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Assessment of Climate Change Impacts of Water Resources in Jordan

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Abstract

Jordan is ranked among the poorest countries in the world in water availability. Resources are already seriously limited and are far below under the water poverty line of (1000) m^3 per capita per year. On a per capita basis, available water from existing renewable sources is projected to fall from (150) m^3/capita/year in year (2003) to (90) m^3/capita/year by the year (2025).Climate change(CC) is expected to increase the water scarcity which will reduce the per capita water share for Jordanians.To study potential impacts of climate change on hydrological system and water resources, two river basins have been selected in the territory of Jordan: the Amman- Zarqa River (3567km^2) and the Yarmouk River (1384 km^2). To simulate potential changes in runoff the WEAP hydrological model has been applied three selected global circulation models (GCM) (HADGEM1, CSIROMK3 and ECHAM5OM) scenarios. It was found from the simulation for base scenario and GCM scenario that the available amounts of surface runoff resulted from precipitation will be highly affected by climate change. As set of mitigation measures and adaption projects are suggested to reduce the impacts of climate change on water resources.

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1. Introduction

There is now considerable evidence of a discernible anthropogenic influence on global climate (IPCC, 2001) associated with greenhouse gas (GHG) emissions. Furthermore, it is highly likely that GHG emissions will increase over the coming decades, and that the human impact on climate is likely to continue. Nevertheless, climate change is projected to cause significant changes in the spatial and temporal distribution of precipitation. This can be expected to cause a wide range of health effects, particularly in communities either within or at the edge of deserts, where water is scarce, highly polluted or salinated, and there are competing demands from household consumption, agriculture and other industrial sectors.

The Intergovernmental Panel on Climate Change (IPCC) reports that by the 2020s approximately 0.5 billion people could see increased water resources stress as a result of climate change (James J. McCarthy ,2001) and (IPCC, 2001). The quality and quantity of water supply have direct effects on two of the largest causes of global ill health - poor water and sanitation, and malnutrition. However, the fact that precipitation changes are more uncertain to predict than changes in temperature and the multiple influences on water supply (including strategies for managing ecosystems to maintain resources) means that the issue has been under-represented in the formulation of health adaptation policy. A more flexible, qualitative, stakeholder driven approach would help to develop an integrated policy to balance competing demands on water supplies. Such an approach would be equally applicable to developing flexible responses to changing patterns of infectious diseases, such as shifting patterns of malaria transmission due to changing precipitation patterns at some

Desert fringes (Shiklomanov, I.A. and V. Yu. Georgiyevsky, (2001).

Jordan is one of the top water resources poorest countries. The area of Jordan is about 90,000 Km2 and it is located between latitude 29 and 33 degrees north and longitudes 35 to 39.5 degrees east. It lies within the semiarid climatic zone and has a typical Mediterranean short, rainy winter and long dry summer. Annual precipitation varies from less than 50 mm in the desert to more than 550 mm in the North West highlands (Figure 1). About 93.5% of Jordan's

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total area receives an average annual rainfall less than 200 mm, only 4% of its areas receive an annual rainfall greater than 300 mm and only 0.7% of Jordan's areas receive an annual rainfall more than 500 mm. The consequences of this situation lead to a large imbalance between supply and demand, continued depletion of valuable aquifers beyond the points of ever being replenished, un-equal water distribution by region, and a tendency to concentrate investments on the development of new water resources (supply management) while neglecting demand management and water saving strategies,Recently the rainy season in Jordan extends from late October to late April or early May; the peak is usually during December, January and February. The long-term average annual precipitation is 8,500 MCM of which an average of 92.2% is lost to evaporation. The high temperatures and low humidity in Jordan result in an extremely high evaporation rate. The long-term average evaporation rate is 92.2%; this ranges from 63% in the highlands to around 99% in the eastern desert (Table 1).

According to FAO report in the 3rd of June 1999, "Severe drought that cut rainfall in Jordan by up to 70 percent has left the country facing its worst cereal harvests in more than 40 years". An FAO/WFP Crop and Food Supply Assessment Mission that visited Jordan in April/May 1999 said that "the unprecedented drought could not have come at a worse time".

As these reports indicates, the limited resources of water not only suffering from increase demand, but also the impacts of climate changes. Climate variability is defined as the natural, often cyclic, and high frequency variation in climate. In contrast, climate change may be either natural or human-induced, and displays longer-term trends.

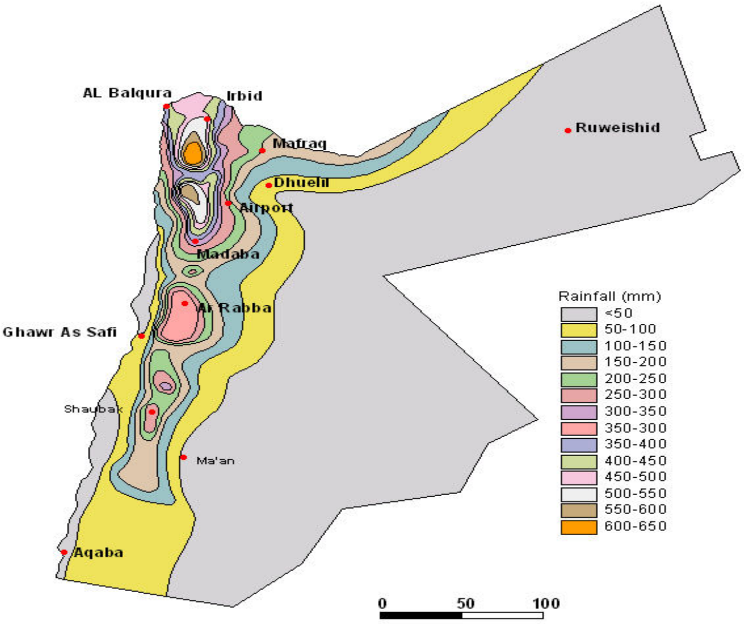


Figure (1): Long-term annual rainfall over Jordan from 1937-2000 (Hammouri and El-Naqa, 2007)

Table (1): Classification by Rainfall Distribution

Classified Zone	Annual Rainfall (mm/yr)	Catchment Area (km²)	Area Ratio %	Rainfall Volume (AD1937 – 2003) (MCM)
Semi-humid	>500	620	0.7	419
Semi-arid	300 – 500	2,950	3.3	1110
Marginal	200 – 300	2,030	2.2	528
Arid	100 – 200	20,050	22.3	2858
Desert	< 100	64,350	71.5	3417
Total		**90,000**	**100**	**8332**

