

# Water scarcity impact of climate change in semi-arid regions: a case study in Mujib basin, Jordan

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**Abstract** Jordan is confronting a severe water scarcity because of its reliance on a highly fluctuating annual precipitation. The impact of climate change on freshwater resources is of primary concern as it may elevate water shortage problem. Therefore, climate change has to be adequately addressed in order to attain proper management and sustainable use of available water resources. In this paper, incremental scenarios of climate change have been deployed to assess foreseen impacts of climate change on water resources in Mujib, a groundwater basin in central Jordan by the aid of Soil and Water Assessment Tool hydrological model. Ten incremental scenarios representing dry, normal, and wet events are tried. Findings indicate that dry scenarios lead to about 20 to 50 % reduction in annual precipitation and surface runoff. However, wet scenarios estimate annual precipitation and surface runoff to increase up to fourfold the baseline values.

**Keywords** Climate change · SWAT · Groundwater · Surface water · Water runoff

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## Introduction

Planning and management of water resources in the twenty-first century is challenging due to conflicting demands by various stakeholders, rapid population growth, urbanization, herbicides and pesticides, and land degradation (Ali and Abdel Kawy 2013). There is a great deal of concern that ongoing global warming and associated climate change may place extra pressure to stretched water resources in territories suffering challenges of water scarcity. Climate change impacts the hydrological cycle through affecting precipitation, surface run off (Al-Hasan and El-Sayed Mattar 2013), soil moisture, the recharge rates of ground water (Ahmed et al. 2013; El-Naqa and Al Kuisi 2013; Essefi et al. 2013; Şen et al. 2012), and a strong impact on salt water intrusion into aquifers as well as salinization of groundwater due to increased evapotranspiration (IPCC 2007).

Groundwater in shallow aquifers is part of the hydrological cycle and is affected by climate variability and change through recharge processes (Chen et al. 2002), as well as by human interventions in many locations (Petheram et al. 2001). Groundwater is a vital source of water in Jordan and several parts of west Asia and North Africa. Unconfined aquifers therein are replenished through rainfall, rivers, and lakes. Therefore, a change in the amount of effective rainfall will alter recharge rates. In addition, expected increased evaporation may cause soil deficits to commence earlier and to persist for longer time (Mailu 1993; IPCC 2001).

Jordan is among the poorest nations in freshwater resources. Annual per capita of freshwater is falling at an alarming rate as it declined from 3,600 m<sup>3</sup>/year in the year 1946 to 150 m<sup>3</sup>/year in the year 2008 (Ministry of Environment 2009). Recent years have witnessed shortage in the rainfall in different parts of the country (Hamdi et al. 2009).

Hammouri and El-Naqa (2007) conducted a research to assess drought conditions in Amman-Zarqa basin of Jordan.

Their findings revealed that drought periods had repeated in a regular manner during the last 50 years. Evaluation of seasonal trends in water quality of Al-Wehda dam over the year 2010 showed strong influences by weathering and leaching of geologic units along with discharge of effluents from the adjacent agricultural lands (Al-Taani 2013). Al Rawashdeh et al. (2013) reported that the water surface area of the Dead Sea has shrunk from 934.26 km<sup>2</sup> in 1973 to 640.62 km<sup>2</sup> in 2004 due to climate change and excessive exploiting of nearby freshwater resources.

It is necessary to improve our understanding of emerging problems under climate change including water availability and water quality. Therefore, the aim of this paper is to investigate the impact of climate change on water resources in Mujib basin, which has not been adequately addressed in climate change analyses. There are two main objectives of this paper: to model the impacts of different climate change scenarios using different incremental climatic change scenarios with the aid of geographic information systems and remote sensing techniques and to assess possible impacts of climate change on water resources in Mujib basin using the Soil and Water Assessment Tool (SWAT).

## Study area

Jordan is a small country situated about 80 km east of the Mediterranean between 29°11' to 23°22' north and 34°19' to 39°18' east. It is situated within the semiarid climatic zone and has a typical Mediterranean short, rainy winter and long dry summer. Mujib basin is located in central Jordan (Fig. 1) and covers an area of about 6,600 km<sup>2</sup>. It consists of two major catchment areas: Wadi Mujib catchment of about 4,500 km<sup>2</sup> and Wadi Wala catchment of about 2,100 km<sup>2</sup>. It is bounded westward by the Dead Sea catchment, northward by the Zarqa basin, eastward by Azraq basin, and southward by Hasa and Jafr basins (Al-Assa'd and Abdulla 2010). Mujib basin is semi-arid to arid, with low rainfall in most parts of the basin in winter and high temperatures in summer. More than 80 % of the basin is covered by desert land, and the remainders 20 % are agricultural lands and residential areas.

