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Climate Change Impacts on Water Resources in Desert Area Considering Irregularity in Rainfall Intensity and Distribution: A Case Study in Wadi Kafrein Basin, Jordan

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Abstract

There is a growing awareness regarding climate change fluctuation as its one of the central issues that affects water resources directly. This research was conducted to evaluate the effect of climate change on surface water resources due to the change in rainfall intensity and distribution and to investigate the sensitivity of water resources to climate change.

WEAP has been utilized to simulate future available water resources and figure out the possible implications of changing climate on Wadi Kafrein Basin which represent the Jordan valley feature in Jordan. Different future scenarios have been built up and analyzed to predict the change in runoff over the period between 2014 and 2050; thus precipitation and evapotranspiration data for the period between 1991 and 2013 have been alerted for the model input to develop four different climate change scenarios.

The simulation shows that annual average runoff in the selected study area would decrease compared with "no change" scenario. This reduction will influence the amount of water stored in Kafrein dam directly which in turns will add additional pressure on the available water resources and thus intensify water scarcity in the country. Climate change could also have effects on monthly runoff distribution. The model predicts that runoff will decrease in a different manner over months. March to June months along with October could face the highest relative decrease in runoff compared to December, January and February months.

Keywords: climate change, hydrological model, WEAP model, Kafrein Basin

1. Introduction

Jordan is located in an arid to semi-arid region with a land area of 90,000 km^2. Deficit in water resources is the most important issue from which Jordan has suffered since the 1960s; so it is characterized as a 'water scarce' country where water resources are limited.

Rainfall is the main water resource that the country depends on. Due to the diversity in climatologically conditions and variation of topographic features of Jordan, this source falls irregularly and varies widely in quantity, intensity and distribution with location from year to year. Precipitation depth ranged from 600 mm in the northwest highlands to less than 50 mm in the eastern desert which covered about 91% of the area (MWI, 2012).

Jordan is also considered as one of the lowest countries in the world on a per capita basis. The available water resources per capita are projected to fall from less than 145 m^3 per capita per year at present to about 91 m^3 per capita per year by 2025 (MWI, 2012). Climate change is expected to intensify this water status and add additional pressure on water availability in the future, it may affect the availability of water resources in the country negatively; this could enlarge the gap between supply and demand.

Water resources are threatened by severe climate change conditions. Over the last decades, the average temperature of the earth's atmosphere has been rising due to the increased amount of green house gases concentration, mainly carbon dioxide. Scientists predict that this growing increase may also lead to global warming during this century. Moreover, global warming may have several implications on the available water resources; evaporation rates as long as precipitation pattern and intensity are the main hydrological variables that are alerted by increasing the average earth's temperature (IPCC, 2001).

It is predicted that rainfall events tend to be more intense with increasing the concentration of greenhouse gases due to climate change; that's because greenhouse gases lead to global warming and thus have an obvious effect on the hydrological cycle, which in turns enhance the change in climate components, and vice versa. Once the climate became warmer, more water tend to evaporate from the earth's surface to the atmosphere and the moisture content held by warm air would increase, as a result, rainfall falls heavily and become more intense, based on the principle of water mass balance of the hydrological cycle.

In general, many models predict higher rainfall intensity and uneven temporal and spatial distribution, the intensity of rainfall events would increase by 10 to 30% due to doubling the amount of carbon dioxide in arid and semi arid areas. But the mass balance theory suggests that the total annual precipitation amount may decline (IPCC, 2001).

The most reliable models, Global Circulation Models (GCMs) based scenarios, are considered in developing future climate scenarios ideally; therefore, the climate simulation resulted from GCMs were used frequently to derive hydrological models and evaluate the effect of climate change on the hydrological cycle. The main limitation of using GCMs climate simulations is resulting in different values of climate variables changes not only a single reliable estimate (IPCC, 2001).

Several GCMs scenarios have been used to model the future change in climate, thirteen GCM models have been analyzed to find out those that match with Jordan's climate conditions by comparing the model outputs with temperature records (Hammouri, 2009), and it was found that three models match the climate of Jordan, they are:

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.

Climate change projections for the 2020s climate parameters in comparison to the period 1961-1990 have been simulated using these three models for the Mediterranean countries, these models show minor changes in rainfall for the region, while mean temperatures are projected to increase significantly (0.8-2.1^{O}C) (IPCC-DCC, 1999).

In general, each degree C of global temperature increase can be expected to increase the evapotranspiration by 7% and to change the precipitation by 5-10% across many regions including the Mediterrean countries (Allen et al., 1998), this increase would further impact the water balance and the river streamflow.

2. Materials and Methods

2.1 Selected Model

The selection of the hydrological model depends on many variables such as the problem objectives and the available data, therefore, the criteria for choosing the model must be determined before.

The hydrological model that is selected to be used in this work is the user-friendly Decision Support System tool WEAP, which is short for Water Evaluation And Planning system. The WEAP model was developed by the Stockholm Environment Institute in 1988. Since then, it has been successfully applied in many world regions, as a database or as a forecasting tool. It can be applied on single catchments up to complex river basin system. (Raskin et al., 1992).

WEAP is a scenario-driven decision support system for evaluating the relationships between hydrology, human water demands, and in stream flow requirements. Using WEAP, planner can analyze a wide range of water approaches through a scenario-based approach. These scenarios could reflect the change in climate variability and watershed condition (Yates et al., 2005).

2.2 Selected Study area

Kafrein hydrological Catchment covers part of the Jordan Valley feature with an area of about 171 km^2 west of Amman within elevation ranges from 1060 m above mean sea level down to 140 m below mean sea level in the Jordan Valley, Figure 1. It is located between (374,000 – 394,000)E longitudes and (524,000 – 544,000)N latitudes. The annual long term average precipitation varies from 550 mm/year in the eastern parts of the catchment and may fall in the form of snow, to 150 mm/year in its western parts in the Jordan Valley. The evaporation ranges from (2400 – 2700) mm/year (Talozi, 2010).