2.Selected Sites

Two watershed were selected for the assessment of climate change impacts on water resources in Jordan, these are (Figure 2):

a) Amman-Zarqa River Basin

The Amman-Zarqa River Basin (AZRB) (Figure 2) is the second main tributary to River Jordan after Yarmouk River, 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 AZRB is located between 213 to 319 East and 140 to 220 North and covers an area of 3567 Km2 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 (2,720,000) from a total of 5.34 million people. It is also considered as one of the major productive ground water basins in Jordan. The natural wadis included in the study area are five major sub-catchments: Wadi Abdoun, Wadi Ain Ghazal, Wadi Al-Sukhnah, Wadi Rumeimin and Wadi Jerash.

b) Yarmouk River Basin

The area belongs to the Yarmouk River basin (YRB) (Figure 2) which has a drainage area of about 6790 km2 of which 1384 km2 lie within Jordan. The natural wadis included in the study area are four major sub-catchments: Wadi Hamra, Wadi Shallala, Wadi Al-Shomar and Wadi Abyad. The maximum elevation is 1150 m above mean sea level at Rass Munif and the minimum elevation is -200 m below mean sea level at the Jordan Valley and at the end of the catchment.

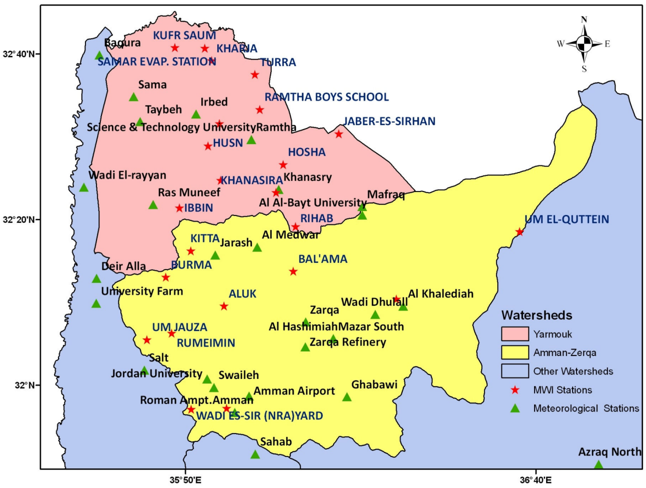


Figure (2): Location map of Zarqa and Yarmouk catchment areas

3.Objectives

The main objectives of the current study are:

- To evaluate the hydrological characteristics of Amman-Zarqa and Yarmouk basins.
- To investigate the impact of climate change on water resources of two major river basins in Jordan namely (Amman-Zarqa and Yarmouk).
- Identification of possible adaptation measures (Policies, Strategies, Action Plans and Sustainable Water Resources Environment) in response to potential climate change

4.Methodology

The general methodology followed in this study appears in figure (3) and it can be divided into the following stages:

a) Data collection

All previous data concerning this work were collected. Hydrology, influencing meteorological stations data including altitude and coordinates from previous years (1960 – 2006) were collected mainly from the different files at Ministry of Water and Irrigation / Jordan. No detailed specified studies with similar objectives have been carried out in Amman-Zarqa and Yarmouk catchments. Furthermore, data from global circulation models (GCMs) were evaluated and selected for the assessment of climate change impacts on water resources assuming that COx concentrations are going to be doubles within the next century.

b) Selecting Hydrological Model

In this study, WEAP model was deployed to estimate the surface runoff resulted form precipitation and used also for the assessment of climate change impacts on surface runoff. The hydrology module in WEAP is spatially continuous, with a study area configured as a contiguous set of sub-catchments that cover the entire extent of the river basin.

This continuous representation of the river basin is overlaid with a water management network topology of rivers, canals, reservoirs, demand centers, aquifers and other features (see Yates et al. 2005a and 2005b for details). Within each sub-catchment (SC), the entire area is fractionally subdivided into a unique set of independent land use/land cover classes that lack detail regarding their exact location within the SC, but which sum to 100% of the SC's area. A unique climate-forcing data set of precipitation, temperature, relative humidity, and wind speed is uniformly prescribed across each SC (Joyce, et. al., 2006).

c) Building up the climate change scenarios

The impacts of climates changes on water resources was assessed by using the outputs from GCM models. Thirteen GCM models were analyzed to determine those that match with Jordan's climate conditions. The matching was based on comparing the temperature values generated from these models and meteorological records obtained from the Department of Metrology. Based on this analyses, the following three models were selected:

1. HADGEM1: HADley Center Global Climate Model, UK.
2. CSIROMK3: Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia.
3. ECHAM5OM: The 5th generation of the ECHAM general circulation model, Max Planck Institute for Meteorology, Germany.

c) Formulations of adaptation and mitigations for climate change

Based on the analyses and results obtained from previous step, a set of adaptation and mitigation procedures were suggested to decrease the impacts of climate change on water resources of the selected watersheds.