## Climatology of the study area

The climate of the study area varies between Mediterranean in the western and northern catchments of Mujib basin to semi-arid in eastern and southern catchments. Mediterranean climate is described by dry-hot summer and rainy-mild winter. Semiarid climate is described by dry-hot-dusty summer and cold winter that receives less than 50 mm/m<sup>2</sup> annually. During summer months, low relative humidity values accompanied by high evaporation rates are expected. During spring and

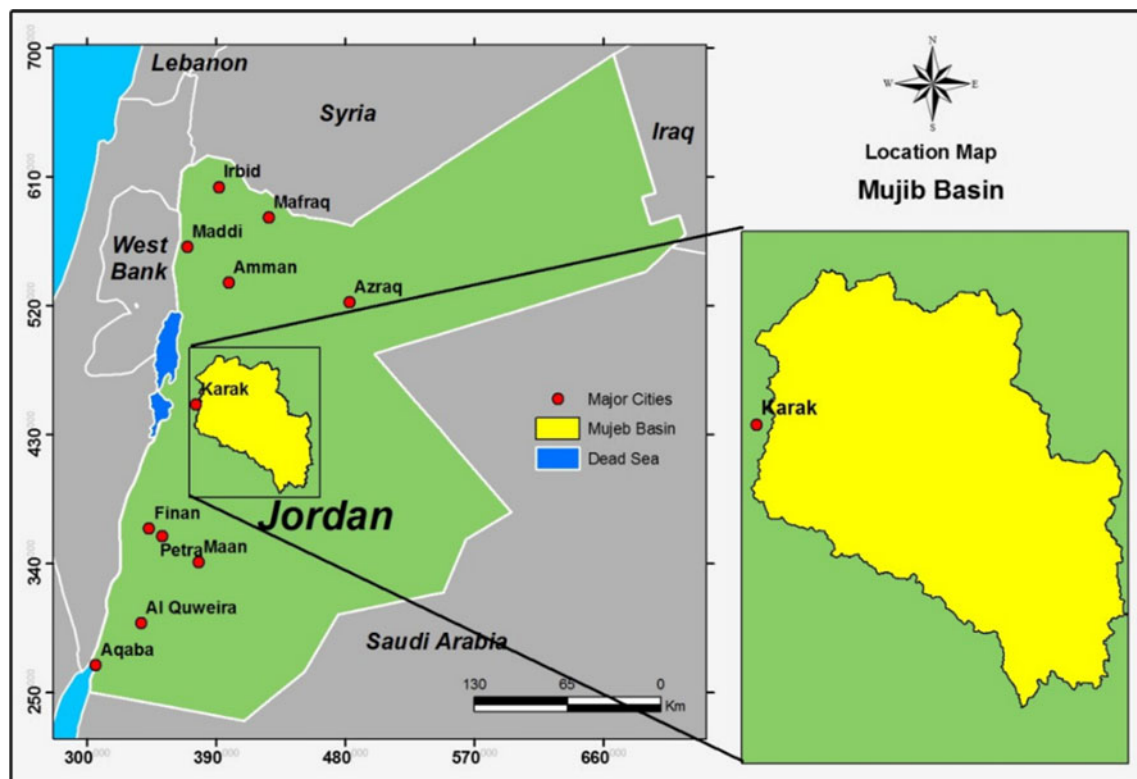
autumn months, the basin experiences several dust storms that intensify in southern and eastern catchments. Rain begins in October and lasts until May, but most precipitation occurs during January. Thunderstorms account for a large percentage of the total rainfall in the basin. Annual rainfall decreases from 300 mm near the western edge of the basin to less than 50 mm at the eastern edge (EXACT 2006; JICA 1986).

