

## Water resources availability under different climate change scenarios in South East Iran

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### ABSTRACT

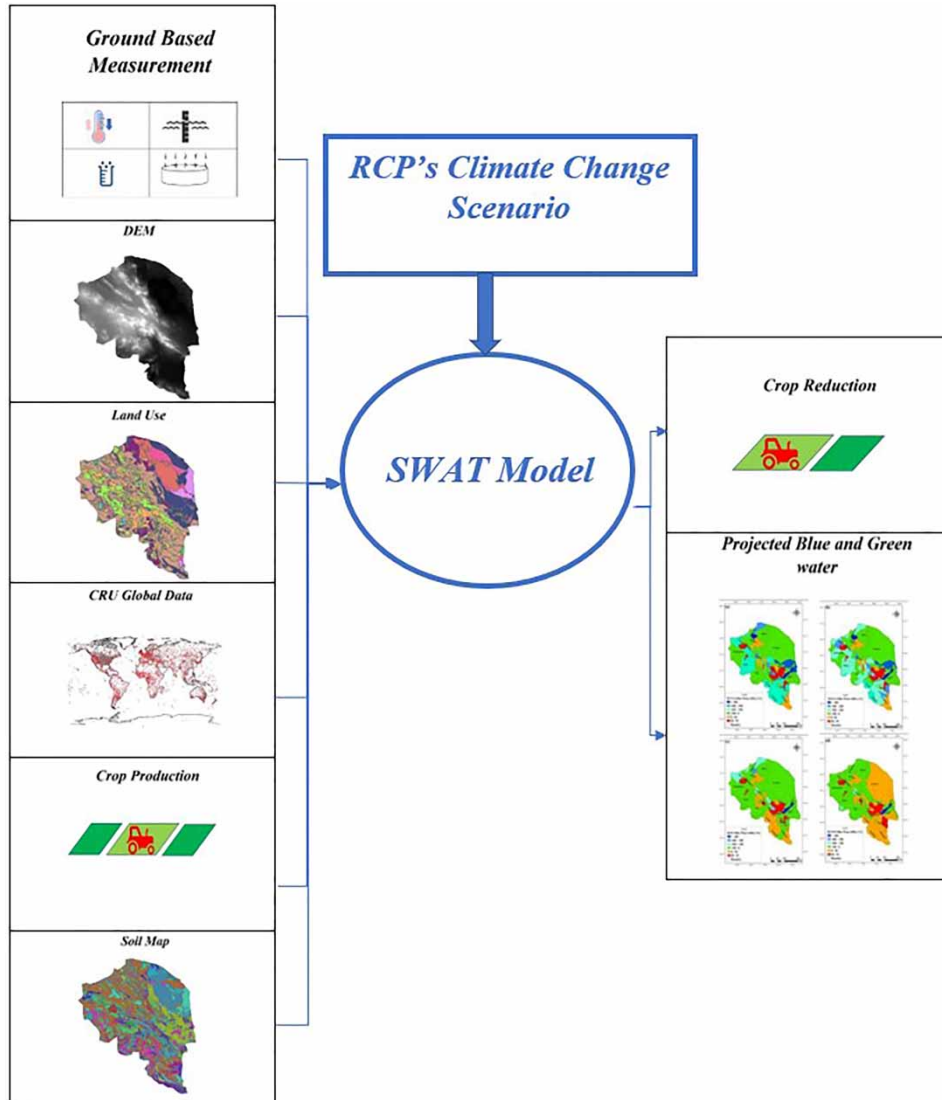
The comprehensive large-scale assessment of future available water resources is crucial for food security in countries dealing with water shortages like Iran. Kerman province, located in the south east of Iran, is an agricultural hub and has vital importance for food security. This study attempts to project the impact of climate change on available water resources of this province and then, by defining different scenarios, to determine the amount of necessary reduction in cultivation areas to achieve water balance over the province. The GFDL-ESM2M climate change model, RCP scenarios, and the CCT (Climate Change Toolkit) were used to project changes in climatic variables, and the Soil and Water Assessment Tool (SWAT) was used for hydrological simulation. The future period for which forecasts are made is 2020–2050. Based on the coefficient of determination ( $R^2$ ) and Nash–Sutcliffe coefficient, the CCT demonstrates good performance in data downscaling. The results show that under all climate change scenarios, most parts of the province are likely to experience an increase in precipitation yet to achieve water balance a 10% decrease in the cultivation area is necessary under the RCP8.5 scenario. The results of the SWAT model show that green water storage in central and western parts of the province is higher than that in other parts.

**Key words:** climate change, management scenarios, SWAT, water resources availability

### HIGHLIGHTS

- The study is carried out in a part of the Middle East where the most severe water crises exist.
- It tries to evaluate the future situation of the available water of the region under climate change impacts.
- It uses the worldwide accepted models, namely SWAT and CCT.
- There are few scientific studies on available water in this region accompanied by some policy to reduce the negative impacts.

## GRAPHICAL ABSTRACT



## INTRODUCTION

Iran is one of many countries that have been increasingly struggling with water scarcity. So far, much research has been done on the risks and impacts of water scarcity in different parts of the world (Kummu *et al.* 2016). Since the main consumer of water resources is the agricultural sector, the main focus of these studies has been the impact of water scarcity on this sector and vice versa. Given the close and direct relationship between water and food production, comprehensive large-scale assessments of available water resources are crucial for protecting food security and developing management strategies for the conservation of water resources (Faramarzi *et al.* 2009). The most important determinants of the amount of water resources available in an area are the climate and hydrological parameters of that area. Due to the future climate change impacts on water resources, long-term water resource management plans should be carried out considering these impacts. Following the change in the climate of a region, naturally, one can expect changes in multiple characteristics of that region, including the discharge regime of rivers, the rate of evaporation from water and soil surfaces, and the rate of evapotranspiration, erosion, and sedimentation (IPCC 2001).

General circulation models (GCMs) output is used to assess the future possible climatic situation under different scenarios. Each scenario deals with a wide range of variables including future population growth and economic and technological

factors that affect the greenhouse gas emissions (IPCC 2014). In this study, the Climate Change Toolkit (CCT)<sup>1</sup> was used to downscale large spatial simulated climatic variables generated by the GCMs. The CCT has been developed by Vaghefi *et al.* (2017) at the Swiss Federal Institute of Aquatic Science and Technology (EAWAG). The Soil and Water Assessment Tool (SWAT) model was used to model available water resources over the Kerman province for a future analysis of the time period. The SWAT was first designed by Jeff Arnold at the U.S. Agricultural Research Service in 1990. This modeling paradigm has been applied in many scientific studies over the past years and the following is a review of some of these studies.