Wadi Al Kafrein drains about 6.4 MCM/year; consisting of a base flow and a flood flow of 4.8 and 1.6 MCM/year, respectively. Additionally, part of the flow that ends up to wadi Al Kafrein comes from Wadi Es sir Wastewater Treatment Plant (WWTP), the effluent of this WWTP measures about 4000 m^3/day in 2014, part of the effluent used in irrigating farms on the way and the rest flows to wadi Al Kafrein or its tributary wadies (Talozi, 2010).

Al Kafrein dam was constructed on Wadi Al Kafrein, in 1967, with a total storage capacity of 8.4 MCM, it receives flood and base flows, a bad quality water of treated and untreated wastewater and a good quality water from groundwater artesian wells and natural springs.

The study area has a Mediterranean climate where rainfall falls irregularly and varies widely in quantity, intensity and distribution with location; precipitation depth ranged from 600 mm at the northern parts and decreases to less than 200 mm when moving southwards. The rainy season starts in October and last to April, during the rainy season, most of the rain occurs between December and March (Haddadin et al., 2010).

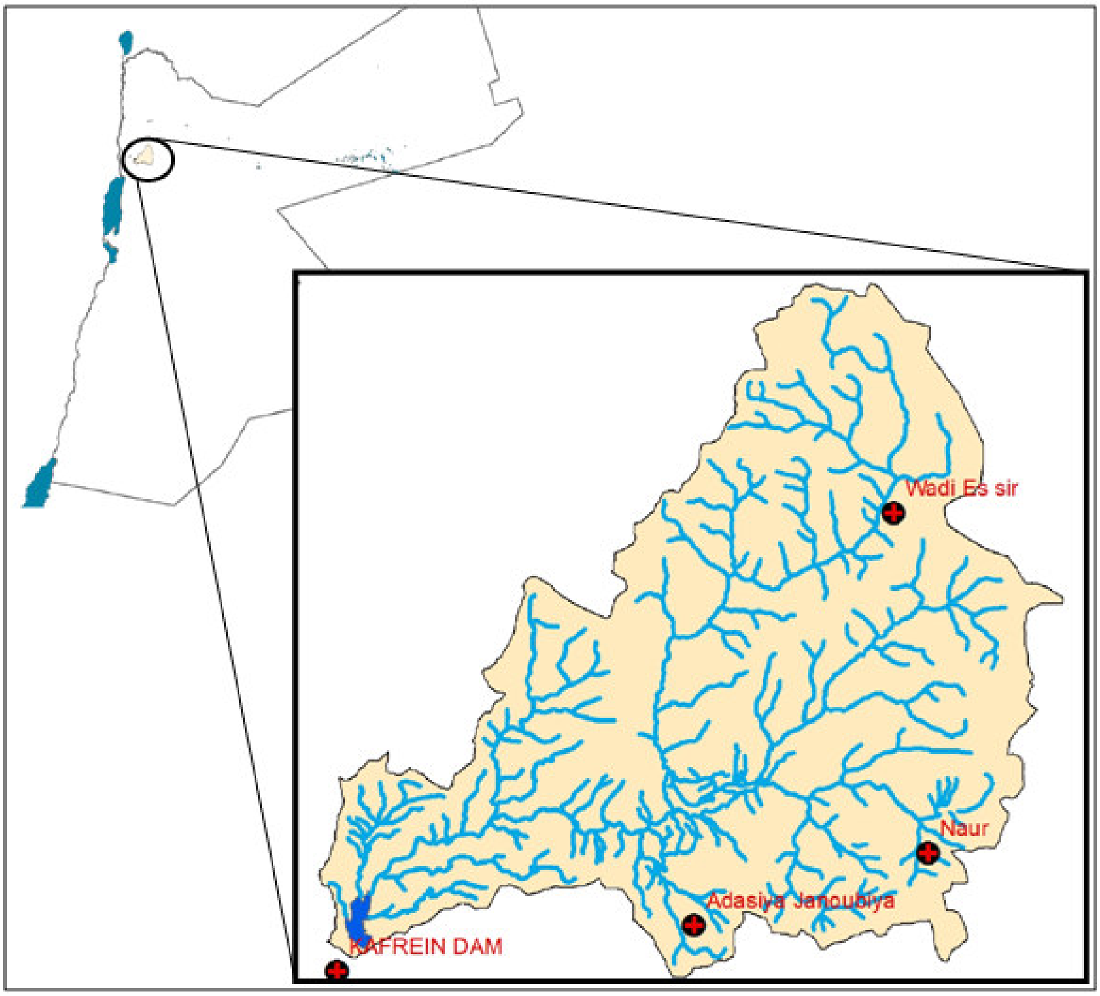

Figure 1: Wadi Kafrein Location Map

2.3 Data Gathering
Data Gathering is the most important step in any hydrological study, all data concerning this work were compiled from different governmental organizations in Jordan; the primary sets of data include geographical coordinates, above the mean sea level elevation, geology, hydrology and hydrogeology.

First, GIS vector data/ digital database layers that cover the study area are required for delineating the watershed, such layers are contour lines with 10 m interval and topographic maps with a scale of (1:50,000) were obtained from the Royal Jordanian Geographic Centre (RJGC).

Historical records of the main climatic variables for existing meteorological stations were used to assess the current climate and future climate changes. These variables, which include, in particular, precipitation, evaporation and runoff, were compiled from the database of the Ministry of Water and Irrigation (MWI). All sites located in the selected catchment were chosen to represent the best possible coverage of the study area. The periods of the collected data vary among meteorological stations and limited to the last 40 years, but to be consistent, the selected time scale for analyzing the climate data was based on the common period between the station datasets, primarily due to the need to compare the datasets of stations without any temporal biases, such as in the determination of the magnitude of change, thus, the period of observations used in the study for all sites is (1990-2013).

