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# ASSESSING THE IMPACTS OF CLIMATE CHANGE ON WATER RESOURCES OF JORDAN

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### **Abstract**

Climate change in Jordan is real, in particular in relation to temperature increases and precipitation decreases. This will add additional stresses on the available limited and stressed water resource in Jordan. 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. This work aims at assessing the direct impacts of climate change on water availability Zarqa River Basin North Jordan.

Therefore, SWAT along with General Circulation Models (GCM) were used to assess the future impacts of climate change on water resources in the study area. Based on the analysis of different GCM GCM models, HadCM3 runs A2 and B2 were found to be the best fits the climate conditions of Jordan.

Using SWAT hydrological model, a decrease in the available monthly stream flow was noticed in the next 80 years in Jordan. The main rainy months in Jordan (Jan, Feb and Mar) will show a decrease in surface runoff amounts that reaches 40% as result of increasing temperature and decreasing precipitation.

The results revealed from this study indicate that the current water strategy plans that managed by Ministry of Water and Irrigation (MWI) should be revised to handle that additional stresses that resulted from the impacts of climate change.

## 1. Introduction

Climate change is expected to affect the quantity and quality of stressed water resources in Jordan. 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 as the third poorest country in the world in water availability, with a per capita availability of 125 m<sup>3</sup>/year. 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, 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. These

impacts should be taken into account in all 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. Impacts of climate change on water resources was the target of enormous research around the world. Reviews by the Intergovernmental Panel on Climate Change (IPCC, 2000), have reported that arid areas, semi-arid areas and those currently suffering a scarcity of water resources (e.g., Middle East and North Africa (MENA Region) and in particular Jordan) will be subject to even greater water deficits in the future, not only in terms of quantity, but also in terms of quality. (IPCC, 2013).

Abdulla et al (2009) reviewed the impacts of climate change risk management on hydrology of Wadi systems in the Arab Region. This study indicated that most of the Arab countries are facing aridity problems and water scarcity. The study indicated that the projected impacts of climate change will exacerbate this problem. The climate change is expected to primarily affect precipitation, temperature, evapotranspiration, and, thus, is likely to affect the occurrence and severity of droughts and flash floods.

According to the recent modeling studies, the Arab region will face any increase of 2 –

5.5°C in the surface temperature by the end of the twenty first century (Abdulla et al 2009).

Kusangaya et al (2013) reviewed the Impacts of climate change on water resources in southern Africa. The outcomes of this review include highlighting studies on detected climate changes particularly focusing on temperature and rainfall, the impacts of climate change are highlighted, and respective studies on hydrological responses to climate change are examined.

Nkomozezi and Chung (2014) studied the effects of climate change on the water resources of the Geumho River Basin, Republic of Korea. Results revealed from this study indicate that climate change will most likely lead to lower water resource levels than are currently present in the Geumho River Basin.

Candela et. al., (2012), assessed the impacts of climate change on water resources in ungauged and data-scarce watersheds. Application to the Siurana catchment (NE Spain). Simulations results from this study show that the projected climate change at the catchment will affect the entire hydrological system with a maximum of 56% reduction of water resources. Furthermore, the most important parameters conditioning future water resources are changes in climatic parameters, but they are highly dependent on soil moisture conditions.

In Jordan, several projects and research were implemented for the same purpose. The First National Communication Report to

the United Nations Framework Convention on Climate Change (UNFCCC) under the theme of “Vulnerability and Adaptation to Climate Change” was published in 1997 (MOEnv 1999). In this report, the generated GCMs and incremental climate change scenarios were applied on the Zarqa River basin to investigate the possible impacts of the climate change on the water budget of the basin. The results revealed that the surface runoff decreases as temperature increases, and the timing of the peak flow is not changed but the magnitude of these peaks are reduced.

The Second National Communication Report to the United Nations Framework Convention on Climate Change (UNFCCC) was published in 2009 (MOEnv 2007). This report has outlined the analysis of potential impacts of climate change on hydrological systems and water resources using the WEAP hydrological model. The analyses showed that, in general, across several possible future climate scenarios, stream flow rates would be strongly affected, dropping by about 30% within the next 50 years, when assuming a 20% reduction in precipitation and 2°C rise in temperature. By 2050 a 20% decreases in the flow rate would be expected in the rainy months of January and February in Yarmouk River Basin.

Abdulla et. al., (2009) implemented a study to assess the Impact of Potential Climate Change on the Water Balance of a Semi-arid Watershed using BASINS-HSPF model. The study shows that climate warming can dramatically impact runoffs and

groundwater recharge in the ZRW. However the impact of warming can be greatly influenced by significant changes in rainfall volume.

