

Assessing climate change impacts on water resources and crop yield: a case study of Varamin plain basin, Iran

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Abstract This research evaluated climate change impacts on water resources using soil and water assessment tool (SWAT) models under representative concentration pathway scenarios (RCP 2.6, RCP 6, RCP 8.5). First, drought intensity was calculated using the standardized precipitation index (SPI) for the period 1987–2016. Then, the coefficients of precipitation as well as minimum and maximum temperature changes were simulated as SWAT model inputs. The results revealed that temperature will rise in future periods and the precipitation rate will be changed consequently. Then, changes in runoff during periods of 2011–2040, 2041–2070, and 2071–2100 were simulated by introducing downscaled results to SWAT model. The model was calibrated and validated by SWAT calibration and uncertainty procedures (SWAT-CUP). Nash-Sutcliffe (NS) coefficients (0.57 and 0.54) and R^2 determination coefficients (0.65 and 0.63) were obtained for calibration

and validation periods, respectively. The results showed that runoff will rise in fall and spring while it will drop in winter and summer throughout future periods under all three scenarios. Such seasonal shifts in runoff levels result from climate change consequences in the forms of temperature rise, snowmelt, altered precipitation pattern, etc. Future-period evapotranspiration will rise under all three scenarios with a maximum increase in the period 2070–2100 under RCP 8.5 scenario. Additionally, rainfed crop yields will decline without considerable changes in irrigated and horticultural crop yields.

Keywords Climate change · SPI index · SWAT model · Runoff · Evapotranspiration · Crop yield

Introduction

Iran is located among arid and semi-arid areas in the global climatic zonation (IPCC 2007). Evidence from historic climatological data and forecasts of Iran's climatic conditions, as elsewhere worldwide, indicate incidence of climate change in recent decades with an ongoing trend in the future (Zarezadeh Mehrizi 2011). One of the consequences of climate change is the occurrence of drought in the region (Climate Change 2001; IPCC 2007). Loukas et al. (2008) reviewed the effects of climate change on the severity of drought in the Thessaly area. They used the SPI index to calculate drought severity and estimated time series for two 30-year periods. They found that climate change greatly affects the severity of drought. The severity of drought

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has increased in Western Europe and decreased in eastern regions. Harmsen et al. (2009) measured the temperature and precipitation data in Puerto Rico using general circulation model. They believed that in the rainfall season, it would be humid while it is projected to be dry in the dry season. They also showed that evapotranspiration would also increase in dry days with diminished rainfall and elevated temperature. Montaseri and Amirataee (2016), using historical data of 50 years of precipitation at 12 stations in different parts of the planet, generated 1000 consecutive series of artificial rainfall and compared different methods of drought monitoring. Their results suggested that the SPI method is the most accurate and realistic indicator for drought analysis. In three central provinces of Iran, using 30-year precipitation data at 20 weather stations, Alipour et al. (2017) revealed that SPI index is more flexible in drought analysis on monthly, seasonal, and annual time scales compared to other methods.

Climatic alterations will also seriously affect water resources, where a vast domain of which including surface waters, ground waters, and water-related constructions will undergo significant changes (Azamzadeh Shouraki et al. 2013). Simulation by hydrological, general circulation, and regional climate models is among the methods for the study of climate change impacts on water resources (Eini 2019). General circulation and regional climate models are available tools for global climate simulation, the outputs (e.g., temperature and precipitation) of which are applied as inputs of hydrological models to assess climate change effects on the hydrological cycle (Xu 1999). Devkota and Gyawali (2015) employed SWAT model for hydrological simulation in order to investigate climate change effects on the management of areas and hydrological water resources at Kushi River basin in Nepal. Their results suggested that climate change was not a large threat to the water available in that area. Nevertheless, the projected flow for the return period was strongly dependent on climate change in implementing the climate model. Elsewhere, climate change and land use impacts on the runoff and water resources in part of Lordegan basin were predicted by SWAT model (Besaltpour et al. 2015). Climate changes in near (2011–2039), middle (2040–2069), and far (2070–2099) futures were studied based on CRU downscaled data obtained from HadCM3 model output as well as projected CO₂ concentration both under A2 emission scenario. The percentage of rainfall changes and mean monthly

temperature were then calculated and incorporated into first and second optimized models. SWAT model presented an acceptable accuracy in both calibration and validation phases. They further found that negative consequences arising from climate change would be more drastic in future periods. Shrestha et al. (2016) applied LARS-WG and SWAT models to study the climate change-related runoff and sediment uncertainty in future periods of 2030 and 2060 under GCM model. They reported increased sediment load and reduced runoff in the future. The influences of climate changes on surface water resources in Pangani basin were assessed by SWAT and WEAP models (Kishiwa et al. 2018). The results indicated 10% rise in the runoff and almost 2 °C elevation in temperature during the 2050s compared to the baseline period. Irrigation was also predicted to undergo a severe shortage necessitating urgent and future planning for water use. Zhou et al. (2018) assessed the quantitative effects of climate change and anthropogenic activities on runoff fluctuations in Dongjiang River basin, China, and detected elevated annual temperature and declined evaporation rate. SWAT model also displayed an acceptable performance. Furthermore, climate change impacts (58%) were slightly greater than those of anthropogenic activities (42%) in the whole basin. Yin et al. (2018) employed the climate models of CMIP5 and SWAT to investigate climate change effects on Jinsha River flow. The results revealed a drop in runoff by 2–5% in response to 1 °C temperature rise, with 0.5–0.8% decrease in precipitation and 1.31–1.87 °C elevation in temperature. Using SWAT model, the impact of climate change on rice yield was studied in Nanliujiang basin, China, suggesting a high ability of SWAT model in simulating the studied basin. Rice yield increased from 1.4 to 10.6% under GFDL-ESM 2M and IPSL-CM5A-LR climate models while HadGEM2-ES model resulted in diminishes yield (Yang et al. 2018). In Awash basin, Ethiopia, Daba (2018) conducted a study on runoff sensitivity to temperature and precipitation. They observed a high runoff sensitivity to both variables, such that annual temperature rises of 1, 2, 3, 4, and 5 °C results in annual runoff reductions to –0.085, –0.88, –1.75, –2.55, and –3.30%, respectively. Al Qatameh et al. (2018) used SWAT model to study climate change impacts on water resources in Jordan, and reported elevated air temperature. However, no changes occurred in the annual precipitation trend. In a study on evaluation of climate change impact on Kan basin runoff