Runoff gauging stations are usually located downstream the main river that flows into a reservoir; the gauging station was selected to represent the streamflow in the reach just before Kafrein dam and discharge depths on a daily basis were collected over the period of study..

2.4 GIS Mapping: Processing of Map Theme Layers
Arc GIS 10.1 was utilized to delineate the watershed main parameters such as drainage area, length of a watershed and drainage slope. Follows are the steps that have been applied on the study area for the delineation process:

- Digital elevation Model (DEM) was extracted from Contour lines with 10 m interval, the contour maps was derived from field measurements and topographic maps with a scale of (1:50,000), Figure 2.

- Flow direction and Flow accumulation were derived from the DEM layer to determine the outlet within the basin; the outlets are located on the largest streams which acquire the highest stream order.

Catchment areas were extracted based on the flow direction and drainage network, the minor catchments extracted were merged together to determine the rough boundaries of the final catchment, and then the actual watershed boundaries were adjusted manually using the contour maps, Figure 3. The main characteristics of the drainage area as delineated using ArcGIS 10.1 were found to be as follows: watershed area 171km^2, Main stream Length 30km and watershed slope 40%.

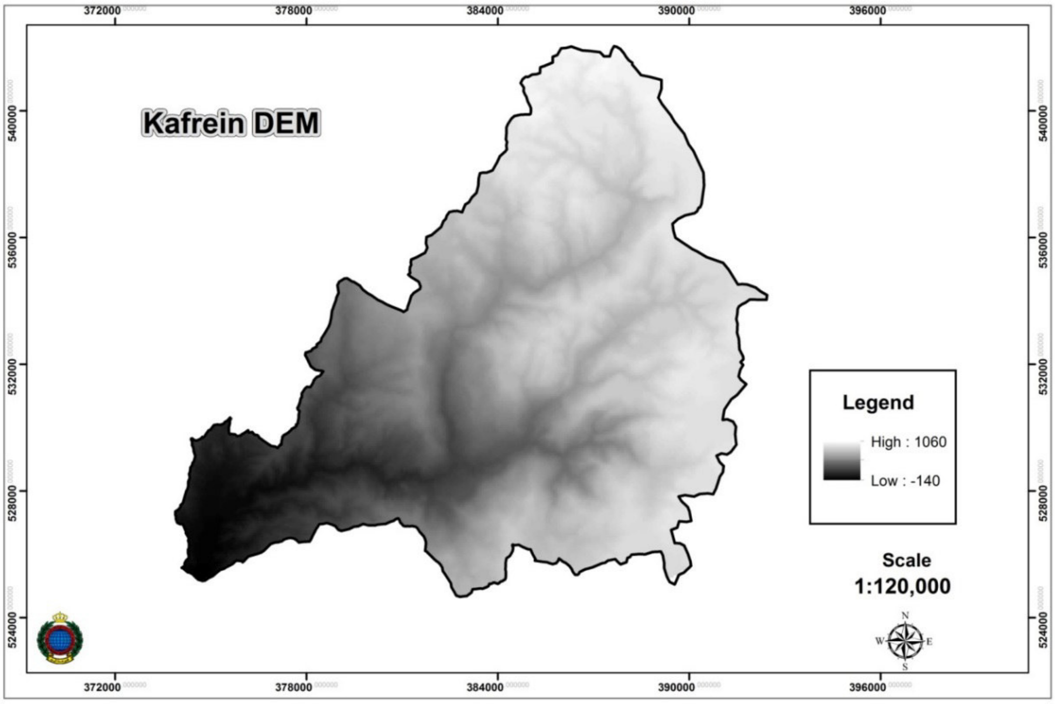

Figure 2: Digital Elevation Model (DEM) for Kafrein Watershed

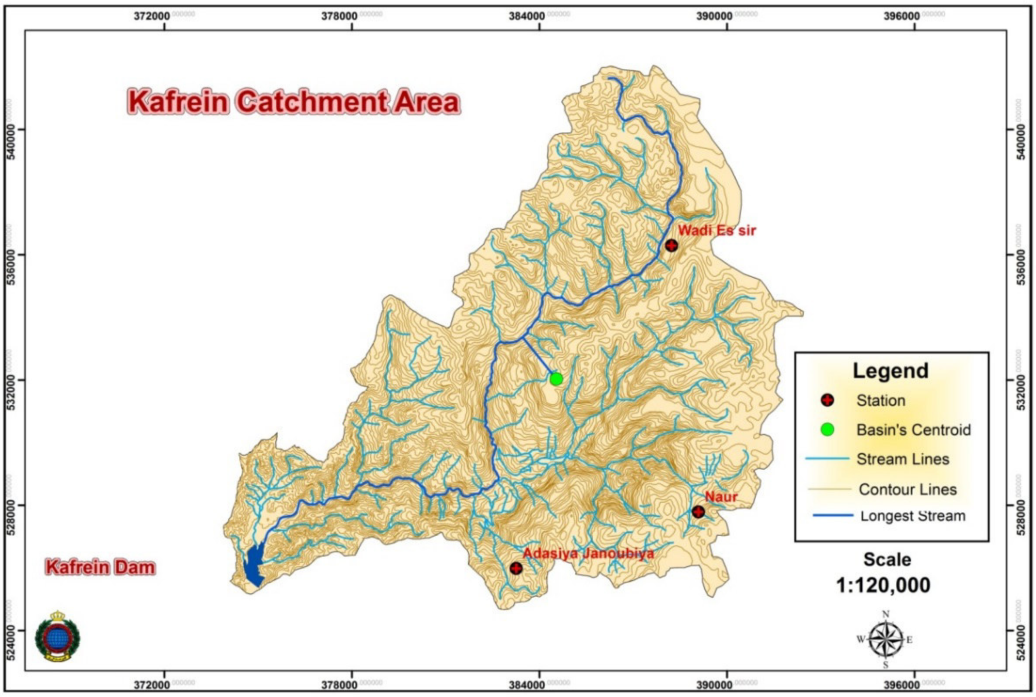

Figure 3: Kafrein catchment area derived from DEM with the main parameters and gauging stations

3. Building and Running WEAP Model

In this study, WEAP model was investigated to figure out the current and the possible future change of runoff; therefore, the investigation consisted of predicting climate scenarios to assess different aspects of climate change on the availability of water resources. WEAP model has been used to simulate the surface runoff resulted from precipitation based on the current account year which is known as the "Base Scenario". Then, different scenarios have been created and analyzed based on a variety of assumptions of hydrological trends known as a "Reference Scenarios".