Al Qinna et. al., (2011), analyzed drought conditions in Jordan under current and future climates. In this work, detailed analyses of both meteorological and vegetative droughts over the period from 1970 to 2005 were presented. Standardized Precipitation Index (SPI) and Normalized Difference Vegetation Index (NDVI) have been used to quantify drought according to severity, magnitude and spatial distribution at Jordan. Results suggest that the country faced during the past 35 years frequent non-uniform drought periods in an irregular repetitive manner. Drought severity, magnitudes and life span increased with time from normal to extreme levels especially at last decade reaching magnitudes of more than 4.

The current study aims at assessing the impacts of climate change through formulating a set of alternative scenarios representing potential conditions in the basin, and assess based on physically based model of the Zarqa River Basin (ZRB). The model was developed using the USDA-ARS Soil and Water Assessment Tool (SWAT). The SWAT mode has been used extensively in research and operation.

Jha et. al., (2006) used SWAT to assess climate change sensitivity on upper Mississippi river basin stream flows. Based on this study, the climate change scenarios

reveal a large degree of uncertainty in current climate change forecasts for the region. The results also indicate that the simulated future hydrology is very sensitive to current forecasted future climate changes.

Lubini and Adamowski (2013), Assessed the Potential Impacts of Four Climate Change Scenarios on the Discharge of the Simiyu River, Tanzania Using the SWAT Model. In this study, The SWAT predictions provide an important insight into the magnitude of stream flow changes that might occur in the Simiyu River in Tanzania as a result of future climatic change.

## 2. Study Area

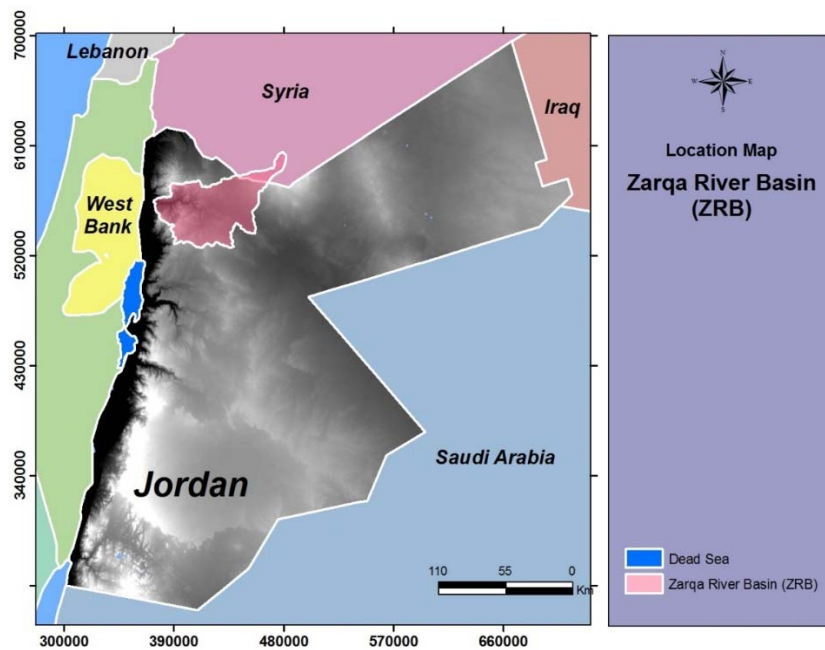
Zarqa River Basin (ZRB) is characterized by a Mediterranean climate with hot, dry summers and moderately cool, wet winters (Figure 1). The river basin drains an area of about 4120 square kilometers where about 95% of its area is within Jordan and only 5% is in Syria. The basin extends from the Syrian city of Salkhad in Jebal al-Arab with an elevation of 1460 m to south of Amman and then westward to discharges its water at its confluence with River Jordan at an elevation of -350 m.

About 2.72 million people (2004) are living in the basin representing about 50% of the total population in Jordan. The main populated centers are the cities of Amman, Zarqa, Jareh and Russaifeh.

The basin represents a transitional area between the semi-arid highlands in the west to the arid desert in the east. The annual rainfall depth ranges from more than 500 mm in the north western part to less than 100 mm in the eastern part with an average precipitation of 280 mm/year. The rain occurs mainly from November until March with occasional thunder storms on October and April. The stream flow of the Zarqa River is impounded by King Talal Dam at an elevation of 120 m and a capacity of 86 MCM. The area behind the river is about 3100 km<sup>2</sup> producing an average annual runoff of about 60 MCM.

The Zarqa River is the third largest river in Jordan in terms of its annual discharge and its waters are extensively used for municipal water supply, irrigation, and industrial needs.

The soil type in ZRB can be classified into four texture groups (Clay, Silty Clay, Silty Clay Loam and Silty Loam). Soil layer thickness ranges from 50-250cm. In certain parts of the basin, the soil thickness can be less than 50cm (JVA, 2010).