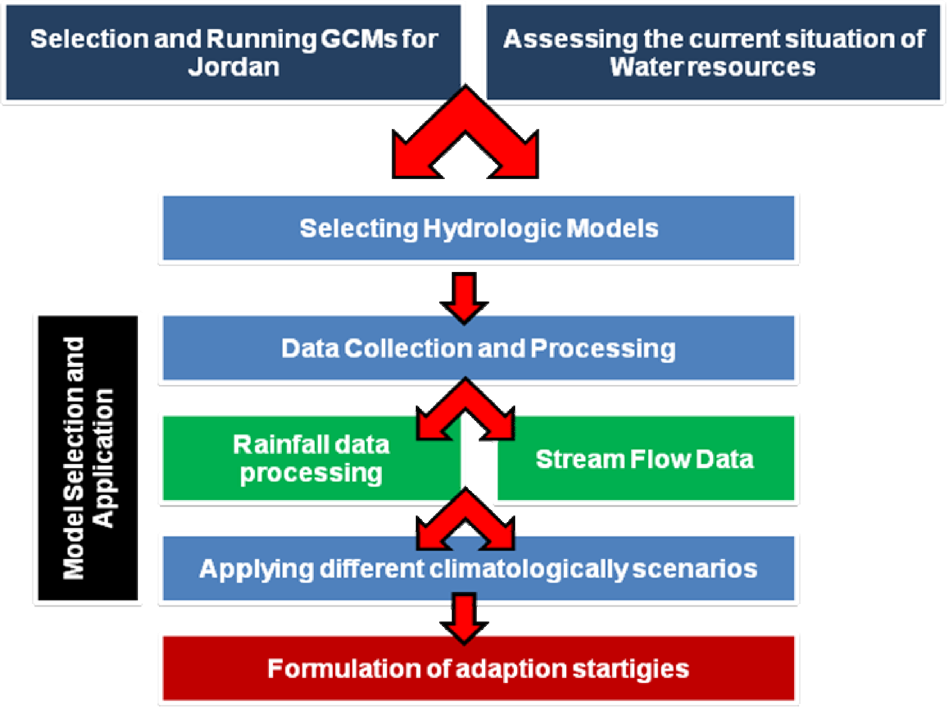


Figure (3): Methodology followed to conduct this study

5.Runoff estimation for base scenario

One of the powerful features of WEAP is its ability to manage and analyze scenarios. The current account of the water system under study is created first (Base Scenario). Then, based on a variety of economic, demographic, hydrological, and technological trends, a "reference" or "business-as-usual" scenario projection is established, referred to as a Reference Scenario. You can then develop one or more policy scenarios with alternative assumptions about future developments (WEAP User's Guide).

The scenarios can address a broad range of "what if" questions, such as: What would happen to the surface runoff if the temperature decreases and precipitation increase.In this regards, the selected GCM models were also implemented as a future scenario. In this case the question becomes: What would happen to the available surface runoff amounts under HADGEM1 GCM scenario.

The base scenario was implemented to take the years from 1970 to 2000 as a current account. The modeling requirements for the Rainfall Runoff Method FAO method are:

- Daily precipitation amounts (mm) (figure 4).
- Evaporation (mm) (figure 5).

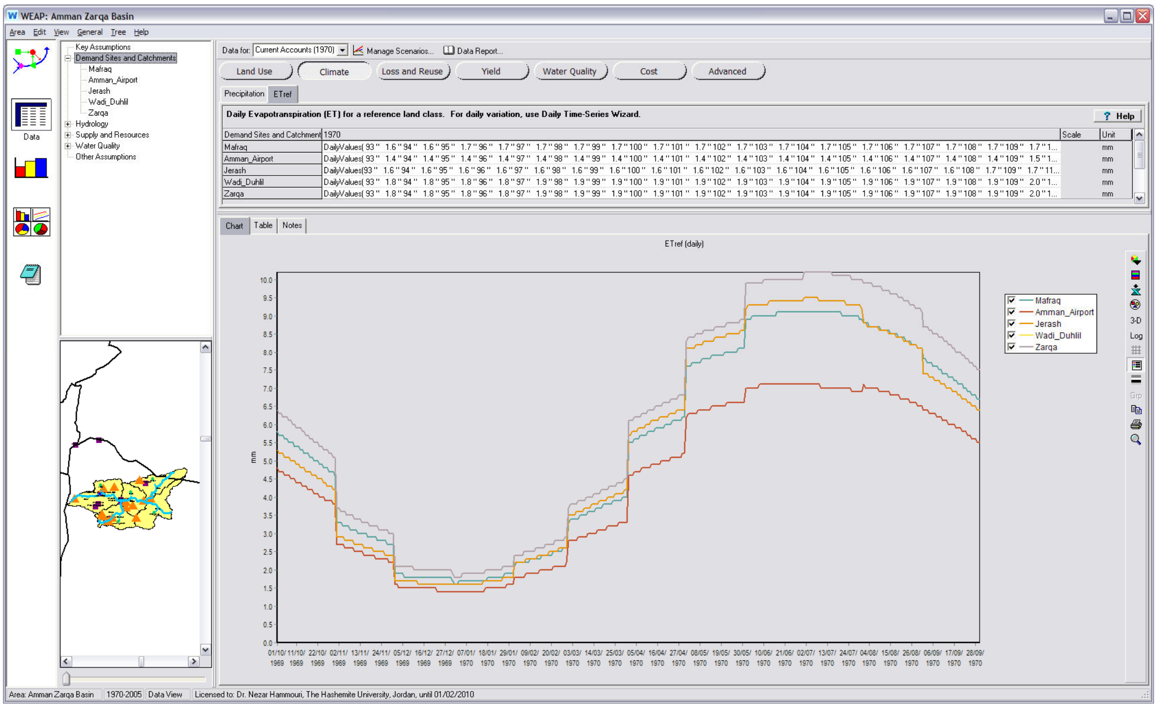
Data for: Current Accounts (1970) Manage Scenarios... Data Report...

Daily Precipitation. For daily variation, use Daily Time-Series Wizard.

Demand Sites and Catchment	1970	Scale	Unit	
Mafraq	DailyValues(93 " 1.4 " 94 " 0.6 " 95 " 1.7 " 96 " 1.8 " 97 " 1.6 " 98 " 0.3 " 99 " 0.7 " 100 " 0.6 " 101 " 1.2 " 102 " 1.1 " 103 " 0.9 " 104 " 0.8 " 105 " 0.8 " 106 " 1.3 " 107 " 2.0 " 108 " 1.0 " 109 " 1...		mm	/day
Amman_Airport	DailyValues(Oct 1" 0.5" Oct 2" 0.5" Oct 3" 0.1" Oct 4" 0" Oct 5" 0.1" Oct 6" 0" Oct 7" 0" Oct 8" 0" Oct 9" 0.3" Oct 10" 0" Oct 11" 0" Oct 12" 0" Oct 13" 0.2" Oct 14" 0.2" Oct 15" 0" Oct 16" 0.3" Oct 17" 1...		mm	/day
Jerash	DailyValues(Oct 1" 0.14" Oct 2" 0.09" Oct 3" 0" Oct 4" 0" Oct 5" 0.11" Oct 6" 0" Oct 7" 0" Oct 8" 0" Oct 9" 0.07" Oct 10" 0.01" Oct 11" 0.02" Oct 12" 0.02" Oct 13" 0.08" Oct 14" 1.11" Oct 15" 0.43" Oct ...		mm	/day
Wadi_Duhlil	DailyValues(Oct 1" 0.4" Oct 2" 0" Oct 3" 0" Oct 4" 0" Oct 5" 0.2" Oct 6" 0" Oct 7" 0" Oct 8" 0" Oct 9" 0.2" Oct 10" 0" Oct 11" 0" Oct 12" 0.1" Oct 13" 0.1" Oct 14" 0.2" Oct 15" 0" Oct 16" 0.4" Oct 17" 0.7...		mm	/day
Zarqa	DailyValues(93 " 0.98 " 94 " 0.98 " 95 " 0.98 " 96 " 0.98 " 97 " 0.98 " 98 " 0.98 " 99 " 0.98 " 100 " 0.98 " 101 " 0.98 " 102 " 0.98 " 103 " 0.98 " 104 " 0.98 " 105 " 0.98 " 106 " 0.98 " 107 " 0.98 " 10...		mm	/day