The current account was implemented to take the years from 1991 to 2013 as a base scenario. The current account year represents the basic definition of the water system as it currently exists, usually the first year of the base scenario, in this case, 1991 water year; that starts at the 1st of October 1990 and ends at 30th of September 1991, the current accounts are also assumed to be the starting year for all scenarios. The last year of scenarios is selected to be the 2050 water year. The time step in WEAP can be daily or monthly; here it is selected to be 365 days each year excluding leap days (i.e. February 29).

Figure 4 presents the WEAP platform for Kafrein dam catchment; it shows the main hydrological elements of the water harvesting system and their linkage as drawn in the WEAP interface.

Data required for the modeling using Rainfall Runoff method were added for the catchment using the ReadFromFile function such as precipitation and evaporation on a daily basis for a representative one gauge station. Fractions of runoff, infiltration and evaporation were 4%, 5% and 91%, respectively (MWI, 2012). These fractions were added to the model and assumed to be constant in the current and reference scenarios.

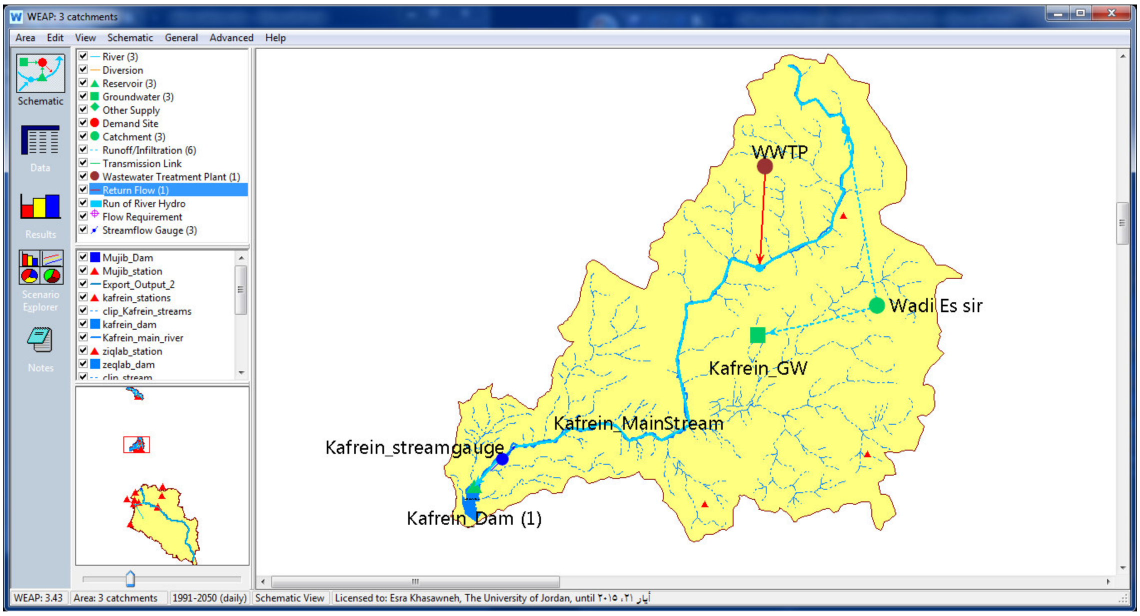

Figure 4: Schematic of the WEAP model for Kafrein Dam catchment

4. Results and Discussion

4.1 First Model Run

Runoff in the main streams has been simulated over the period between 1991 and 2050. The first attempt for the annual simulated runoff from the base scenario over the period from 1991 to 2013 and the predicted runoff simulation for the reference scenario over the period between 2014 and 2050 are displayed in Figure 5, it reveals that the simulated runoff cycle have obvious pattern.