**Figure (1):** Location map of ZRB.

### 3. Methodology

The SWAT was used to model the ZRB and run alternative scenarios to assess the impacts of potential climate. 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. 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 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<sub>2</sub>O),
- $SW_o$**  : initial soil water content on day  $i$  (mm H<sub>2</sub>O),
- $t$**  : time (days),
- $R_{day}$**  : amount of precipitation on day  $i$  (mm H<sub>2</sub>O),
- $Q_{surf}$**  : amount of surface runoff on day  $i$  (mm H<sub>2</sub>O),
- $E_a$**  : amount of evapotranspiration on day  $i$  (mm H<sub>2</sub>O),
- $w_{seep}$**  : amount of water entering the vadose zone from the soil profile on day  $i$  (mm H<sub>2</sub>O),
- and
- $Q_{gw}$**  : amount of return flow on day  $i$  (mm H<sub>2</sub>O)

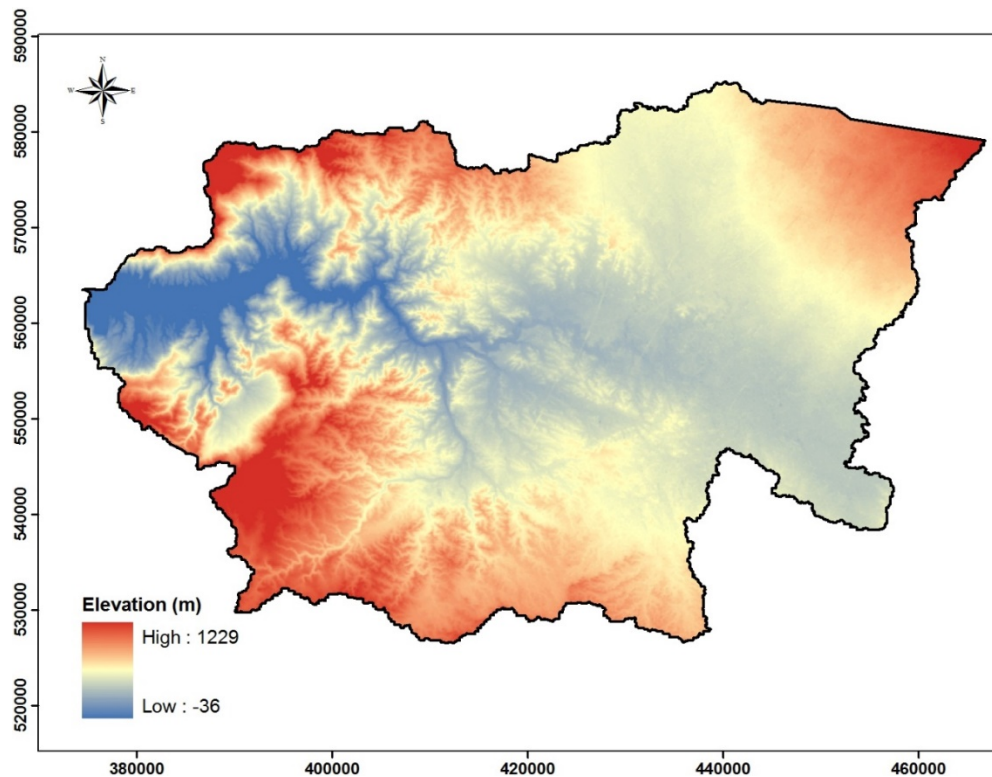
The potential pathways of water movement simulated by SWAT in the hydrologic response unit (HRU) are illustrated in Figure (2).



