Water Harvesting Research Vol. 4, No. 2, Autumn & Winter 2021, Original Paper p. 191-209

University of Birjand

10.22077/JWHR.2022.4990.1050

Simulation of Low Flow Using SWAT Under Climate Change Status

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Received: 27 December 2021/ **Revised**: 20 February 2022/ **Accepted**: 21 February 2022

Abstract

One of the climate change impacts is an increase in the severe drought frequencies. Recently, low flow frequency analysis has been considered in the study of hydrological drought. This study aims to forecast low flow by 2099 in the Kan River Basin in order to assess climate change impacts on low flow in this region. For this purpose, temperature and precipitation data were simulated by HadCM3 model using SDSM downscaling model under the scenarios A2 and B2 by 2099. Runoff simulation was estimated using SWAT while calibration and validation were implemented using the SWAT-CUP software and SUFI-2 algorithm. The optimal parameters obtained from monthly and daily calibration were projected via SUFI-2 algorithm. The results showed an increase in temperature but decrease in precipitation rate, which in the most pessimistic scenario, proves an increase in maximum temperature up to 4.2 °C and for the precipitation, a decrease down to 10.8% by 2099 is expected, as well. Furthermore, the accuracy analysis of the simulated runoff based on the monthly and daily calibration results showed a good fit between observed and simulated values. In fact, their correlation coefficient with the measured values differed less than 0.03. Meanwhile for maximum flow values, daily calibration led to a more accuracy. The results of runoff forecasts showed a decrease in runoff, which is expected for spring and summer however an increase would be for autumn and winter. Overall, a 15 to 21 percent reduction in runoff was projected by 2099.

Keywords: Climate change, Hydrological drought, Discharge, SWAT model, Kan basin.

1. Introduction

Over the past century, global climate change has been observed which has had impacts on regional water resources through vivid changes in precipitation and temperature (IPCC, 2007). There are considerable evidences proving that the global climate change is undergone, due to increase in the concentration of CO_2 and other GHGs which may cause an altered patterns of precipitation (Backlund et al, 2008). Furthermore, it is expected that the alteration may occur in frequencies, severity and duration of extreme events such as drought, flash floods and fire outbreaks in the forests and rangelands. Quantifying the impacts of climate change on water resources for better planning of their operation using hydrological models, is suitable for assessing water resources, understanding hydrological processes and predicting the effects of land use and climate change. One of the first researches in Iran on the subject of climate change effects goes back to the study done by Massah Bavani (2006) who studied the impacts of climate change on the surface water resources of Zayandehrud basin in 2005. Furthermore in 2011, Goodarzi et al. studied climate change impacts on surface runoff in the upper Karkha basin and concluded that in future periods the temperature will increase by 0.7 to 1.2 °C and surface runoff will be reduced down to 11% - 19%. In their research, the semi-distributed Soil and Water Assessment Tool (SWAT) model had been used as a rainfall-runoff model. Goodarzi et al, (2016) investigated the changes in climate parameters of the Urmia Lake watershed under the influence of climate change using statistical downscaling methods of Statistical DownScaling Model (SDSM) and Lars-WG weather generator. In another study, they examined the evapotranspiration caused by climate change in the same area. In another study, Ghermezcheshmeh et al, (2014) investigated the effect of morpho-climatic factors on the accuracy of SDSM downscaling model. Based on the results, the precipitation data for the stations located in different corners of the HadCM3 cell were simulated with less accuracy than the stations located in the center of the cell. Moreover, they proved maximum temperature values were more accurate at the stations where altitude was close to the average cell height. They finally concluded that the selected predictors depend on the climatic conditions of each station. In another study conducted by Haji Mohammadi et al, (2015) a greater increase in temperature in the future for urban areas than non-urban areas was forecasted.

The SWAT hydrological model is one of the most widely used models in this field providing information on climate, soil characteristics, topography, vegetation, land-use management and land use practices. It simulates physical processes related to water movement, sediment, plant growth, nutrient cycling, etc. directly from input parameters. The results of many studies such as Abbaspour et al. (2006), Grusson et al. (2015), Yang et al. (2016), Gholami and Nasiri (2015) confirm the performance of this model in runoff simulation and basin management studies. Moreover, in many studies, this model has been used to predict the flow condition under climate change, which can be referred to the study of Morid et al. (2016) in the Kordan River. In this work, future climate forecasting was performed using the HadCM3 data under the scenarios A2 and B1. Then, the SWAT model simulated hydrological indicators such as the quantity, duration, time and frequency of maximum flows for the base and future periods. The results showed a decrease in flow and a change in the time of occurrence of the minimum and maximum flow for both scenarios. In another study, Xu et al. (2017) examined the effect of climate change on flood risk in a basin of Michigan. In this study, one global climate model (CESM1-CAM5) and two regional models (CRCM-CGCM3, RCM3-GFDL) and two downscaled regional dynamic models (RCM4-GFDL, RCM4-HadGEM) were employed. The SWAT hydrological model was used to simulate runoff on a daily basis to finally determine the flood risk by the indicators related to the probability, duration, quantity and frequency of floods. Comparison of temperature and precipitation between the base (1983-1999) and future (2044-2060) periods showed an increase of 3.32-3.69 °C in annual temperature and changes in annual precipitation around 3% - 12% compared to the far period. The results of this study showed that the risk of flood in this basin will decrease compared to the next period if the increase in rainfall is less than 10% due to the effect of temperature and evaporation, and if the rainfall increases more than 20%, the risk of flood will increase, as well. In a study conducted by Shresta and Htut (2016) in the Indrawati River Basin in Nepal, the potential effects of climate change on the hydrology and water resources of this basin were investigated. Climatic scenarios from one RCM model (HadGEM3-RA) and two GCM models (MIROC-ESM and MRI-CGCM3) were introduced to the SWAT hydrological model. The results showed that by the end of the present century, the basin temperature will increase by 2.5 - 4.9 ° C and also the increase in the average annual rainfall for the future period was predicted. This study showed an increase in annual discharge in both Malamchi and Indrawati rivers. In a study conducted by Woldesenbet et al. (2017), the changes in water flow and hydrological balance under different climate change and land use scenarios for the period 2016-2030 in Tana and Beles basins were investigated using the SWAT model. The simulated average short-term climate showed a warmer condition compared to the base period (1980-2013). Climatic scenarios in near future showed an intensification of the extreme events with an increase of droughts and a decrease of precipitation in the rainy season. Bajracharya et al, (2017) studied the impact of climate change on the water balance and hydrological regime of the Kaligandaki Basin, Nepal. The SWAT model was used to predict flow changes under the RCP4.5 and RCP8.5 scenarios of the CMIP5 general circulation model. A 4°C increase in the average annual temperature and a 26% increase in the average annual rainfall until the end of the 21st century was predicted under the RCP8.5 scenario. The results of the model showed a 50% increase in discharge at the basin outlet. According to the study, available water in this area is unlikely to decrease in the 21st century.