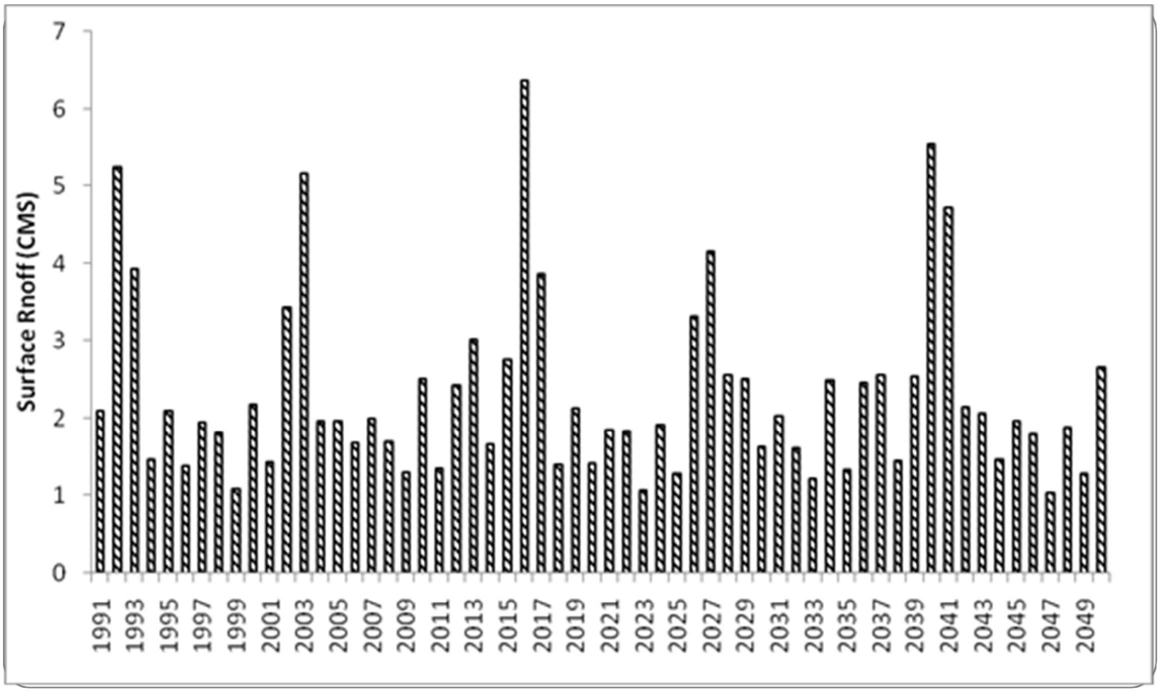

Figure 5: The Base Scenario Simulation Results over the period between 1991 and 2050

4.2 Model Calibration and Validation

Model calibration is an essential step before proceeding with future prediction, this is to ensure that the simulated runoff resulted from modeling process are matching those measured values in the current account. Model validation usually follows calibration; Statistical Package for the Social Sciences (SPSS) software was performed to evaluate the confidence in the model to represent the optimum fit of the model output to historical measurements of streamflow.

The Root Mean Square (RMS) error is also used to further check the accuracy of the simulation; the smaller the RMS value, the better the performance of the model, for a perfect model, RMS must equals to 0. It has been calculated for the simulated runoff values using the following formula:

$$m_x = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\delta_{xi})^2}$$

Where;

mx: RMS

δxi: Deference between observed and simulated values

n: No. of Observations

The aim of calibrating the rainfall runoff model in WEAP was to have a good representation of the actual streamflow that could be help as a base for further climate change analysis rather than representing the exact conditions and runoff properties of the catchment.

The period between 1991 and 2013 of the streamflow data were used for calibration and validation of the model, Figure 6 displays a visual comparison between modeled and observed streamflow before calibration, the first attempt shows that, the simulated annual average streamflow was over-predicted; in other words, the model simulation of discharge was higher than the observed. However, the model shows year to year different performances.

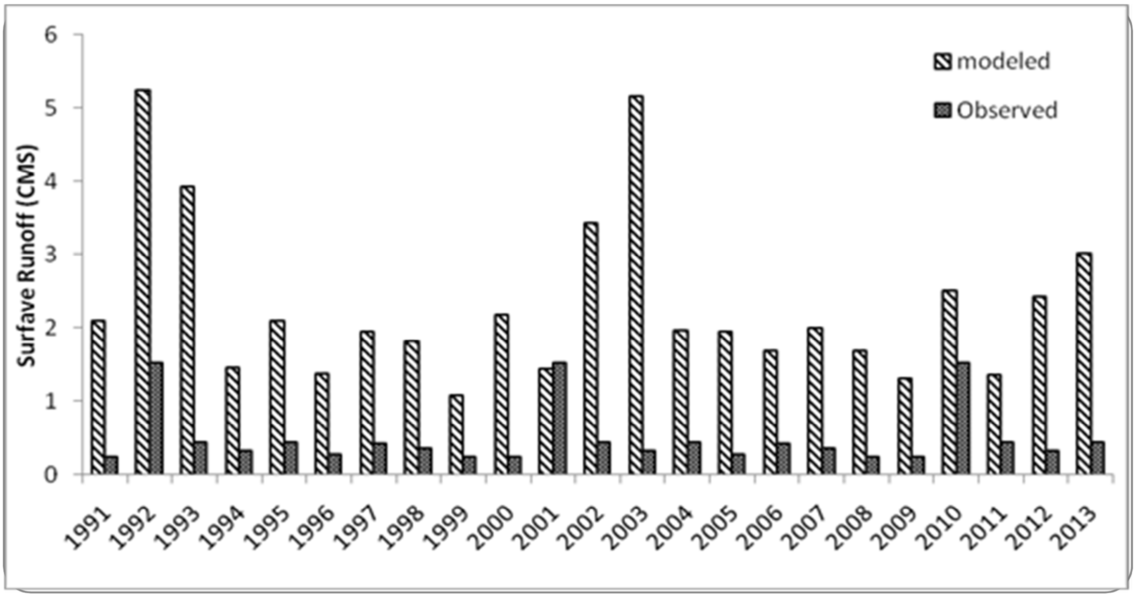

Figure 6: Simulated Surface Runoff (un-calibrated) versus Observed Streamflow Values for the Reference Scenario

Two main assumptions must be taken into account before calibration; the first is that, the basic characteristics of the catchment, such as the areas, land use and soil properties, will not change along the period of analysis to 2050, the second is that, changing in temperature and precipitation will enhance the evapotranspiration and thus affect the runoff simulation, but the catchment runoff characteristics will not be affected by these changes.

For calibrating the streamflow, modification of the input parameters was done manually via trial and error in order to select the optimum values that minimize the gap between modeled and observed streamflow. An obvious comparison between the calibrated simulated streamflow and the measured values is first made by visual check of the modeled versus observed runoff graph, before validating the values statistically. However, this enables only an assessment of the overall performance of the model.

Figure 7 shows a comparison between modeled and observed streamflow at Kafrein main river after calibration. As can be seen from the graph, the results obtained from the model is fit well with the observed runoff from the gauging station in most of the years, however, the model shows some differences which sometimes it overestimates and sometimes underestimates the runoff. The simulated runoff only fits the observed between the periods 1991 to 1999 and 2004 to 2011, and the extreme difference particularly in 2003 shows that runoff was over-estimated in that year.