Area: Amman Zarqa Basin | 1970-2005 | Data View | Precipitation: Jerash, 21/03/ 1970 = 1.6 mm/day

Figure (4): Precipitation data as shown from WEAP interface



Data for: Current Accounts (1970) Manage Scenarios... Data Report...

Daily Evapotranspiration (ET) for a reference land class. For daily variation, use Daily Time-Series Wizard.

Demand Sites and Catchment	1970	Scale	Unit
Mafraq	DailyValues(93 " 1.6 " 94 " 1.6 " 95 " 1.7 " 96 " 1.7 " 97 " 1.7 " 98 " 1.7 " 99 " 1.7 " 100 " 1.7 " 101 " 1.7 " 102 " 1.7 " 103 " 1.7 " 104 " 1.7 " 105 " 1.7 " 106 " 1.7 " 107 " 1.7 " 108 " 1.7 " 109 " 1.7 " 1...		mm
Amman_Airport	DailyValues(93 " 1.4 " 94 " 1.4 " 95 " 1.4 " 96 " 1.4 " 97 " 1.4 " 98 " 1.4 " 99 " 1.4 " 100 " 1.4 " 101 " 1.4 " 102 " 1.4 " 103 " 1.4 " 104 " 1.4 " 105 " 1.4 " 106 " 1.4 " 107 " 1.4 " 108 " 1.4 " 109 " 1.5 " 1...		mm
Jerash	DailyValues(93 " 1.6 " 94 " 1.6 " 95 " 1.6 " 96 " 1.6 " 97 " 1.6 " 98 " 1.6 " 99 " 1.6 " 100 " 1.6 " 101 " 1.6 " 102 " 1.6 " 103 " 1.6 " 104 " 1.6 " 105 " 1.6 " 106 " 1.6 " 107 " 1.6 " 108 " 1.7 " 109 " 1.7 " 11...		mm
Wadi_Duhlil	DailyValues(93 " 1.8 " 94 " 1.8 " 95 " 1.8 " 96 " 1.8 " 97 " 1.9 " 98 " 1.9 " 99 " 1.9 " 100 " 1.9 " 101 " 1.9 " 102 " 1.9 " 103 " 1.9 " 104 " 1.9 " 105 " 1.9 " 106 " 1.9 " 107 " 1.9 " 108 " 1.9 " 109 " 2.0 " 1...		mm
Zarqa	DailyValues(93 " 1.8 " 94 " 1.8 " 95 " 1.8 " 96 " 1.8 " 97 " 1.9 " 98 " 1.9 " 99 " 1.9 " 100 " 1.9 " 101 " 1.9 " 102 " 1.9 " 103 " 1.9 " 104 " 1.9 " 105 " 1.9 " 106 " 1.9 " 107 " 1.9 " 108 " 1.9 " 109 " 2.0 " 1...		mm

Area: Amman Zarqa Basin | 1970-2005 | Data View | Licensed to: Dr. Nezar Hammouri, The Hashemite University, Jordan, until 01/02/2010

Figure (5): Evaporation data as shown from WEAP interface.

Figure (6) shows the simulation results for the different sub-catchments of Amman-Zarqa Basin, and table (2) shows the average monthly runoff (CMS).