Parajuli *et al.* (2016) investigated the effect of climate change and tillage operations on runoff, sediment, and crop yield in a watershed in the Mississippi River basin. The results of this study showed that the combined effect of climate change and tillage operations does not have a significant impact on yield, but reduced tillage reduces the amount of sediment produced in the downstream. Many similar studies have been conducted in this field, for example, by Li *et al.* (2015), Zuo *et al.* (2015), Yuan *et al.* (2015), and Li *et al.* (2016) on the effect of climate change and land-use change on runoff, by Verma *et al.* (2015) and Ramos & Martínez-Casasnovas (2015) on the impact of climate change on runoff and sediment, and by Palazzoli *et al.* (2015) on the effect of climate change on runoff and crop yield. Also, Abbaspour *et al.* (2009) used a similar approach to study the impact of climate change on water resources in Iran and also on blue water and green water in this country. These researchers used the Coupled Global Climate Model to model climate change and used the SWAT to model hydrological changes in Iran. Ultimately, they concluded that given the current trends of climate change, wet parts are likely to receive more rainfall and dry regions are likely to receive less rainfall in the future. Faramarzi *et al.* (2013) also investigated the effects of climate change in Africa using the SWAT model. Bhatta *et al.* (2020) investigated the performance of the SWAT model in simulating the impacts of climate change on the hydrology of the Himalayan River basin in Nepal. These researchers reported a decrease in river discharge under the RCP8.5 scenario and also verified the good performance of the SWAT model. Fazeli Farsani *et al.* (2019) used the SWAT model to study the effects of climate change on blue water and green water in mountainous basins and reported a decrease in blue water and an increase in green water. In a study by Anand & Oinam (2019) on the impact of climate change on the river regime, it was reported that climate change has many effects on river regime and evapotranspiration is very sensitive to changes in temperature and precipitation.

The impact of climate change on runoff, blue water, green water, and dry spell length has been investigated by many researchers and organizations including IPCC (2014), Bartolomeu *et al.* (2016), Krysanova *et al.* (2015), Vaghefi *et al.* (2014), and Vorosmarty *et al.* (2000). In a study by Hashemi *et al.* (2010), in which they compared the outcomes of using LARS-WG and SDSM in the simulation of extreme rainfall events in the Clutha Basin in the South Island of New Zealand, the results showed that both models perform similarly well in this application. Other studies conducted to examine the performance of LARS-WG and SDSM, including Cheema *et al.* (2013); Kazmi *et al.* (2014), Nury & Alam (2014), Goodarzi *et al.* (2015), and Sobhani *et al.* (2015), have all confirmed the accuracy of these two models in simulating future climate change in different parts of the world. In a study carried out by Vaghefi *et al.* (2017), they developed another model called the CCT for simulating the impact of climate change. In this research, which was conducted on a basin in California, the results showed that this model produces excellent outputs for the study of climate change and its impacts.

In summary, the above review shows that while many researchers have used LARS-WG and SDSM to study the effects of climate change in different regions, very few have used the CCT for this purpose; this can be largely attributed to the relative novelty of this software package. Therefore, this study used the CCT to forecast the impacts of climate change based on down-scaled outputs of GCMs under different RCP scenarios.

Kerman is the largest province of Iran and also one of the region's most important agricultural hubs. Hence, monitoring the impact of climate change as well as water usage on water resources of this province is of vital importance for the country's food security and agricultural output. This study primarily aimed to calibrate the SWAT model for Kerman province at the sub-basin level, use this model to formulate climate change scenarios and project their impacts on water balance, and determine which changes in the area under cultivation can help us maintain the current water balance without undermining food security and agricultural production. The secondary objective of the study was to estimate the available water on a monthly basis and decompose it into its components, namely blue water (sum of surface runoff and deep aquifer recharge), green water storage (soil moisture), and green water flow (actual evapotranspiration). The study also examined the performance of CCT in climate change impact simulation.

<sup>1</sup> <https://www.2w2e.com/home/CCT>.

## MATERIALS AND METHODS

### Study area

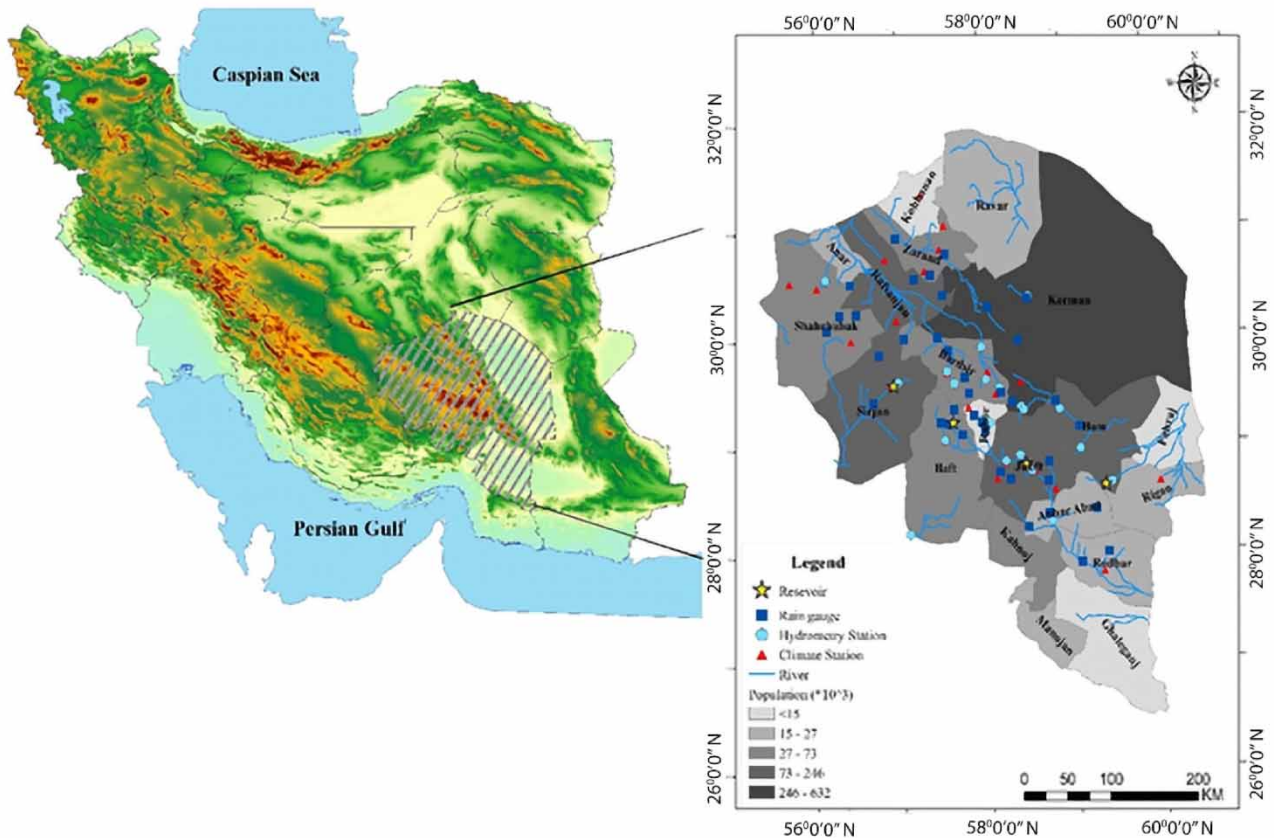
Kerman province is located in the southeast of the central Iranian plateau between  $53^{\circ}26'$ – $59^{\circ}29'$  eastern longitudes and  $25^{\circ}55'$ – $32^{\circ}00'$  northern latitudes. According to the census conducted in 2016, this province has a total population of 3,164,718. Constituting more than 11% of the area of Iran, Kerman is the largest province of this country. Figure 1 shows the location of Kerman province in the map of Iran and the distribution of meteorological stations, hydrometric stations, and dams in this province.