(Ghermezcheshmeh et al. 2018), temperature and precipitation variables were simulated by data from the large-scale model HadCM3 under A2 scenario and SDSM downscaling model. The runoff was simulated monthly by SWAT hydrological model. The results indicated falling precipitations and rising temperatures across all selected stations. The developed climate scenarios finally demonstrated ascending and descending runoff levels in winter and other seasons, respectively. In another study, Delavar et al. (2018) investigated the effects of climate change on crop yield in Zaribar basin. Their results showed that the crop yield and the recharge of aquifers faced the greatest damage under climate change condition. Furthermore, Sharannya et al. (2018) evaluated the hydrological impacts of climate change on rainfall, temperature, and streamflow. They used water data of baseline and future RCP 4.5 scenarios to run SWAT model. The results showed that the impact of climate change on the annual streamflow yielded a decreasing trend at the rate of 1.2 Mm³ per year and 2.56 Mm³, respectively, for the past and future scenarios. In another research, Bajracharya et al. (2018) modeled the impact of climate change on the water balance and hydrological regime using SWAT model for a future projection of changes based on RCP 4.5 and RCP 8.5 scenarios. Their study demonstrated that the important water balance components of snowmelt, evapotranspiration, and water yield will be most affected by the increasing temperatures and

precipitation. Leta et al. (2018) studied the impacts of climate change on daily streamflow using SWAT model under the RCP scenarios. They found that while the considered climate change scenarios generally show considerable negative impacts on daily streamflow, the extreme peak flows are expected to increase by as much as 22% especially under the RCP 8.5 scenario. Given different climate changes around the world, Iran cannot be excluded from these large-scale changes, the consequences of which are observed in many Iranian basins. In this study, climate change impacts on drought, runoff, evapotranspiration, and crop yield simulated for future periods under climatic scenarios using SPI index and SWAT model. Results show that climate change has adverse effects on runoff and evapotranspiration. In addition, study area will experience severe droughts in the future.

Materials and methods

Study area

This study was followed on Salt Lake sub-basins viz. Lavasanat, Damavand, and Varamin plain basins located at 35° 0' 0" to 36° 0' 0" N latitude and 51° 0' 0" to 52° 0' 0" E longitude (Fig. 1).

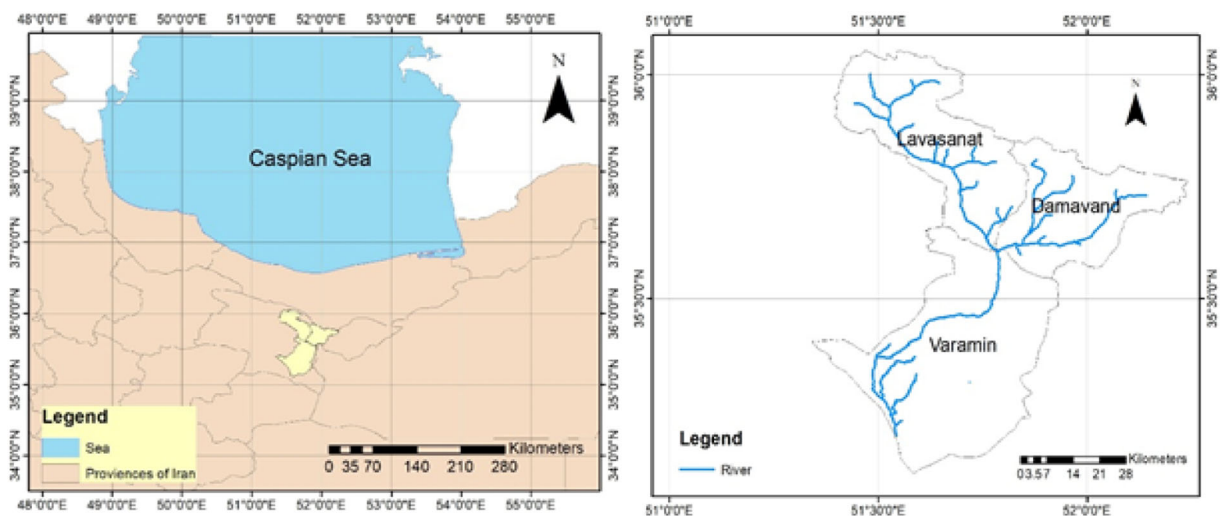


Fig. 1 Region location

Table 1 Average precipitation changes under climate scenarios (mm)

Scenario	Periods	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RCP 6	2011–2040	1.02	0.93	0.98	1.11	0.92	0.85	0.89	1.29	1.32	1.06	1.12	0.96
	2041–2070	1.07	0.91	0.92	1.03	0.81	0.69	0.61	0.82	1.03	0.95	1.09	0.98
	2071–2100	1.09	0.96	0.97	0.95	0.64	0.48	0.38	0.53	1.05	1.26	1.35	1.07
RCP 8.5	2011–2040	1.01	0.97	0.99	1.11	0.91	0.9	0.91	1.23	1.14	1.02	1.13	0.95
	2041–2070	1.08	0.95	0.91	1.02	0.78	0.67	0.64	0.88	1.26	1.26	1.21	1.03
	2071–2100	0.99	0.83	0.74	0.76	0.55	0.43	0.4	0.68	0.94	1.11	1.14	0.99
RCP 2.6	2011–2040	1.08	0.94	0.99	1.14	0.96	0.97	0.86	1.15	1.27	1.06	1.2	1.05
	2041–2070	1.05	0.86	0.85	0.94	0.74	0.7	0.77	1.16	1.26	1.05	1.13	1.02
	2071–2100	1.02	0.88	0.93	1.05	0.86	0.74	0.6	0.73	1.19	1.22	1.21	1.12