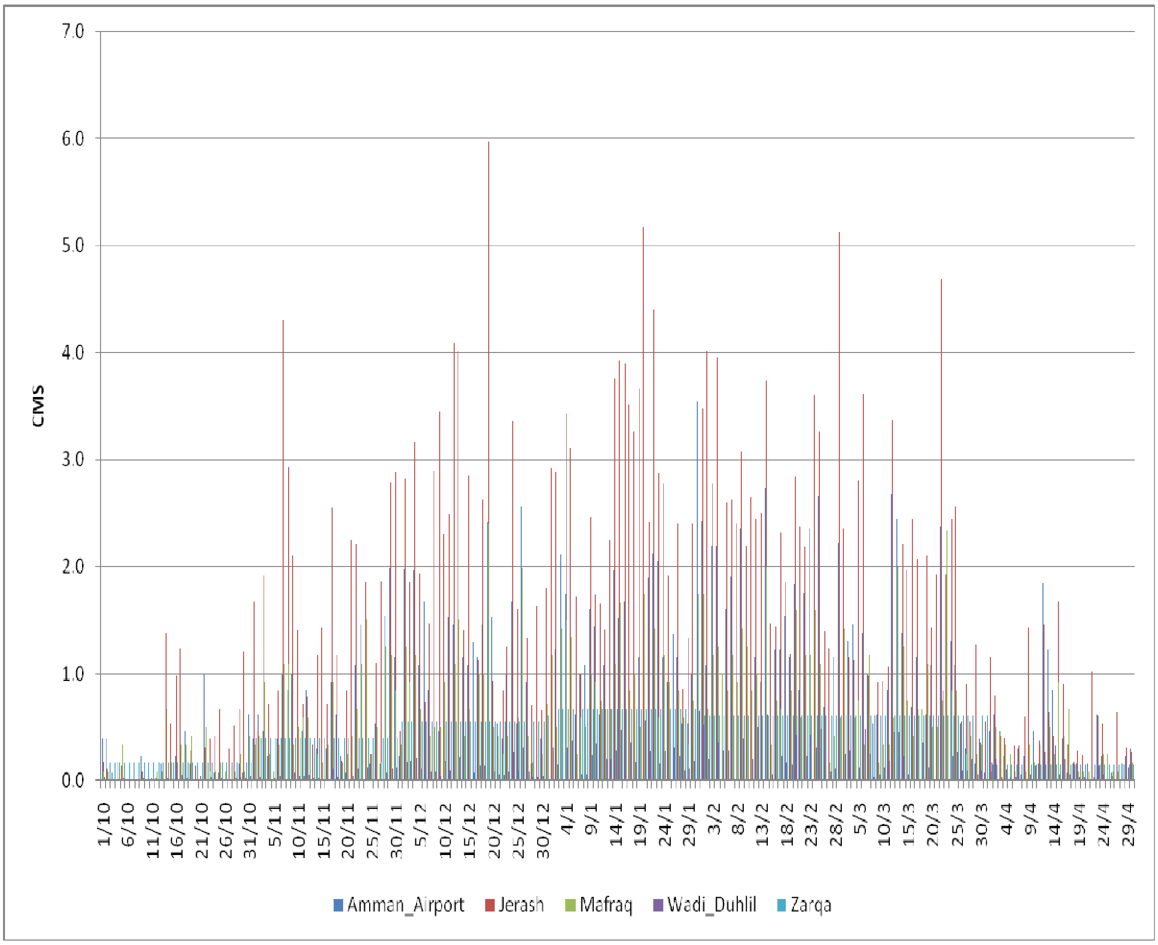


Figure (6): The base scenario simulation results for Amman Zarqa Basin

Month	Amman	Jerash	Mafraq	Wadi Duhlil	Zarqa	Total
Jan	1.52	2.82	0.96	0.25	0.66	**7.16**
Feb	1.59	2.54	0.96	0.28	0.61	**6.73**
Mar	1.06	1.87	0.74	0.24	0.61	**5.03**
Apr	0.35	0.58	0.23	0.08	0.14	**1.55**
May	0.06	0.10	0.05	0.02	0.00	**0.26**
Jun	0.00	0.00	0.00	0.00	0.00	**0.01**
Jul	0.00	0.00	0.00	0.00	0.00	**0.00**
Aug	0.00	0.00	0.00	0.00	0.00	**0.00**
Sep	0.00	0.01	0.01	0.00	0.00	**0.03**
Oct	0.19	0.34	0.15	0.01	0.16	**1.00**
Nov	0.64	1.58	0.56	0.05	0.39	**3.69**
Dec	1.20	2.11	0.79	0.12	0.55	**5.52**
Total	**6.61**	**11.95**	**4.44**	**1.07**	**3.14**	**30.97**

Table (2): Monthly average simulated runoff for Amman Zarqa sub-catchments (CMS).

6.Model calibration and Validation

Automatic calibration was done during the years from 1/1/1970 to 31/12/1990. The rest of date (from 1991-2000) were used for validation. Data available from Jerash Bridge gauging (AL0060) was used for this process. The main objective of this process was to insure that resulted obtained from modeling process are matching those measured vales. This is an essential process before considering the model for future prediction.

Figure (7) shows a comparison between simulated runoff values for Jerash sub-catchment and Jerash Bridge Gauging. Table (8) shows the Root Mean Square (RMS) calculated for the simulated runoff values. As this table shows, the RMS for the model used to simulate runoff values was about 0.2

The RMS error is a quantitative method to check the accuracy of the simulation. It has been calculated according to the following formula (Norman et. Al, 2004):

$$m_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n} \delta {x_i}^2}.$$

Where

m_x : RMS

δ_{xi} : Deference between observed and simulated values

n : No. of Observations

As can be seen from figure (7) and table (3), the results obtained from the model is fit well with the observation data from gage station. The WEAP model is suitable for monthly and daily time intervals. However, yearly time series are not supported by WEAP and the results appears here represents the average monthly or daily values over the base scenario interval

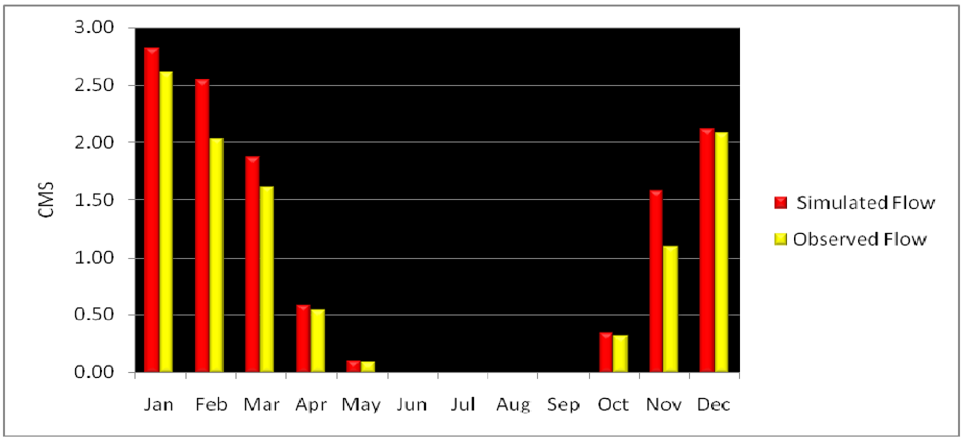
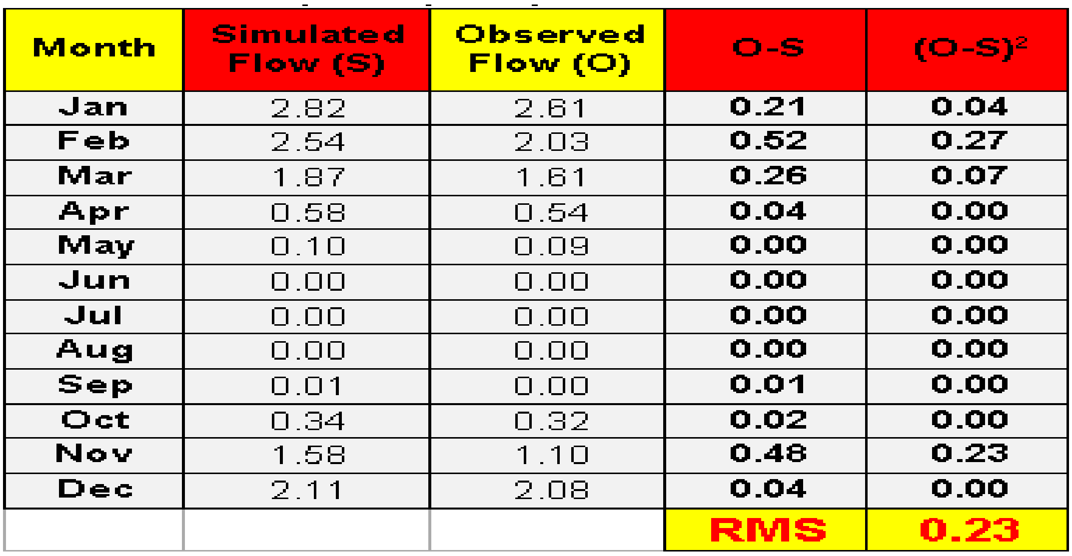