### Data

The data used in this study and the sources from which they were gathered are listed in Table 1. To ensure better density and dispersion of meteorological data, the study used a combination of observed data and global Climate Research Unit (CRU) data. Besalatpour *et al.* (2013) have shown that using a combination of observed climatic data (from the stations within the basin) and global CRU data improves the accuracy of the SWAT model. Global CRU data accompanied by the regression method was used to fill data gaps in this study.

### Climate change toolkit

The CCT is an efficient software toolkit for performing data extraction, interpolation, and deviation correction operations on the data obtained from global climate models (Vaghefi *et al.* 2017). The CCT makes use of five GCMs from ISI-MIP and four RCP scenarios. For the mentioned models and scenarios, the toolkit uses the Bias Correction Statistical Downscaling method to correct biases for the chosen region (Vaghefi *et al.* 2017). In recent studies, it has become a common practice to use multiple GCMs to reduce uncertainty. However, a study by Liess *et al.* (2018) has shown that this is not a good solution to reduce uncertainty. After testing the approach with 38 GCMs, these researchers reported that even removing the poor models using the ensemble method did not make a significant change in the obtained mean and standard deviations. The present study



**Figure 1** | Location of the study area and distribution of meteorological stations, hydrometric stations, and dams in this area.

**Table 1** | Source of data used in the research

Station/map	Data	Source
Hydrometric station and dam data	Runoff – sediment load	Ministry of Energy
CRU data	Precipitation – max, min temperature	<a href="http://www.cru.uea.ac.uk">www.cru.uea.ac.uk</a>
GFDL-ESM2M data	Precipitation – max, min temperature	<a href="http://www.2W2E.com">www.2W2E.com</a>
Rain gauge	Precipitation	Ministry of Energy
Climate station	Precipitation – max, min temperature – pan evaporation	Ministry of Energy
Synoptic station	Precipitation – max, min temperature – relative humidity – wind – solar radiation	WSIMO
Topography	DEM	NCC
Soil map	Soil data	FAO
Land-use map	Land use	USGS
Crop yield	Crop yield	MOJA

used GFDL-ESM2M and four RCP scenarios to project precipitation and maximum and minimum temperatures. GFDL-ESM2M was chosen because it has been developed recently by the NOAA and GFDL to better understand the Earth's bio-chemical cycle, including human activities and their interaction with the climate system. Also, GFDL-ESM2M uses the land model version 3.0 (LM3.0), which includes new hydrology, physics, and terrestrial ecology components. Also, the ESM2M version of this model uses new components instead of the ocean dynamical/physical component of the previous version (Dunne *et al.* 2012).

### Soil and Water Assessment Tool

The SWAT has been designed to predict the long-term and large-scale impacts of different land management practices on water resources, sediment production, and movement of agricultural chemicals in large basins with different types of soil and land use. The primary advantage of this model is that it can be used in the simulation of basins for which extracted data are limited (Stehr *et al.* 2008). It also allows us to quantify the relative impact of input data (changes in management practices, climate, and land use) on water quality and other variables of interest. The SWAT can work with any type of input data that is available and is computationally efficient, which makes it perfect for fast simulation of large and complex basins with a wide variety of management solutions. Before the simulation, the basin must be segmented into a number of sub-basins. The use of sub-basins in simulation is especially useful when different parts of the basin have different types of soil or land uses and this heterogeneity can affect the hydrology of the basin. Dividing the basin into sub-basins also enables the model to factor in the differences in the amount and intensity of evapotranspiration from different plants and soils. In this model, runoff in each hydrological response unit is estimated independently, and in the end, the total amount of runoff in the basin is determined based on these estimations.

### Sensitivity analysis, calibration, and validation

Calibration is the act of modifying sensitive parameters in the model, such that outputs become more consistent with the observed data (Abbaspour *et al.* 2007). For the SWAT, this can be achieved only by changing the parameters repeatedly, which can become an arduous and time-consuming task. Hence, an interface program called SWAT-CUP has been developed to facilitate this process. In this study, this process was carried out using the SUFI-2 algorithm in SWAT-CUP. SUFI-2 makes sure that the modeling factors in all major uncertainties, including those in inputs, conceptual model, parameters, and measured data. After calibration, the model needs to be validated. For this purpose, the data simulated for different time periods using the calibrated model must be compared with the corresponding observed data. Basically, validation means establishing the reliability of the model (Abbaspour *et al.* 2007).

In this study, simulations were performed based on the data pertaining to the 23-year statistical period from 1990 to 2012, the first 2 years of which were used for the model warming-up process. During this process, the model adjusts itself by moving from initial states to optimal ones. Since most of the hydrologic data are nonstationary, using a calibration data set can derive an optimal set of parameters which may not be valid for another data set, so it is not possible to set a data boundary for this purpose. In this study, of the total runoff and evapotranspiration available data, 70% were used for model calibration and the

remaining 30% were used for model validation in a chronological order. These data percentages were derived by a trial-and-error method to achieve the best model parameter set. Calibration was evaluated by the use of the coefficient of determination ( $R^2$ ), Nash–Sutcliffe coefficient (NS), and  $P$ -factor as measures of accuracy. While there are no specific criteria for determining which values,  $R^2$  or NS, will be good enough in a given research, *Moriasi et al. (2007)* have suggested that in hydrological studies and studies on pollutant transfer on a monthly time scale, NS values should be greater than 0.5 for the results to be acceptable. It is also common to use the same criterion for  $R^2$  (*Moriasi et al. 2007*).

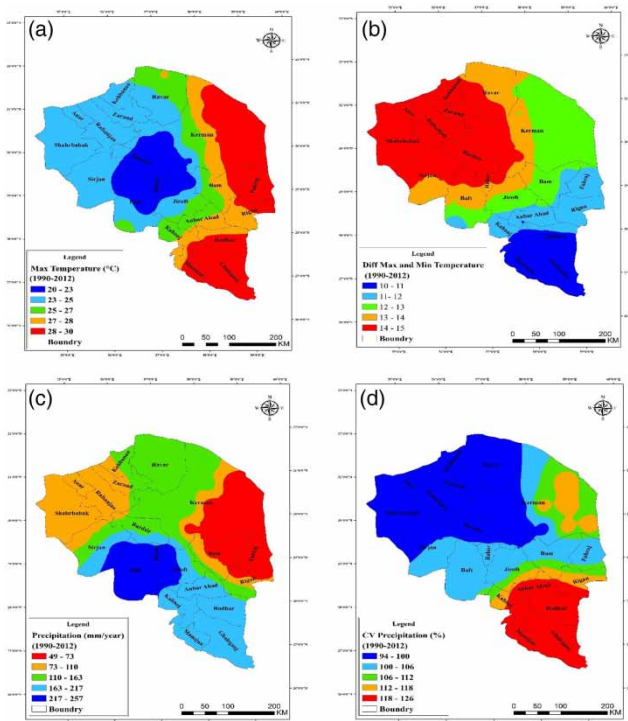
## RESULTS

The results presented in this section are divided into three sub-sections. In the first sub-section, the trends of climate change in the base statistical period (1990–2012) and the future period (2020–2050) are examined. In the second sub-section, the results of hydrological simulation using the SWAT are presented. The third sub-section discusses the impact of climate change on available water resources in Kerman province and the degrees to which water balance can be preserved by reducing the area under cultivation.

