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Research Article

Assessment of Climate Change Impact on the Gharesou River Basin Using SWAT Hydrological Model

The evaluation of climate change and its side effects on the hydrological processes of the basin can increasingly help in dealing with the challenges that water resource managers and planners face in future courses. These side effects are investigated using the simulation of hydrological processes with the help of physical rainfall-runoff model. Hydrological models provide a framework for examining the relationship between climate and water resources. This research aims at the investigation of the effect of climate change on the runoff of Gharesou, which is one of the main branches of the ''Karkheh'' River in Iran during the periods 2040–2069. To achieve this, the distributed hydrological model Soil and Water Assessment Tool (SWAT) – a model that is sensitive to the changes in land, water, and climate – has been used with the aim of evaluating the impact of climate change on the hydrology of the Gharesou Basin. For this reason, first, the continuous distributed model of rainfall-runoff SWAT for the period 1971–2000 has been calibrated and validated. Next, with the aim of evaluating the impact of climate change and global warming on the basin hydrology for the period 2040–2069, HadCM3-AR4 global climate model data under the A2 scenario – from the SRES scenario set-haves been downscaled. Eventually, the downscaled climate data haves been introduced in the SWAT model, and the future runoff changes have been studied. The results showed that the temperature increases in most of the months, and the precipitation rate exhibits a change in the range of $\pm$30%. Moreover, the produced runoff in this period changes from -90 to 120% during different months.

Keywords: HadCM3; Modeling; SWAT; Water resource

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1 Introduction

In recent decades, the industrial revolution and consequent increased consumption of fossil fuels on the one hand and the destruction of forests and agricultural land use change on the other hand have increased the greenhouse gases, especially CO_2 emissions. The concentration of this gas has increased from 280 ppm in 1750–379 ppm in 2005 [1, 2]. Researchers have shown that if the current trend of fossil fuel consumption continues, the concentration of this gas can reach to more than 600 ppm by the close of the twenty-first century. This increase in greenhouse gases has resulted in certain changes in the earth's climate, which is known as the climate change in scientific terms [1].

Meteorological data and results of the climate change simulation models show that the average atmospheric temperature is increasing. This phenomenon leads to a decrease in summer rainfall, an increase in the probability and intensity of droughts and heat waves, especially in arid and semi-arid areas [3]. On the other hand, it is expected that climate change continues in the twenty-first century. So, the emission of greenhouse gases would exacerbate this effect. Any change in climate variables can, therefore, affect the water resources, which is the focus of this study [4, 5].

Massah and Morid [6] investigated the effects of this phenomenon on the Zayandehrood River flow by the global circulation model of HadCM3. They applied the A2 and B2 scenarios in the periods 2010–2039 and 2070–2099. On the other hand, the analysis showed a decrease in rainfall and an increase in temperature till 2100, especially in the second half of the century. Entrained simulated flood into the Chadgan Dam using the neural network technique shows a decrease in the flow up to 5.8%. The comparison between the A2 and B2 scenarios showed that the A2 scenario is encountered during a more critical condition in this basin. The consideration of climate change and its effects on the water resource is very important, which was not considered seriously by the previous researchers in Iran [6]. The climate change leads to changes in the duration, intensity, shape, and time of rainfall on different parts of the earth; this phenomenon can cause drought and flood. In addition, it can cause changes in the volume and time of runoff. Most parts of Iran suffer the lack of metrological and hydrological data along spatio-temporal scales.

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Abbreviations: **AOGCM**, atmosphere ocean general circulation model; **GIS**, Geographic Information Systems; **HRU**, hydrological response unit; **SWAT**, Soil and Water Assessment Tool

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Abbaspour et al. [7] studied the effect of climate change on the water resources in Iran. In this research, they used the Soil and Water Assessment Tool (SWAT) Hydraulic model to investigate the future climatic effect on Iran's water recourses. The future climate was produced for A1B, B1, and A2 scenarios for the periods 2010–2040 and 2070–2100 by using CGCM3.1 general circulation models that were downscaled in the case of 37 stations. These researchers applied the hydrological model with the aim of analyzing the impact of climate experienced in the future during these periods on precipitation, blue water, green water, and the wheat yield in various parts of the country. They discovered that generally, in future, there would be greater precipitation in wet areas, whereas there would be less precipitation in dry areas [7].