## Hydrology of the study area

Mujib drains in the Dead Sea through Wadi Mujib which drains much of the southern part of the basin with an annual runoff of 26 million m<sup>3</sup>/year and Wadi Wala which drains the northern part of the basin with an annual runoff of 23 million m<sup>3</sup>/year. Average annual base flow in the basin is 35 million m<sup>3</sup> maintained by discharges of several small springs in the two wadis (JICA 1986). The lower reaches of Wadi Wala, which is called Wadi Heidan, drains base flow with an annual groundwater runoff of 20 million m<sup>3</sup> (JICA 1986). Flood water depends on intense storms that occur during the rainy season which extends from late October to early May. Total flood flows are estimated to be 65 million m<sup>3</sup>/year (JICA 1986). Floods arrive in the Dead Sea a few days after a rainstorm hit and most wadies dry up. In Qae'lhafira and Abyad muddy swamps at the southeastern catchment, water stagnates for several weeks before it dries up. Stagnant water is estimated to be about 3 million m<sup>3</sup>/year (JICA 1986).

## Biodiversity in the study area

Seasonal and permanent streams that flow through many of the Wadis in the western part of the basin maintain lush strips along wadis' beds, which enable this otherwise arid area, according to the Royal Society for the Conservation of Nature, to incorporate prosperous wildlife with over 300 plant species, ten carnivore species, and several species of resident and migratory birds. Flora includes Palm, Wild Fig, Tamarix, Reedbed, and beautiful Oleander shrubs. The steep mountain slopes support several highly adapted mammals, including Rock Hyrax, Eurasian Badger, and Nubian Ibex. Caracal, a medium-sized cat with black and white ear-tufts, lives in rocky wadis. In addition, Mujib is an important route for migrating birds during late summer and early autumn. Received birds include White Stork, Black Storks, Buzzards, Honey Buzzards, Levant Sparrow Hawks, and much more. At least nine species of birds breed in the basin every spring. Breeding birds include Bonelli's eagle, Short-toed Eagle, Long-legged Buzzard, Barbary Falcon, and the endangered Lesser Kestrel (Royal Society for the Conservation of Nature 2012).



**Fig. 1** The location of the study area in the central part of Jordan

## Research methodology

Weather and hydrological data are gathered, analyzed, and fed into the SWAT model in order to calculate surface runoff and other parameters at Mujib basin for years 2012–2033.

### SWAT model

SWAT is a watershed scale model used to predict the hydrological impacts of land-use practices in large complex watersheds over long periods of time using available meteorological and runoff data (Neitsch et al. 2005). It has been developed based on earlier models including Simulator for Water Resources in Rural Basins model (Williams et al. 1985; Arnold et al. 1993), Chemical Runoff and Erosion from Agricultural Management System (Knisel 1980), Ground Water Loading Effects on Agricultural Management Systems (Leonard et al. 1987), and Erosion-Productivity Impact Calculator (Williams 1975).

### Model input and data treatment methods

In order to run SWAT, various information are required including digital elevation model (DEM), soil data, slope, land use, maximum and minimum daily temperatures, precipitation, wind speed, solar radiation, and relative humidity (Arnold et al. 2011). Weather data are necessary for the prediction of soil moisture as well as model calibration.