Shrestha and Wang (2017) employed SWAT model to simulate sediment load in the cold Athabasca River basin in Canada. In this study, the data of three climate models were used for two scenarios (RCP4.5 and RCP8.5) and two middle and late 21st century periods. The results showed that both warmer and wetter climates had an increasing impact on sediment load. The increase in sediment load in the future period in agricultural lands was 0.97 tons per hectare per year and more than the soil formation rate in the region.

One of the consequences of climate change is hydrological drought, and one of the criteria for the evaluation of hydrological drought is low flow frequency analysis. Low flow is defined as the flow of river during long dry climates (Smaktin, 2001). In fact, the lowest flow is the lowest average flow in several consecutive days such as 5, 7, 30, 60 up to 180 days during a year (Eslamian et al, 2005). The purpose of this study is to investigate the effect of climate change on the low-flow of the Kan River. So far, several studies have been conducted on the impacts of climate change in this basin. In a study conducted by Haji Mohammadi et al. (2018), the effect of climate change on runoff in this basin was investigated. The results showed an increase in temperature and a decrease in precipitation, and in general, a 7% decrease in runoff by 2040 was predicted under the scenario A2. In another study, Ghermezcheshmeh and Haji Mohammadi (2018a) identified the effective parameters in runoff simulation by SWAT hydrological model. In this study, model calibration was performed based on the SUFI-2 algorithm and Nash Sutcliffe objective function. According to results, snow parameters and hydrological parameters such as manning coefficient and hydraulic conductivity of the canal were recognized as sensitive parameters and groundwater parameters were introduced as the least sensitive parameters. In another study, Ghermezcheshmeh and Haji Mohammadi (2018b) studied the effect of the accuracy of digital elevation model (DEM) on runoff simulation by the SWAT model in the Kan Basin. The comparison of the values obtained for P-factor, d-factor, R^2 and NS in the models implemented via the DEMs with different accuracy showed a significant correlation at the 95% level between DEM map accuracy and simulation accuracy. Ghermezcheshmeh (2014) simulated low-stream flow in a SWAT model. In this study, the model was calibrated by SUFI-2 on a monthly basis and the results showed 0.27 m^3 overestimation in low flow simulation. In another study conducted by Ghermezcheshmeh et al. (2016), a 26% decrease in low flow in this river by 2040 was predicted under the scenario A2.

In this study, in order to investigate the effect of climate change on the low flow of the Kan River until 2099, under scenarios A2 and B2, the SWAT hydrological model is calibrated on a monthly and daily basis and the results are compared together.

2. Materials and methods

2.1. Study area

Kan Basin is one of the central sub-basins of the country. It covers an area equal to 206.7 km^2. It supplies part of consuming water of the capital city of Tehran. Most parts of the study area classified in semi-arid and arid regions. Minimum and maximum altitudes of the study area are 1400 and 3800 meters above the sea level. The geographic location of study area is shown in Figure 1.

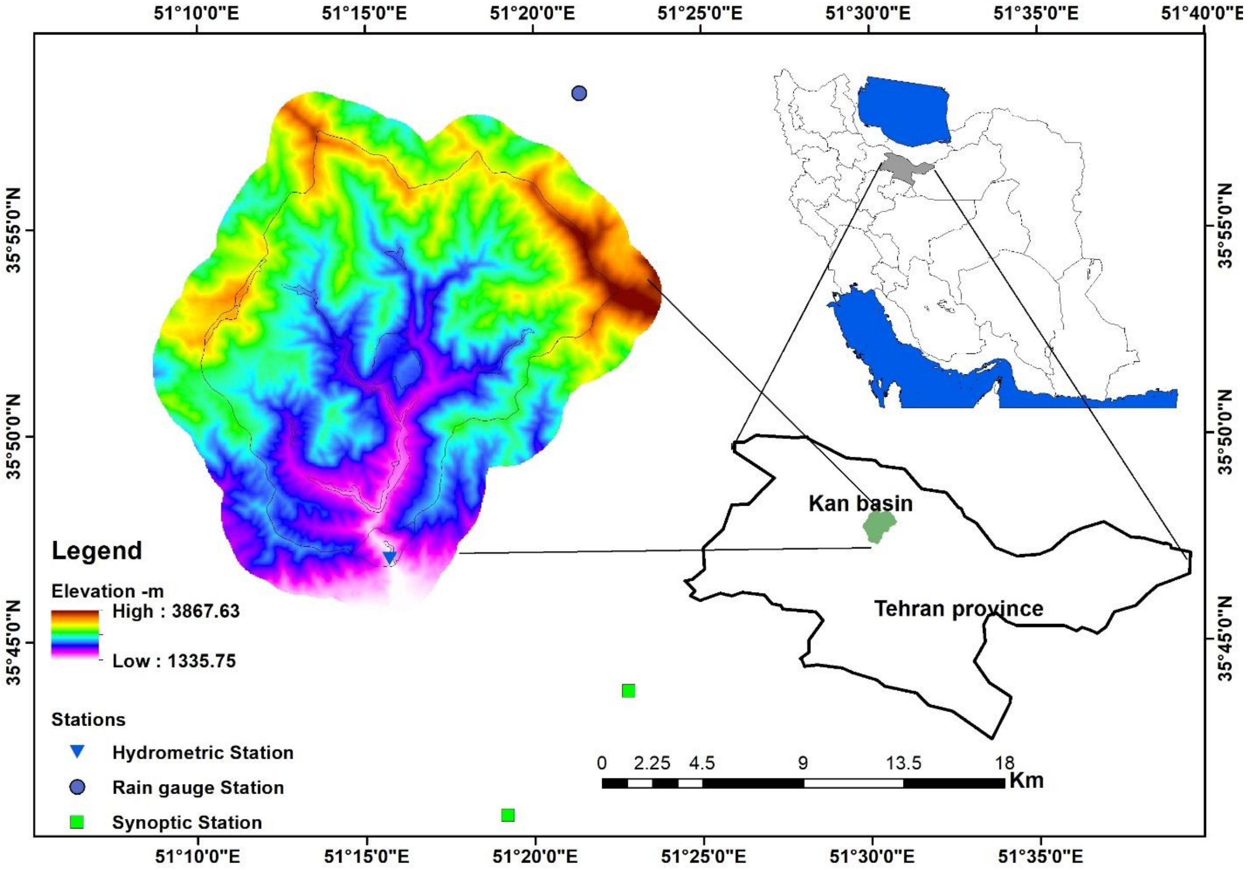

Fig. 1. Geographic location of the study area

The main goal of this research is to estimate low-flow of the Kan River considering climate change status using SWAT model. In order to project climate change impacts and predict the values of temperature and precipitation by the horizon of 2099, microscale forecasting and large-scale HadCM3 data under the scenarios A2 and B2 with temperature and precipitation data of the stations near the basin (with sufficient records) (Table 1) were utilized within the SDSM 4.2.8 downscaling model environment. This model is based on the linear multiple regression techniques between large-scale variables and local observational variables. Therefore, from 26 large-scale predictor variables, 4 to 6 variables that had a good correlation with the observational data were selected by considering the internal correlation (Debik and Coulibaly, 2006). Table 2 identifies the chosen predictor variables for each station. After determining the predictor variables, temperature and precipitation values for the base period (1961-2001) and three periods, the near future (2011-2040), the mid-future (2041-2070) and the far future (2071-2099) under the scenarios A2 and B2 of the HadCM3 model were simulated. Finally, temperature and precipitation changes due to climate change were identified.