Hydrological models provide a framework for assessing the relationship between climate, human activities, and water resources [8, 9]. These models are classified into three groups: empirical or black-box, conceptual or gray-box, and distributed physically based or white-box. In the first group, the physical law of the processes is not considered clearly, and input is transferred to output with the help of a transformation function [9]. Conceptual models are based on limited studies of hydrological processes in a watershed system; unlike the physical-based models, these models are based on an understanding of system behavior. The physical distribution-based models attempt at presenting all hydrological processes through physical meanings. Thus, by an understanding of the physical process of precipitation, system behavior can be determined under any changes. Since the determination of system behavior is under physical processes and observations, input data should be measured directly in both the laboratory and the field [10]. Physical models consider main properties of the earth such as: elevation, slope, land cover, soil type, and some climate characteristics, including the distribution of precipitation, temperature, and evapotranspiration, because model parameters directly depend on these factors. Distributed hydrological models are very important in the analysis and prediction of the effects of climate change on stream flow [8, 11, 12].

Semi-distributed models allow the spatial variation of the parameters by dividing the basin into a number of sub-basins. The main advantage of these models is that their structure is more physically based than the structure of lumped models, and that they are less demanding on input data than fully distributed models. Nowadays, different models have been developed to predict the effects of climate and land cover change on the hydrological process. Recently, hydrological simulation models such as a SWAT model have been developed partly to quantify the influence of change in land cover and management practices on the hydrologic cycle [13–17]. Moreover, with the development of the Geographic Information Systems (GIS) and remote sensing (RS) techniques, the hydrological catchments models have been more physically based and distributed to enumerate various interactive hydrological processes that consider spatial heterogeneity [18]. Hence, the ability of a hydrological model to integrate GIS for hydrologic data development, spatial model layers and interface may be considered model selection criteria.

The SWAT model developed at USDA-ARS [19] is a modeling experience that spans approximately 30 years. The model is a semi-distributed, physical-based simulation one and can predict the impact of land use change and management practices on hydrological regimes in watersheds with a variety of soil, land cover and management conditions during the large-term period.

A SWAT interface compatible with GIS software (ArcSWAT) that uses a geo-database approach and a programming structure consistent with component object model protocol has recently been developed. In SWAT2005, the impacts of spatial variations on topography, land use, soil, and other watershed characteristics related to hydrology are considered in the subdivisions [20].

The SWAT model has been widely used to predict water quantity and quality under varying land use and water use regimes [21, 22]; this model has also been applied to study potential climate change impacts on water resources [17, 23, 24].

We have examined the effect that climate change has on river flow in the Gharesou Basin in Iran. We used the hydrological SWAT with the aim of analyzing the impact of climate change at the basin level that served as a monthly time step for the Gharesou Basin.

The results will contribute to the scientific community's understanding of climate change impacts on water resources, and also provide information that supports future water resources planning and management in the Gharesou Basin and other basins that experience similar climatic conditions.

2 Materials and methods

2.1 The study area

The Karkheh Basin has an area of 50 764 km^2, and is located in the west, the middle, and the southwest regions of the Zagros Mountains, between 46°06′ and 49°10′ E and 30°58′ and 34°56′ N. Approximately 27 645 km^2 of the basin is mountains and around 23 119 km^2 of it is plains and foothills.

The mountain regions are mostly concentrated in the eastern and central parts, and the plains that are located in the northern and southern parts cover about 45% of the total basin area. Although the climate is mostly semi-arid or arid, the basin exhibits a tremendous diversity in soil and water resources, topography and land use systems. Rangelands, rain-fed farming, forests and irrigated farming are the main land use types. The rain-fed farming and range lands are scattered in almost all parts of the basin with varying degrees of coverage. Apart from the natural factors, the anthropogenic land use variations (low forest canopy covers and high erosion rates) make the complexity of the hydrology system and the degradation of the water resources of the basin more complex.

