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RESEARCH ARTICLE

Evaluation of climate change effects on extreme flows in a catchment of western Iran

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Abstract Investigation of the relationship between catchment hydrology with climate is essential for understanding of the impact of future climate on hydrological extremes, which may cause frequent flooding, drought, and shortage of water supply. The purpose of this study is to investigate the effects of climate change on extreme flows in one of the subcatchments of the Ilam dam catchment, Iran. The changes in climate parameters were predicted using the outputs of HadCM3 model for up to the end of the current century in three time periods including 2020s, 2050s, and 2080s. For A2 scenario, increases of 1.09°C, 2.03°C, and 3.62°C, and for B2 scenario rises of 1.18°C, 1.84°C, and 2.55°C have been predicted. The results suggest that for A2 scenario, the amount of precipitation would decrease by 12.63, 49.13, and 63.42 and for B2 scenario by 47.02, 48.51, and 70.26 mm per year. Also the values of PET for A2 scenario would increase by 51.18, 101.47 and 108.71 and for B2 scenario by 60.09, 89.86, and 124.32 mm per year. The results of running the SWAT model revealed that the average annual runoff would decrease by 0.11, 0.41, and 0.61 m^3/s and for B2 scenario by 0.39, 0.47, and 0.59 m^3/s. The extreme flows were then analyzed by running WETSPRO model. According to the results, the amounts of low flows for A2 scenario will decrease by 0.02, 0.21 and 0.33 m^3/s and for B2 scenario by 0.19, 0.26 and 0.29 m^3/s in the 2020s, 2050s and 2080s, respectively. On the other hand, the results show an increase of peak flows by 11.5, 19.1 and 48.7 m^3/s in A2 scenario and 11.12, 25.93 and 48.1 m^3/s in B2 scenario, respectively. Overall, the results indicated that an increase in return period leads to elevated levels of high flows and diminished low flows.

Keywords climate change, extreme flows, Ilam dam watershed, Iran

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1 Introduction

The report of accredited global organizations in recent years suggests that the effects of climate change have increased with changes in extreme weather events including floods, storms, and droughts (WMO, 2011). Therefore, the casualties and injuries caused by such disasters have also intensified the demand for services related to these events.

For investigating climate change effects, several models for predicting future climate variables have been created and their confidence in outputs is increased, which are in turn used as inputs to watershed and hydrological models. As a consequence, several studies have shown the impacts of future climate change on freshwater budgets (Jiang et al., 2007; Bae et al., 2011; Leta et al., 2016) and streamflow (Rahman et al., 2014; Devkota and Gyawali, 2015; Ahiablame et al., 2017; Bodian et al., 2018).

Although climate change impacts on hydrologic parameters have been studied widely, effects on extreme flows including high and low flows have been studied much less frequently. The purpose of the current study is to examine the effects of climate change on extreme flows in a catchment of western Iran. In this catchment, which has been located in the semi-arid region, water supply largely depends on surface water availability. Hence, understanding potential impacts of climate change on high and low flow is considerably important for water supply planning, flood control, waste water assimilation, recreation, and habitat for aquatic life.

Assessing future extreme values is also needed due to their significant impact on the economy, environment, and human life (Mohammed et al., 2017). Hence, hydrological extremes (floods, droughts) under future climate change scenarios are gaining major importance and related studies can help water management and decision makers as exploratory tool for evaluating the consequences of climate change on hydrological extremes.

Kavvas et al. (2006) argued that the incidence and magnitude of phenomena such as floods and droughts have a profound effect on the zoning capacity in a region, as well as socio-economic activities of the people in that region. Hence, in recent years much attention has been devoted to tracking changes in these events and various methods for their prevention (Yan et al., 2002; Tank et al., 2009). For instance, Baguis et al. (2010) examined the effects of climate change on extreme events. They simulated precipitation and Potential Evapo-Transpiration (PET) for the late 20th century using climatic models (11 regional climatological models (RCMs)) and applying A2 and B2 emission scenarios. The results of simulation of the climatic models (decrease of rainfall in the summer and its increase in winter, temperature rise and PET throughout the year) were then combined. The results indicated increased frequency of low flow in summer and winter. Also, when high flows occur, the effect of predicted increased rainfall due to climate change with reductions in temperature and PET declines.

Basher et al. (2010) evaluated the effects of climate change on extreme hydrological events in the Kaydu catchment, China. They estimated the climate variables of temperature, rainfall, and PET using the general atmospheric circulation models under A2 and B1 emission scenarios. The results of this study unveiled that the severity of flood and drought will be significantly affected by climate change. Poelmans et al. (2011) assessed the changes in the high flows in Mullenbeek Catchment, Belgium. They concluded that the high flows increase due to climate change, with urban development scenarios being less effective. Artlert et al. (2013) examined and analyzed the changes in precipitation due to climate change in Man, Chi, and Mekong Rivers in Thailand through simulation of general atmospheric circulation and the SDSM model. They indicated that the SDSM model could well calibrate observational rainfall with physical and statistical structures during the 1975−1961 period and validate it for the 1976−1990 period. Tavakoli et al. (2013) investigated the impact of climate change and urban development on extreme flows in the Grote Nete Catchment, Belgium. They used three scenarios for climate change and three scenarios for urban development (a total of nine scenarios) as well as the hydrological WetSpa model. The results revealed that low flows are affected by climate change, but are less sensitive to urban development. In contrast, high flows are affected by both climate change and urban development. They concluded that the effects of climate change and urban development could significantly increase the frequency of floods during the winter and reduce low flow during the summer. Garner et al. (2015) investigated the hydroclimatology of river flows in temperate regions of Europe. They provided an overview of the region in which the expression of climatic conditions and spheres led to: 1) defining the fundamental concepts of excess flows; 2) defining climatic characteristics and areas that lead to extreme flows; 3) discovering the future of climate change which is particularly affected by humans; and 4) the uncertainties that will develop with future climate change and hydrology. Collet et al. (2017) assessed the changes in extreme runoff for a 100-year return period across Great Britain as a result of climate change using the future flow hydrology database. The Generalized Extreme Value (GEV) and Generalized Pareto (GP) models are automatically fitted for 11-member ensemble flow series available for the baseline and the 2080s. The analysis evaluates the uncertainty around the Extreme Value (EV) and climate model parameters. The result suggested that GP and GEV give similar runoff estimates and uncertainties. The result suggested that from the baseline to the 2080s, overestimation of uncertainties is evident in Eastern England. With the GEV, the uncertainty attributed to the climate model parameters is greater than with the GP (around 60% and 40% of the total uncertainty, respectively). This implies that when fitting both EV models, the uncertainty around their parameters has to be accounted for when assessing extreme runoffs. Leta et al. (2018) evaluated the effects of climate change on streamflow and extremes in two watersheds in the Island of Oahu (Hawaii) to the end of current century. Overall, they found that climate change impacts will be amplified by the end of this century and the extreme peak flows are expected to increase, on the other hand it may cause earlier occurrence of hydrological droughts when compared to the current situation. They suggested to water resources managers, ecosystem conservationists, and ecologists to implement mitigation measures to climate change.