SWAT hydrological model was used to simulate runoff. The information required to execute the SWAT model is both numerical and spatial information. Numerical information includes rainfall, temperature, relative humidity, wind and solar radiation. SWAT is a semi-distributed, physical, continuous model that can be used to simulate surface runoff, infiltration, transpiration evaporation, erosion, nutrient and pesticide transport, groundwater flow, channel transfer losses, and reservoir storage at various short and long-term intervals (Winschel et al, 2010).

In this model, the basin was divided into a number of sub-basins based on topography and flow network. After that, each sub-basin was divided into a number of hydrological response units (HRU) according to vegetation characteristics and soil map, so that each hydrological unit did not have significant changes in soil properties, topography, cover and land use. The output of the model (surface runoff) in each sub-basin was obtained from the total surface runoff calculated for each hydrological unit by weighted average method. In this study, the climatic data from Mehrabad synoptic station and precipitation information of Shahrestanak, Sierra and Bileqan stations located around the basin were used. The model was also calibrated using the observed water discharge of the Suleqan hydrometric station located at the basin outlet (Table 1). It should be noted that the data of North Tehran station were not used in runoff simulation due to insufficient statistical period length and were considered only to predict the temperature and precipitation of the future period. Spatial information required to implement the model includes digital elevation model, information related to land use and soil of the studied basin, provided by the Tehran Office of Natural Resources Studies. The land use classes are semi-dense rangelands, orchards, dense rangelands, low-density rangelands and urban area, respectively. In this study, Kan basin was divided into 9 sub-basins and 98 HRUs based on spatial information and threshold ranges.

Table 1. Attributes of selected stations

Station	Type	Long.	Lat.	Altitude (m)	Period
Mehrabad	Synoptic	51° 19'	35° 41'	1190.8	1961-2010
North of Tehran	Synoptic	51° 29'	35° 48'	1549.1	1988-2010
Shahrestanak	Rain gauge	51° 21'	35° 58'	2193	1970-2010
Sira	Rain gauge	51° 09'	36° 02'	1790	1970-2010
Bileqan	Rain gauge	51° 02'	35° 50'	1360	1970-2010
Suleqan	Hydrometry	51° 15'	35° 47'	1430	1970-2010

Table 2. Selected predictor variables for predictant variables

Station	Climatic variable	Predictor
Mehrabad	precipitation	P-z, P5-z, R500, Rhum
	Max. Temp.	P5-z, P500, P8-u, Shum, Temp
	Min. Temp.	P-v, P5-f, P500, P8-u
North of Tehran	precipitation	P-z, P5-z, P500, Rhum
	Max. Temp.	P500, P8-u, Shum, Temp
	Min. Temp.	P-v, P5-u, P500, Shum
Shahrestanak	precipitation	P5-u, P5-z, P500, P5-zh, Rhum
Sira	precipitation	P-z, P5-f, P5-z, P500, Rhum
Bileqan	precipitation	P-z, P5-z, P500, R500, Rhum

P-z: Surface vorticity, Pv: Surface meridional velocity, P5-f: Flow power at 500 hPa, P5-u Orbital velocity at 500 hPa, P5-z: Panel at 500 hPa, P500: Geo-potential at 500 hPa, P5-zh :Divergence at 500 hPa, P8-u: orbital velocity at 850 hPa, r500: specific or relative humidity at 500 hPa, shum: surface specific humidity, Rhum: relative surface humidity, Temp: average temperature at 2 m altitude.

2.2. Calibration and uncertainty analysis of SWAT model

In this study, SUFI-2 method was used to calibrate and analyze the uncertainty of the SWAT model. The implementation steps of the SUFI-2 program were as follows: 1. Objective function was determined 2. Minimum and maximum absolute values of the parameters were determined 3. Sensitivity analysis of all parameters was performed in the initial calibration steps 4. Amplitude of the initial uncertainty was evaluated and assigned for the sampling method. 5. Sampling was performed and up to n simulations were run based on the objective function. 6. Sensitive parameters were identified and the optimization of sensitive parameters during calibration was completed. Uncertainty was determined by p-factor, which represents the percentage of measured data within the 95% uncertainty band (95ppu). The 95ppu criterion is obtained by calculating the corresponding values of 2.5% probability as the lower limit and 97.5% as the upper limit, using sampling and the elimination of 5% very bad simulation. Then another factor in estimating calibration quality and analyzing uncertainty titled r-factor, which is equal to the average thickness of 95ppu divided by the standard deviation of the observed data. The ideal condition in a simulation is when the p-factor value is close to one and the r-factor value is close to zero (Abbaspour, 2011). In this research, in addition to the above two facts, two functions R^2 and NS are used for statistical evaluation of the calibrated model. These two evaluation functions are based on the Equations 1 and 2, as follows:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(Q_{obs,i} - \overline{Q_{obs}})(Q_{sim,i} - \overline{Q_{sim}})\right]^2}{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs})^2 \sum_{i=1}^{n}(Q_{sim,i} - \overline{Q_{sim}})^2} \qquad (1)$$

$$NS = 1 - \frac{\sum_{i=1}^{n}(Q_{obs} - Q_{sim})_i^2}{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs})^2} \qquad (2)$$

where, Q_{obs} denotes the measured values, Q_{sim} is the simulated value, Q_{obs} is the average of the measured values, Q_{sim} is the average of the simulated values and n is the number of observations. The coefficient R^2 indicates the concordance of the observed and simulation values using the regression analysis method and its value varies between 0 and 1. The Nash-Sutcliffe coefficient (NS) shows the relative difference between the observed and simulated values, and the value of this factor varies infinitely between one and negative. NS values should be greater than 0.5 so that on a monthly basis, the model results are acceptable for hydrological studies as well as simulation of processes related to pollutant transfer, which is usually the same criterion used for parameter R^2 (Moriasi et al, 2007).

At the end of the calibration phase, the model is validated. Finally, the validation determines the reliability of the calibrated model for the application by independent data and in future time periods. The simulated flow rate was calibrated by the model during the years 1983 to 1991 and then the calibrated model was validated in the period 1996-1992. In this study, the calibration and validation of the SWAT model was performed as a daily and monthly time steps to compare the accuracy of the model in simulating runoff and low flow for these two modes. Then, after calibrating the SWAT model, both daily and monthly runoff based on the optimal values obtained for the sensitive parameters in both cases were simulated and compared to determine whether the accuracy of the runoff simulation by the optimal values obtained in, led to a significant difference between monthly and daily calibration? Finally, after ensuring the accuracy of the model, low flow values with the durations of 3, 5, 7, 9, 11, 15, 30 and 60 days were calculated for different periods and compared to investigate the effect of climate change on low flow. Then the model with temperature and precipitation of the future period was executed with the scenarios A2 and B2 and finally runoff was calculated with two daily and monthly models and the minimum discharge was calculated with different time base. The steps of conducting the research are shown in Figure (2) as a flowchart.