Lavasanat basin (983 km²) is a Salt Lake sub-basin located at geographical coordinates of 35° 45' to 36° 5' N, 54° 50' to 51° 20' and 51° 58' E, with an average annual temperature of 13.5 °C. Here, the annual precipitation reaches an average level of 187 mm. August is the driest month with a mean precipitation of < 1 mm, while precipitation is maximum in March with 32 mm

on average. Damavand basin (766 km²) is another Salt Lake sub-basin situated at geographical coordinates of 35° 33' to 35° 52' N and 51° 47' to 52° 14' E, with a mean annual temperature of 12.1 °C. The annual precipitation amounts to an average of 149 mm. August with a mean precipitation of < 1 mm is the driest month, while the maximum average precipitation of 32 mm

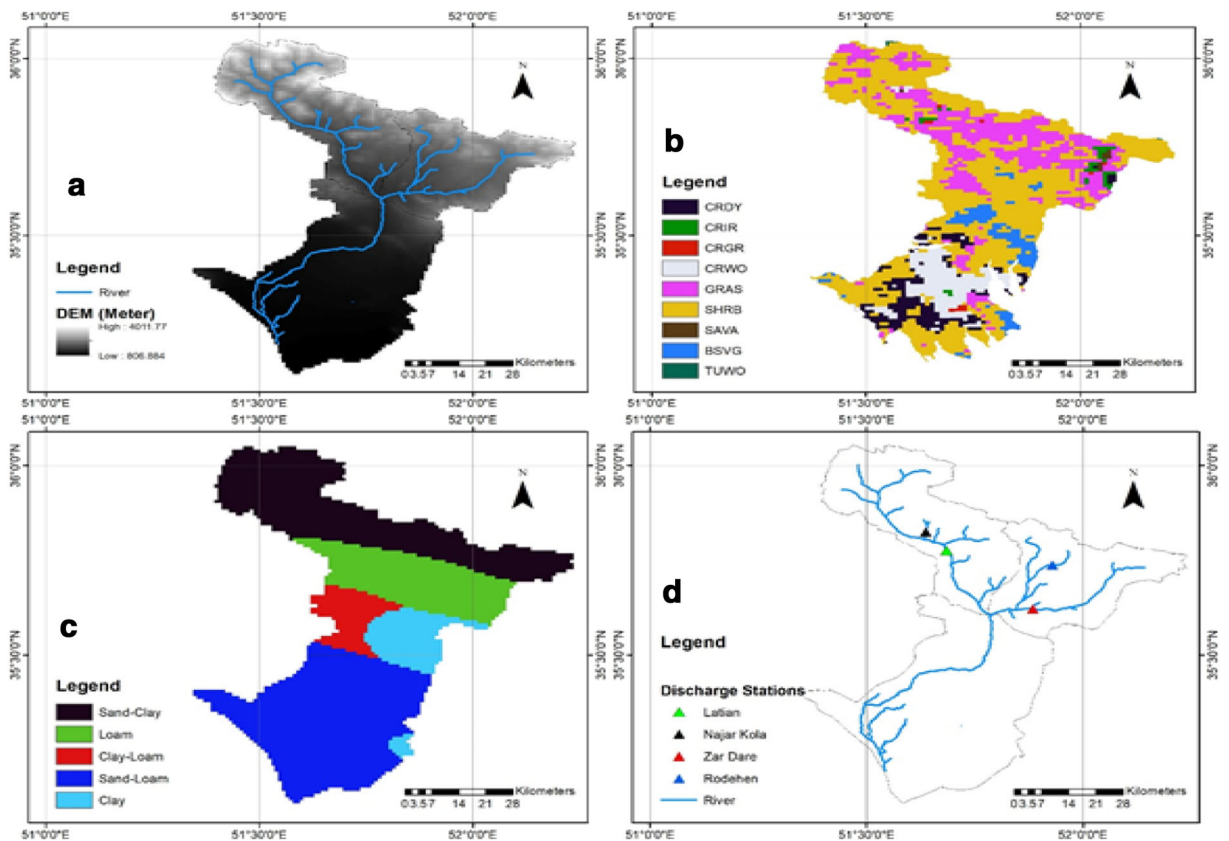


Fig. 2 DEM (a), land use (b), soil map (c), and hydrometric stations (d)

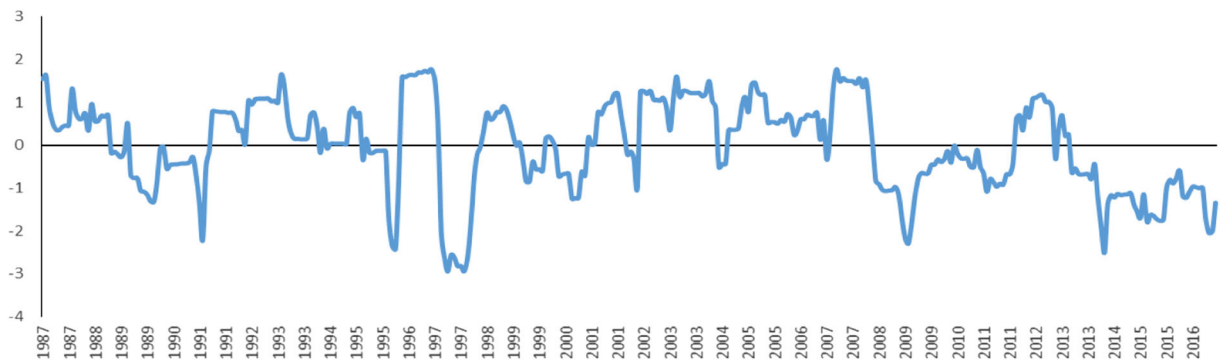


Fig. 3 SPI index chart of Varamin plain (1987–2016)