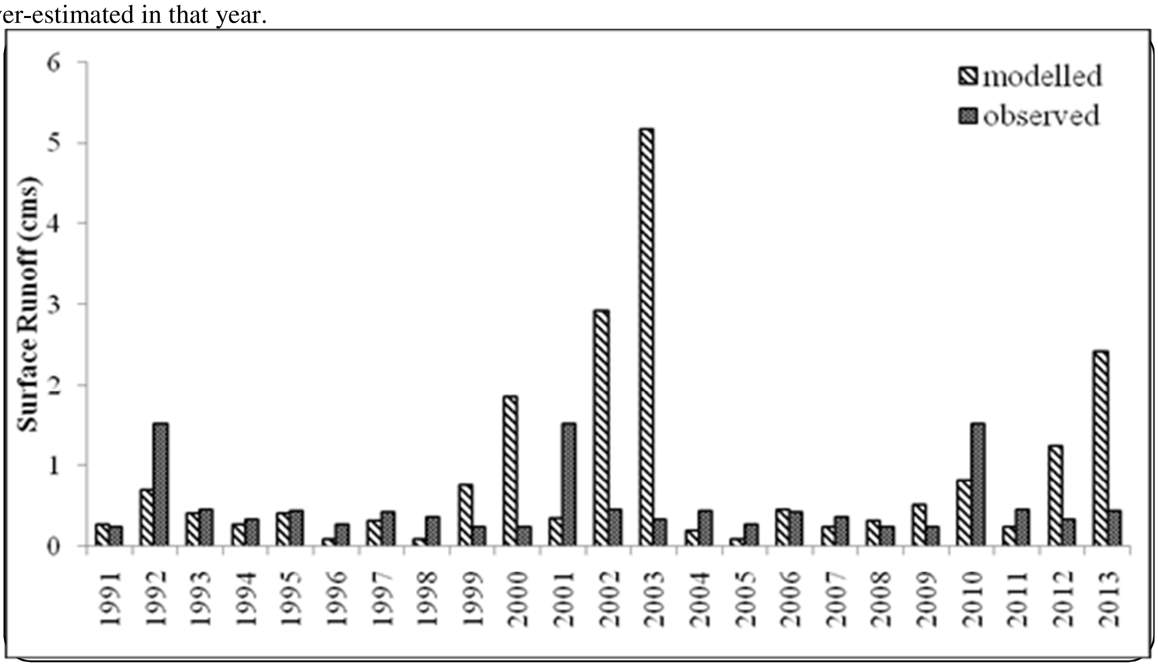

Figure 7: Simulated Surface Runoff (calibrated) versus Observed Streamflow Values for the Reference Scenario

With regards to the model performance criterion, a scatter plot of annual modeled (calibrated) versus observed runoff using SPSS statistical software is shown in Figure 8. Even after final calibration has been done, the simulated runoff was over-estimated in the years 2000, 2002, 2003 and 2013; the extreme values were excluded when measuring the modeling performance. The correlation between the scattered dots using SPSS found to be 0.68; this means that the simulated and observed runoff values are well correlated to each other.

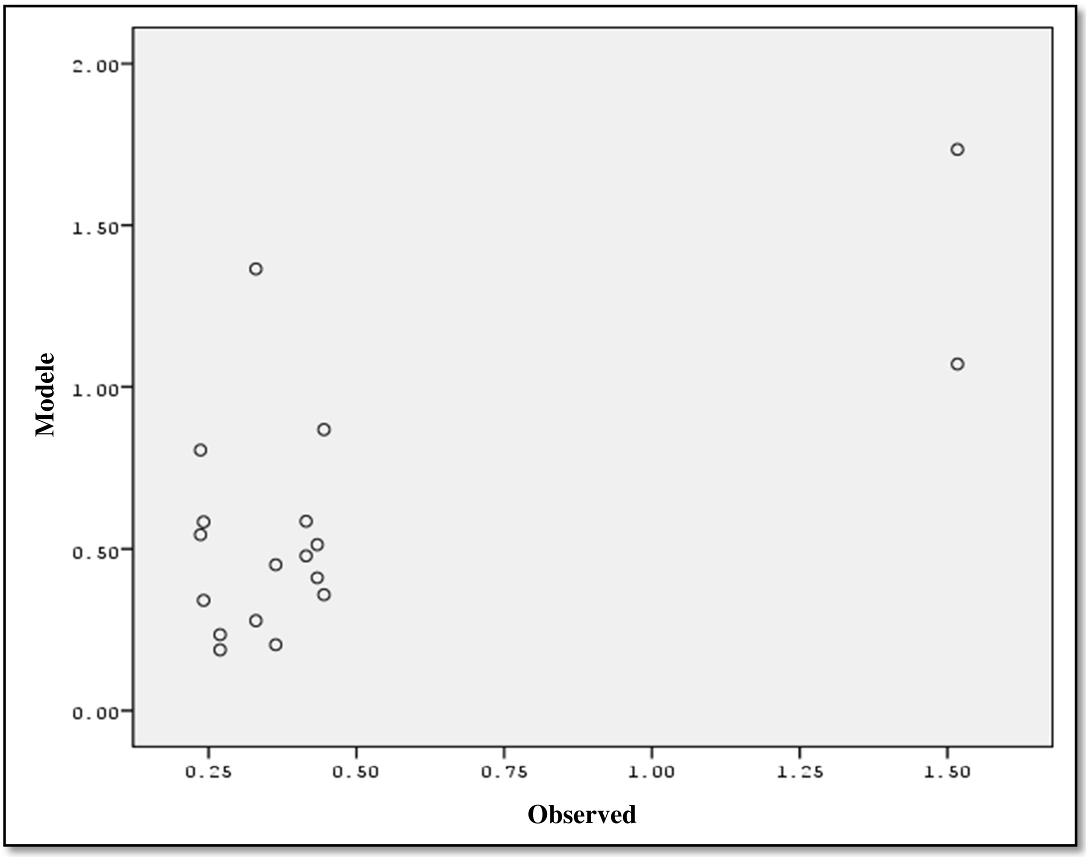

Figure 8: Scatter Plot of Annual Simulated Surface Runoff (calibrated) versus Observed Streamflow Values for the Reference Scenario

The RMS calculated for the simulated runoff values are presented in Table 1. From the table, it was found that the RMS for the model used to simulate runoff values was 0.382. This indicates that the model did an adequate job in reproducing the measured data reasonably well.