3. Results

3.1. Temperature and precipitation forecasts

In this study, in order to predict the changes in the variables of maximum temperature, minimum temperature and precipitation, the predicted values were computed based on the HadCM3 predictors under the scenarios A2 and B2, which are the most pessimistic and optimistic scenarios for future, respectively. The simulations in the three periods of near future (2011-2040), middle future (2041-2070) and far future (2071-2099) were compared with the base period (1961-2001). The results for each variable are as follows:

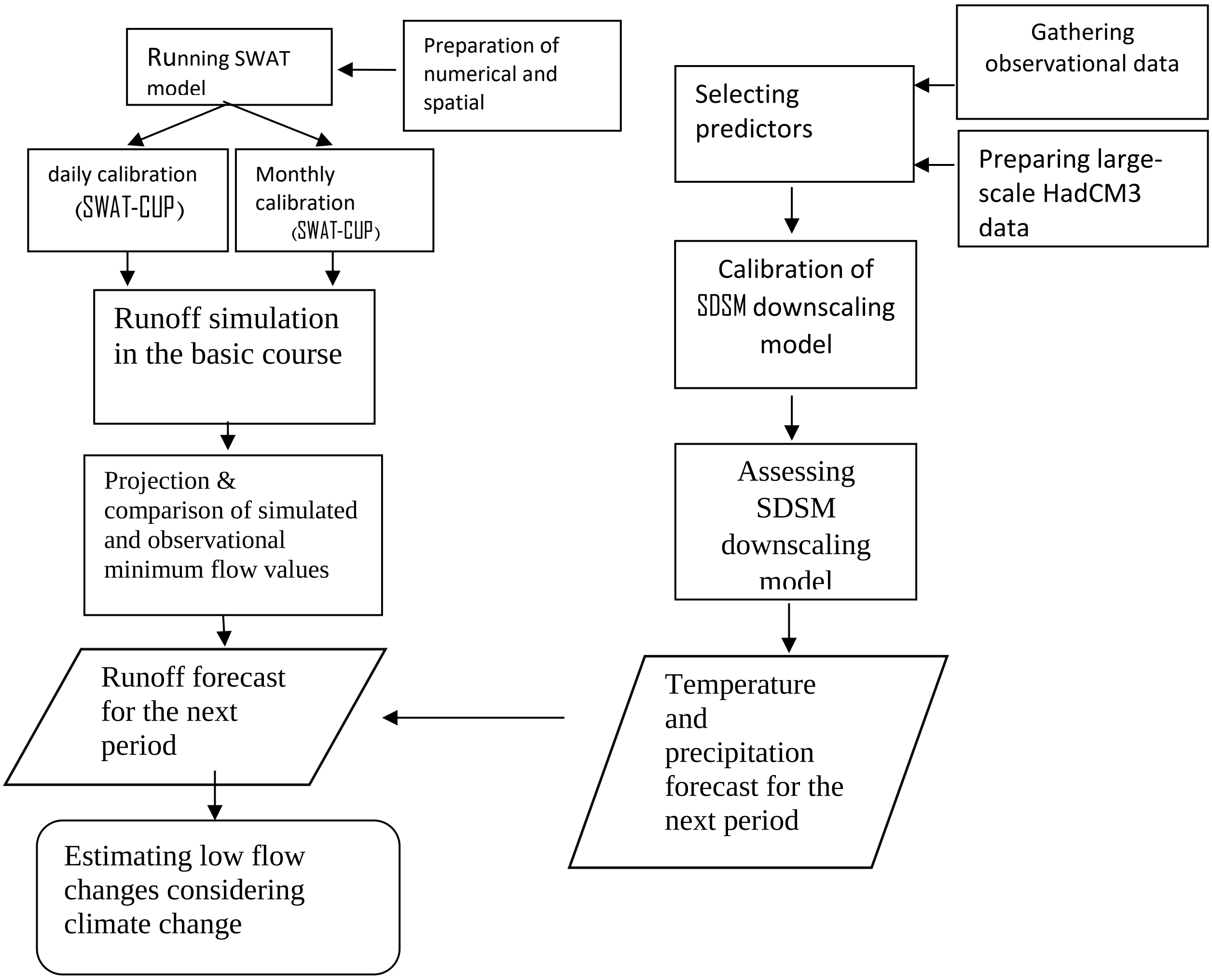

Fig. 2. Research flowchart

3.2. Temperature forecast

The values of maximum and minimum temperature changes for the future three periods and under the various scenarios are given in Table 3. Based on the results, the increase in maximum and minimum temperature was predicted for both stations, which was higher under the scenario A2, in comparison with the scenario B2.

3.3. Precipitation forecast

The values of precipitation changes for the future three periods and under different scenarios are given in Table 4. Accordingly, in all stations except Sira station, decrease in precipitation was predicted under both scenarios and the amount of decrease was higher for the A2 scenario, compared to the A1. The increase in precipitation at Sira station was related to its increase in winter for mid-term and long-term periods, and the highest decrease in precipitation at other stations was predicted for spring. The highest decrease was obtained for the Mehrabad station, which was 10.8% in the worst condition and 7.5% decrease in the best condition. And the lowest amount of decrease was calculated for the Sira station which was 0.62% (worst case). A 0.8% increase in precipitation in the best case (scenario B2) was obtained for the Sira station, as well.

Table 3. Changes in max. and min. temperatures compared to the base period

Annual	Winter	Fall	Summer	Spring	Period	Scenario	Station	Variable
1.4	0.9	1.6	1.5	1.5	2011-2040	A2	Mehrabad	Maximum Temperature
2.7	2	3	3.3	2.6	2041-2070			
4.9	3.5	5	5.7	5.3	2071-2099			
1.5	1	1.2	2	1.7	2011-2040	B2		
2.3	1.7	2.2	2.8	2.3	2041-2070			
3.4	2.5	3.5	4	3.5	2071-2099			
1.3	0.8	1.7	1.2	1.6	2011-2040	A2	North of Tehran	
2.5	1.6	3.1	2.8	2.6	2041-2070			
4.6	2.8	5.1	4.8	5.6	2071-2099			
1.3	0.8	1.1	1.6	1.8	2011-2040	B2		
2.1	1.4	2.2	2.3	2.4	2041-2070			
3.1	2	3.6	3.3	3.5	2071-2099			
0.8	0.4	1	0.9	1	2011-2040	A2	Mehrabad	Minimum Temperature
1.6	0.8	1.9	2.1	1.7	2041-2070			
2.9	1.3	2.9	3.8	3.4	2071-2099			
0.8	0.3	0.7	1.1	1.1	2011-2040	B2		
1.3	0.6	1.3	1.7	1.6	2041-2070			
1.9	1	2	2.5	2.2	2071-2099			
0.8	0.6	1.1	0.5	1.1	2011-2040	A2	North of Tehran	
1.8	1.2	2.3	1.5	2	2041-2070			
3.1	2.3	3.5	2.8	3.9	2071-2099			
0.9	0.7	0.9	0.7	1.3	2011-2040	B2		
1.5	1.2	1.5	1.3	1.9	2041-2070			
2.2	1.8	2.3	1.9	2.8	2071-2099			