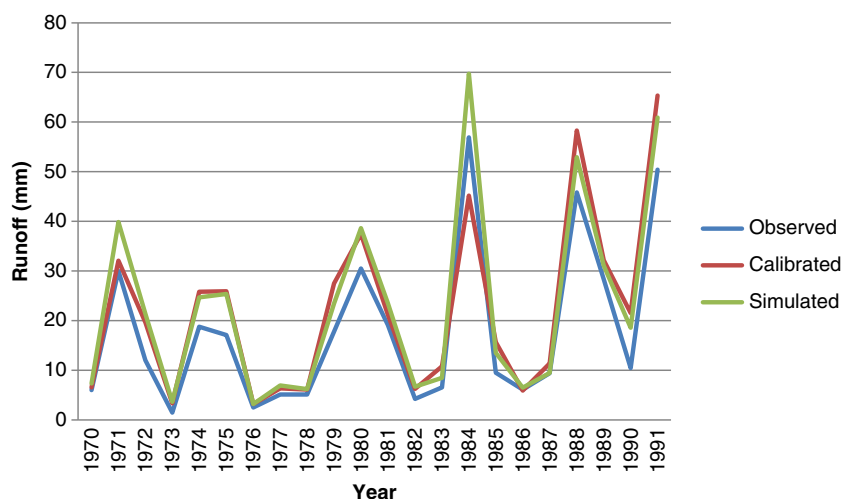
### Land-use and soil map data

Land-use and soil map data of 30 m resolution are acquired from the Jordanian Ministry of Agriculture. Study area is classified into seven land-use classes with bare soil and non-cultivated lands dominate the basin. Six types of soil textures are identified in the basin and matched with SWAT soil codes. Silty clay loam soil, which dominates the basin, allows moderate infiltration rates, whereas clay soil maintains moderate water holding capacity.

**Table 1** Increments used to construct ten incremental climatic change scenarios

	Scenario ID	Change in temperature	Change in precipitation
Dry scenarios	S1	+2	−10 %
	S2	+4	−10 %
	S3	+2	−20 %
	S4	+4	−20 %
Normal scenarios	S5	+2	Normal
	S6	+4	Normal
Wet scenarios	S7	+2	+10 %
	S8	+4	+10 %
	S9	+2	+20 %
	S10	+4	+20 %

**Fig. 2** Baseline scenario vs. observed and autocalibrated results



### Weather data

There are six weather stations and 13 rainfall stations distributed within the study area. Several stations do not have full data records and exhibit many missing gaps. Vlookup formula has been used to generate missing data for rainfall, maximum temperature, and minimum temperature during the time period 1970 to 2010. Missing air temperature data were filled with  $-99$ .

### Watershed delineation

The basin is delineated using the digital elevation model in order to construct sub-basin systems, estimate water runoff, and create hydrological response units (HRUs) that are used to account for climate change, land use, and soil types. The model fills all of the non-draining zones (sinks) to create a flow vector and superimposes the digitized stream networks into the DEM to define the location of the stream network. Calculated parameters of the constructed sub-basins include slope gradient, slope length of the terrain, and characteristics of the stream network such as channel slope, length, and width.

ArcSWAT is employed to divide the basin into a number of hierologically connected sub-basins based on flow directions and accumulations. It suggests minimum area, maximum area, and suggested threshold area of the sub-basins in order to define the minimum drainage size required to form a stream origin. Excessive details, which require long processing time and vast space, concerning the drainage networks are required to divide the basin into smaller areas. Therefore, Mujib basin is divided into six sub-basins and 149 HRUs using two outlets.

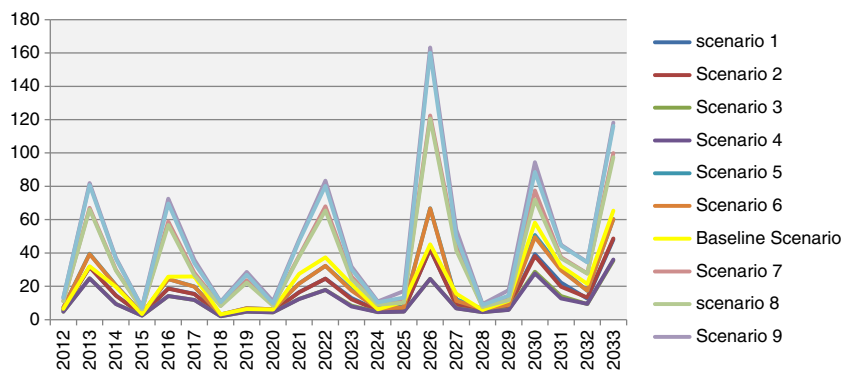
### HRU definition

The HRU analysis tool in ArcSWAT creates hydrological response units and integrates up to five land slope classes that are used for the development of land-use and soil input parameters. Digital elevation model indicates that the slope classes at Mujib basin are in the range 0–9,999, which is divided into three classes: 0–15, 15–45, and 45–9,999.