Climatic variation is not very clear on precipitation alone, and many of the studies that have been performed to describe climate change in Iran have been only based on the rainfall parameter, and the relationships between climate parameters and extreme flows have remained understudied. Moradi et al. (2014) simulated and predicted some of the climatic parameters using SDSM and general atmospheric circulation models in Neishabour catchment. The results indicated elevated temperature and diminished rainfall in the region, along with a higher compatibility of the outputs of the HadCM3 model under the A2 scenario with the base period. For hydrological modeling, Kavian et al. (2017) examined the effects of climate change on discharge in the Haraz River. In this research, using the SWAT model A2 scenario, the trend of climate change was investigated in the catchment for the period of 2011−2030. The climate model results revealed that the annual minimum and maximum temperatures will grow by 0.7°C and 0.62°C, respectively. Also, the average annual rainfall for the study area would decline by 18%. Similarly, the results of comparing the simulated flow indicated that the peak flow rate would increase for the upcoming period, while the average flow of the river will drop by 12%.

In this study, the effects of climate change have been investigated on extreme flows in one of the subcatchments of the Ilam dam catchment in the west of Iran. The steps taken in this research include prediction of climate variables, hydrologic modeling, prediction of future hydrological conditions and extreme flows separation, and analysis of the results.

2 Materials and methods

2.1 Study area

Golgol catchment with an area of 24,950 hectares is located in Ilam Province, West of Iran, is one of the subcatchments of Ilam. In terms of hydrology, this subcatchment is one of the water supply districts of the Ilam dam, which has an average height of 1828 meters and a mean slope of 20%. According to the stations in the area and around it, the average rainfall during the 30-year period has been 623 millimeters. Further, the average annual temperature at Ilam station is 16.9°C. The region's climate based on Domarton method is Mediterranean (Weather Administration of Ilam Province website). Figure 1 displays the location of the catchment in Ilam. In this study, data have been extracted from the Golgol hydrometric station and the Ilam synoptic station (Table 1).

2.2 Methodology

In this study, for investigating the effects of climate change on extreme flows in the Golgol catchment, the Soil and Water Assessment Tool (SWAT) hydrological model and the SDSM climatic model have been used. In the first step, models calibrated and validated based on observed data and then, their efficiency was evaluated in the reproduction of past data and future simulation of the catchment. Then, the output of the Hadley Centre Coupled Model, version 3 (HadCM3) GCM model was downscaled under A2 and B2 emission scenarios. Scenario A2 predicts a population growth to 15 billion by the year 2100 and moderate, primarily regionally oriented economic development, while scenario B2 predicts a population growth to 10.5 billion with also moderate economic development, but with more emphasis on local solutions that require less energy consumption (IPCC, 2007). The precipitation as well as the minimum and maximum temperatures by the end of century in three periods (2020s, 2050s, 2080s) were compared with the previous period (baseline). Also, the changes in these parameters were introduced into the SWAT model to predict the variations of water resources in the catchment. In the last step, the results of the previous stage were introduced into the Water Engineering Time Series PROcessing (WETSPRO) model, and then, using the POT (Peak Over Threshold) method, the extreme flows were separated and evaluated in future periods.

2.2.1 General Circulation Model (GCM)

There are several centers around the world for investiga-

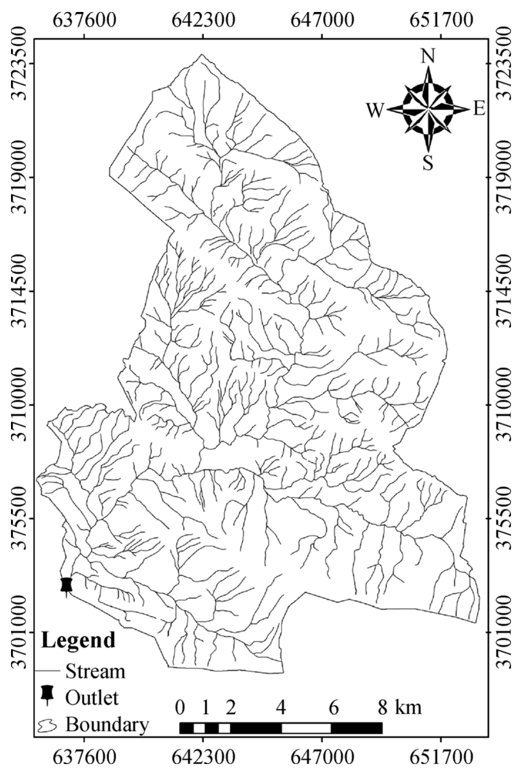

Fig. 1 Location of the study area in Ilam Province.

Table 1 characteristics of stations

Period	Elevation	Latitude (UTM)	Longitude (UTM)	Station type	Station name
1961–2001	1360	3716936	629940	Synoptic	Ilam
1980–2014	1052	3703826	637736	Hydrometric	Golgol

tion of climate change which present different data for related studies. In this research, the variables of NCEP (large variables of the scale of observation of the area) have been used for calibration and validation. Also, the outputs of the HadCM3 model were used under A2 and B2 emission scenarios to predict future climate variables. The statistical period and their data type are given in Table 2.