The Gharesou River Basin is located northwest of the Karkheh Basin and in the west of Iran (Fig. 1). Its area is approximately equal to 5793 km^2, and the maximum and minimum of its heights are 1237 and 3350 m, respectively. The average of annual rainfall varies from 300 to 800 mm. Table 1 depicts the characteristics of selected stations.

2.2 Downscaling the climate model and emission scenario to the study area

At present, various methods are used for generating climate scenarios in future periods. These methods include producing synthetic scenarios, using past climate parameters, and using the atmosphere ocean general circulation model (AOGCM) [6].

Currently, the most reliable tools for producing climate scenarios are three-dimensional (3D) coupled models of ocean-atmosphere general circulation [25, 26]. The AOGCM is based on physical laws and mathematical relationships; these relationships are solved in a 3D network of the earth surface. In order to simulate the earth's

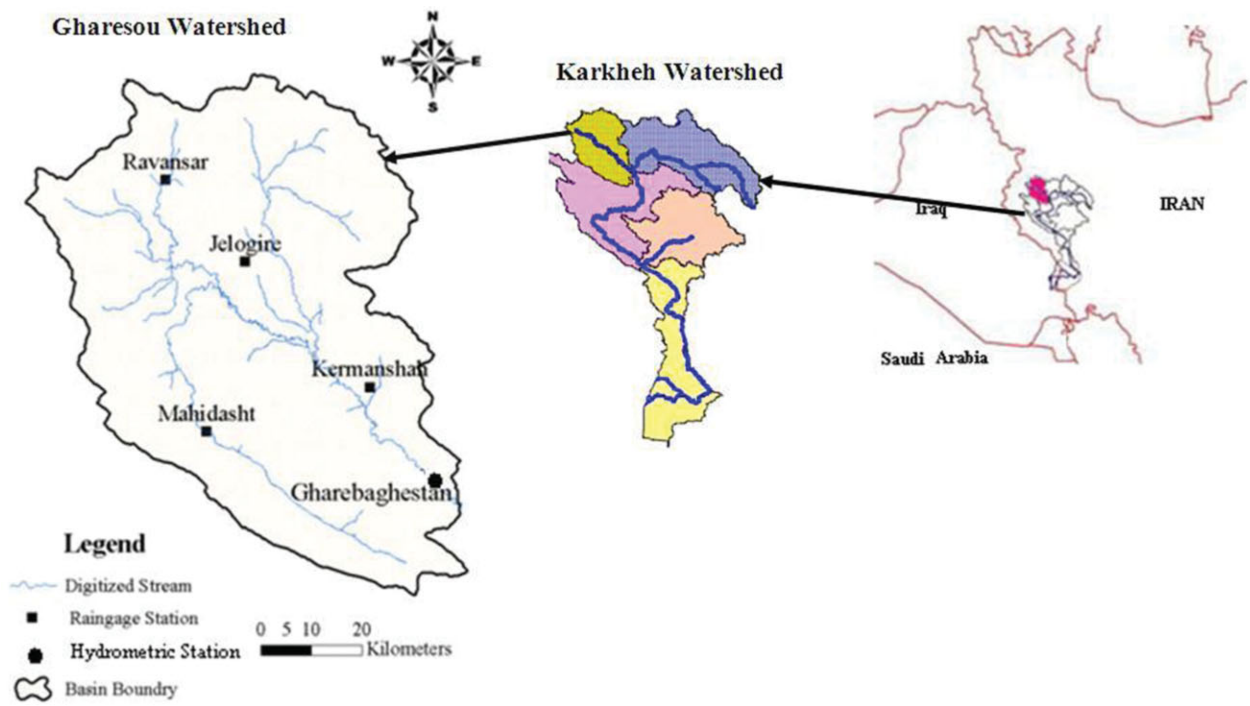

Figure 1. The location of the Gharesou Basin in Iran.

climate, the main climate processes (atmosphere, ocean, earth surface, ice crust and biosphere) are coupled to the AOGCM form.