### Climate change

*Figure 2(a)* displays the average annual maximum temperature of Kerman province. In general, the average annual maximum temperatures in the base period have varied from 20 to 30 °C. *Figure 2(b)* shows the difference between the average annual maximum and minimum temperatures of Kerman province in the base period. *Figure 2(c)* shows the average annual precipitation of Kerman province in the base period. As can be seen, precipitation in this period has varied from 49 to 257 mm. *Figure 2(d)* shows the coefficient of variation (CV) of precipitation in the base period. Large values in the CV indicate severe fluctuations in the precipitation amount that may have a significant effect on increasing prolonged droughts and hence crop production in the region (*Faramarzi et al. 2013*).

After using the CCT for data downscaling, its accuracy was evaluated for the testing period in terms of NS. The NS values obtained for precipitation and minimum and maximum temperatures in all stations ranged from 0.8 to 0.95 and from 0.88 to



**Figure 2** | Average maximum temperature (a), difference between average annual maximum and minimum temperatures (b), average annual precipitation (c), and CV of precipitation (d) in the base period (1990–2012).

0.99, respectively. Figure 3 shows the NS values obtained for all stations in the study area. These results demonstrate the acceptable accuracy of the model in simulating precipitation and temperature data.

For a closer examination of the accuracy of data produced by the CCT, simulated and measured monthly mean precipitation values for two stations (Darzin and Hosseinabad) and simulated and measured monthly mean maximum temperature values for another two stations (Rabor and Zehkalot) are plotted in Figures 4 and 5. Darzin and Hosseinabad stations classify as arid and semi-arid, respectively, and Rabor and Zehkalot stations classify as semi-arid and hyper-arid, respectively.

### Trends of temperature and precipitation variations under climate change scenarios

After establishing the accuracy of model projections, the model was used to project the future trends of temperature and precipitation under different climate change scenarios. Figure 6 shows the degree of change in precipitation in the near future period compared with the base period under different RCP scenarios. As can be seen, under all scenarios, there will be an increase in precipitation in all parts of the province except southern and central parts. In some places, this increase will reach as high as 60%. In the southern and central parts of the province, however, precipitation will decrease by 10–40%.

This increased precipitation in the northern regions and decreased precipitation in the southern regions can be attributed to differences in the latitude. In a study by Ahmadi *et al.* (2015) on the effects of climate change on Khorasan province, the results showed an increase in precipitation in higher (northern) latitudes and a decrease in precipitation in the lower (southern) latitudes of this province. Khorasan province is located in the north east of Iran. From this, Ahmadi *et al.* concluded that the impact of climate change in Khorasan is more influenced by latitude than by altitude. Since a similar trend is observed for Kerman, it can be argued that latitude has a more prominent role in how this province is influenced by climate change than other factors such as altitude.

In contrast, the average monthly maximum temperature projections obtained under different scenarios show the high likelihood of temperature increase in all stations. Under the scenario RCP8.5, the maximum temperature in central, western, and northern parts of the province will be 20% higher and in southern and eastern parts will be 12% higher than the corresponding figures in the base period.

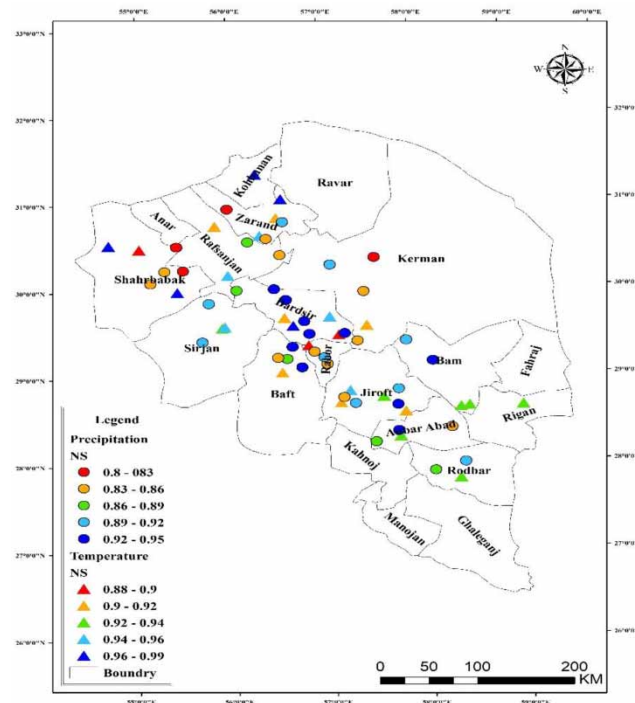
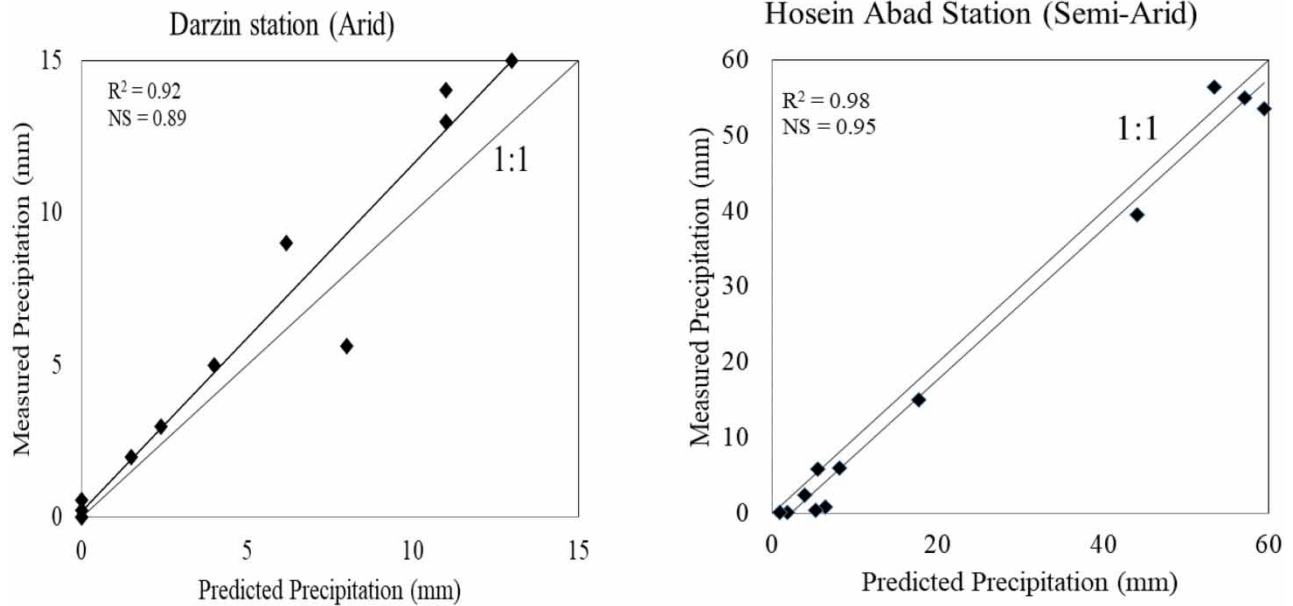
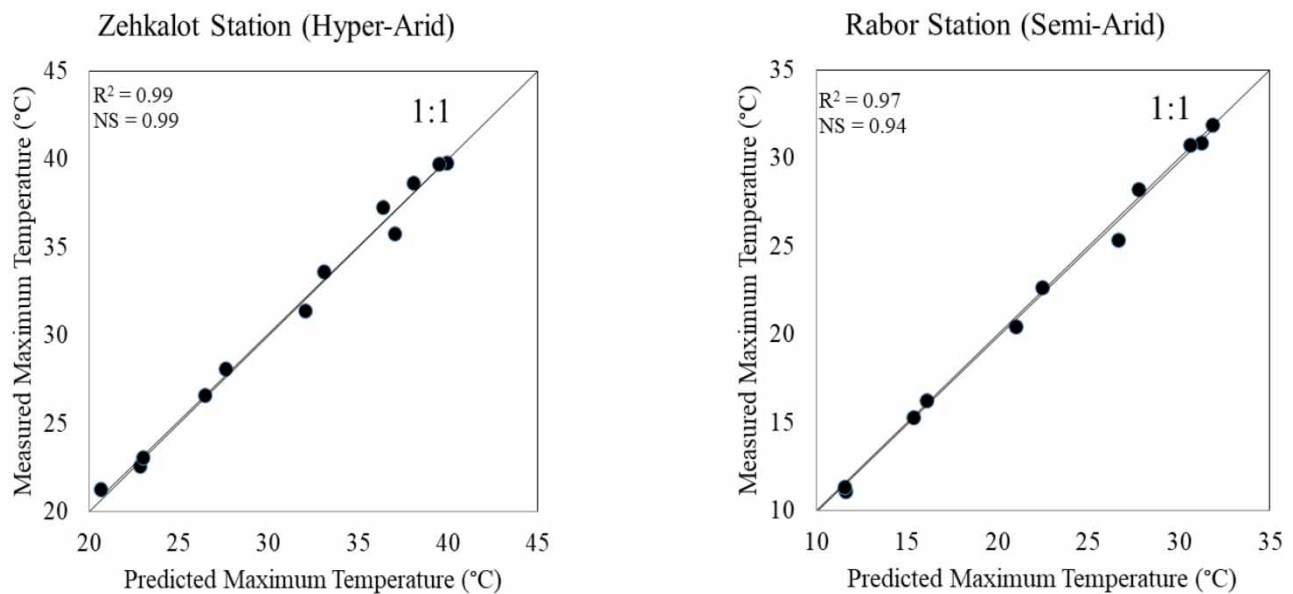