occurs in March (Table 1). As another Salt Lake sub-basin, Varamin basin (1720 km²) is located at geographical coordinates of 35° 7' to 35° 39' N and 51° 26' to 51° 55' E, with a mean annual temperature of 16.9 °C. The annual precipitation averages an amount of 149 mm. The driest month is August with a mean precipitation of < 1 mm, while the maximum average precipitation of 32 mm happens in March. The Jajrod, Kandrod-Galandook, Damavand, and Ah Rivers are located in the study basin. Among all, Jajrod watershed is the most of interest in which it has Latian Dam reservoir upstream (Alamdarlo et al. 2014).

Data

In this study, SWAT hydrological model was developed using a 30-m Digital Elevation Model (DEM) layer, land use layer of 2010, and FAO v2 soil layer with 1 km dimensions (Fig. 2a–c). In the first phase of modeling, the basin was divided into some sub-basins based on topography and dividing line network in ArcGIS environment. Then, each sub-basin was

divided into some hydrological response units (HRUs) according to land use features, soil profile, and slope. The studied basin was totally divided into 68 sub-basins and 257 HRUs.

Daily data of minimum and maximum temperatures as well as precipitation from Varamin, Garmsar, and Dushan Tappe meteorological stations (were introduced into the model to simulate the processes of interest for the period 1986–2016 using SWAT software (Ver. 2012) as a program in ArcGIS 10.2 software. The model was then calibrated and validated using monthly water yield from four hydrometric stations by SWAT-CUP software through SUFI-2 algorithm. The location of hydrometric stations is presented in Fig. 2d.

SWAT structure

SWAT is a continuous model on the basin scale designed to project the impacts of various management strategies on water levels, sediments, and chemical-agricultural substances on vast and complex basins with different soil, land use, management, and morphological

Table 2 Average minimum temperature changes under climate scenarios (°C)

Scenario	Periods	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RCP 6	2011–2040	0.21	0.12	0.6	0.46	0.64	0.63	0.99	0.5	0.55	0.16	0.62	0.57
	2041–2070	1.28	1.16	1.94	2.06	2.46	2.75	3.27	2.59	2.24	1.53	1.9	1.75
	2071–2100	2.2	2.03	2.99	3.46	4.4	4.88	5.3	4.53	3.82	2.71	2.81	2.7
RCP 8.5	2011–2040	0.34	0.29	0.74	0.57	0.72	0.63	0.94	0.4	0.58	0.35	0.9	0.69
	2041–2070	1.23	1.1	1.77	1.85	2.27	2.6	3.13	2.47	2.22	1.54	1.73	1.51
	2071–2100	2.51	2.55	3.54	4.19	5.46	6.16	6.37	5.34	4.66	3.67	3.67	3.09
RCP 2.6	2011–2040	0.21	0.16	0.69	0.52	0.59	0.47	0.92	0.57	0.64	0.25	0.65	0.51
	2041–2070	0.92	0.88	1.66	1.81	2.35	2.57	2.71	1.76	1.61	1.2	1.58	1.32
	2071–2100	1.79	1.8	2.34	2.39	3.05	3.41	3.87	3.15	2.44	1.45	1.8	1.95

Table 3 Average maximum temperature changes under climate scenarios (°C) periods

Scenario	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
RCP 6	2011–2040	0.09	−0.23	0.45	0.4	0.88	0.61	0.73	0.47	0.62	−0.01	0.54	0.54
	2041–2070	1.14	0.85	1.77	1.99	2.73	2.74	3	2.55	2.28	1.37	1.82	1.74
	2071–2100	2.06	1.69	2.8	3.43	4.64	4.87	5.03	4.53	3.87	2.55	2.73	2.64
RCP 8.5	2011–2040	0.19	−0.06	0.61	0.52	0.98	0.6	0.68	0.39	0.62	0.17	0.82	0.68
	2041–2070	1.08	0.78	1.59	1.79	2.54	2.6	2.86	2.44	2.25	1.36	1.64	1.51
	2071–2100	2.37	2.2	3.37	4.14	5.7	6.12	6.11	5.33	4.69	3.49	3.6	3.06
RCP 2.6	2011–2040	0.08	−0.18	0.55	0.46	0.84	0.43	0.66	0.54	0.72	0.09	0.56	0.5
	2041–2070	0.76	0.55	1.48	1.73	2.61	2.55	2.44	1.73	1.61	1.03	1.51	1.3
	2071–2100	1.66	1.47	2.21	2.35	3.3	3.4	3.6	3.13	2.48	1.27	1.73	1.92

conditions in the long term. It is a physical-distributional model for assessing soil and water issues. Instead of associating regression equations to describe input-output interrelationships of variables, the model uses data related to weather, soil profile, topography, vegetation, management strategies, and land use in the basin.

River flow simulation

SWAT model uses water yield equation (Eq. 1) to simulate the hydrological cycle. The simulated hydrological processes involve evapotranspiration, runoff, snowmelt, surface seepage, deep seepage, groundwater flow, and subsurface flows.

In this research, HRUs are first formed and then divided by introducing the above maps. Thereafter, the parameters related to each main component called vegetation (DAT), edaphic (Sol), groundwater (GW), management (Mgt), and riverine (Rte) are introduced into the model.

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})_i \quad (1)$$

SW_t : final soil water content on day t , SW_0 : initial soil water content, T : time (days), R_{day} : precipitation rate on day t , Q_{surf} : runoff level on day t , E_a : evapotranspiration on day i , W_{seep} : water seepage from root zone on day i , and Q_{gw} : returned flow on day i .