Figure (7): Simulate surface runoff values vs. observed stream flow values

Table(3): Root Mean Square (RMS) calculation for the model results



Month	Simulated Flow (S)	Observed Flow (O)	O-S	$(O-S)^2$
Jan	2.82	2.61	0.21	0.04
Feb	2.54	2.03	0.52	0.27
Mar	1.87	1.61	0.26	0.07
Apr	0.58	0.54	0.04	0.00
May	0.10	0.09	0.00	0.00
Jun	0.00	0.00	0.00	0.00
Jul	0.00	0.00	0.00	0.00
Aug	0.00	0.00	0.00	0.00
Sep	0.01	0.00	0.01	0.00
Oct	0.34	0.32	0.02	0.00
Nov	1.58	1.10	0.48	0.23
Dec	2.11	2.08	0.04	0.00
			RMS	0.23

7.Impacts of climate change on surface runoff

In this study, the outputs from global circulation models (GCMs) were deployed to assess the impact of doubling the amounts of CO_2 in the atmosphere within the next (forty years) century.

The climate scenarios based on these selected GCM models were used to simulate the surface runoff under these climate conditions. This will result in the assessment of climate change impacts on surface runoff resulted from precipitation.

Figure (8) shows the results obtained from WEAP modeling process for the base scenario and the selected GCMS scenarios. Table (4) summarizes these results.

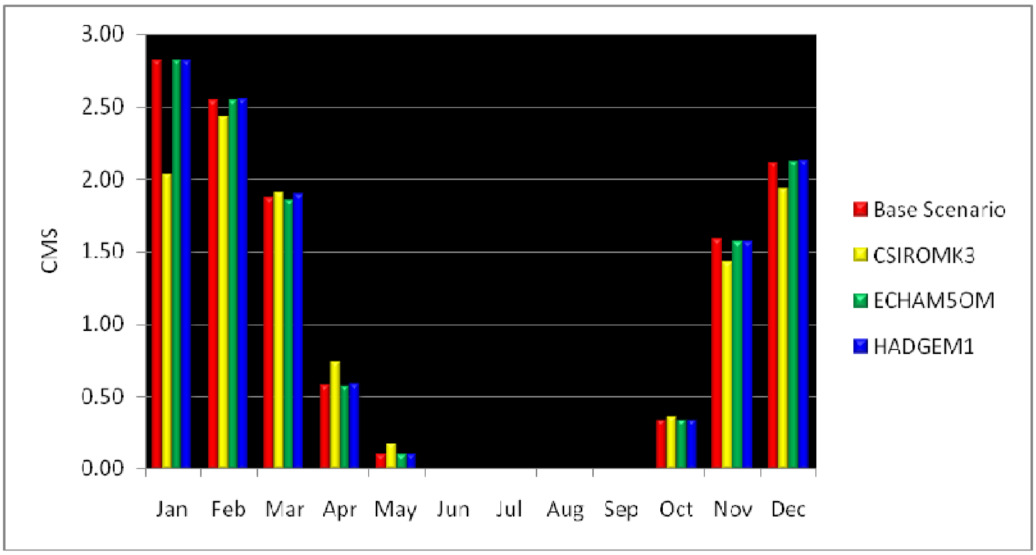
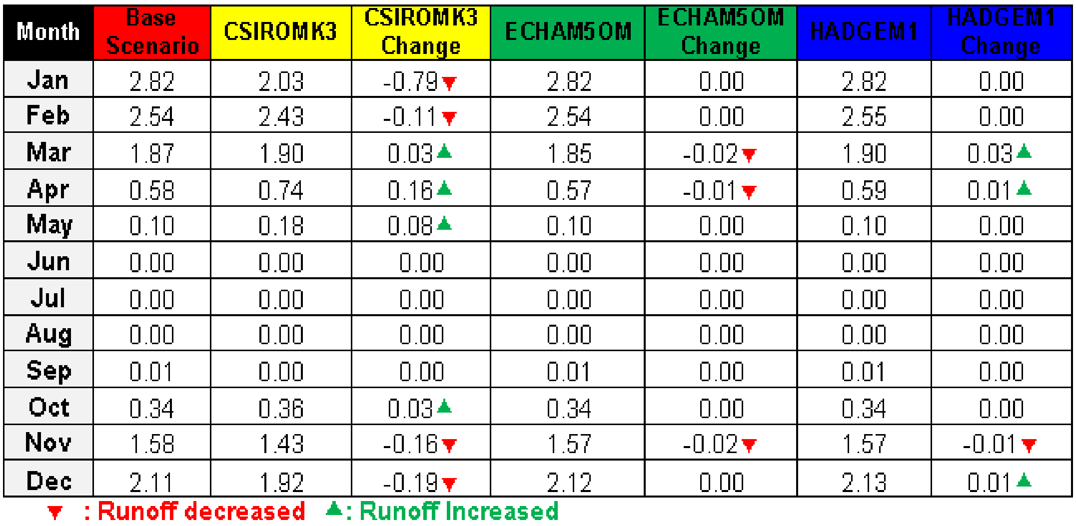


Figure (8): Results obtained for base scenario and GCM models

Table(11): Summarised results obtained from WEAP simulation for base scenario and selected GCM scenarios (CMS)