Figure 3 | NS values obtained for the stations in the study area.



**Figure 4** | Comparison of observed and projected precipitation data.



**Figure 5** | Comparison of observed and projected maximum temperature data.

## Hydrological simulation

### Calibration and validation of the SWAT model

Given the large area of Kerman province and the variability of climate, land use, soil type, and topography in this area, to calibrate the SWAT model for the province, it was segmented into four zones based on climate, soil, topography, and land use. This is a common practice in the simulations where the studied area is large in size or heterogeneous in attributes (Schuol *et al.* 2008; Abbaspour *et al.* 2009; Faramarzi *et al.* 2009; Faramarzi *et al.* 2013). These zones are illustrated in Figure 7. The list of sensitive parameters of the SWAT model, which were identified in a sensitivity analysis conducted after calibration, is provided in Table 2. This sensitivity analysis was carried out in terms of two criteria: *P*-value and



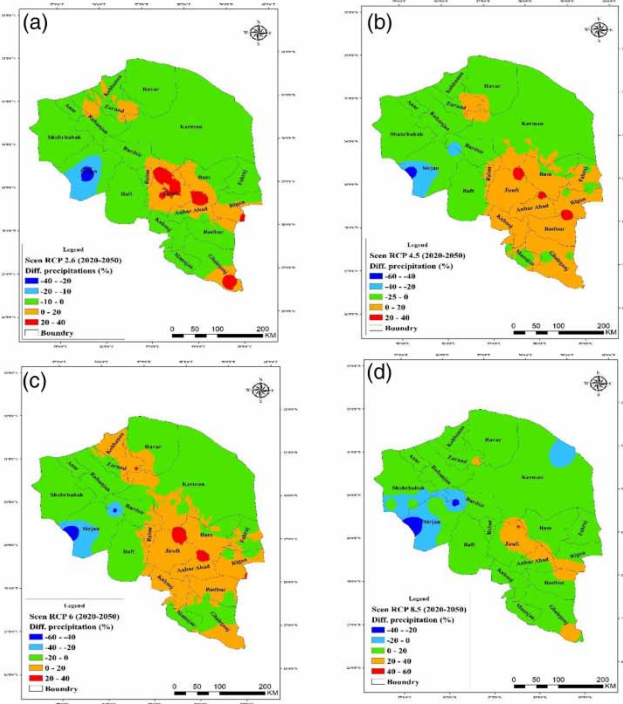


Figure 6 | Percentage change in precipitation in the near future period compared with the base period under different RCP scenarios.

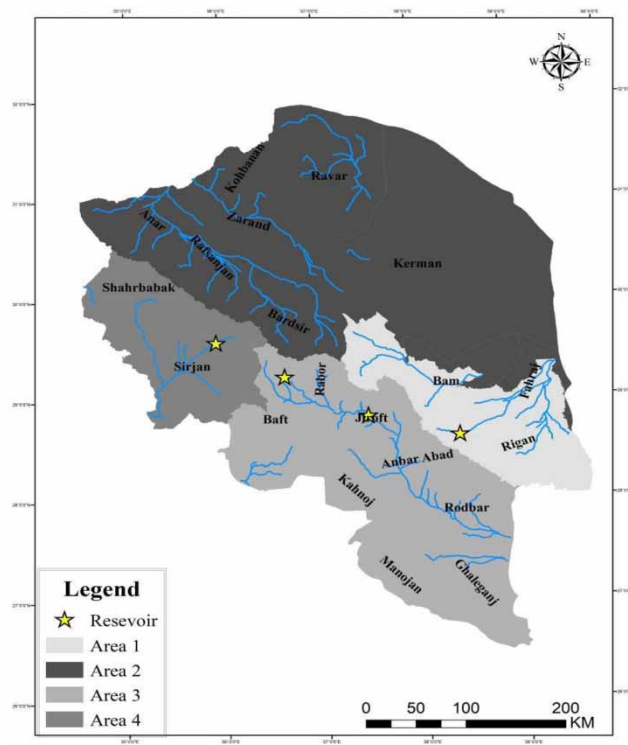


Figure 7 | Segmentation of Kerman province.