Table 4. Rainfall changes in three periods compared to the base period

Annual	Winter	Fall	Summer	Spring	Period	Scenario	Station
-12.3	-1.2	-1.5	-2.4	-7.2	2011-2040	A2	Mehrabad
-14.8	-3.9	-2.2	-3.2	-5.6	2041-2070		
-35.8	-8.1	-4.7	-5.9	-17	2071-2099		
-9.9	-1.5	3.6	-3.9	-8	2011-2040	B2	
-13.7	-2.5	-1.2	-3.7	-6.2	2041-2070		
-19.4	-2.8	-4	-4.3	-8.2	2071-2099		
-20.6	3.5	-0.6	-3.7	-19.8	2011-2040	A2	North of Tehran
-20.2	5.2	0.9	-6.2	-20.2	2041-2070		
-57.1	16.5	-10.9	-9.6	-53.2	2071-2099		
-11.6	3.9	3.5	-5.5	-۱۳/۵	2011-2040	B2	
-15.4	7	-3.8	-5.5	-۱۳/۱	2041-2070		
-26.4	12.9	-11	-7.2	-۲۱/۱	2071-2099		
-33	-1.5	-5.5	-10.9	-15.1	2011-2040	A2	Shahrestanak
-13.5	13	-9.8	-19.6	2.8	2041-2070		
-67.1	10.8	-22.4	-27.4	-28.1	2071-2099		
-40.1	0.3	-4	-17.2	-19.3	2011-2040	B2	
-27.2	2.9	-7.4	-21.1	-1.6	2041-2070		
-41.3	12.3	-16.8	-24	-12.8	2071-2099		
-17.4	8.3	-7.5	-12	-6.1	2011-2040	A2	Sira
13.8	30.4	-8.6	-17.2	9.3	2041-2070		
-8	51.1	-25	-25.1	-9	2071-2099		
-16.4	8.9	-3	-17.9	-4.5	2011-2040	B2	
17.1	25.3	-4.6	-17.3	13.7	2041-2070		
14.5	49	-18.9	-21.9	6.3	2071-2099		
-16.9	-2.8	-2.2	-2.5	-9.4	2011-2040	A2	Bileqan
-18.1	-0.1	-10	-4.1	-3.9	2041-2070		
-42.3	4.7	-18.7	-6.6	-21.7	2071-2099		
-2.7	8.4	-0.6	-3.4	-7	2011-2040	B2	
-4	12.2	-7.6	-4.4	-4.2	2041-2070		
-13.1	16.1	-14.5	-5.2	-9.4	2071-2099		

3.4. SWAT calibration and validation

In this research, the model was calibrated once by the SUFI2 algorithm based on the Nash Sutcliffe objective function on a daily and also monthly basis. The optimal values of the parameters for both cases were determined. Finally, runoff was simulated and compared daily based on the optimal values calculated in both cases. Table 5 shows the final values fixed for the most effective parameters. The selected parameters, their sensitivity, range and optimal values for both daily and monthly conditions in the calibration period (1983-1991) were presented in Tables 6 and 7. In this study, optimization was performed in two replications in both modes and 200 simulations were performed for each replication. The calibration results of the model for both daily and monthly time steps with uncertainty band are shown graphically in Figures 3 and 4. The performance metrics of the model for both modes are also presented in Table 8. According to the obtained results, the model simulation accuracy was acceptable for both time steps. According to the studies by Santhi et al. (2001), Moriasi et al. (2007) and Van Liew et al. (2003), if R^2 and NSE are higher than 0.5, the performance of the model is very good. Accordingly, the values related to these indicators in both calibration and validation periods were higher than 0.5. In addition, the value of the objective function in the monthly calibration was better than the daily time step. In other studies, such as the study conducted by Xu et al. (2017) in a field in Michigan, the daily NSE and R2 calibration metrics of the model was 0.60 and 0.69, respectively. While in monthly calibration, the values related to those indicators were higher and equal to 0.72 and 0.77, respectively. Also, in a study conducted by Li et al. (2017) in southeast China, the accuracy of the model in acceptable monthly calibration (above 0.5) was obtained, while the results were not acceptable for daily calibration.

Table 5. Final values for runoff simulation in model calibration

Parameter	Monthly calibration	Daily calibration
Temp. gradient	-7.3	-7.2
Snowfall temperature	0.39	0.30
Snowmelt temperature	3.29	4.90
Snowmelt factor June 21	9.65	7.72
Snowmelt factor Dec. 21	2.39	2.42

Table 6. Sensitivity analysis in daily model calibration (1983-1991)

Parameter	Lower limit	Upper limit	p-value	t-stat	Optimized
V__ALPHA_BF	0	0.6	0.0	9.57	0.4
V__GWQMN	500	1500	0.03	2.15	1482
V__CH_N2	0.02	0.3	0.08	1.73	0.14
V__CH_K2	30	280	0.16	1.4	180.6
R__CN2	-0.1	0.2	0.7	0.38	0.12
V__GW_REVAP	0.02	0.2	0.52	0.64	0.16
V__REVAPMN	50	200	0.46	0.73	68.3
V__ESCO	0.2	0.9	0.13	1.49	0.86

V__GW_DELAY	0	3	0.10	1.64	1.1

Table 7. Sensitivity analysis in daily calibration (1991-1993) of the model

Parameter	Lower limit	Upper limit	p-value	t-stat	Optimized
V__ALPHA_BF	0	0.6	0	11.11	0.38
V__CH_K2	30	280	0	4.8	190.6
V__GW_REVAP	0.02	0.15	0.13	1.48	0.14
V__GWQMN	800	1000	0.19	1.31	984.5
V__CH_N2	0.1	0.3	0.45	0.75	0.26
V__ESCO	0.4	0.9	0.56	0.58	0.79
V__GW_DELAY	0	3	0.65	0.45	0.18
V__REVAPMN	0	100	0.85	0.19	83.25
R__CN2	0	0.2	0.88	0.15	0.13

Where ALPHA_BF: Groundwater Flow Response Coefficient, GWQMN: Minimum Aquifer Flow Baseline, CH_N2: Main Waterway Manning Coefficient in Each Sub-Basin, and CH_K2: Main waterway hydraulic conductivity (mm / h), CN2: Curve number, GW_REVAP: Deep aquifer intrusion coefficient or capillary ascent from surface aquifer, REVAPMN: Minimum surface aquifer water storage capacity to occur revap (mm), ESCO: Soil Evaporation Correction Coefficient, GW_DELAY: Groundwater Delay Time (days).