Table 2 Output and time period of general circulation model data

Data type	Period	Application
NCEP	1961–2001	Calibration & Validation
A2	1961–2099	Future prediction
B2	1961–2099	Future prediction

2.2.2 Downscaling

For downscaling the data in this research, the SDSM model was used which is a downscaled statistical model and has the ability to quickly and inexpensively downscale data in the form of daily, monthly, seasonal, or annual information (Wilby et al., 2001). Within the catchment, there are three simple precipitation stations (Mishkash, Tolab, and Golgol) with insufficient length of climate data. Since the use of climatological models requires long precision data for calibration and validation of the model, the daily weather data of Ilam synoptic station was used. The SDSM correlates between the daily observation time series and NCEP variables. The most important step in the statistical downscaling is the selection stage of effective parameters and model calibration. In order to evaluate the performance of the HadCM3 and SDSM models for calculating and predicting precipitation, temperature, and PET, the calculated data were compared with the observed data. For all variables, data from 1986 to 1997 were used for calibration and those from 1998 to 2001 were utilized for validation. Finally, the calibrated model was used for predicting future climate variables under three time steps including 2011–2039 (2020s), 2040–2069 (2050s), and 2070–2099 (2080s).

2.2.3 SWAT hydrologic model

The hydrological model of SWAT was an abbreviation for Soil and Water Assessment Tool developed by Geoff Arnold in 1998 for the Agricultural Research Service. This model is a physical, semi distributed, and continuous model for simulating hydrological processes on a catchment scale. The details, methodology, and equations used in this model are available on the SWAT site. The inputs of this model include two categories of meteorological data (precipitation, maximum and minimum daily temperature), as well as the data related to the catchment area (DEM map, soil map, and land use map), along with the data related to soil parameters such as the thickness of the horizons, soil texture, etc. In this research, after preparing the input maps and adjusting the necessary data, the model was implemented for the period of 1992–2014. The calibration was performed using 17-year daily data for the period of 1992–2008 and 6-year period of 2009–2014 for validation. Many parameters are involved in the model. The outputs should be more sensitive to the accuracy of these parameter. Therefore, sensitivity analysis as the first essential step in calibration was performed under the SUFI-2 algorithm in the SWAT-CUP program, which is linked to the SWAT model. One of the aims of SUFI-2 program is to reduce uncertainty, so that most of the observed data are at 95 ppu. After sensitivity analysis and calibration of the model, the important question is how to evaluate the model, for which in this study, the coefficients R^2, NS, *r*-factor and *p*-factor were used. According to studies and resources, the optimal value for these indexes is one, one, values less than one, and one respectively (Bitew et al., 2011).

2.2.4 Extreme flow separation

In the current study, the WETSPRO program was used for separating high and low flows as well as their changes under different scenarios as extreme flows. This software was developed by Patrick Willems in 2009. The WETSPR running under Excel software includes standard pages for importing and displaying results, with algorithms in Visual Basic. The continuous time series of hydrologic variables (discharge, water level, precipitation intensity, pollution concentration, etc.) are used as inputs in this software (Willems, 2009).

The WETSPRO software has several sections for various applications including POT (Peak Over Threshold) method, which has been used in this study. In the past, only annual maximum and minimum flows were commonly used for estimating the return period without taking the length of data into account. Therefore, the length of the data period is the major concern in this approach. If the length of the data period is short, the number of annual maxima or minima will be lower, which yields large uncertainty while performing extreme value analysis. To reduce this uncertainty, independent POT can be used for short aggregation time (daily or hourly) data (Willems, 2004). In order to investigate the effect of climate change on extreme flows, first SWAT model was run for the past and future decades (baseline, 2020s, 2050s, 2080s) under A2 and B2 emission scenarios. The output of each of these scenarios was introduced into the WETSPRO software and POT method was used for selecting the peak flows based on the methodology of Willems (2009). The low flows were selected based on the lowest annual flow. In the next step, the extreme flows selected for each scenario were ranked (from high to low for peak flows and from low to high for low flows), and the return period associated with each flow extreme was determined as:

$$P = \frac{r}{N+1}, \tag{1}$$

where, P: probability of occurrence; N: number of years of simulation,

$$T = \frac{1}{P}, \tag{2}$$

T: return period (years).

In the next step, in order to investigate the trends of changes in these flows, the graphs of each flow were drawn using the calculated return periods as well as the discharge separated by the POT method. Finally, the results of these calculations were used for comparing the predicted extremes in future and in the past.

3 Results

3.1 Climate change modeling results

After entering the observation data and the corresponding NCEP values, the SDSM model selects and specifies the parameters with the greatest effect on simulation. Table 3 presents the most important parameters affecting the predictors in this study. The downscaling results of the charts of maximum temperature, minimum temperature, PET, and precipitation are presented in Figs. 2−5 for calibration and validation periods, respectively. The results of the SDSM model outputs reveal satisfactory performance of the model in downscaling the climate data. In general, the calibration results show the suitable performance of the model, especially in temperature simulation and PET, compared to precipitation. Meteorologically, precipitation is a conditional parameter in relation to other parameters such as temperature. This means that the precipitation parameter depends on other parameters such as temperature, while the other parameters are somewhat independent and easier to simulate. This high accuracy of simulation is consistent with Azari et al. (2013), Kazmi et al. (2014), confirming the efficiency of the SDSM model in downscaling.

After evaluating the model, the cluster parameters were generated according to the selected variables. Figures 6–8 indicate the time series of the average temperature, PET, and precipitation during the simulated periods of 2010–2039 (2020s), 2040–2069 (2050s), 2070–2099 (2080s), and the baseline (1961–1990) for A2 and B2 emission scenarios.

Figure 6 demonstrates that under scenario A2, the highest temperature rise for the 2080s would be in April, May, and June by 4.06°C, 5.05°C, and 4.92°C, respectively and under scenario B2, this rise would be in May, June, and October by 3.4°C, 3.1°C, and 3.2°C, respectively. In general, the maximum increase occurs in the spring.