The AOGMCM is a valid tool that is used for simulating climate change and producing hydrological model inputs. Recently, several studies have been conducted on the effect of climate change on runoff by combining the outputs of both general circulation models and hydrological models [4, 7, 13, 27]. The first attempt at evaluating the effect of climate change on the hydrology of the basin needs the simulation of the AOGCM at the basin scale.

For future simulation (2040–2069), the climate output has been directly used from an ensemble of versions of the HadCM3 (Intergovernmental Panel on Climate Change from the Hadley Center Coupled Ocean-Atmosphere Model) climate model $2.5 \times 3.75^\circ$ latitude–longitude resolution. The outputs have been downscaled and applied from a general circulation model (HadCM3) for the A2 emission scenario of the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (IPCC SRES).

An extremely heterogeneous world is depicted through the A2 storyline and scenario family. Independence and the preservation of the local identity serve as the underlying theme. A slow convergence of fertility patterns is observed in various regions, which results in a continuous increase in the population. Economic development is mainly oriented at a regional level, and compared with other storylines, per capita economic growth and changes in technology seem to be not slower but also more fragmented [1, 28].

One of the major limitations of using the AOGCM outputs is their large-scale resolution, which does not match the required precision of the hydrological models along spatio-temporal scales. Different methods are used for producing regional climate scenarios from the AOGCM, and these methods are called downscaling [25].

A relatively straightforward and popular procedure for rapid impact assessment involves the use of change factors (CFs). In this method, monthly change is obtained from a historical series. First, climate change scenarios with regard to temperature and precipitation are produced. Therefore, in order to calculate the climate change scenarios in each model, the ''difference'' values for temperature (Eq. (1)) and the ''proportion'' for precipitation (Eq. (2)) are calculated for each cell of the computational network. These calculations are done for the average of large-term monthly data in the future period 2040–2069 and the simulated basic period (1971–2000) with the same model [29].

$$\Delta T_{\mathrm{i}} = (\overline{T}_{\mathrm{GCM,fut,i}} - \overline{T}_{\mathrm{GCM,base,i}}) \quad (1)$$

Table 1. Characteristics of selected stations

Station name	Station type	Height	Latitude	Longitude
Kermanshah	Synoptic	1318.6	34°21′	47°9′
Ravansar	Synoptic	1379.7	34°43′	46°39′
Jelogireh	Rain gage	1280	34°35′	45°51′
Mahidasht	Rain gage	1415	34°16′	46°49′
Gharebaghestan	Hydrometric	1238	34°14′	47°15′

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$$\Delta P_{\rm i} = \left(\frac{\overline{P}_{\rm GCM,fut,i}}{\overline{P}_{\rm GCM,base,i}}\right) \quad (2)$$

where $\Delta T_{\rm i}$ and $\Delta P_{\rm i}$ are the indicators of climate change for temperature and precipitation, respectively, for an average 30-year long-term period ($1 \leq i \leq 12$). $\overline{T}_{\rm GCM,fut,i}$ is the 30-year mean temperature simulated by AOGCM for each month in the future period (2040–2069), and $\overline{T}_{\rm GCM,base,i}$ is the 30-year mean temperature simulated by AOGCM for each month in the period as well as the observed period of 1971–2000. All these parameters can also be established for precipitation.

The CF method is used for generating a time series of climate scenarios. According to this method, climate change scenarios were added to the observed values (here 1971–2000):

$$T = T_{\rm obs} + \Delta T \quad (3)$$

$$P = P_{\rm obs}\Delta P \quad (4)$$

where $T_{\rm obs}$ indicates the temperature time series in the base period (1971–2000), T is the time series of temperature resulting from climate scenarios in the future period (2040–2069), and ΔT is the downscaling climate change scenario. The parameters in Eq. (4) can be established for precipitation as well.

2.3 The process-based SWAT model

Many models that are used for evaluating basin hydrology are also utilized by water resource managers and researchers. These models are helpful for estimating and specifying the effect on runoff from a special development program.