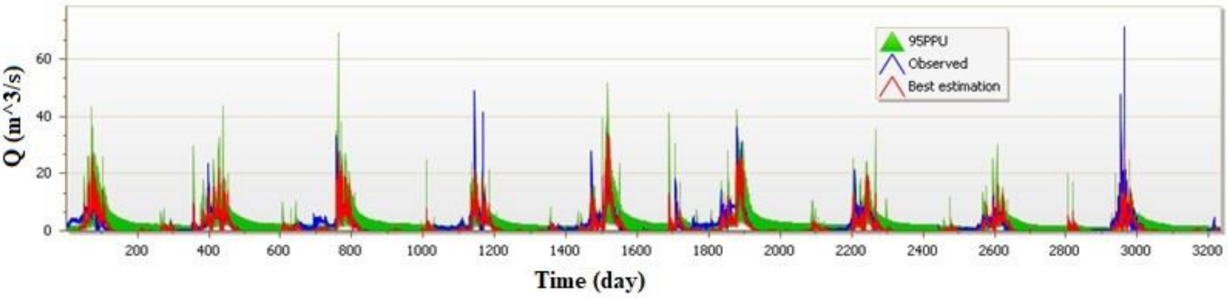

Fig. 3. Daily simulated flow & observations during calibration period (1991-1993)

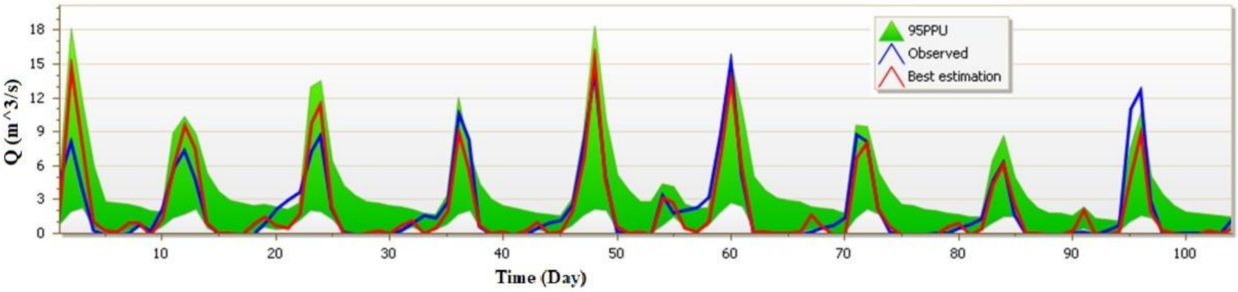

Fig. 4. Monthly simulated flow & observations during calibration period (1991-1993)

The model in the years 1992 to 1996 was validated based on the range obtained for the selected parameters during the calibration phase. The results of model validation are shown graphically in Figures 5 and 6, and also the results of model performance during the validation period are represented in Table 8. According to the results, the performance of the model in the validation period was also acceptable, only the values of r-factor and p-factor were slightly lower. These findings can be supported through the study conducted by Shrestha and Htut (2016) in Nepal.

Table 8. Calibration results of the model for both daily and monthly time steps

Stage	Time step	r-factor	p-factor	R^2	NS
Calibration	Daily	1.05	0.54	0.63	0.61
	Monthly	1.08	0.61	0.84	0.83
Validation	Daily	0.72	0.52	0.63	0.61
	Monthly	0.78	0.52	0.87	0.84

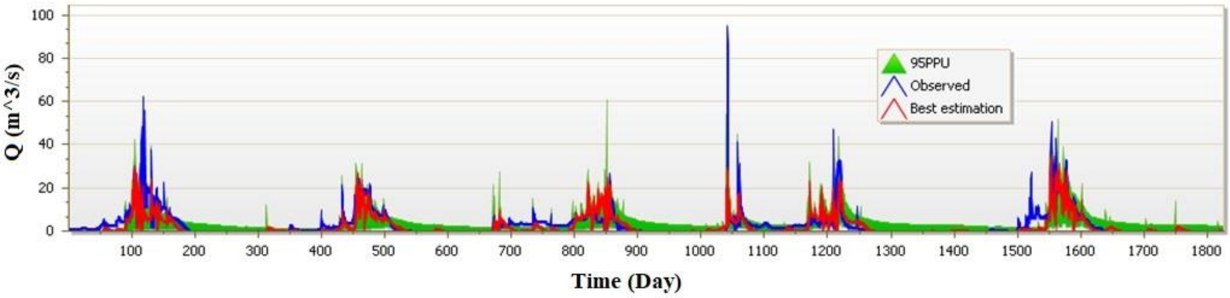

Fig. 5. Daily simulated flow compared to the observations during validation period (1996-1992)

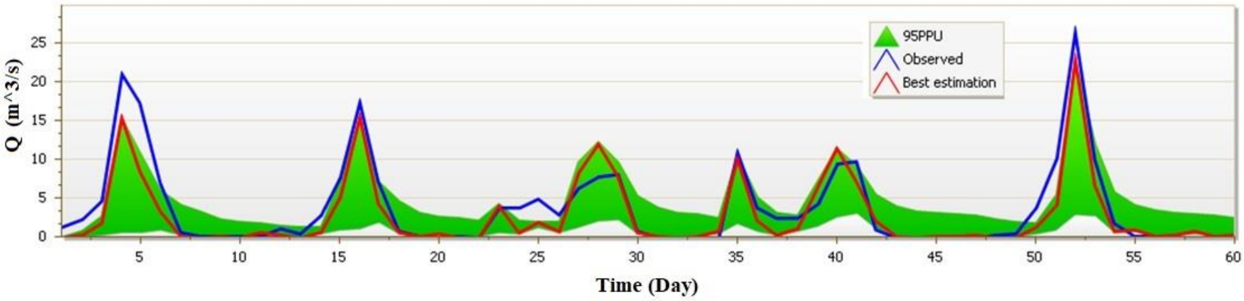

Fig. 6. Monthly simulated flow compared to the observations in the validation period (1992-1996)

After calculating the optimal values related to the parameters affecting runoff simulation, runoff values were daily simulated and compared based on the values obtained from monthly and daily calibration. Figure 7 shows the correlation of the observed runoff with the runoff simulated via daily and monthly calibration. A slightly higher daily value was obtained. Table 9 shows the error values of the absolute mean difference for the mean, maximum and minimum values of the simulated flow in the two time steps, relative to the observed flow. According to the results in monthly calibration, the error of the absolute mean difference was moderate for the minimum values, but for the maximum calibration, the accuracy values were obtained on a daily basis. Thus it can be concluded that the correlation coefficient was higher in daily calibration due to its higher accuracy. Figure 8 shows the observed and simulated runoff for the two cases in the form of a diagram. Due to the shape of simulated runoff based on daily calibration, simulated runoff based on monthly calibration in March has a lower estimation than observational value; however they were almost the same in terms of maximum values. According to the mentioned results, in general, the accuracy of simulated runoff based on daily and monthly calibration was mainly similar. Furthermore, in both time steps, the largest difference between the simulated runoff and the observed runoff was observed in January, February and March.