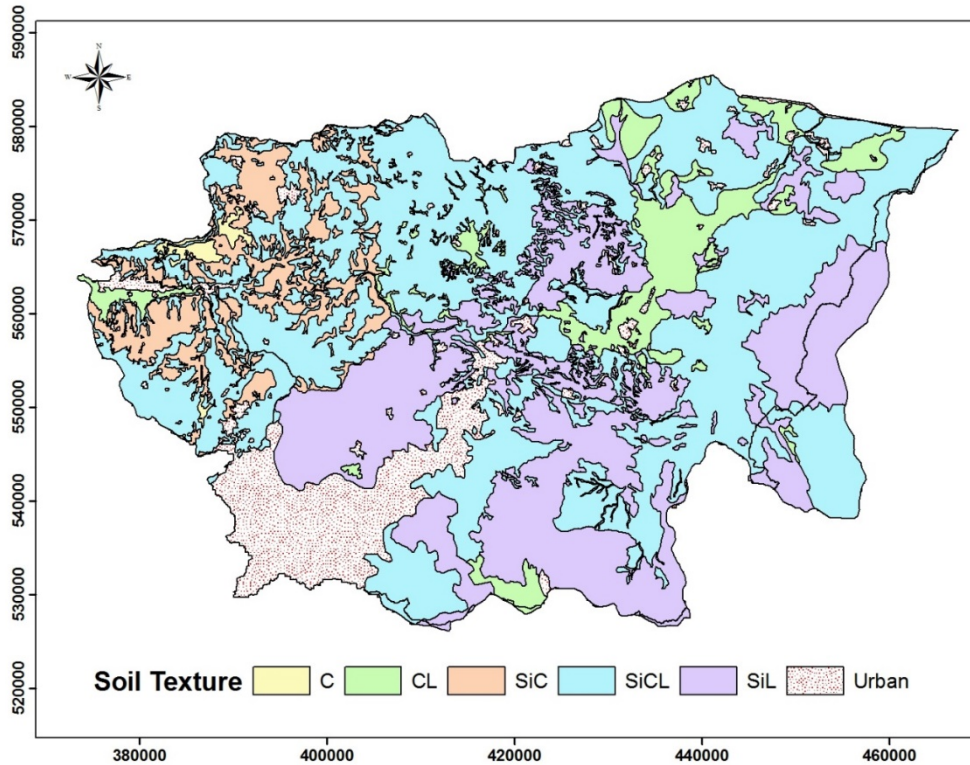




northeastern parts of the study area contain more than 90 % of agricultural activities and vegetation. Agricultural land, forest land and pasture land are concentrating in the western part of Zarqa basin. Urban land presents in the southwestern part of Zarqa basin (the north part of Amman city and Zarqa city). Barren land presents in the eastern part of Zarqa basin. In general 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). 4) Slope information were extracted using DEM and ArcMAP Spatial Analyst Extension™, the generated slope map appears in Figure (8). 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. 5)



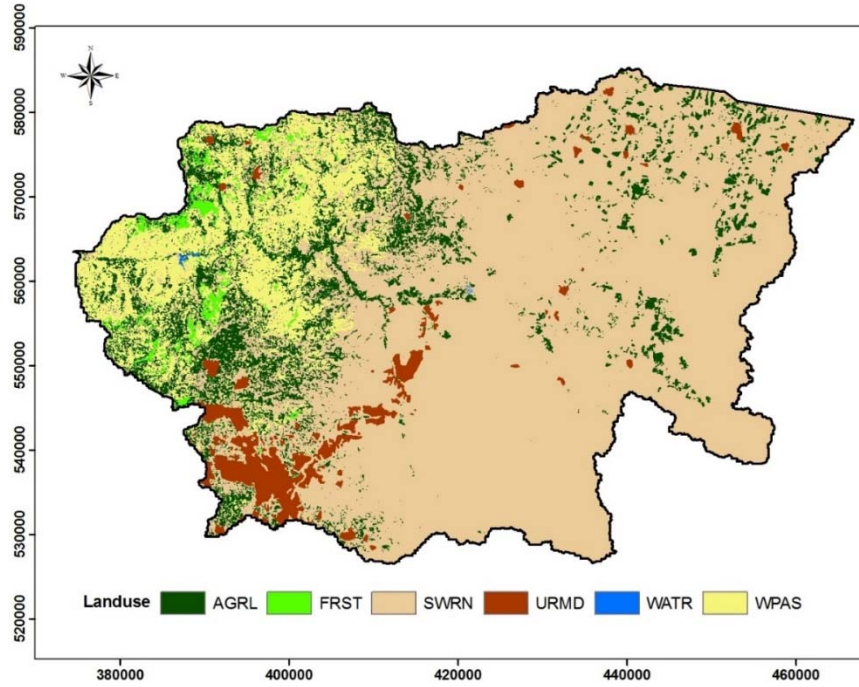
**Figure (3):** SRTM Digital Elevation Model (DEM) with 30m Resolution