SWAT sensitivity and calibration analysis

As there are many parameters in SWAT model and due to concurrent simulation of many hydrological and agricultural variables in this model, SWAT-CUP has been developed to analyze its sensitivity and calibration. There are two analyses including local sensitivity, or a parameter in a time, and global sensitivity. In local sensitivity analysis, one input is changed within predefined limits while keeping other inputs constant. Then the model output changes are examined depending on changes in each parameter. The parameter with a higher absolute value of t -stat and a P value close to zero will have a greater effect on the variable. The model is calibrated by coefficient of determination (R^2) and NS coefficient.

Table 4 Calibration and validation results for each hydrometric station in the period 1987–2016

Station	River	Station code	R^2 Calibration	NS	R^2 Validation	NS
Latian	Jajrod	41,119	0.65	0.58	0.5	0.49
Nejarkola	Kandroud-Galandook	41,159	0.67	0.57	0.54	0.47
Zar Dareh	Damavand	41,870	0.64	0.6	0.55	0.46
Rodehen	Ah	41,929	0.61	0.49	0.58	0.51

Results and discussion

SPI index

In order to investigate the drought phenomenon and its severity, the 12-month SPI index was calculated. In years when the SPI number is less than 0, there is drought while, in those years when this number is higher than one, it is a mild period. As displayed in Fig. 3, the largest mild period is 5 years. Since 2008, relatively severe droughts have occurred in the plain of Varamin. Since 2013 onwards, the drought became very severe during this period, and the SPI index reached the value of -1 . In 2015, this figure was -1.31 , and in 2016, the

SPI index was lower than -2 . The greatest drought had happened in the base year of 1997 with the SPI index of -3 . On the other hand, the best mild period was in 1996 with an index over $+2$.

Generation of daily climate scenarios

Precipitation as well as minimum and maximum temperatures in the studied station was forecasted in most RCP 6, RCP 8.5, and RCP 2.6 scenarios for the periods 2011–2040, 2041–2070, and 2071–2100. Tables 6 and 7 provide the monthly changes in long-term time series along with average results of precipitation and

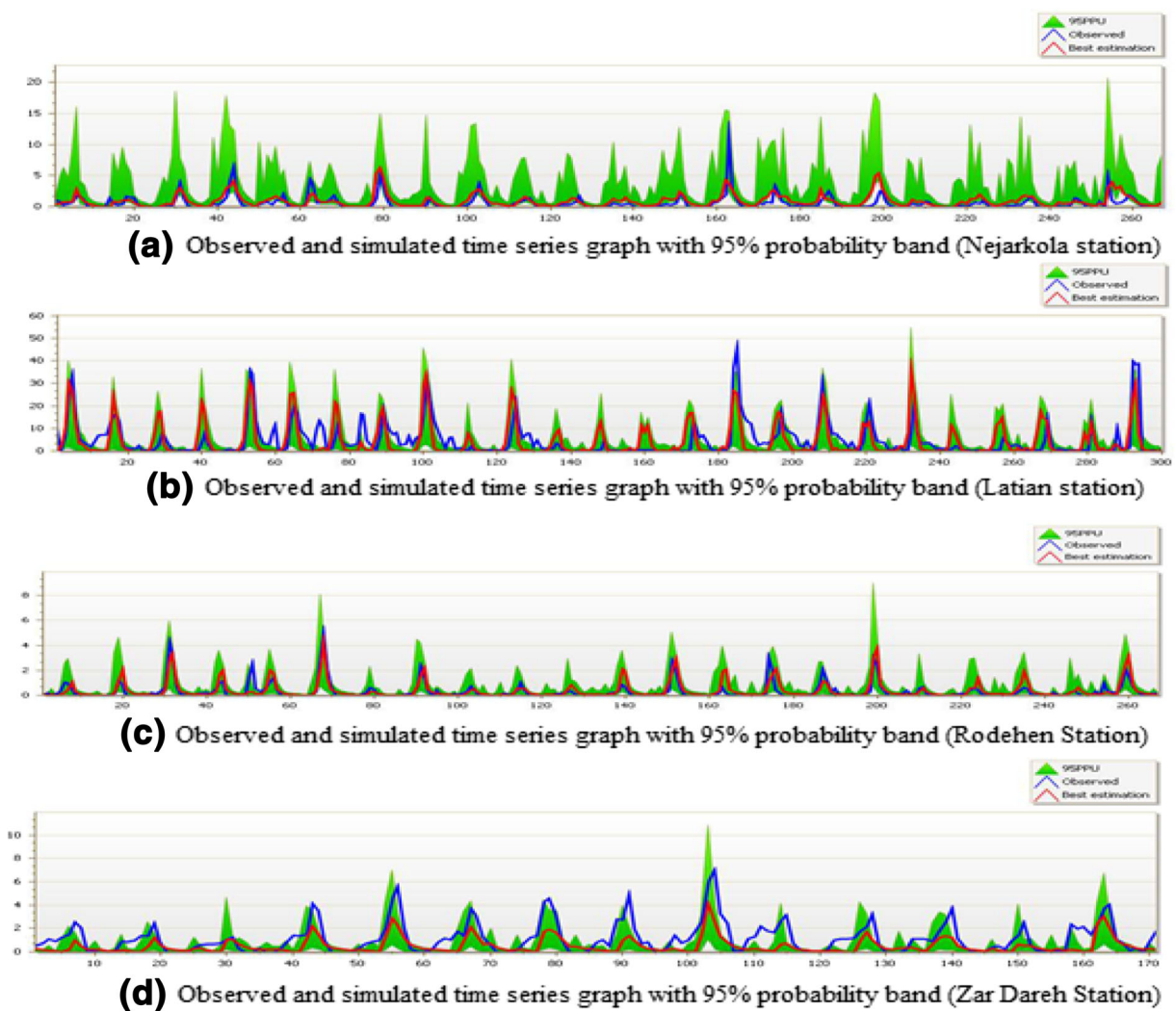


Fig. 4 Observed and simulated time series graph with 95% probability band: **a** Nejarkola station, **b** Latian station, **c** Rodehen station, and **d** Zar Dareh station