Table 1: Root Mean Square (RMS) calculation for the model results

Year	Simulated Flow (S)	Observed Flow (O)	O-S	$(O-S)^2$
1991	0.2685	0.2414	-0.0271	0.0007
1992	0.6987	1.5169	0.8182	0.6694
1993	0.3973	0.4451	0.0478	0.0023
1994	0.2678	0.3299	0.0620	0.0038
1995	0.4068	0.4336	0.0268	0.0007
1996	0.0808	0.2693	0.1885	0.0355
1997	0.3124	0.4148	0.1024	0.0105
1998	0.0815	0.3634	0.2819	0.0795
1999	0.7541	0.2362	-0.5178	0.2681
2004	0.1888	0.4336	0.2448	0.0599
2005	0.0865	0.2693	0.1828	0.0334
2006	0.4515	0.4148	-0.0368	0.0014
2007	0.2421	0.3634	0.1212	0.0147
2008	0.3069	0.2362	-0.0707	0.0050
2009	0.5061	0.2414	-0.2647	0.0701
2010	0.8080	1.5169	0.7089	0.5025
2011	0.2293	0.4451	0.2159	0.0466
2012	1.2373	0.3299	-0.9075	0.8235
			RMS	0.3821

4.3 Simulated Scenarios

Once the current account is created, a "reference" or "business-as-usual" scenario projection is established, based on a variety of economic, demographic, hydrological, and technological trends. The scenarios can address a broad range of "what if" questions, such as: What if climate change alters the hydrology? What would happen to the surface runoff if precipitation decreases and temperature increases? (WEAP User's Guide).

A set of hypothetical scenarios were implemented as a future scenario. In this context, a parameter of interest was added or subtracted by a defined quantity or percentage to assess the possible change due of climate change. The advantage of using such scenarios is its simplicity in presenting a wide range of adjustments for the average annual changes in precipitation and temperature.

The reliable method in projecting future scenarios are those simulated from GCMs. Under the three GCMs scenarios that are applicable on Jordan climate, the worst case scenario predict a temperature change of $+2^{O}C$ (El-Fadel and Bou-Zeid, 2001). In general, each degree C of global temperature increase can be expected to increase the evapotranspiration by 7% and to change the precipitation by 5-10% across many regions including the Mediterrean countries (Allen et al., 1998).

Moreover, hypothetical increases in temperature of $+2^{O}C$ combined with no change and with a change of plus and minus 10% in precipitation have been applied to the baseline period 1991 to 2013 to develop climate change scenarios for further investigation. Combinations of changes of these two parameters results in four different scenarios as summarized in Table 2. These scenarios were built and used for further analysis the change in runoff for the period (2014-2050) and thus the water availability in the basin. The outcomes of the scenario were compared against the results of the base scenario and thus assessing their impact on the water system.

Table 1: Hypothetical climate change scenarios

Scenario	$\Delta T\ ^{O}C$	ΔP %
base scenario	0	0
scenario 1	2	0
scenario 2	2	+10
scenario 3	2	-10

4.4 Climate Change Impacts on Surface Runoff

Surface runoff has been simulated based on the four climate in order to assess the impacts of climate change on runoff resulted from precipitation. This will help in quantifying the water availability within the catchment for the period from 2014 to 2050.

Runoff is directly affected by temperature and precipitation changes. It is expected that the simulation will result in four different changes in the amount of available water due to different prescribed climate change conditions used for each scenario. Figure 9 depicts the results obtained from WEAP simulation process for the projected change in runoff for Kafrein Dam Catchment.

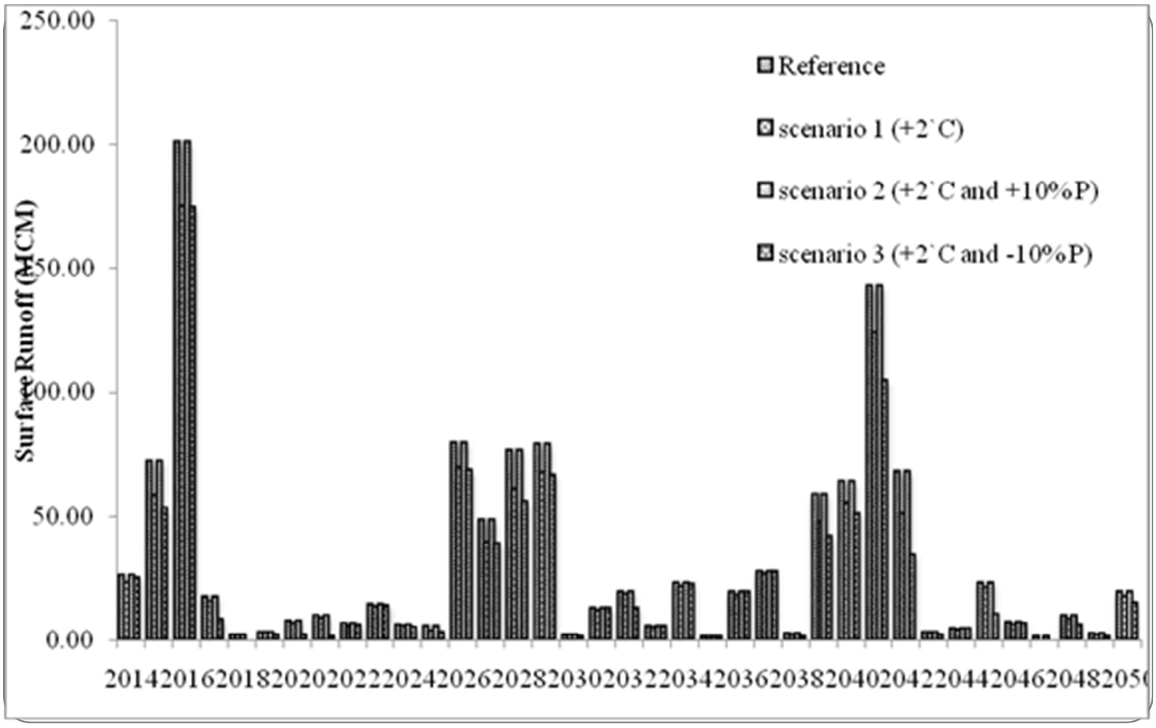

Figure 8: Projected Runoff Obtained from WEAP over the Period between 2014 and 2050 under Different Climate Change Scenarios