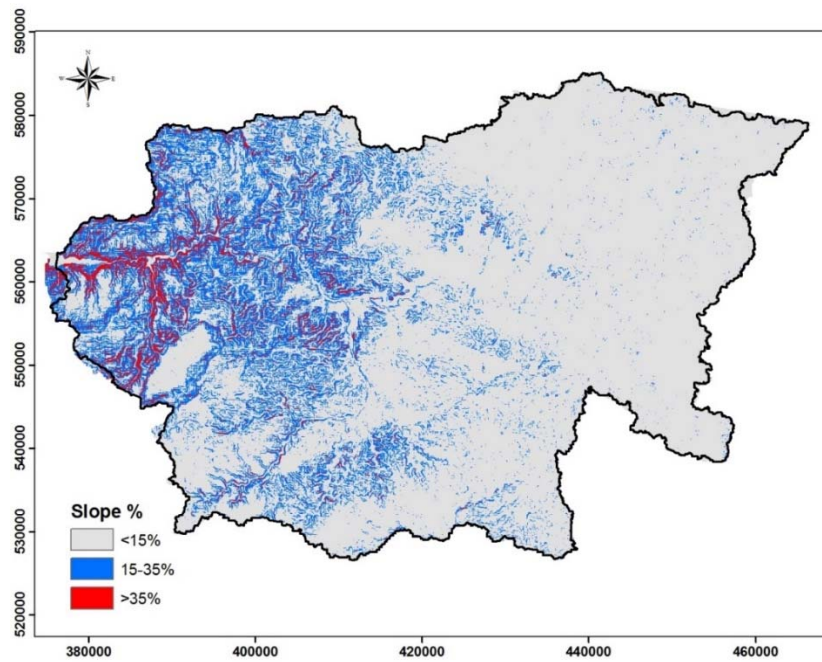
**Figure (4):** Spatial Distribution of Soil Texture Classes at ZRB.

**Table (3).** 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 (5):** Spatial Distribution of Land uses Classes at ZRB.



**Figure (6):** Spatial Distribution of Slope % at ZRB.

**Table (2):** Required datasets used by ArcSWAT

Data set	Resolution	Source
1 Digital Elevation Model	30m	The CGIAR Consortium for Spatial Information (CGAIR-CSI) website ( <a href="http://srtm.csi.cgiar.org/">http://srtm.csi.cgiar.org/</a> ).
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

### 3.2. Model Calibration, Validation and Sensitivity Analysis

Using ArcSWAT tools, the necessary input files to SWAT model were prepared.

The model was calibrated using downstream gage data using 30 years stream flow record extending from year 1970 until year 2000. The model was also validated using 9 years independent record that extending from year 2001 until 2009. Normal, wet and dry conditions were reflected in the calibration period, and it was performed using ArcSWAT automated calibration utility. The used objective functions was to minimize the sum squares of differences between observed and simulated flows.

The calibration process was performed by selecting the most optimal values for SWAT parameters (Table 4).

To identify the most critical SWAT model parameters, a sensitivity analyses was performed using Sensitivity Analysis Index  $S_i$  (Lenhart et. Al. 2002).  $S_i$  is given by

$$S_i = \frac{y_2 - y_1}{2\Delta x} \cdot \frac{x_0}{y_0}$$

Where

$y$ : is the SWAT model output,

$x$  is the model parameter,

$x_0$  is the optimal  $x$  value obtained through the through calibration, and

$y_0$  is the corresponding model output.

$y_1$  is the model output obtained by increasing  $x_0$  by  $\Delta x$ .

**Table (4):** Parameters used in SWAT model Calibration for ZRB.

Name	Definition	Estimated value	Calibrated value	Units	Possible range	
					Min	Max
<b>CN2</b>	Curve number	80.1	82.6	None	0	100
<b>SOIL_ALB</b>	Moist soil albedo	0.21	0.81	None	0	1
<b>EPCO</b>	Plant uptake compensation factor	0.41	0.95	inches	0	1
<b>ESCO</b>	Soil evaporation compensation factor	0.099	0.1200	inches	0	1
<b>SOIL_K</b>	Saturated hydraulic conductivity	0.9100	0.9100	mm/hr	0	2000
<b>CANMX</b>	Maximum canopy storage (mm H <sub>2</sub> O).	0.186	0.27	mm	0	2.5
<b>REVAPMN</b>	Threshold depth of water in the shallow aquifer	0.13	0.65	mm	-1	1

### 3.3. Base line scenario

ArcSWAT was used as described earlier to build up the hydrological model for ZRB. The model was simulated from the period of 1/1/1970 to 31/12/2009. However, and 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 (5) shows the sensitive parameters used in the calibration process.

### 3.4. Future climate change scenarios.

The assessment of future potential climate change impacts requires projecting future climatic data. This could be established through proposing different climate scenarios representing alternative combination of daily temperature and daily rainfall.

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.

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).

In this study, different GCM outputs were carefully analyzed to find out those that matches the climate of Jordan. Records from the selected GCM models were used to assess the potential impacts of climate change by integrating these data with the calibrated SWAT model.