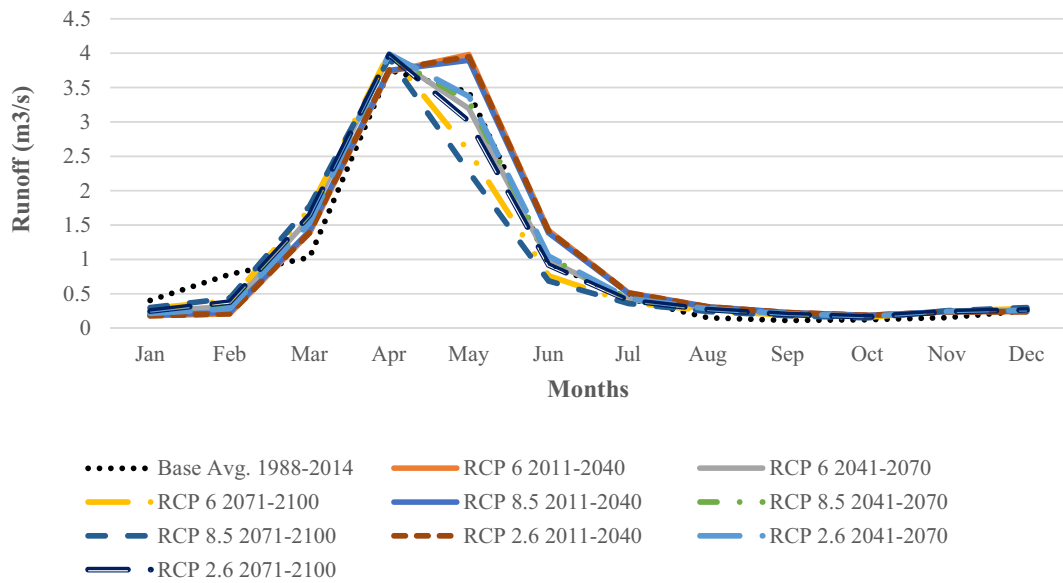


Fig. 5 Monthly average runoff chart of Nejarkola hydrometric station under climatic scenarios

temperature variables in future periods compared to the measured period, respectively.

As projected, the minimum temperatures will rise in all months; also the maximum temperatures will also grow across all months, except in February and October, during the statistical period 2011–20,400 (Tables 2 and 3). Wilby and Harris (2006) found similar results. Growing temperature will be associated with the most

devastating effect of climate change, i.e., increasing drought in the area. As represented in Table 1, changes have occurred both in precipitation rate and in its patterns. Hence, precipitation will decline in most months, with the greatest decline occurring in summer under RCP 8.5 scenario during the period 2071–2100. Delavar et al. (2018) found similar results using different climatic scenarios.

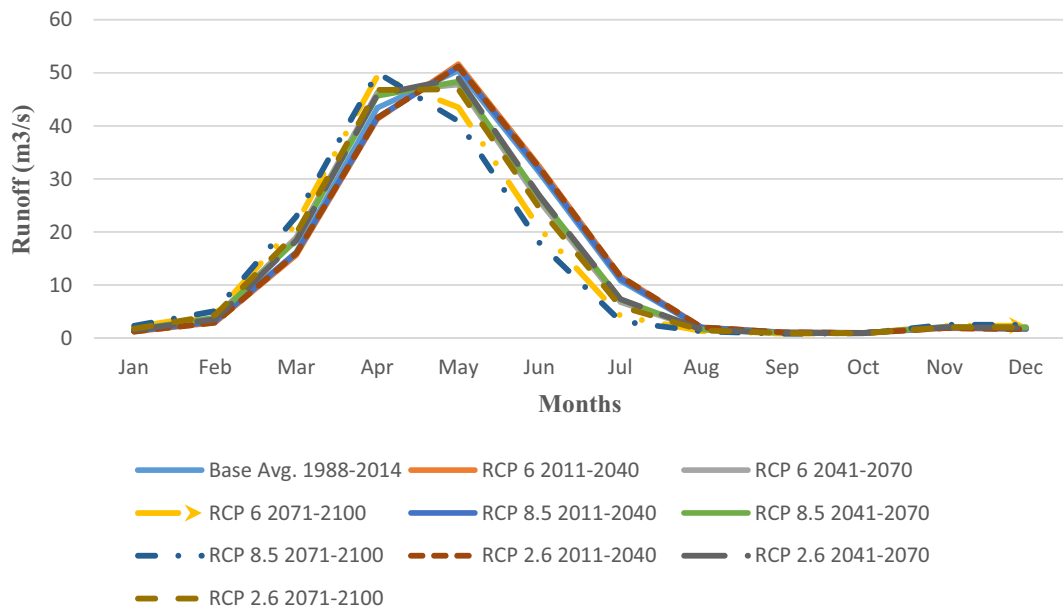


Fig. 6 Monthly average runoff chart of Latian hydrometric station under climatic scenarios