On an annual basis, the figure demonstrates that an increase in temperature of 2^{O}C (scenario 1) will cause a slight decrease in runoff over the period from 2014 to 2050; it would be reduced by 14%. While in Scenario 2, a 2^{O}C temperature increase combined with 10% increase in precipitation would have no effect on surface runoff. The worst case scenario is scenario 3, which projects a combination of temperature increase with 10% of precipitation decrease, this would cause a significant decrease in runoff over the period from 2014 to 2050; it would be reduced by 22%.

Year to year fluctuations are also projected. The graph shows that runoff, which represents the inflow to the dam, vary from year to year with some years are projected to face a minor or no change in annual average runoff while others are expected to be encountered by severe changes. This would cause a variation in the annual dam storage by year.

4.5 Climate Change Impacts on Monthly Distribution of Runoff

Climate change could have impacts on runoff distribution over months. Runoff under the three scenarios has been simulated on a monthly basis to figure out the possible changes in distribution. Different trends have been observed regarding the projected mean monthly runoff volumes; results of monthly runoff indicate future changes in the seasonal runoff distribution, it generally decreases in all months. Figure 10 illustrates the projected runoff on monthly basis over the period between 2014 and 2050 under different climate change scenarios.

The Figure reveals that results of modeling of the long term mean monthly discharges at Kafrein mainstreams decreases under both scenarios 1 and 3, while it is expected to remain the same under scenario 2.

The magnitude of change differs from one month to another; there will be a slight decrease in the surface runoff amount during the rainy season that extends from December to February, while the highest relative decrease in runoff in comparison with the reference scenario is expected to be in March to June months along with October. This decrease could be caused by: (1) an increase in rainfall intensity as a result of increasing air temperature and (2) a shift in rainfall distribution pattern from the autumn and spring months to the winter period.

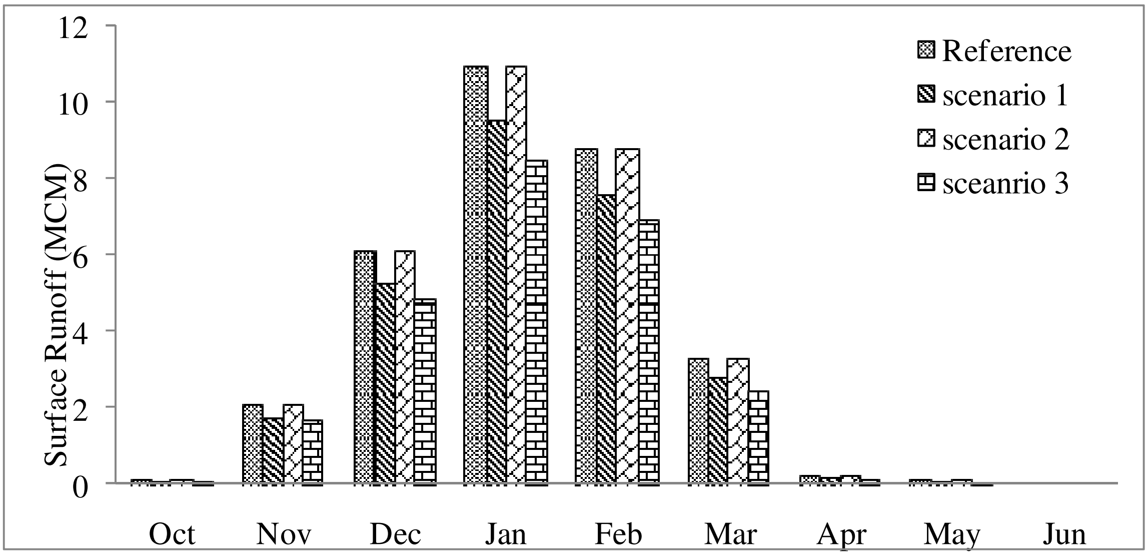

Figure 9: Projected Runoff over the Period (2014–2050) on Monthly Basis under Different Climate Change Scenarios

5. Conclusion

The results illustrate that the reservoir inflow changes during the simulated period were measured by changes in annual mean inflow into the dams. Impacts on inflow were measured by changes in climate variables; precipitation and temperature. The precipitation and evapotranspiration data for the period between 1991 and 2013 have been alerted for the model input to develop four different climate change scenarios. Generally speaking, the model was capable of investigating the possible future impacts of climate change on annual and monthly streamflow.

Based on research results, the primary findings were as follows:

- Simulation results obtained from the four scenarios were compared to the reference scenario and it was found that the annual average runoff will be affected negatively by climate change.
- Under scenario 1, the long term annual decrease in runoff is projected to be 14%. Scenario 3, the worst case scenario, projected a significant decrease in runoff by 22% in comparison with the reference scenario.
- The reduction in annual runoff will influence the storage of the dams; as a result, this will add additional pressure on the available water resources in Jordan for later time horizon.
- The seasonal runoff pattern is greatly influenced by climate change, it could generally be concluded from the investigated scenarios, that the highest relative decrease in runoff will face March to June months along with October, while a slight decrease would occur during the rainy season months that extend from December to February.

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