As shown in Fig. 7, under scenario A2, the maximum PET would occur in May, June, and August by 0.99, 1.04, and 0.86 mm per day, respectively. Also, under scenario B2 the highest increase would happen in May, June, July, and August by 0.62, 0.7, 0.4, and 0.67 mm, respectively.

The prediction also shows that the greatest decrease in rainfall during the 2080s under the A2 scenario would have happened in November by 1.12 mm followed by January, February, March (winter) by 0.48, 0.85 and 0.54 mm. On the other hand, the highest extent of precipitation reduction

Table 3 The most important predictor variables of the studied station

Number	Parameter	PET	Min temperature	Max temperature	Precipitation
2	ncep__faf		√		
4	ncep__vaf		√		
8	ncep5__faf	√		√	
9	ncep5__uaf	√	√	√	
10	ncep5__vaf				√
14	ncep5zhaf				√
20	ncep500af	√	√	√	
22	ncepr500af				√
25	ncepshumaf				√
26	nceptempaf	√	√	√	

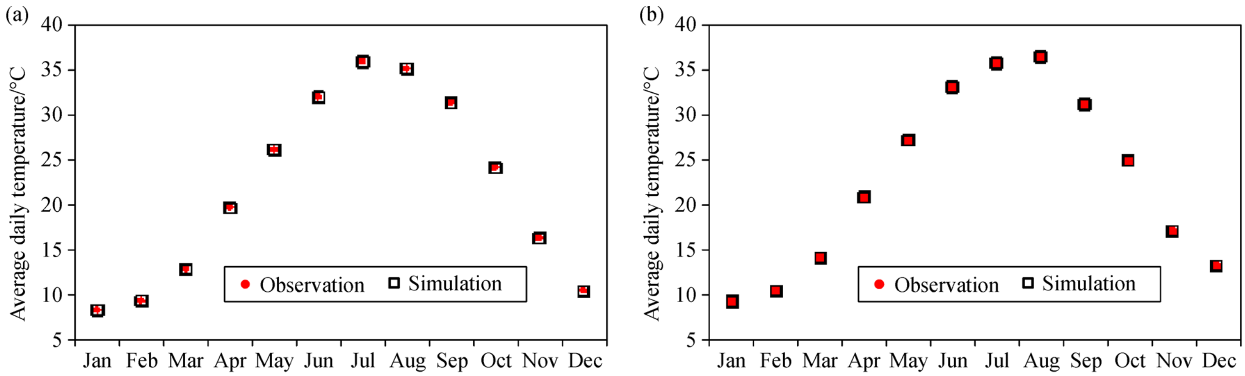

Fig. 2 Comparison of daily average of observed and simulated maximum temperature in calibration (a) and validation (b) period.

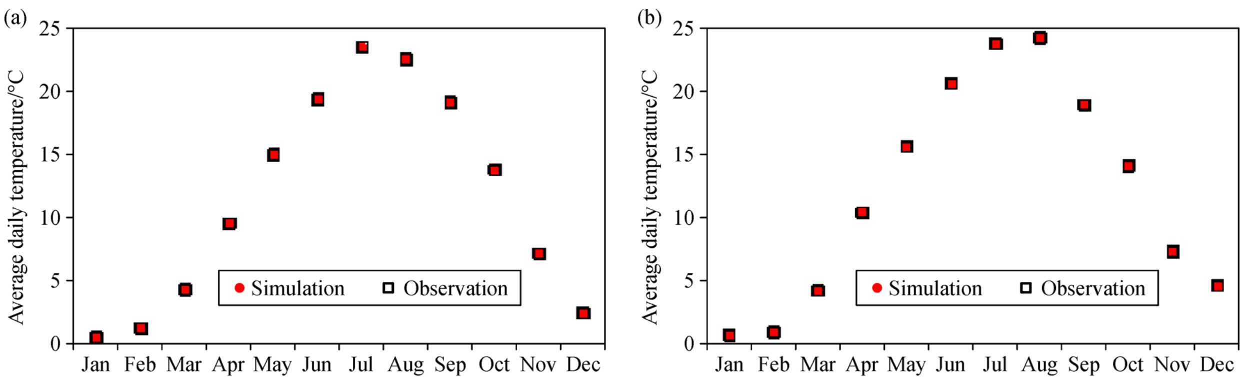

Fig. 3 Comparison of the daily average of observed and simulated minimum temperature in calibration (a) and validation (b) period.

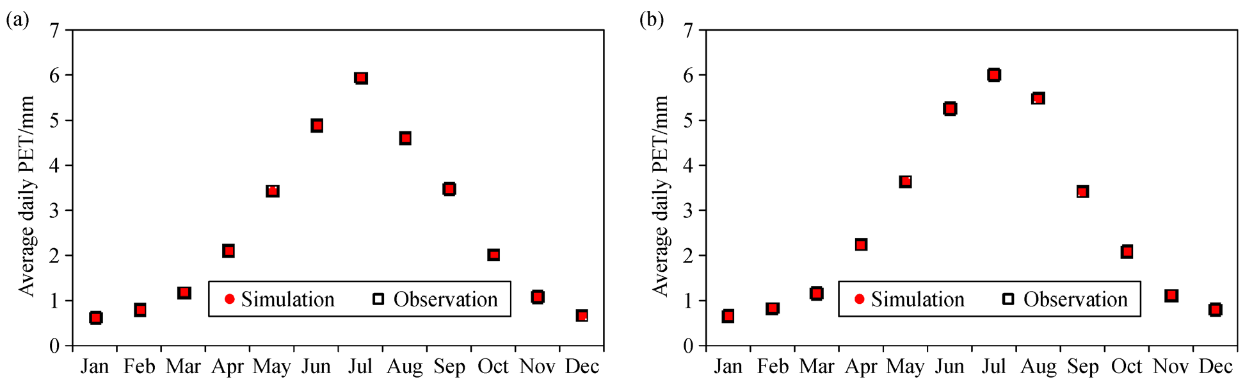

Fig. 4 Comparison of the daily observed PET and simulated in calibration (a) and validation (b) period.

under the B2 scenario would be for February, March, and November by 0.43, 0.82, and 0.66 mm respectively (Fig. 8).