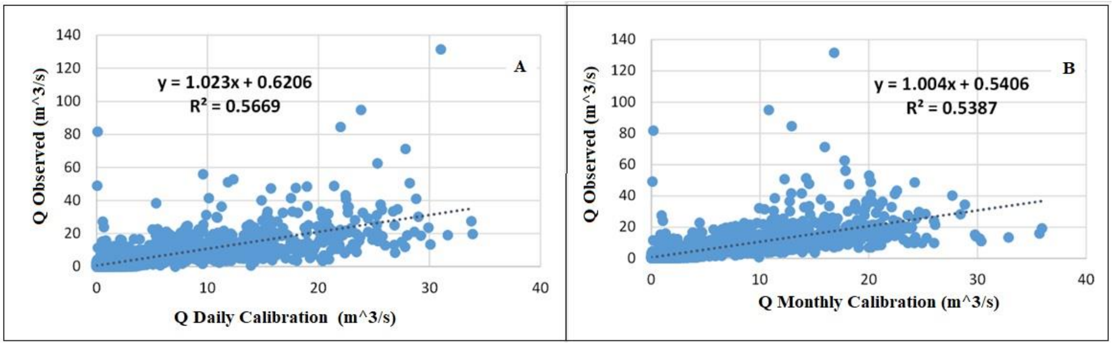

Fig. 7. Simulated and observed runoff in A) (daily), and B) (monthly) time steps

Table 9. Comparison of values of the mean absolute error (daily and monthly)

Min. discharge MAE	Max. discharge MAE	Mean Discharge MAE	Step
0.86	5.07	1.24	Daily calibration
0.78	5.29	1.19	Monthly calibration

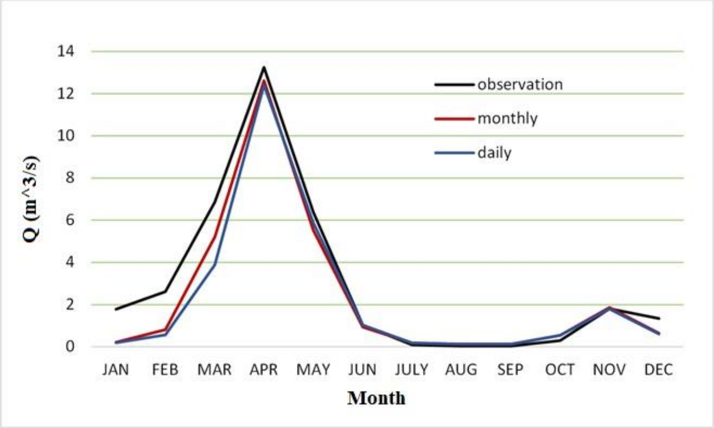

Fig. 8. Comparison of observational flow with simulated flow (monthly and daily)

Then low flow values with durations of 3, 5, 7, 9, 11, 15, 30 and 60 days were calculated based on daily and monthly calibration. The observational discharge values of Suleghan station for the period 1983-1996 were also plotted in Figure 9. According to the diagram, in both calibration time steps, a slight overestimation was observed in the low flow simulation, which was higher in the daily calibration, so that for a 3-days duration in daily calibration, a 0.004 m^3/s overestimation was observed. While in the monthly calibration for the same duration, an estimate of 0.003 cubic meters per second was obtained. Furthermore, this difference was higher for 30, 60-days durations, so that in daily calibration it was estimated to be 0.013 m^3/s and in monthly calibration it was estimated to be 0.009 m^3/s and 0.045, respectively. The flow of 0.041 m^3/s was observed for 60-days continuity in daily and monthly calibrations, as well. According to the results, low flow values of the simulated runoff based on monthly calibration results were more accurate than the simulated values based on daily calibration results and were closer to the observed values.

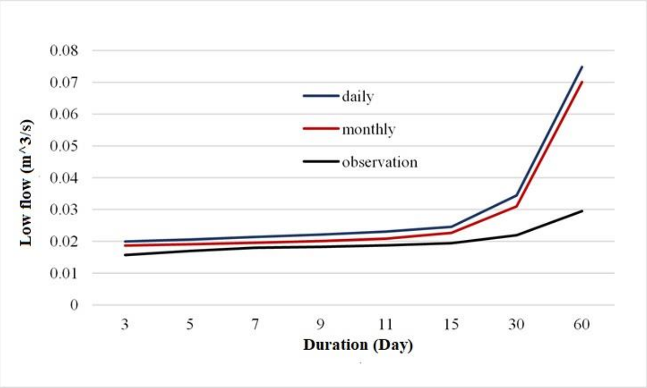

Fig. 9. The comparison of observational values with simulated low flow (daily and monthly)

3.5. Runoff simulation

Finally, runoff was daily simulated based on the results of monthly and daily calibration for the future three periods and the base period. The results of runoff changes in different periods and under A2 and B2 scenarios for both daily and monthly time steps are represented in Figures 10 and 11. As can be seen, in all cases, runoff increased in the months of autumn and winter seasons and decreased in spring and summer, with the highest decrease in April. Furthermore, runoff values for monthly calibration under A2 scenario showed a further decrease until 2099, so that based on monthly calibration, the amount of runoff reduction under the scenarios A2 and B2 was respectively 21.7 and 15.06. The flow values based on a daily calibration for the scenarios A2 and B2 was equal to 20.8 and 14.5, respectively.

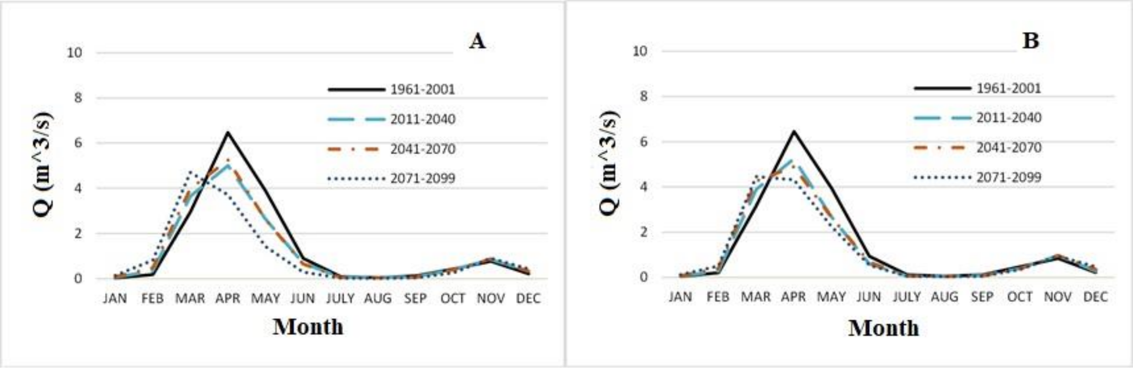

Fig. 10. Runoff changes in different periods (daily calibration)