Month	Base Scenario	CSIROMK3	CSIROMK3 Change	ECHAM5OM	ECHAM5OM Change	HADGEM1	HADGEM1 Change
Jan	2.82	2.03	-0.79▼	2.82	0.00	2.82	0.00
Feb	2.54	2.43	-0.11▼	2.54	0.00	2.55	0.00
Mar	1.87	1.90	0.03▲	1.85	-0.02▼	1.90	0.03▲
Apr	0.58	0.74	0.16▲	0.57	-0.01▼	0.59	0.01▲
May	0.10	0.18	0.08▲	0.10	0.00	0.10	0.00
Jun	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jul	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Aug	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sep	0.01	0.00	0.00	0.01	0.00	0.01	0.00
Oct	0.34	0.36	0.03▲	0.34	0.00	0.34	0.00
Nov	1.58	1.43	-0.16▼	1.57	-0.02▼	1.57	-0.01▼
Dec	2.11	1.92	-0.19▼	2.12	0.00	2.13	0.01▲

▼ : Runoff decreased ▲: Runoff Increased

As can be seen from figure (10) and table (8), ECHAM5OM and HADGEM1 results are almost the same. Furthermore, results from these two scenarios indicate that there will be a minor or no change on surface runoff values.

On the other hand, the CSIROMK3 shows different results, it shows that runoff will decrease in January, February, November and December; and will increase in March, April and May.

8.Hydrological modeling of Yarmouk Basin

Figure (9) shows the modeling setup for Yarmouk Basin using WEAP modeling tools; where the same approach followed as in case of Zarqa Basin. Yarmouk basin has been divided into three major sub-catchments. It's important to mention that the molding process takes only into account the Jordanian part of the Yarmouk basin ignoring the larger parts located in the Syrian territory.

Figure (10) shows the simulated mean daily runoff values obtained for base scenario (1970-2000) and figure (11) shows the mean monthly runoff values (CMS).