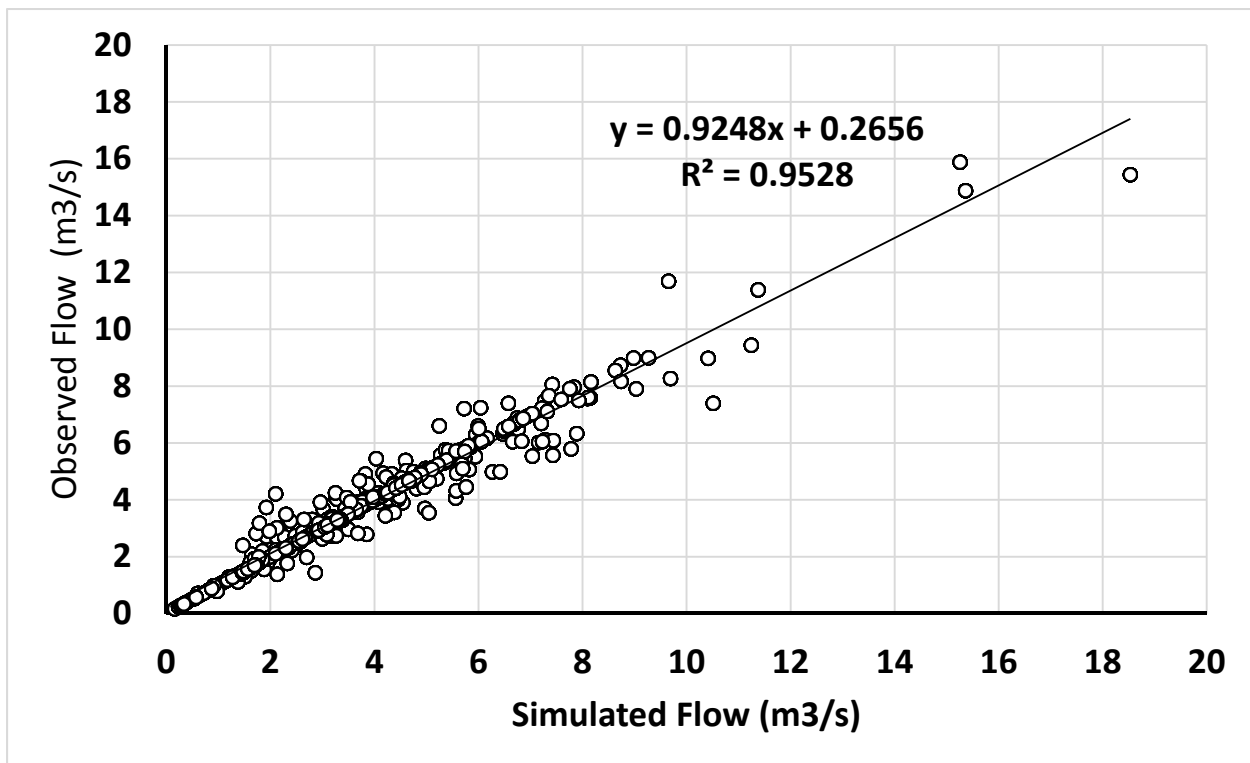
In this study, the A2 and B2 families of scenarios HadCM3 GCM model were selected to generate future projections of climate change scenarios. Data from these two experiments were downscaled using Statistical Downscaling Model (SDSM) version 4.2 developed by Wilby et al (2002) to generate site-scale or 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.

The outputs from downscaling analyses were used to build future simulation model using SWAT to assess the impact of future climate changes on water availability at ZRB. Two type series of HadCM3 (A2 and B2) were used in this study. Figure (15) shows the simulation mean annual results for the types of GCM data.

#### **4. Results and Discussion**

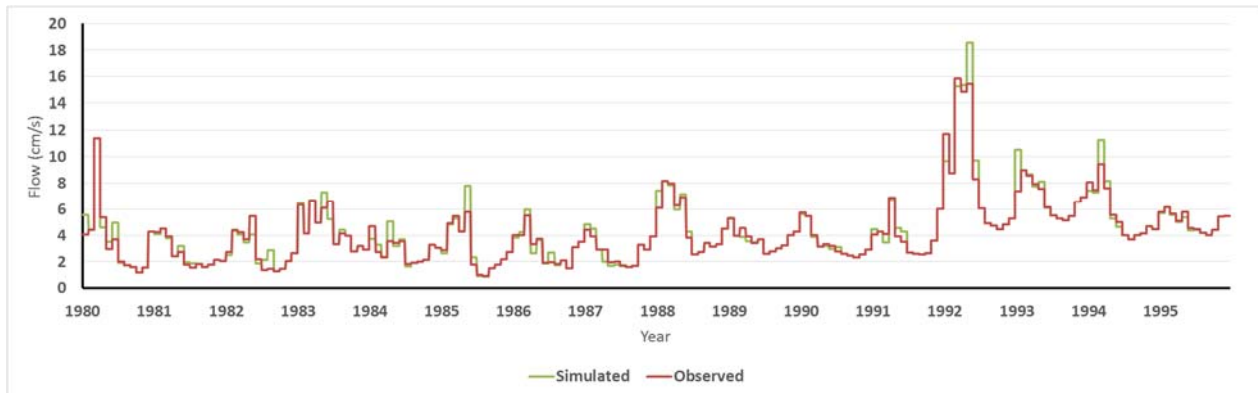
SWAT model was used in this study to estimate surface runoff amounts for the study area. ArcSWAT tools was used to prepare different SWAT input files. Results obtained from SWAT simulations were automatically calibrated using measured runoff values. This resulted in a good correlations between observed and estimated runoff values. Figure (7) shows how close the estimated runoff values as compared to observed values. As seen from this figure, the correlation coefficient is about 0.95. A comparison between observed and simulated monthly values appears in Figure (8). As revealed from this figure, the model in some years overestimated the monthly stream flow values, as in years 1985, 1993, and 1994 for example. In another years, the model