According to predictions, precipitation would decrease under both scenarios by the end of the current century, although there is no steady trend throughout the year. The maximum average monthly rainfall variation compared to the base period under the A2 scenario ranges from −1.12 to 0.82 mm, and under the B2 scenario from −0.82 to 0.5 mm. The total annual precipitation would fall by 12.63, 49.13, and 63.42 mm under scenario A2, and 47.02, 48.51, and 70.26 mm respectively under scenario B2. The results of this section are in line with as the findings obtained by Tavakoli and De Smedt (2011) who suggested that rainfall reduction is expected in the future.

According to the downscaling results, under both scenarios, in this area the temperature would rise until the end of the century compared to the baseline. However, the A2 scenario predicts an increase in temperature larger than that of the B2 scenario. Under the A2 scenario, the

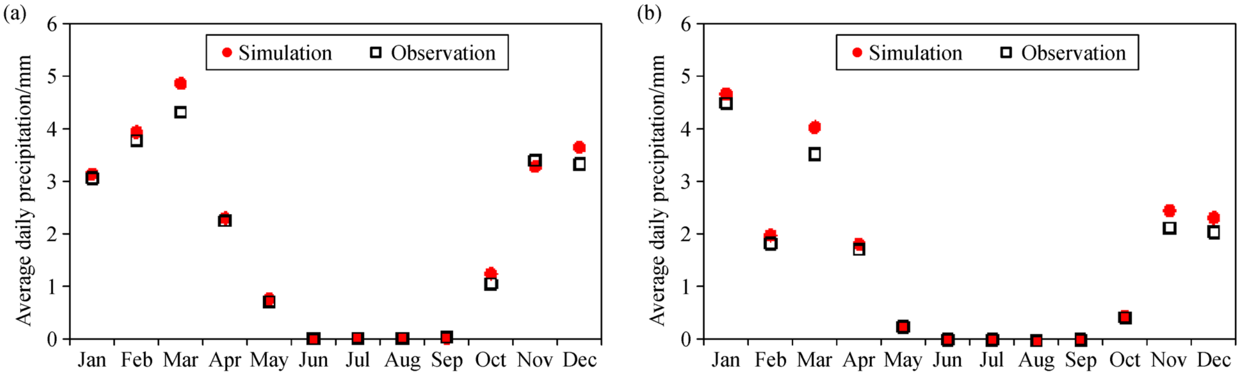

Fig. 5 Comparison of the daily average of observed and simulated precipitation in calibration (a) and validation (b) period.

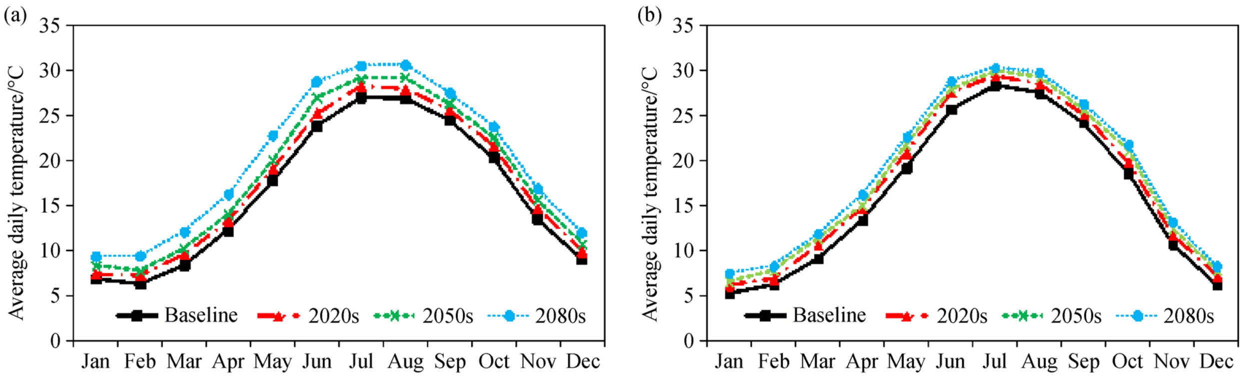

Fig. 6 Changes in the average temperature of future periods comparing to the baseline under A2 (a) and B2 (b) emission scenarios.

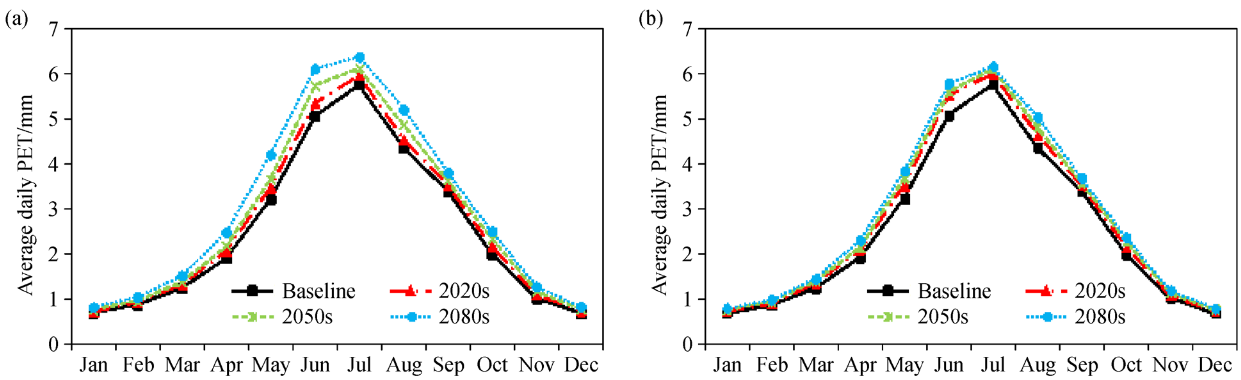

Fig. 7 PET changes in the future periods comparing to the baseline, under A2 (a) and B2 (b) emission scenarios.