Continuous flow models provide a better understanding of basin hydrological responses due to their climate and vegetation changes.

Watershed models are used to gain a better understanding of the role played by hydrological processes in controlling the movement of surface and subsurface water. The choice of a proper model strongly depends on several factors such as the simulation of design parameters (surface runoff, groundwater, sediment load, etc.), accuracy, available data, and spatiotemporal scales. The watershed models can be classified into two major groups based on their performance with regard to spatial components. Lumped models consider the basin as an integrated unit without considering the spatial changes in the processes, inputs, boundary conditions, or hydrological characteristics of the basin. In contrast, the distributed models consider the spatial changes by solving the equations of each pixel in the basin network [30, 31].

In this study, the SWAT model has been used for evaluating the water balance of the basin. This model has process-based and semi-distributed parameters that have been developed with the aim of predicting the effect of land use changes, climate changes and management practices in large and complicated basins [13]. We used A SWAT2005 interface compatible with GIS software.

The SWAT model has been implemented with the aim of predicting the impact of land management activities with regard to water, sedimentation, and chemical–agricultural agents in the presence of a variety of soil, land cover, and management conditions during long period. This model is a semi-distributed process model, and it uses specific information related to climatology, soil, topography, vegetation, and land cover in the basin instead of using the equations that describe the relationships between input and output.

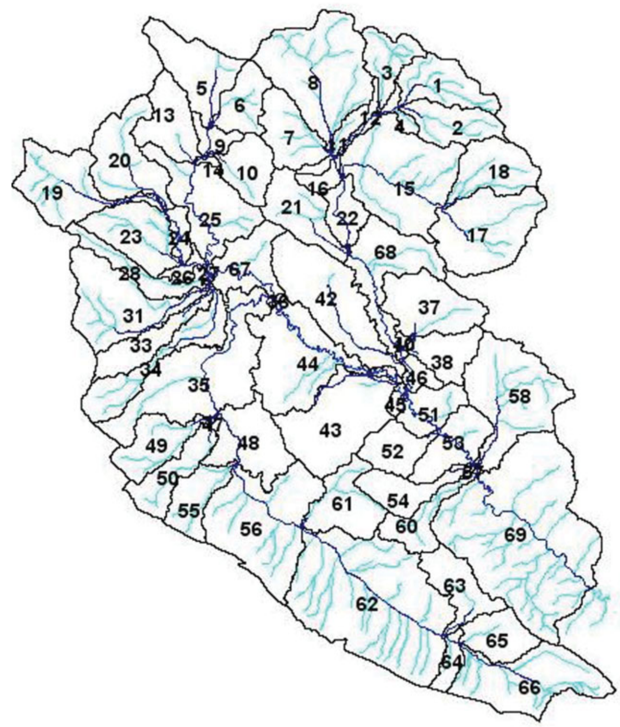

Figure 2. Sub-basins of the Gharesou Basin using SWAT model.

Sub-basins are divided into hydrological response units (HRUs). SWAT uses the USDA Soil Conservation Service method or the Green and AMPT method for calculating the volume of runoff for each HRU. Runoff in the SWAT Model is predicted separately for each HRU, and it is routed to obtain the total runoff for the watershed [32]. The sub-basins of the Gharesou Basin are depicted in Fig. 2.

The sub-basin components can be categorized into the following components: hydrology, weather, erosion, and sedimentation, soil temperature, plant growth, nutrients, pesticides and land management. The SWAT model requires calibration and validation in the study basin to ensure that the model parameters represent the study area. It uses the following hydrologic balance equation for the hydrologic cycle simulation:

$$\Delta {\rm SW} = \sum_{i=1}^{t} (R_{\rm day} - Q_{\rm surf} - E_{\rm a} - W_{\rm seep} - Q_{\rm gw}) \quad (5)$$

where ΔSW is the soil water content change, t is the time (daily scale), $R_{\rm day}$ is the daily rainfall, $Q_{\rm surf}$ is the surface runoff, $E_{\rm a}$ is the actual evapotranspiration, $W_{\rm deep}$ is the amount of water into the deep aquifer, $Q_{\rm gw}$ is the amount of return flow on day.