underestimate these values as for example for the year 1988. A comparison for the yearly stream values are shown in Figure (9).

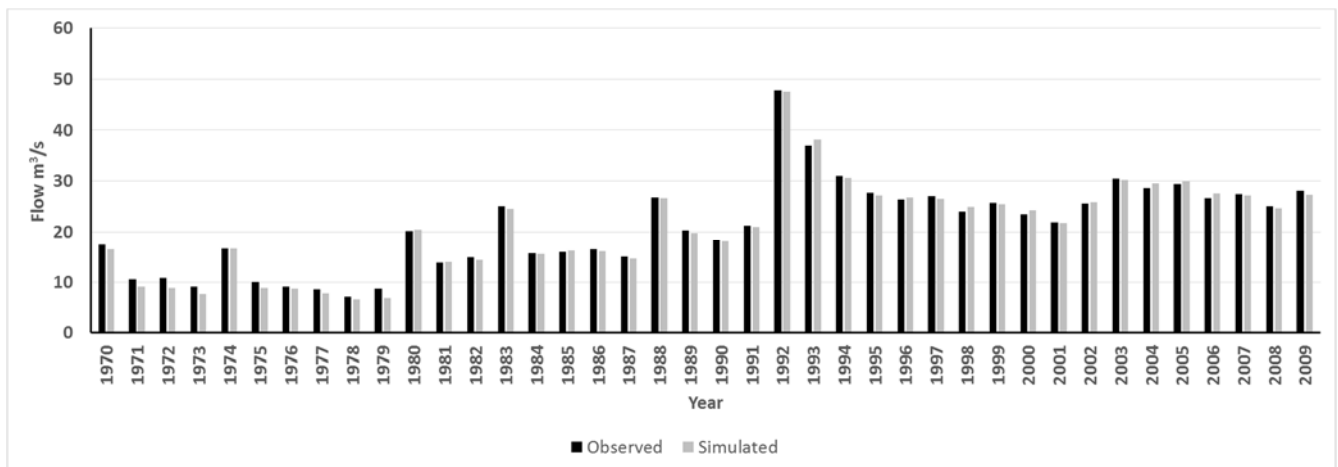


**Figure (7):** Scatter plot for the relationship between observed and simulated mean flow in  $\text{m}^3/\text{s}$





**Figure (8):** Comparing calibrated monthly mean flow (m<sup>3</sup>/s) against observed.

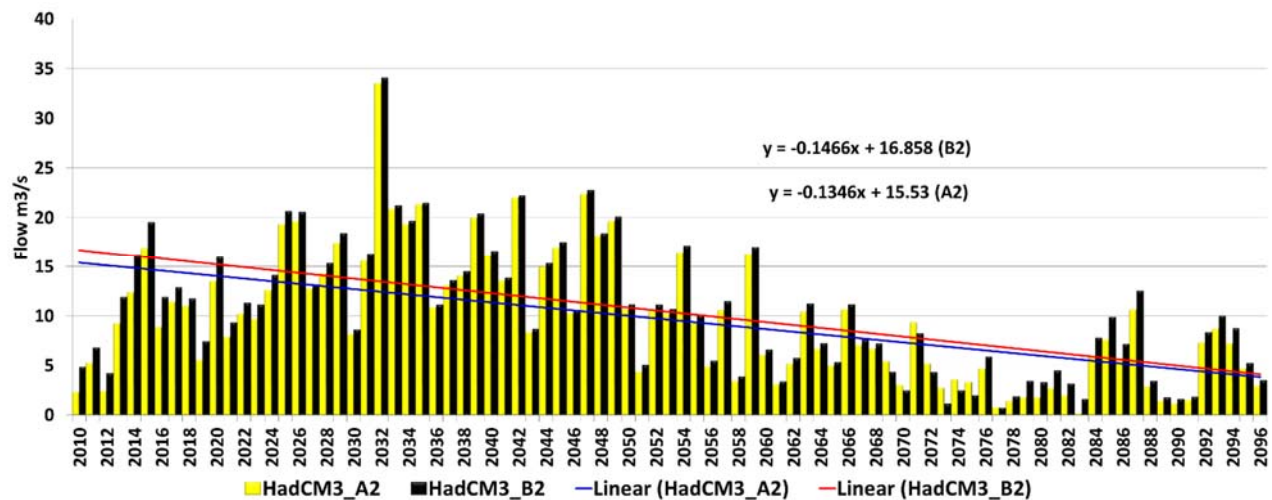


**Figure (9):** Comparing calibrated yearly mean flow (m<sup>3</sup>/s) against observed.

The impacts of climate change were assessed with the aid of GCM models. Before setting up the future climate models, it was necessary to analysis the different available climate models to find those that matches the climate of Jordan. About 19 different GCM models were analyzed with A2 and B2 runs. Based on these analyses, it was found the model HadCM3 which generated by Hadley Centre for Climate Prediction and Research was the most appropriate model for the study area.

Climatic data from HadCM3 was plugged into SWAT to assess potential future climate change impacts on water resources of the study area. The results from running the two GCM climate scenarios through the calibrated SWAT models are presented in Figure (10).

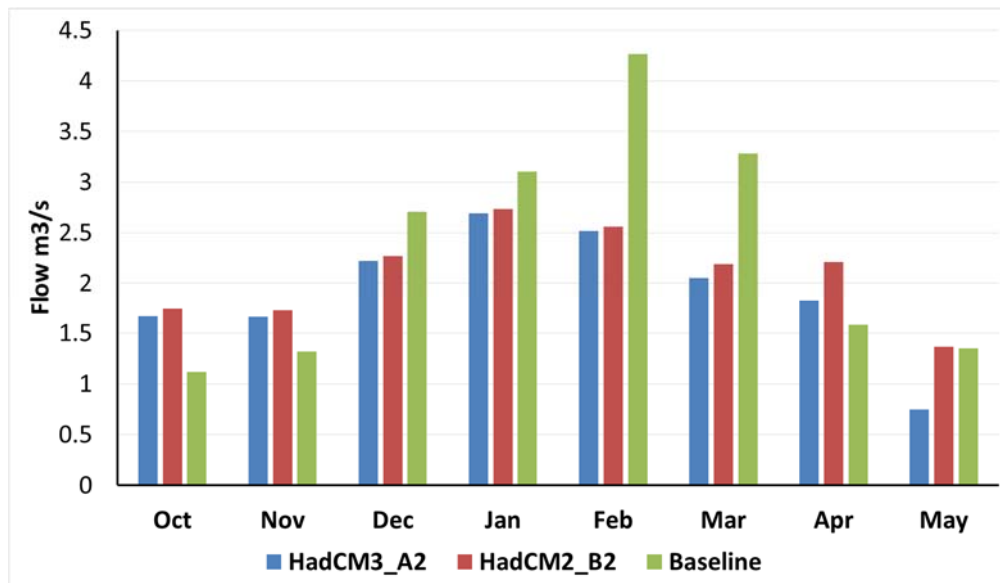
As this figure indicates, and based on A2 and B2 experiments, the amount of stream flow values are expected to decrease by year 2096.



**Figure (10):** Simulated mean annual surface runoff amounts from 2011 – 2096

In this study, the impacts of climate change on water resources in ZRB was assessed using SWAT model and GIS. The baseline scenario, which describes the current conditions in the basin, was successfully calibrated using observed data from a downstream gage station. The calibrated model was then used to build future scenarios for the Basin. GCM models were used to help in building the future meteorological record of the