increase would be 1.09°C, 2.03°C, and 3.62°C, while under the B2 scenario, it would be 1.18°C, 1.84°C, and, 2.55°C during the three periods, respectively. In general, more increases occur in the spring, with temperature rises being more severe at the end of the century. Growth of the temperature may intensify the precipitation decline in the form of rain rather than snow. It is also anticipated that at the end of the century not only will rainfall decrease, but also the impact of mountain snow reserves will drop. The results of this prediction are highly consistent with other similar studies, including Tatsumi et al. (2013) and Kavian et al. (2017). Also, based on the results, PET will increase by the end of the current century under both A2 and B2 scenarios. Scenario A2 predicted this growth by 51.18, 101.47, and 180.71 mm and under scenario B2 by 60.09, 89.86, and 124.32 mm in the three periods, which is greater in summer and spring. This result is also in accordance with the results of Moradi et al. (2014).

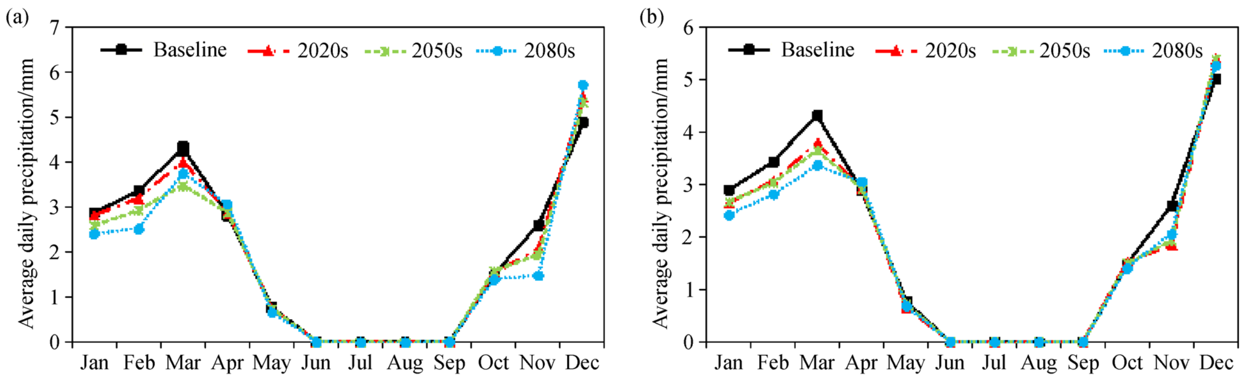

Fig. 8 Changes in precipitation for future periods comparing to the baseline, under A2 (a) and B2 (b) emission scenarios.

3.2 Flow simulation

The results of the model output after the sensitivity analysis in the part of the 1994–2008 period have been presented as calibration. Once the model was calibrated, its validity was validated for the period 2009–2014, with Fig. 9 summarizing the results.

As can be seen in the Figs, proper calibration of the model has helped the SWAT to simulate the flow of the domain in calibration and validation periods to an acceptable level. Also, the coefficients obtained from the calibration and validation steps (Table 4) indicate a small difference between observation and simulated data. The results of various studies such as Gholami and Nasiri