**Table 2** | Parameters of the SWAT model after final calibration

Parameter	Description	Range			
		Area 1	Area 2	Area 3	Area 4
r_ESCO.hru	The correction factor evaporation from soil	0.35–0.64	0.25–0.55	0.15–0.4	0.4–0.7
r_EPCO.hru	Plant uptake compensation factor	0.38–0.45	0.35–0.55	0.3–0.45	0.35–0.55
v_SURLAG.bsn	Delay surface runoff coefficient	2.5–8	3.5–5	3.5–6.5	4.2–7
r_SLSOIL.hru	Longitudinal slope for drainage sub (m)	–0.35– 0.35	–0.35– 0.35	–0.35–0.35	–0.35– 0.35
r_CN2.mgt	Curve number	–0.18– 0.18	–0.18– 0.18	–0.18–0.18	–0.18– 0.18
v_GWQMN.gw	Threshold depth of water in shallow aquifer (mm)	74.5–84.5	50–80	60–75	87–95
r_REVAPMN.gw	Threshold depth of water in shallow aquifer for Revap (mm)	0.88–0.92	0.45–0.65	0.4–0.6	0.52–0.65
v_GW_REVAP.gw	Groundwater 'Revap' factor	0.1–0.2	0.1–0.2	0.1–0.2	0.1–0.2
r_ALPHA_BF.gw	Ks groundwater flow	–0.8, 0.8	–0.8, 0.8	–0.8, 0.8	–0.8, 0.8
r_SOL_BD(..).sol	Bulk density (g/cm <sup>3</sup> )	–0.2, 0.2	–0.2, 0.2	–0.2, 0.2	–0.2, 0.2
r_SOL_K(..).sol	Saturated hydraulic conductivity (mm/h)	–0.5, 0.5	–0.4, 0.4	–0.45, 0.55	–0.5, 0.5
v_CH_K2.rte	Hydraulic conductivity of the main stream (mm/h)	40–80	40–80	40–80	40–80
v_CH_N2.rte	The main channel Manning coefficient	0–0.3	0–0.3	0–0.3	0–0.3
r_OV_N.hru	Manning roughness coefficient for surface flow	–0.8–0.8	–0.8–0.8	–0.8–0.8	–0.8–0.8
r_SLSUBBSN.hru	Average slope length (m)	–0.5–0.5	–0.5–0.5	–0.5–0.5	–0.5–0.5
r_HRU_SLP.hru	Average slope steepness (m/m)	–0.3–0.3	–0.3–0.3	–0.3–0.3	–0.3–0.3
r_SOL_AWC(..).sol	Available water capacity (mmH <sub>2</sub> O/mmsoil)	–0.2–0.2	–0.2–0.2	–0.2–0.2	–0.2–0.2
v_USLE_P.mgt	USLE support practice factor	0.1–0.9	0.1–0.9	0.1–0.9	0.1–0.9
r_USLE_K().sol	USLE soil erodibility factor	–0.4–0.4	–0.4–0.4	–0.4–0.4	–0.4–0.4
r_SPCON.bsn	Linear parameter for calculating the maximum amount of sediment	0.001–0.01	0.001–0.01	0.001–0.01	0.001–0.01

*T*-statistic. *P*-value represents the importance of the sensitivity of the parameter (the closer the *P*-value is to zero, the more important the parameter is for the model), and *T*-statistic represents the degree of sensitivity (the larger the absolute value of *T*-statistic, the higher the sensitivity of the parameter).

These stations were selected from among hydrometric stations that are located near dams and also based on climate (such that different climate would be represented in the data). The NS values obtained for all hydrometric stations in the validation phase are plotted in Figure 8.

Charts of Figure 9 illustrate the results of the calibrated SWAT model for a select group of stations. As these results show, the calibrated SWAT model was successful in simulating the hydrological changes in the study area. It should be noted that based on the temperature, the SWAT model estimates the discharge originating from snow water equivalent in mountainous regions.

### Available water

Available water can be divided into two components: blue water and green water. Blue water is the sum of surface water and deep aquifer recharge. Green water itself consists of two components: 1 – Green water flow, which refers to the actual amount of evapotranspiration, and 2 – green water storage, which refers to soil water or soil moisture. Soil moisture is a reversible resource that can be used in management plans for rainfed agriculture. The examination of blue water can benefit planning and decision-making in relation to artificial recharge, construction of small dams, and pollution control.

In this part of the study, after calibrating the model, the quantities of blue water and green water were estimated on a sub-basin scale. Figure 10 shows the quantity and CV of blue water and green water in the base period. The projected changes in blue water under different climate change scenarios are plotted in Figure 11.

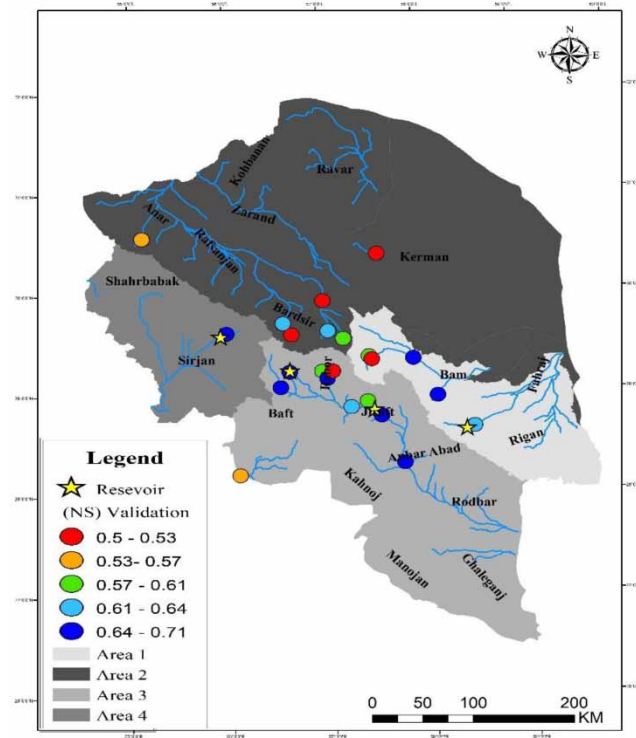


Figure 8 | NS values obtained in the validation phase.