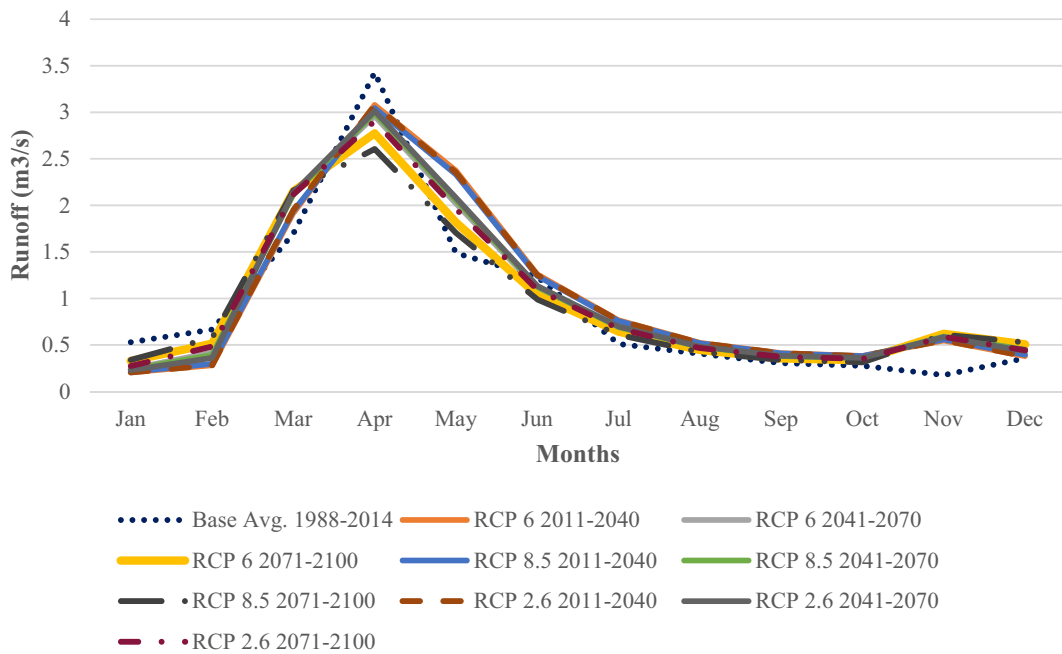


Fig. 7 Monthly average runoff chart of Rodehen hydrometric station under climatic scenarios

Sensitivity analysis of model parameters

Finally, the period 1998–2016 was selected. Then, calibration and validation of SWAT model were performed through preparing monthly time series of the measured data using SWAT-CUP software and SUFI-2 algorithm. A total of 103 sensitive parameters were calibrated and validated to simulate

runoff in the model. The parameter with a relatively higher *t*-stat absolute value and a *P* value close to 0 has had a greater impact on the stream flow. In this study, parameters with relatively greater impacts on the streamflow were CN2.mgt (Scs runoff curve number), PLAPS.sub (Precipitation lapse rate (mm/km)), and SOL_BD (...)sol (Moist bulk density (mg/m³)).

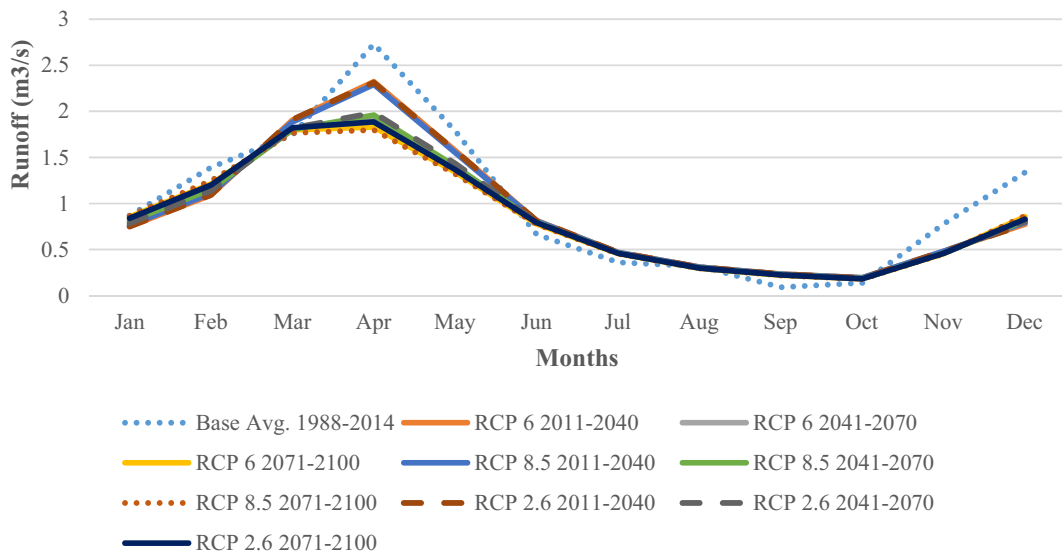
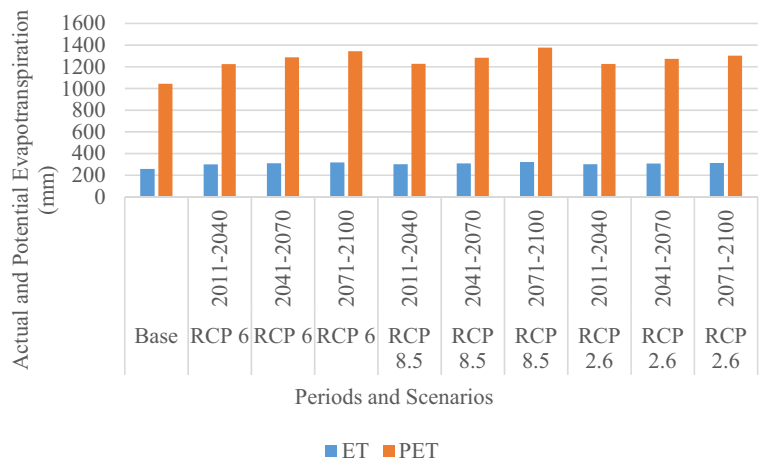


Fig. 8 Monthly average runoff chart of Zar Dareh hydrometric station under climatic scenarios

Fig. 9 Evapotranspiration under climatic scenarios



Calibration and validation of SWAT model

After sensitivity analysis, the model was calibrated and validated using monthly statistics from four hydrometric stations. The model simulations were evaluated by coefficient of determination (R^2) and NS coefficient (Table 4). Despite the vastness of the basin, the final calibration values indicated the ability of SWAT model in simulating the basin. Figure 4 displays the measured and simulated time series of stream flow with 95% confidence level.

