainfall station AL0059

Scenario Name	Jan	Feb	March	April	May	Oct	Nov	Dec	total
Average	0%	0%	0%	No recharge	No recharge	0%	0%	0%	0%
S1	-28%	-20%	-17%	No recharge	No recharge	-16%	-16%	-29%	-22%
S2	-51%	-38%	-35%	No recharge	No recharge	-34%	-34%	-47%	-43%
S3	-67%	-54%	-56%	No recharge	No recharge	-54%	-54%	-59%	-59%
S4	29%	37%	20%	No recharge	No recharge	14%	41%	46%	37%
S5	63%	77%	49%	No recharge	No recharge	27%	104%	95%	76%
S6	103%	123%	87%	No recharge	No recharge	41%	164%	149%	121%