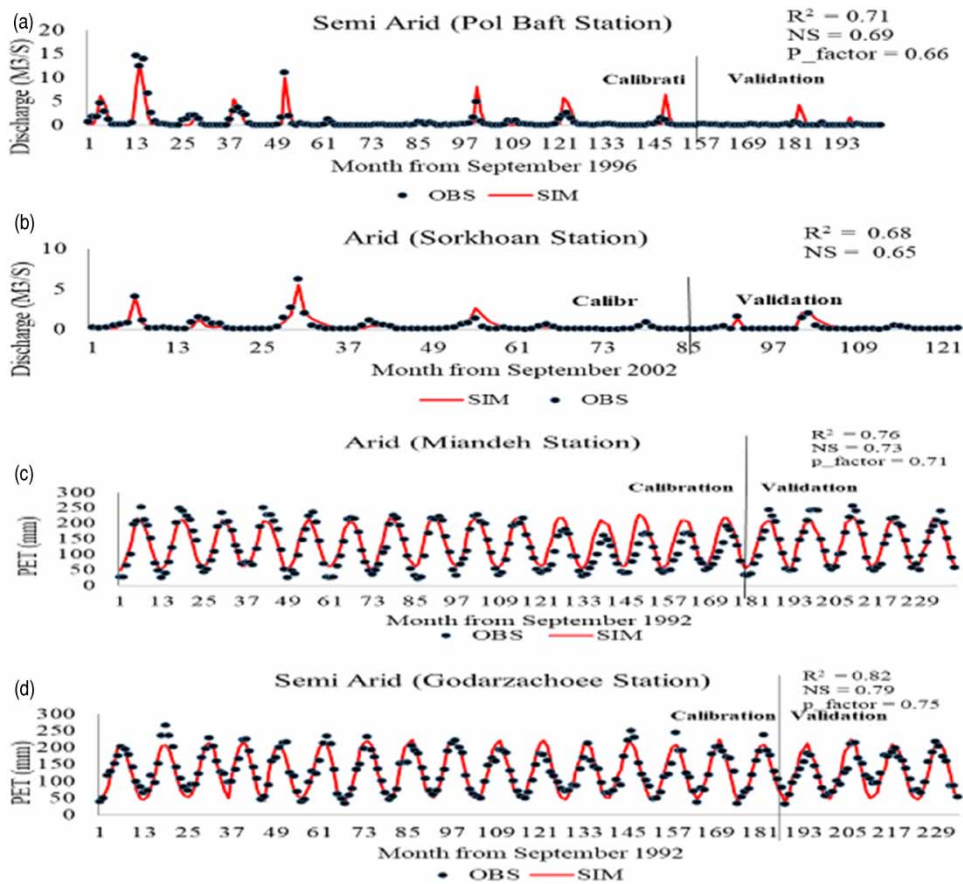
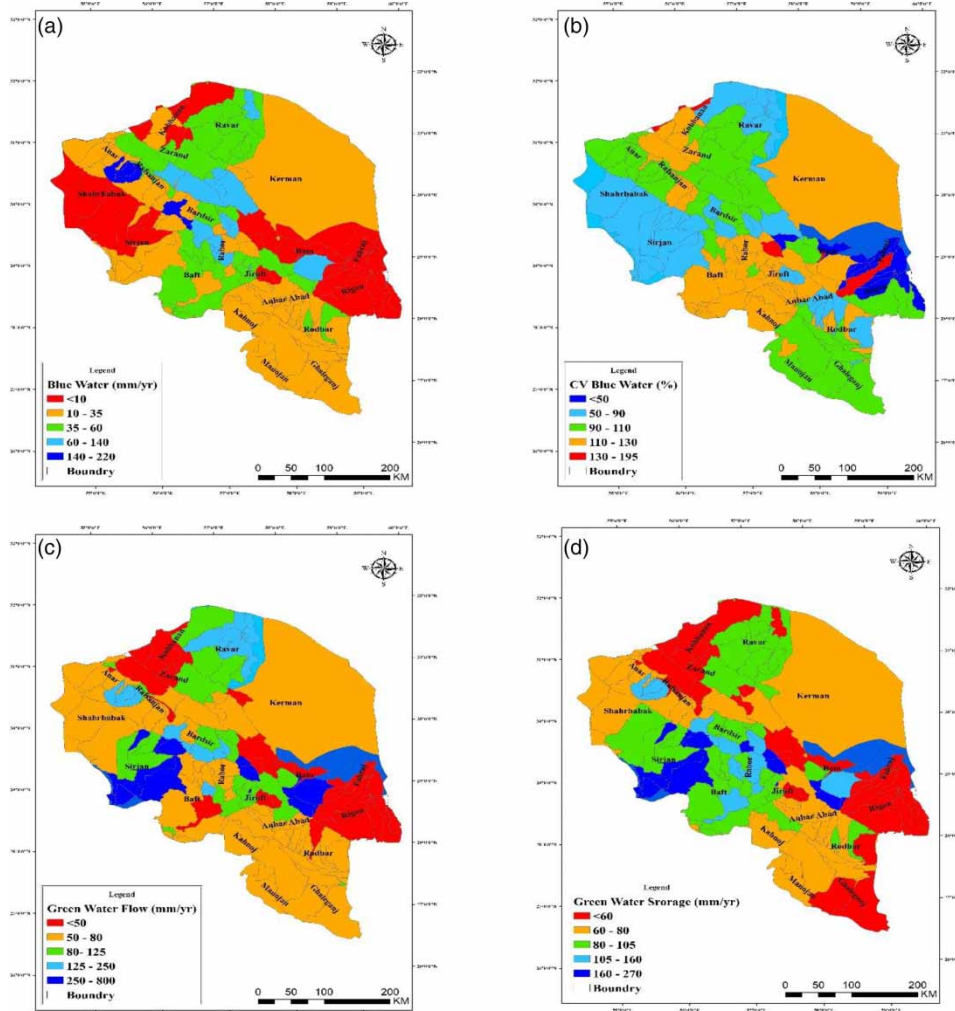


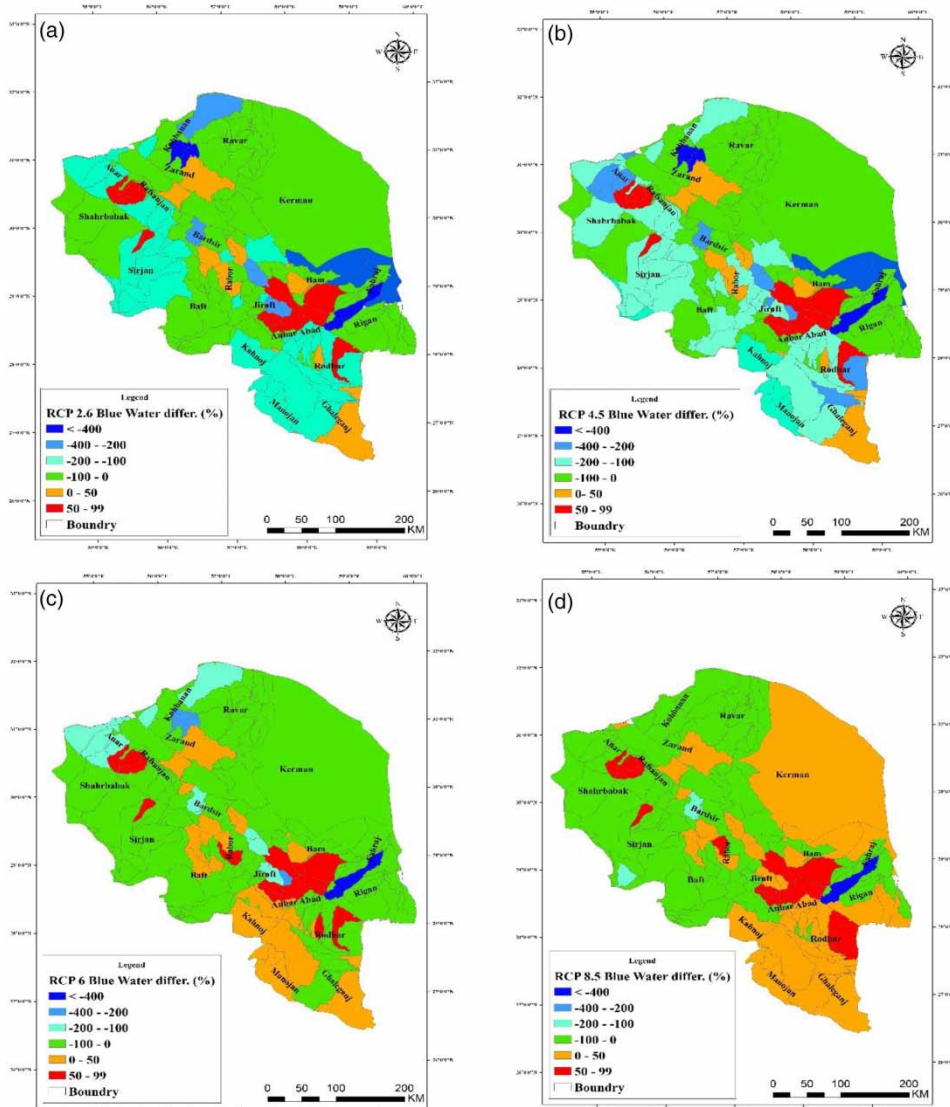
Figure 9 | Results of the calibrated SWAT model for a select group of stations: runoff (a and b) and potential evapotranspiration (c and d).