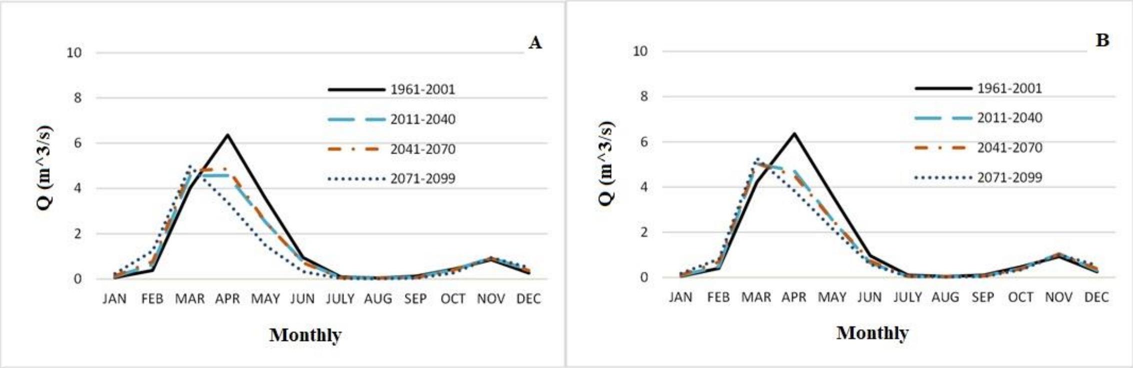

Fig. 11. Runoff changes in different periods (monthly calibration)

3.6. Low flow prediction

Low flow values with durations of 3, 5, 7, 9, 11, 15, 30 and 60 days related to different periods were estimated based on two scenarios A2 and B2. Figures 12 and 13 show the low flow changes for the future three periods compared to the base period. According to the results, low-flow values at short durations (less than 30 days) did not change significantly. Due to the uncertainty of large-scale GCM models, SDSM and SWAT model, low flow values with short durations can be considered as affected by these errors. However, in the simulation based on the results of monthly calibration, had a higher accuracy in low flow simulation. Based on both scenarios for the far future period (2071-2099), a decrease in low flow was observed in all durations. In general, low flow reduction was calculated for all periods. In low flow simulation based on the results of monthly calibration of the model for a 30-days durations, a 49.8% (0.012 m^3/s) reduction of low flow based on scenario A2 and 24.8% (0.006 m^3/s) reduction based on scenario B2 was achieved until 2099. Low flow values with a duration of 30-days in the simulation based on daily results under scenario A2, shows 0.008 m3/s (34%) and based on scenario B2, established 0.002 m^3/s (7.6%) decrease by 2099. In all cases, low flow values for scenario B2 were calculated higher than the A2 scenario. Moreover for 60-days duration, a flow reduction of 40 to 60 percent (0.018 to 0.027 cubic meters per second) in daily calibration and 46 to 64 percent (0.020 to 0.027 cubic meters per second) in monthly calibration was observed. Altogether, for the duration of 30-days, a low flow reduction was observed based on both scenarios.

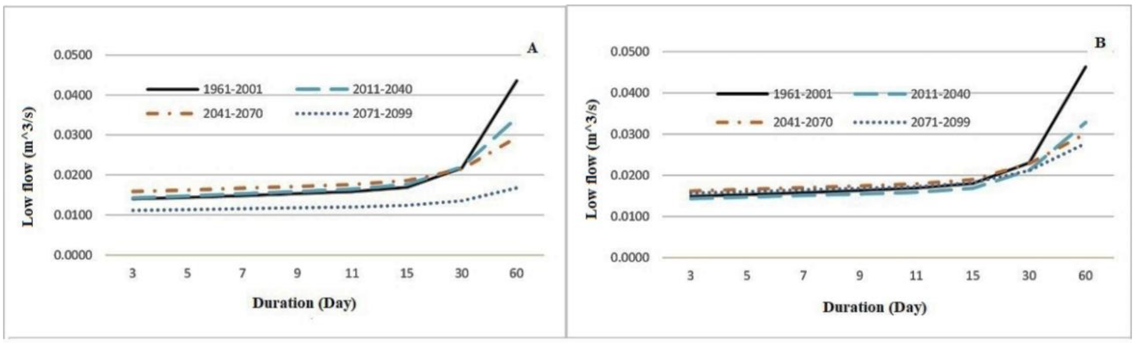

Fig. 12. Low flow changes with different durations (daily calibration)

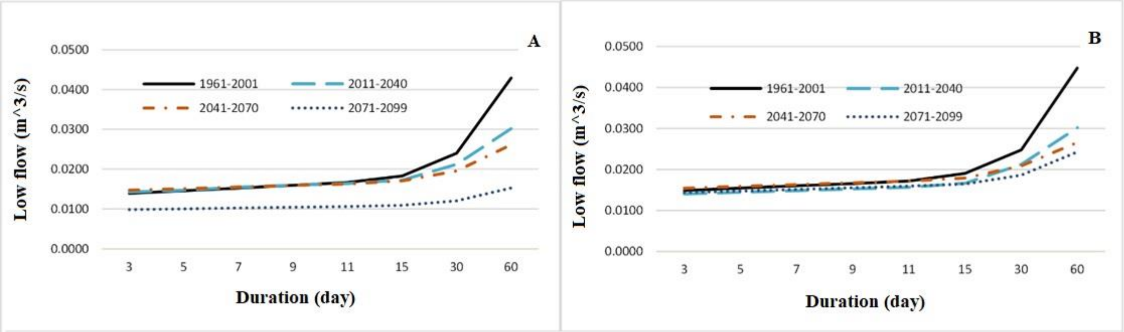

Fig. 13. Low flow changes with different durations (monthly calibration)

4. Conclusion

One of the most important and very sensitive steps of runoff simulation by SWAT model is calibration phase which is very time consuming. In the studies, usually the SWAT-CUP extension and the SUFI-2 algorithm are used in order to achieve higher accuracy in a shorter time. In general, comparing the calibration of the model on a daily and monthly basis, it can be concluded that the behavior of the parameters was similar in both cases, especially in the case of important parameters such as temperature gradient and snow parameters, whose values were fixed in the first step. Furthermore, the accuracy of the simulated runoff based on the monthly and daily calibration results showed that the results did not differ much and their correlation coefficient with the measured values was only 0.03. The accuracy of the monthly simulation for low flow and the mean values was slightly better than the daily simulation, while for the maximum flow values the daily calibration results led to the higher accuracy. Finally, low flow values for both simulation time steps and based on the scenarios A2 and B2 (HadCM3 model) were reduced by 34 to 50 percent in the most pessimistic state and 7 to 24 percent in the most optimistic state for a 30-days duration. By 2099, it also showed that a low flow reduction (64%) is expected for a 60-days duration, while no significant difference was achieved for a shorter duration. The results of this research can be used in other studies conducted by the SWAT-CUP model as well as policies and planning related to water resources.

5. Conflicts of Interest

No potential conflict of interest was reported by the authors.

6. Acknowledgement

The paper is extracted from a research implemented in Soil conservation and Watershed management Institute titled: investigation impact of climate change on low flow by using SWAT, IHACRES and ANN models in Kan Basin. The authors are extremely thankful of the authorities of Soil conservation and Watershed management Institute and other contributors for the help and cooperation in carrying out the project.

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