Simulation of runoff influenced by climate change

Following climate data for future periods, a 30-year time series of the data for all three future periods was prepared to be introduced into SWAT model. Afterwards, SWAT output with the applied coefficients was analyzed by SWAT-CUP, and monthly runoff level was simulated based on the baseline period duration for future periods under climate scenarios. Figures 5, 6, 7, and 8 illustrate climate change effects on the mean monthly runoff levels for hydrometric stations.

As displayed in Figs. 5, 6, 7, and 8, the streamflow curves for future periods under all three scenarios are shifted rightward compared to the baseline period suggesting ascending and descending runoff levels in winter, as well as in summer and spring, respectively. Such a shift results from climate change impacts (snowmelt, altered precipitation pattern, etc.) on the basin runoff. Among the hydrometric stations, that of Latian Dam presented the minimum runoff level. According to the results, runoff will increase in spring and summer, but it

will drop in fall and winter. The minimum and maximum runoff levels occur during the 2070–2100 period under RCP 8.5 scenario in summer and winter, respectively. These results are similar to Bajracharya et al.’s results in 2018.

Evapotranspiration influenced by climate change

As represented in Fig. 9, both actual and potential evapotranspiration were simulated for future periods under climate scenarios and compared with the baseline period. Accordingly, both future-period actual and potential evapotranspiration indicate a rising trend with potential evapotranspiration being always higher than actual values.

Simulation of crop yield

The representative crops including wheat, barley, and alfalfa were introduced to SWAT model. Then, the mean crop yields were simulated in years without water tension for average amounts of 4 t/ha (irrigated) and 1.2 t/ha (rainfed) crops.

Table 5 Comparison of the yield of basic and simulated agricultural products

Products	Base period yield (tons per hectare)	Simulated yield (tons per hectare)
Irrigated crops	3.7	4
Rainfed crops	1.8	1.2
Horticultural products	9.8	9.5

Table 6 Predicted yield of agricultural products in future periods under climate scenarios

Scenario	Period	Irrigated crops	Rainfed crops	Horticultural products
RCP 6	2011–2040	4	1.1	9.7
	2041–2070	4.1	1.2	9.8
	2071–2100	3.9	1.1	9.5
RCP 8.5	2011–2040	4	1.3	9.6
	2041–2070	4.2	1.5	9.9
	2071–2100	4.1	1.2	10
RCP 2.6	2011–2040	4.1	1.1	9.2
	2041–2070	4	1.1	9.2
	2071–2100	3.9	1.2	9.4

The mean crop yields are 3.7 t/ha and 1.8 t/ha for irrigated and rainfed crops, respectively. In the areas under investigation, major horticultural products are cherry, walnut, pomegranate, and olive, all of which were introduced to SWAT model. Based on the reports by the Energy and Agriculture Jihad ministries, the average yields of these products have been recorded as 9.8 t/ha. SWAT model simulated an average yield of 9.5 t/ha in years without water tension (Table 5).

According to our findings and thanks to the high accuracy of SWAT model in simulating crop yields, it can be used for crop yield simulation in future periods. Table 6 outlines the simulation of crop yields for future periods under RCP climate scenarios.

Table 7 Estimated yield of representative crops under climatic scenarios

Scenario	Period	Wheat	Barley	Alfalfa	Horticultural products
Base		5.2	4.9	5.1	6.5
RCP 6	2011–2040	5.2	4.87	5.12	6.8
	2041–2070	5.1	4.81	5.19	6.77
	2071–2100	5.1	4.78	5.15	6.6
RCP 8.5	2011–2040	5.32	4.88	5.1	6.51
	2041–2070	5.24	4.98	5.3	6.21
	2071–2100	4.95	4.68	5.16	6.25
RCP 2.6	2011–2040	5.33	4.9	5.21	6.54
	2041–2070	5.29	4.85	5.2	6.55
	2071–2100	5.22	4.84	5.1	6.44

Agronomical and horticultural products in the surveyed basin have not undergone considerable changes compared to the baseline period given the use of groundwater for irrigation of crops. This is because irrigation by groundwater is always constant and not dependent upon surface water and precipitation. Basin feeding by precipitation has been reported to be less than 7%. Also, SWAT model considers groundwater as a reservoir containing water forever. No visible changes are practically seen in crop yields irrigated with groundwater (Table 7).

Conclusion

This study examined climate change impact on the surveyed basin runoff during the periods 2011–2040, 2041–2070, and 2071–2100 using SWAT models under RCP 6, RCP 8.5, and RCP 2.6 emission scenarios. Variations in precipitation and temperature were analyzed as two climate-introducing variables. The mean downscaled results of the baseline period shifted rightwards suggesting ascending and descending runoff levels in winter, as well as in summer, respectively. Such a shift results from climate change impacts (snowmelt, altered precipitation pattern, etc.) on the basin runoff. In other words, an increase in spring runoff can be caused by temperature rise, snowmelt, altered precipitation pattern, and other factors. Elevating temperature will be associated with the most detrimental effect of climate change, i.e., increasing drought in the area. Negative effects of rising temperature on water resources may be exacerbated by evaporation leading to lowered quantity and quality of water resources. Future-period evapotranspiration will grow under all three scenarios with adverse consequences on water resources of the area. Diminishing precipitation in future periods will lead to reductions in rainfed crop yields. However, since both agronomical and horticultural products are irrigated by groundwater, climate change will not have considerable impacts on the yields of such crops. It is recommended that land use alterations be also studied together with climate change in future investigations.

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