basin. The simulation was run for the period from 2011 until 2096 as shown in figure (10). By referring to this figure, the following can be inferred; Both experiments (A2, B2) predict that the amounts of surface runoff are going to be decreased within the next 90 years. This decrease will be highly noticed after the year 2050. The two experiments show similar behavior about the future amounts of surface runoff. The maximum amount of surface runoff would be received in 2032 based on the two experiments. The maximum peak flow will drop from about 50 m<sup>3</sup>/s recorded in the baseline scenario to less than 35 m<sup>3</sup>/s in the future scenarios. 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 (11) shows the future predicted change in monthly stream flow values in percent according to HadCM3 GCM model experiments A2 and B2. By referring to these two figures the following can be noticed; 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 to 50% especially in February. On the other hand, an increase in the surface runoff amounts will be noticed on other months where 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 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 (11):** Long term monthly mean values from future climate modes (HadCM3 A2, B2) as compared with Baseline Scenario.

## 5. Conclusions

Jordan is a country with limited water resources. As a result of population increase, the gap is always widening between demand and supply. The situation is expected to become worst as a result of the expected impacts that may result from climate change. Therefore, this study aims

at assessing the impacts of climate change on water resources in Amman – Zerqa Basin, North Jordan using SWAT model.

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 4oc. 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.

### **Acknowledgments**

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