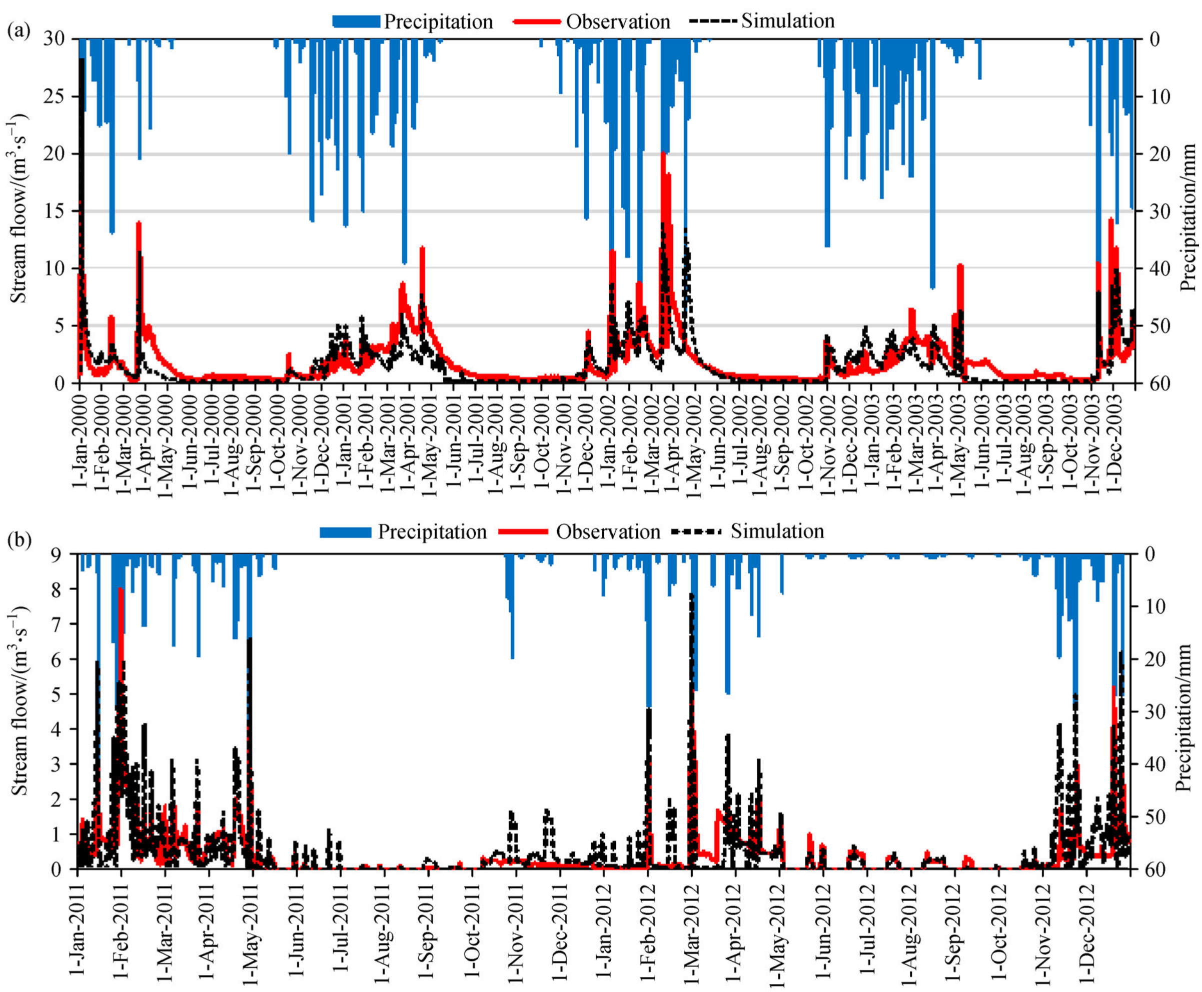

Fig. 9 Simulated and observed hydrograph in calibration (a) and validation (b) period.

Table 4 Model accuracy in calibration and validation period modeling

Statistical indexes	NS	R^2	*r*-factor	*p*-factor
Calibration period	0.58	0.6	0.49	0.34
Validation period	0.51	0.54	0.48	0.32

(2015) confirm the high accuracy of the modeling and success of the SWAT model in optimal field flow simulation in the calibration phase.

3.3 Flow changes under climate scenarios

Using the SWAT model, the future simulated climate conditions used as the input of the hydrological model were investigated along with the conditions of water resources of the catchment. After importing time series of temperature and precipitation parameters under the A2 and B2 emission scenarios, flow simulation was implemented (Fig. 10) in the baseline and three upcoming periods of 2020s, 2050s, and 2080s. With the change in temperature rise, evaporation, and reduction of rainfall in the area, a change also occurred in the river flow hydrograph. The average annual runoff would decrease by 0.11, 0.41, and 0.61 m^3/s and for B2 scenario will decrease by 0.39, 0.47, and 0.59 m^3/s in the 2020s, 2050s, and 2080s, respectively. Based on the annual percentage, reductions of 6.6%, 15%, and 24% in the A2 scenario and 14.5%, 17.5%, and 21.5% in the B2 scenario were predicted, respectively. The results of Azari et al. (2013), Zarghami et al. (2011) are consistent with the results of this section.

The reduction of the flow due to precipitation decline, temperature rise, and PET increase is obvious. As could be seen, the greatest decrease is expected in the summer season, due to reduced precipitation and elevated temperature, and thus increased PET.

3.4 Results of extreme flows changes under climate scenarios

The analysis of the graphs obtained from the output of the WETSPRO model (POT method) indicated that the increase in the return period leads to elevated levels of high flows and diminished low flows. As the end of the century approaches, this ascending and descending trend exacerbates (Figs. 11 and 12). According to the results, the amounts of low flows for the A2 scenario will decrease by 0.02, 0.21, and 0.33 m^3/s and for the B2 scenario by 0.19, 0.26, and 0.29 m^3/s in the 2020s, 2050s, and 2080s, respectively. On the other hand, the results show an increase of peak flows by 11.5, 19.1, and 48.7 m^3/s in scenario A2 and 11.12, 25.93, and 48.1 m^3/s in scenario B2, respectively. The effect of these factors will increase the frequency of floods in the winter and shortage of water in the summer, followed by a decrease in its quality. The results of Basher et al. (2010), Tavakoli et al. (2013), and Ashofteh and Massahbouani (2010) are consistent with the results of this section.

4 Conclusions

In this study the SWAT model was run for simulation of observed daily streamflow hydrographs and extremes and their temporal evolution at a gauging station and the calculated NSE values were greater than 0.5 for both calibration and validation periods. Although it gives an acceptable accuracy, with improving the equipment and methods of stream measurement, increasing accuracy and decreasing uncertainty are expected. HadCM3 general circulation model and SDSM have been used for simulation of historical and future climate data. These simulations and projections also have uncertainties and to deal with the uncertainties in climate change projections, an ensemble of models needs to be used to comment on

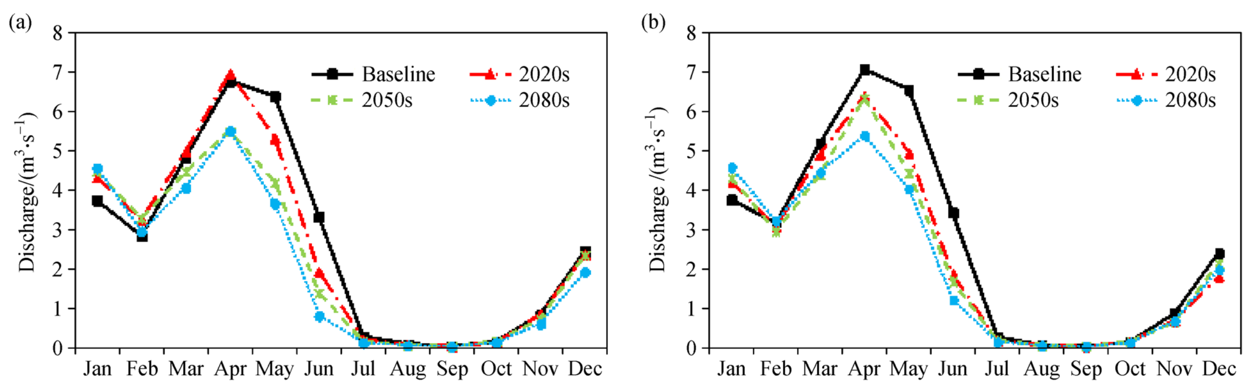

Fig. 10 Predicted daily mean stream flow at Golgol gauging station for the baseline (1961–1990) and future periods (2010–2039, 2040–2069, and 2070–2099) under A2 (a) and B2 (b) emission scenarios.