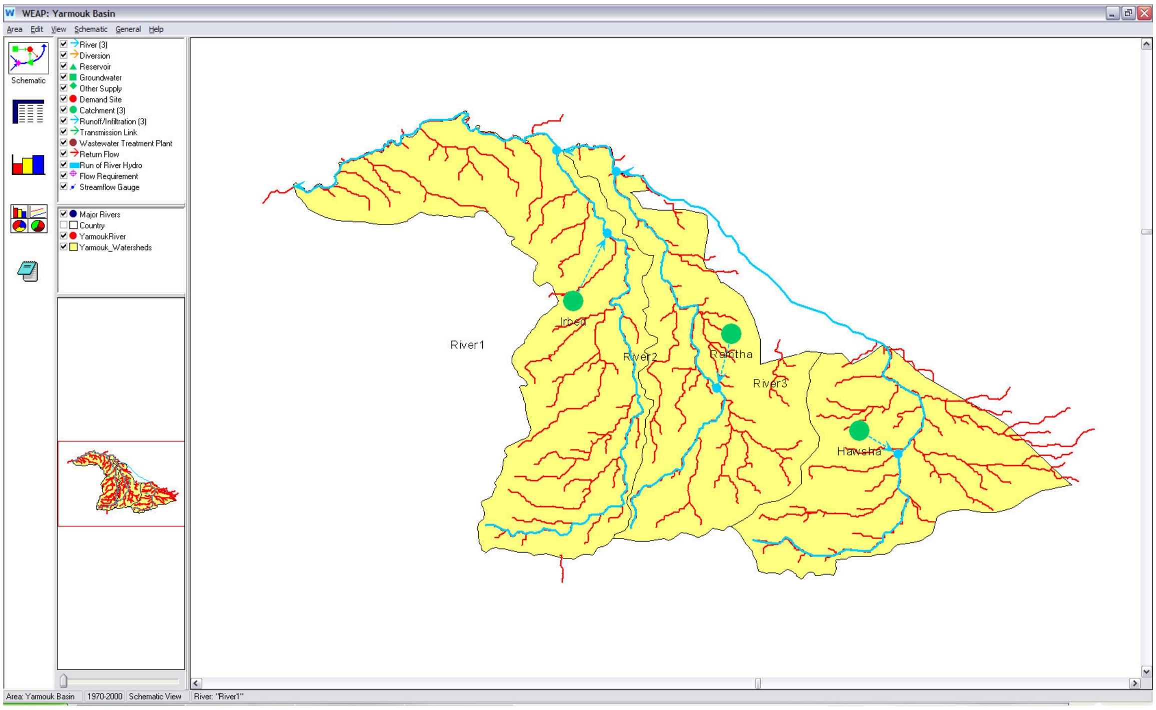


Figure (9): Yarmouk Basin Model Setup under WEAP interface

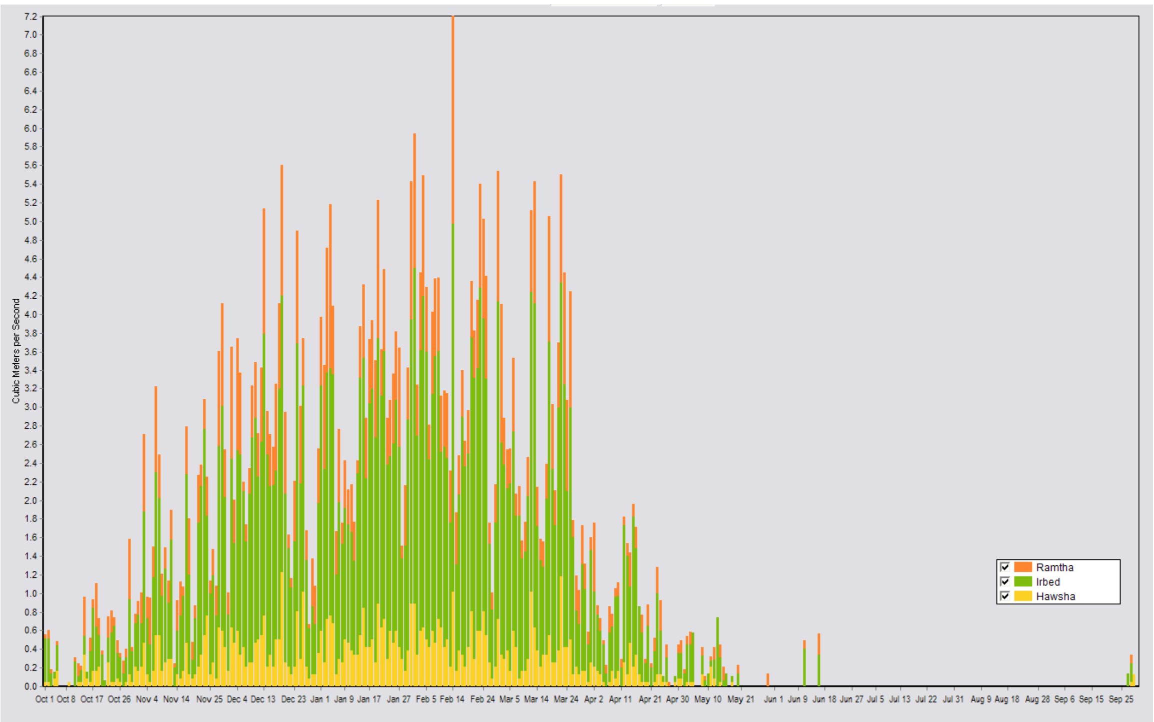


Figure (10): Simulated Mean Daily Surface Runoff for Yarmouk Basin

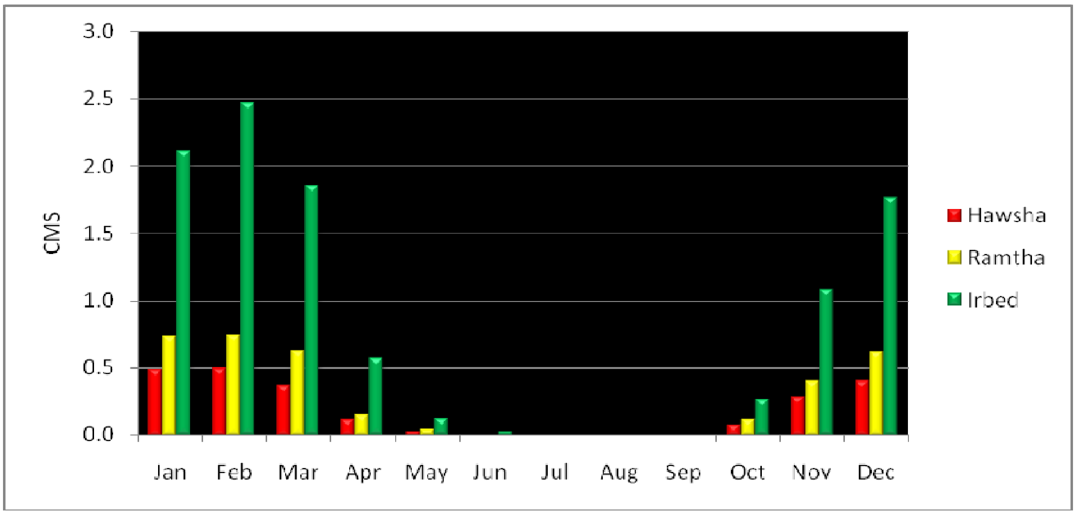


Figure (11): Simulated Mean Monthly Surface Runoff for Yarmouk Basin

The impacts of climate change using the selected GCM scenario were also applied to Yarmouk Basin. Figure (12) shows the results of this simulation where the following conclusions can be derived:

- According to CSIROMK3 model, there will be a slight increase in the surface runoff amount during the rainy season.
- The ECHAM5OM simulation results show that there will be no change on surface runoff resulted from precipitation in January, and there will be a decrease in the other months.
- HADGEM1 simulation predicated a major increase in surface runoff values in March and a decrease in October and November. While the other months shows no change in surface runoff values.
- The three models shows slight or no change on surface runoff values for January, February, May and October

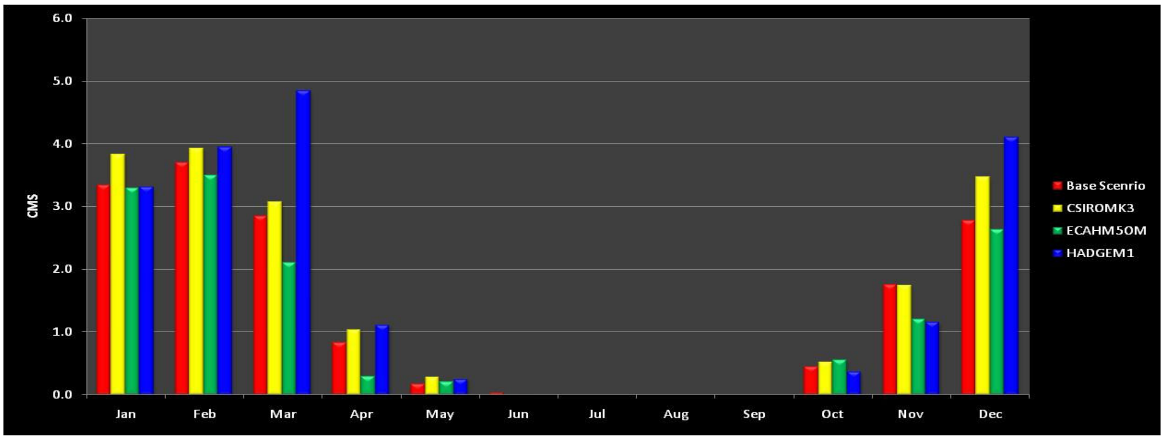


Figure (12): Results obtained for base scenario and GCM models for Yarmouk Basin

Conclusion

This study aimed at the assessment of climate change impacts on water resources in Jordan through the selection of two sites for detailed study. These sites were Amman Zarqa basin and Yarmouk basin. The necessary meteorological data were collected and analyzed to study the current situation of the water resources with the selected sites. WEAP model was used to simulate surface runoff resulted from precipitation and taking into account the temperature values. The obtained results was calibrated and validated against measured runoff vales.

To assess the impact of climate change on water resources of the selected sites, 13 global circulation models (GCM) were tested to select three models whose records are matching those of Jordan climate. The selected models were CSIROMK3, ECHAM5OM and HADGEM1. Records from these three models were used to calculate the surface runoff assuming that Cox will be doubled in the next century.

Simulation results obtained from base scenario and GCM scenarios were compared and it was found that the amounts of surface runoff resulted from precipitation will be highly affected by climate change. This will add another stress on the water resources of Jordan; knowing that the currently available resources suffers from the increasing demand as a result of demographic and limitation of these resources.

References

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