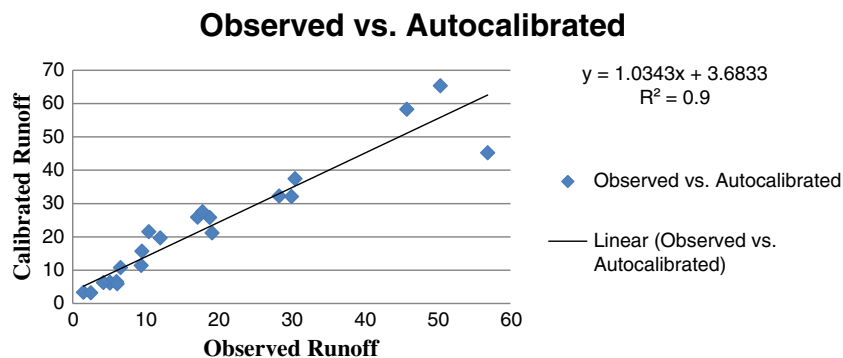
### Importing weather data

After the definition of HRUs, precipitation and temperature data are imported. Each sub-watershed is linked to one gage.

**Fig. 3** Incremental scenarios in comparison with baseline scenario



**Fig. 4** Flow correlation for run period at Mujib basin



Data for years 1970–1991 from four rainfall and temperature stations in Mujib basin are used to set up and run SWAT.

#### Climate change scenarios

A climate scenario describes techniques where particular climatic (or related) elements are changed incrementally by plausible though arbitrary amounts (e.g., +1, +2, +3, +4 °C change in temperature) (IPCC 2001). They might not be physically plausible, but they are the simplest perturbation method that projects changes in future rainfall. In addition, assuming uniform climate changes throughout a particular time period is not accurate as the estimated warming in summer months is practically much greater than in winter months. Nevertheless, incremental scenarios are suitable for Jordan, which exhibits clear spatial and temporal variation in annual precipitation (Ministry of Environment 2009).

Two and 4 °C increases in air temperature combined with five precipitation scenarios (Table 1) are considered to run the SWAT model. The five precipitation scenarios are: normal precipitation, where no change in rainfall is anticipated; two dry scenarios, where rainfall is projected to exhibit 10 and 20 % decreases in annual precipitation; and two

wet scenarios, where rainfall is projected to exhibit 10 and 20 % in annual precipitation.

## Results and discussion

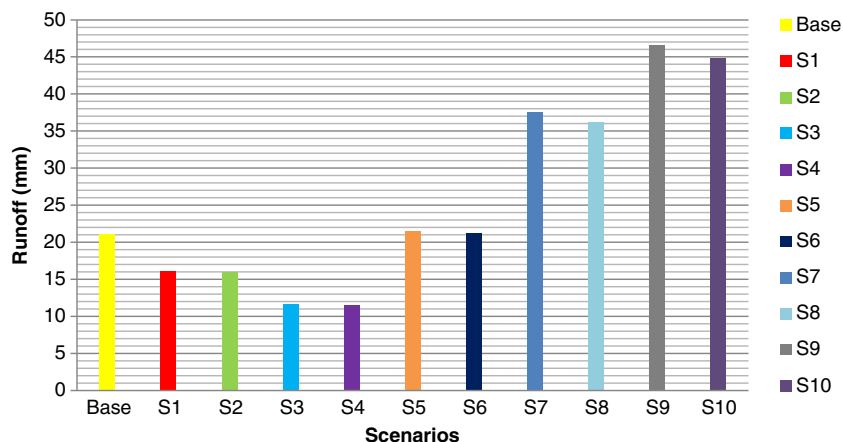
### Model calibration and validation

We have performed SWAT modeling using all monthly and yearly base flow and surface runoff data using the Parasol method for the years 1970–1991. Output results are calibrated against real data. Real data from the period 1992–1997 are assigned for model validation. Favorable agreement between observed and simulated runoff data is attained (Figs. 2 and 3). Statistical output values found to be 0.90, 0.81, and 0.12 and root mean square error (RMSE) are for the calibration process (Fig. 4), and  $R^2$  and Nash–Sutcliffe (NS) values are 0.99 and 0.81, respectively, for the validation process.