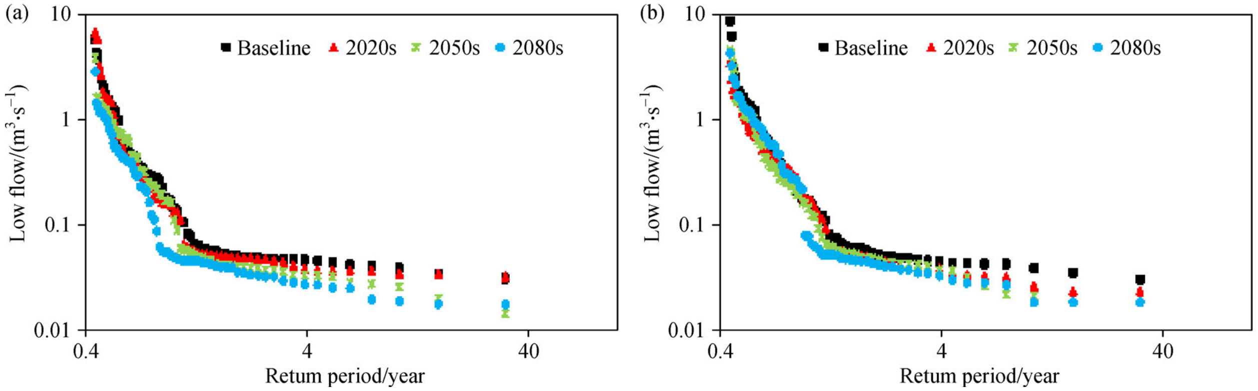

Fig. 11 Simulated low flows changes under A2 (a) and B2 (b) emission scenario.

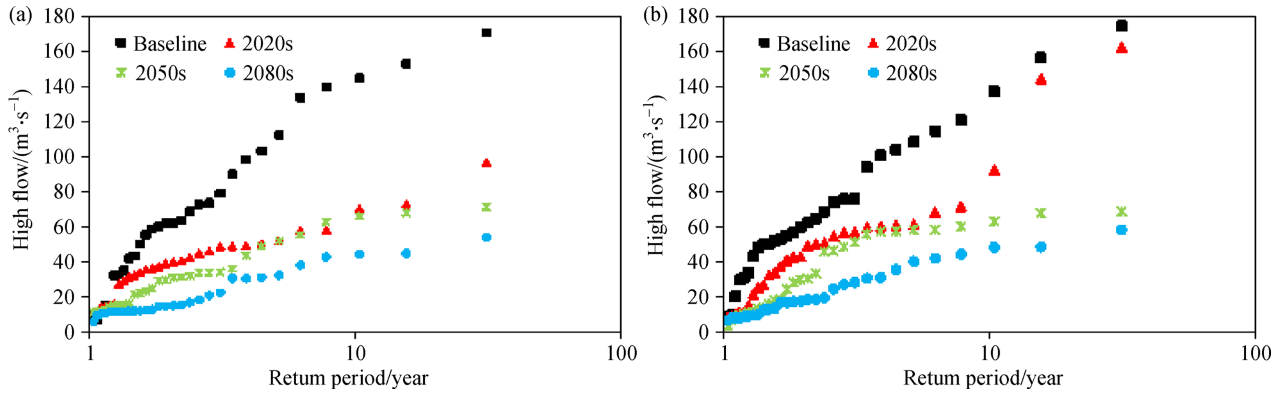

Fig. 12 Simulated high flows under A2 (a) and B2 (b) emission scenario.

how the results differ by using different models to explore the impacts.

According to the studies, it can be concluded that the river flow regime would be affected along the baseline under the influence of climate change in the upcoming periods. Therefore, in this research, the effect of climate change was investigated on extreme flows in the Golgol catchment in Ilam Province in the upcoming periods under A2 and B2 emission scenarios. The results of investigating low flows and high flows can be analyzed if the results of the simulation of climate models are examined in combination. The results obtained from application of the general circulation model and flow simulation in this study indicated that warmer and drier months are anticipated in future periods, and therefore, we will witness lower precipitation. Hence, reduced snow coverage due to increased temperatures and lack of snow melt in the winter would be expected. Hansen et al. (2008) reported that a change of only 2 to 4°C could have a significant effect on snow accumulation and melting speed. Also, the temperature increase can also change the time and speed of snow melting. Such a situation will lead to a reduction in water supply in the catchment area and will lower the flow of the river in dry seasons. Also, the increase in temperature leads to diminished rainfall and alteration of its pattern (as a storm), as well as elevated evaporation and transpiration. Notably, the combination of these factors exacerbates each other. Hence, it can be concluded that drop in rainfall and changes in the precipitation pattern (in the form of storm) reduce the amount of water entering aquifers, fall in the groundwater level, and decreased amount of flow in the summer, thereby reducing low flows. Low flow is a good indicator for investigating hydrological drought. It can also be used to study the ecosystem conditions, estimate aquifer feeding, plan drinking and agricultural water requirements, especially in the Golgol catchment, and adjust the entry of wastewater into rivers and wastewater discharge in river shafts. Thus, its reduction can have detrimental effects on the condition of the area. From an environmental point of view, the decrease in the low flow elevates the concentration of pollutants and, as a result, reduces dissolved oxygen, leading to death of fish and other aquatic animals, as well as severe damage to the river's environment. In addition to raising the frequency of floods in winter and causing severe erosion in the region, the growth of high flows can also affect the structures designed according to the intensity of past discharges. Therefore, these issues should be addressed by managers in the field of soil conservation and watershed management. Overall, analysis of the results confirms that the effects of climate change are significant and worrisome.

Overall, hydrological drought occurrence is expected to occur earlier in comparison to the current hydrological conditions, and we suggest a need for groundwater conservation efforts. Because of such severe consequences of climate changes, water resources decision makers, planners, and ecological conservationists may need to prepare appropriate mitigation measures, such as enhancing groundwater availability through recharging groundwater aquifers from water captured by water harvesting structures. On the other hand, because of increasing peak flows, designing stream and river structures with higher return periods are suggested.

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