**Figure 10** | (a) Quantity of blue water, (b) CV of blue water, (c) green water flow, and (d) green water storage in the base period (1990–2012).

After comparing the components of water balance under different climate change scenarios with the corresponding figures in the base period, the following conclusions were made:

1. The average precipitation in central and southern parts of Kerman province is higher than that in northern parts. But in the near future, the average precipitation is likely to increase in northern parts and a decrease in central and southern parts.
2. We are likely to witness an increase in temperature in all parts of Kerman province, but this increase will be more pronounced in northern parts.
3. Under all climate change scenarios, there will be an increase (compared with the base period) in the amount of blue water in northern parts of the province and a decrease in other parts. These trends match the trends projected for precipitation in northern and southern parts of the area under different climate change scenarios. From this, it can be concluded that blue water is highly sensitive to changes in precipitation. An interesting point in the blue water projections made for Kerman province is the higher quantity of blue water in Baft County and the southern counties in the RCP8.5 scenario than in the RCP6 scenario. Since the RCP8.5 scenario has the greatest increase in temperature and the greatest decrease in precipitation, one can reasonably expect it to have the lowest amount of blue water, but this has not happened. This can be attributed to slightly higher (4%) green water flow (evapotranspiration) and slightly lower (11%) green water storage (soil moisture) in RCP8.5 compared with RCP6, which means that a larger portion of the rainfall has turned into blue water.



**Figure 11** | Impacts of climate change on blue water under different scenarios compared with the base period.

4. Under all climate change scenarios, the quantity of green water will decrease in southern parts of the province (because of reduced rainfall) and increase in northern and central parts (because of increased rainfall and temperature). In each scenario, the highest green water flow has increased in proportion to temperature increase in that scenario. Beside increasing temperature and decreasing rainfall, the other reason for this increase in green water flow is the stimulation of plant growth because of increased  $\text{CO}_2$ .
5. For Kerman, the trend of change in green water storage under climate change scenarios (compared with the base period) matches the trend of change in precipitation and temperature.
6. Overall, we are likely to witness an increase in average blue water and average green water storage in Kerman and a decrease in average green water flow in this area.

### Cultivation reduction scenarios

Since many agricultural products are water-intensive, it is vital to constantly monitor and predict water balance in order to avoid stressing water resources and ensure the long-term stability and security of agricultural output. A vital question about the conservation of available water that policymakers encountered is: Is it necessary to shrink agricultural activities of the province in coming years? and if the answer is yes, to what degree it must be reduced.

**Table 3** | Water balance under the RCP8.5 climate change scenario and different cultivation reduction scenarios

	15% reduction in the area under cultivation	10% reduction in the area under cultivation	5% reduction in the area under cultivation
Change in available water compared with the base period	109%	97%	87%

In Kerman, central and southern parts of the province have the highest area under cultivation (Zone 3 in Figure 7). The main crops cultivated in these zones are wheat, summer crops, and date palms. Therefore, in this study, cultivation reduction scenarios were applied to this zone. Three cultivation reduction scenarios were defined: 1–5% reduction in the area under cultivation, 2–10% reduction in the area under cultivation, and 3–15% reduction in the area under cultivation. To apply these scenarios to projections, after calibrating and validating the model for the base period, the area under cultivation was changed by using the said amounts and then the climate change conditions were applied to the model. Also, it was assumed that in the future, all fields will be irrigated by modern (mechanized) irrigation systems with an irrigation efficiency of 85%. The results obtained under the most pessimistic climate change scenario (RCP8.5) are provided in Table 3.

As can be seen, a 5% reduction in the area under cultivation will result in a 13% reduction in available water compared with the base period. Applying a 15% decrease in the area under cultivation will lead to a 9% increase in available water, but this may have unacceptable implications for food security and agricultural production. Reducing the area under cultivation by 10% will result in only a 3% decrease in available water compared with the base period. Therefore, considering the success of this scenario in stabilizing water balance at its current level with the least impact on agricultural output, reducing the area under cultivation by 10% seems to be the best option among the defined cultivation reduction scenarios.

## CONCLUSION

In this study, precipitation and maximum and minimum temperature data of Kerman province for a 23-year base period (1990–2012) were used to assess the performance of CCT, and then this toolkit was used with the GFDL-ESM2M GCM to project the impacts of climate change on this area in the near future (2020–2050) under four RCP scenarios. In this process, first, the CCT was used to downscale and interpolate the data of GFDL-ESM2M. After calibrating the model and validating the accuracy of its projection, the model was used to project changes in precipitation and maximum and minimum temperatures for the near future period (2020–2050). The results showed that under all climate change scenarios, there will be an increase in precipitation in all parts of the province except southern and central parts, and in some places, this increase will be as high as 60%. But in southern and central parts of the province, precipitation will decrease by 10–40%. In contrast, the average monthly maximum temperature projections showed an increase in temperature in all stations under all scenarios and, consequently, the irrigation water demand is projected to increase for sure.

One of the goals of this study was to evaluate the performance of CCT. Considering the variety of features and options provided in this toolkit and the accuracy of simulations performed in this study with the help of this tool, CCT must be acknowledged as a quite efficient and accurate instrument for conducting climate change research and analyses related to the length of wet/dry spells. Also, since the CCT is linked to four other GCMs (HadGEM2-ES, IPSL-CM5A-LR, MIROC, and NoerESM1-M), future studies can use other GCMs to analyze the future trends of maximum and minimum temperature and precipitation and dry spell length.

In the present study, the integrated simulation capabilities of the SWAT were used to project the impact of climate change on the hydrological parameters of Kerman province. For this purpose, SWAT modeling was performed in order to construct and calibrate a hydrological model, capable of handling uncertainties, for Kerman province at the sub-basin level. Then the calibrated model was used to estimate the effect of the worst climate change scenario on the water balance of the region with and without a reduction in the area under cultivation. Also, available water was estimated on a monthly scale, and finally, the components of available water including blue water (sum of surface runoff and deep aquifer recharge), green water storage (soil moisture), and green water flow (actual evapotranspiration) were projected. While decomposing the available water into its constituting components allows for more detailed planning and management of available water resources, this practice has not received sufficient attention in hydrological studies on Iran's basins and watersheds. Therefore, one of the goals of this

study was to demonstrate how new practical tools of water availability assessment can be used in conjunction with this approach to better manage water resources.

The analysis of runoff and evapotranspiration simulation results showed that the SWAT model performed very well in the hydrological modeling of Kerman province. The findings of other studies (Abbaspour *et al.* 2009; Hashemi Nasab *et al.* 2013) and the research on the irrigation needs of Iranian agricultural and horticultural products, which has been carried out by Iran's Meteorological Organization and Ministry of Agriculture, support the accuracy of this conclusion.

After calibrating the SWAT model, the outputs of CCT were used to analyze the hydrological conditions of Kerman province in the near future period (2020–2050). This analysis showed that under all climate change scenarios, we can expect a decrease in the average quantity of blue water, an increase in average green water flow, and a decrease in average green water storage (soil moisture) compared with the base time period. Also, the estimations made after applying the cultivation reduction scenarios showed that if combined with modern irrigation systems, a 10% decrease in the area under cultivation will be enough to stabilize the water balance of the region at the current level.

## DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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