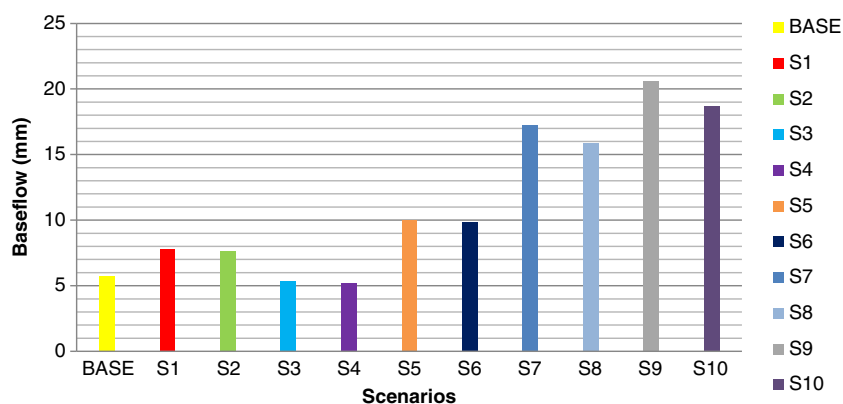
### Incremental scenarios

SWAT model has been run using data that represent the ten incremental scenarios in order to estimate base flow,

**Fig. 5** Long-term annual average runoff for all scenarios



**Fig. 6** Long-term annual average base flow for all scenarios



surface runoff, and evapotranspiration for years 2012–2033 (Figs. 5, 6, and 7). Data calculated by assuming normal scenarios where temperature and precipitation do not change (S5 and S6) matched real values, which advises that SWAT generates dependable hydrological data for Mujib basin.

Scenarios S3 and S4 which assume 2° and 4° increases in air temperature and 20 % decreases in annual precipitation yield the lowest surface runoff values of 11.66 and 11.55, respectively. Base flow and evapotranspiration values have shown similar increments. However, the two wet scenarios (S9 and S10) predict substantial increases in surface runoff, base flow, and evapotranspiration values.

Hydrological data at monthly bases have been also generated and examined in order to envision which month would be mostly affected by the proposed climatic change scenarios (Tables 2 and 3; Figs. 8 and 9). It is likely that November would demonstrate a significant increase in surface runoff, but May would experience the largest decline in surface runoff values under the proposed incremental scenarios.

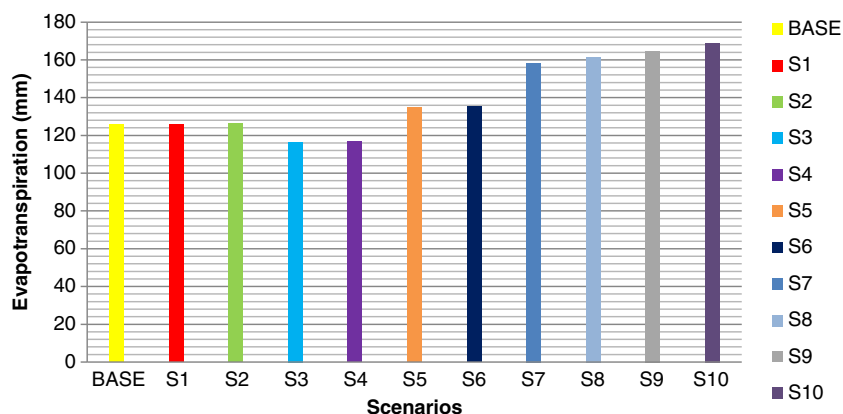
### Water strategy

The findings of this study indicate that water budget in Jordan is anticipated to decrease due to the ongoing global climatic change. This fact places an invaluable trust in the custody of water policy makers and stakeholders in Jordan. Water is our elixir of life; therefore, it should be managed wisely and effectively.

Outside of domestic population growth, it is estimated that 70 % of people living in Jordan are refugees from countries such as Palestine, Syria, and Iraq. In this region, refugee movement is happening constantly and will add to the population at random in the future. This larger population is projected to leave Jordanians with 91 m<sup>3</sup> of water per capita per year by 2025. If water management is not run efficiently and effectively in Jordan, the results could be devastating for its people.

In Jordan, this management falls under the Minister of Water, who is the head of three departments—the Jordan Valley Authority, the Ministry of Water, and the Water Authority of Jordan, which is further divided into Miyahuna, the Aqaba Water Company, and the Yarmouk Water Company.

**Fig. 7** Long-term annual average evapotranspiration for all scenarios



**Table 2** Incremental scenarios

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Base	2.62	5.30	6.36	2.16	0.31	0.00	0.00	0.00	0.00	0.07	0.45	3.23
S1	1.96	3.49	4.72	1.53	0.12	0.00	0.00	0.00	0.00	0.06	0.37	2.56
S2	1.95	3.34	4.67	1.54	0.12	0.00	0.00	0.00	0.00	0.06	0.37	2.55
S3	1.55	2.37	3.44	1.14	0.09	0.00	0.00	0.00	0.00	0.04	0.31	2.06
S4	1.54	2.29	3.41	1.14	0.09	0.00	0.00	0.00	0.00	0.04	0.31	2.06
S5	2.46	4.76	6.07	2.04	0.26	0.00	0.00	0.00	0.00	0.07	0.45	3.12
S6	2.45	4.65	5.97	2.00	0.26	0.00	0.00	0.00	0.00	0.07	0.45	3.11
S7	5.15	8.20	9.57	3.84	0.55	0.00	0.00	0.00	0.00	0.26	1.73	5.09
S8	4.92	7.83	9.16	3.66	0.55	0.00	0.00	0.00	0.00	0.26	1.67	5.01
S9	6.41	10.17	11.63	4.77	0.92	0.00	0.00	0.00	0.00	0.31	2.13	6.13
S10	6.07	9.69	11.06	4.54	0.91	0.00	0.00	0.00	0.00	0.31	2.05	6.01

The Ministry of Water and Irrigation is responsible for overseeing and planning all water-related projects and expenditures; the Jordan Valley Authority controls bulk supply for agricultural, industrial, and domestic use in the Jordan Valley as well as promoting land development; and the Water Authority of Jordan controls bulk supply and distribution in the other areas in which water sales have not been commercialized. The Jordanian bureaucracy for the control of water is clearly defined, minimizing governmental overlap which can cause resources to be wasted.

From an economic standing point, water should be going to the sectors in which it can yield a profit in the most efficient manner and therefore generate a larger public surplus, the ultimate goal of any government. However, there is a tradeoff that must be kept in mind when discussing which sector receives the water, as there is no direct production from the domestic sector as far as GDP numbers. Indirectly, the water that goes to the domestic section fuels the whole economy, as the workers in the agricultural and industrial sectors must

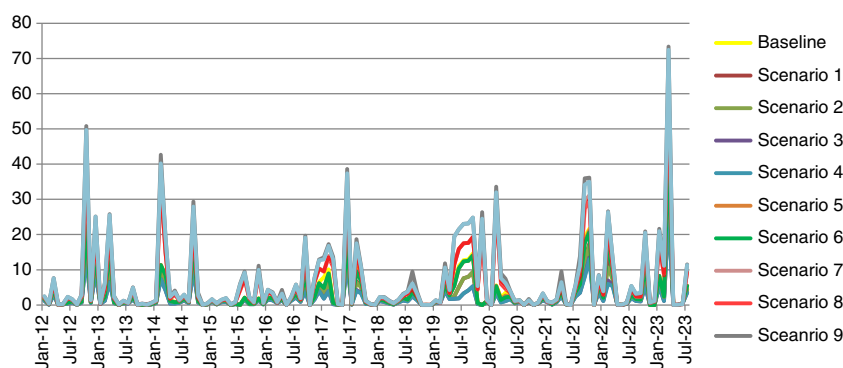
have water in their homes to be able to work effectively. Nonetheless, the governments must allow the agricultural sectors in each country to be productive as well in order to feed the workforce. The perfect balance must be found so that the subsidizations to the agricultural sector are not more expensive than the imports of the food that would be produced with that water. In order for the government of Jordan to even begin to eliminate its debt from water, it must increase the water prices that have been too low for years. Although this move will not be popular politically, it is a necessary move, as allowing the markets to decide who receives water will increase total welfare in the economy.

Moving forward, government of Jordan must change its water supply plans if it is to provide enough water to its people. This plan consists of two steps: First, the government must raise the water prices to allow the market to equilibrate to allocative efficiency. By doing this, the economy will in fact grow, as the most effective water users will be willing to outbid the others,

**Table 3** Incremental scenarios/baseline

	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
Base	100 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
S1	74.57	65.91	74.10	71.09	39.97	77.07	83.43	79.22
S2	74.41	63.08	73.43	71.32	39.97	77.07	83.43	79.08
S3	58.95	44.82	54.02	52.95	29.27	58.60	68.29	63.80
S4	58.91	43.29	53.53	52.99	29.27	58.60	68.29	63.78
S5	93.69	89.92	95.46	94.58	85.59	98.09	99.90	96.59
S6	93.33	87.81	93.89	92.68	85.59	98.09	99.90	96.38
S7	196.60	154.87	150.33	177.94	179.94	359.24	385.87	157.60
S8	187.64	147.81	143.98	169.68	179.79	357.32	373.48	155.22
S9	244.63	191.93	182.73	221.15	299.11	436.94	477.24	189.91
S10	231.52	182.91	173.86	210.57	298.81	430.57	458.33	186.29

**Fig. 8** Incremental scenarios and baseline scenario on monthly basis



thus generating revenues and expanding, employing more people, and so on. The trickle-down effect from this increased welfare will help all classes of people moving forward. In addition, the government revenues from this project (all water resources are state-owned) will allow it to perform the infrastructural improvements necessary to help its self-sufficiency for water. These improvements involve fixing leaky pipes, fixing broken meters, and increasing wastewater treatment production so that all water that can be used and reused is indeed given to the people. Secondly, the government must try to recycle more of its water used. The environment cannot sustain the current levels of withdrawal from aquifers, so wastewater and gray water recycling plants must be installed to replace what is currently being overdrawn from the ground.

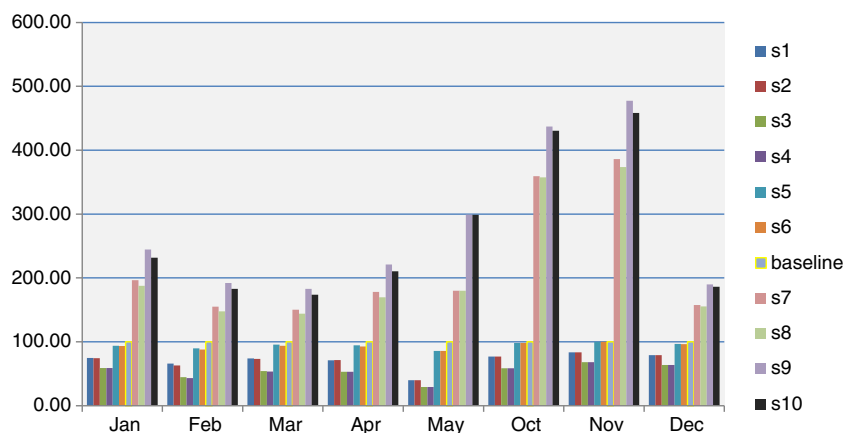
### Summary and conclusion

The evaluation of the effect of climate change on water resources in Mujib basin has been carried out by applying SWAT model using downscaled gridded daily weather data in four stations. Ten incremental scenarios representing normal, dry, and wet projections in Jordan are proposed for the purpose of studying the impacts of climate change on water

resources in the basin. Proposed incremental scenarios include four dry scenarios, two normal precipitation scenarios, and four wet scenarios in this study. Investigated hydrological parameters are surface runoff, base flow, and evapotranspiration. SWAT outputs have been calibrated against observed surface runoff dataset and the  $R^2$  correlation factor. NS and RMSE were used to indicate the validity of the calibration results. Overall, results indicate that SWAT is able to produce reliable and valid hydrological data for Mujib basin. Based on SWAT model outcomes, it is evident that air temperature is the most important parameter that would impact the hydrology of Mujib basin by increasing or decreasing the surface runoff as well the base flow under different climate change scenarios. Main findings could be summarized as follows:

- Six incremental scenarios (normal and dry) predicted a decrease in rainfall and surface runoff at Mujib basin during rainy season months.
- Runoff would exhibit more than 30 % decrease in surface runoff if air temperature increases by 2 or 4 °C and rainfall decreases by 10 %.
- Runoff would decrease by more than 50 % if temperature increases by 2 or 4 °C and rainfall decreases by 20 %.
- Runoff would show a slight decrease in surface runoff if air temperature increases by 2 or 4 °C provided that precipitation does not change.

**Fig. 9** Monthly incremental scenarios



- Wet scenarios which propose an increase in annual precipitation by 10 and 20 % predict a substantial (up to fourfold) increase in surface runoff and base flow during wintertime.

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