2.4 Model calibration

The meteorological data required for the model include precipitation as well as daily minimum and maximum temperature (from 1971 to 2000). The other meteorological data required include radiation, wind speed, and relative humidity, which are simulated by the present model. Rainfall data were obtained from the Mahidasht and Jelogire rainfall stations and two synoptic stations, that is, the Kermanshah and Ravansar stations; daily temperature were derived

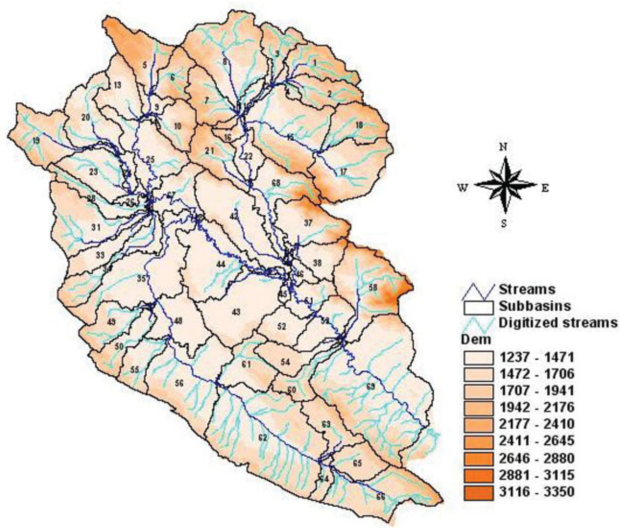

Figure 3. Digital elevation model.

from the Kermanshah and Ravansar stations. The hydrometric station of the Gharebaghestan is located in the outlet of the Gharesou Basin, and is selected as the base station for model calibration (Table 1 and Fig. 1).

The data required for simulation by the SWAT model, in addition to the meteorological data, include topography, climate, vegetation, soil, and management data. Topographic data in the form of the digital elevation model (DEM) and the soil map, both at the scale of 250 000: 1 (pixel size $50 \times 50\,m^2$, Fig. 3), were provided by the Institute of Agriculture Soil Conservation and Watershed Management. The land use map was extracted from satellite images. These data were used in the model after being cleaned and processed with GIS software and were converted into raster data (Fig. 4).

In order to calibrate the model, some of the observed climate and hydrological data were used. Thus, after inserting the data into the model and simulating the river flow, the results were compared with the observed river flow available. After calibration, the validation of the model with the parameters obtained in the calibration processes was measured by the observation data not used in the calibration phase. When the simulation results showed a good correlation with the observed flow, the model was ready to be used for further scenario assessments [33].

Automated model calibration needs the systematic changes of uncertain parameters, and after the simulation of the model, it needs the outputs of observable data related to computational data. The most important function is providing a relationship between the model and the calibration program. SWAT-CUP is an optimum communicating program that is developed for the SWAT model. The calibration and uncertainty that are associated with SWAT-CUP are easily achieved. The Sequential Uncertainty Fitting (SUFI-2) is one of the uncertainty analysis programs which is incorporated in an independent program called SWAT Calibration and Uncertainty Program (SWAT-CUP) [34].

Several parameters were selected for calibrating the model. All the parameters that affected river flow were adjusted to match the observed flow (hydrometric station data of Gharabaghestan). These parameters had been selected according to the previous research conducted in the field of calibration of the SWAT model [35]. In this study, the calibration process had begun with several parameters in the SWAT-CUP (SUFI-2) algorithm, but in the last iteration only nine parameters were found to be sensitive to discharge, because high correlated parameters with the smallest sensitivities were not changed any longer during the iteration process. The sensitivity analysis has pointed out nine crucial parameters (CN2, SOL_AWC, SMTMP, ESCO, SMFMN, CH_K2, REVAPMN, GW_REVAP, and ALPHA_BF) that control the hydrological processes of the studied area. However, CN2 and REVAPMN were found to be more crucial than other parameters.

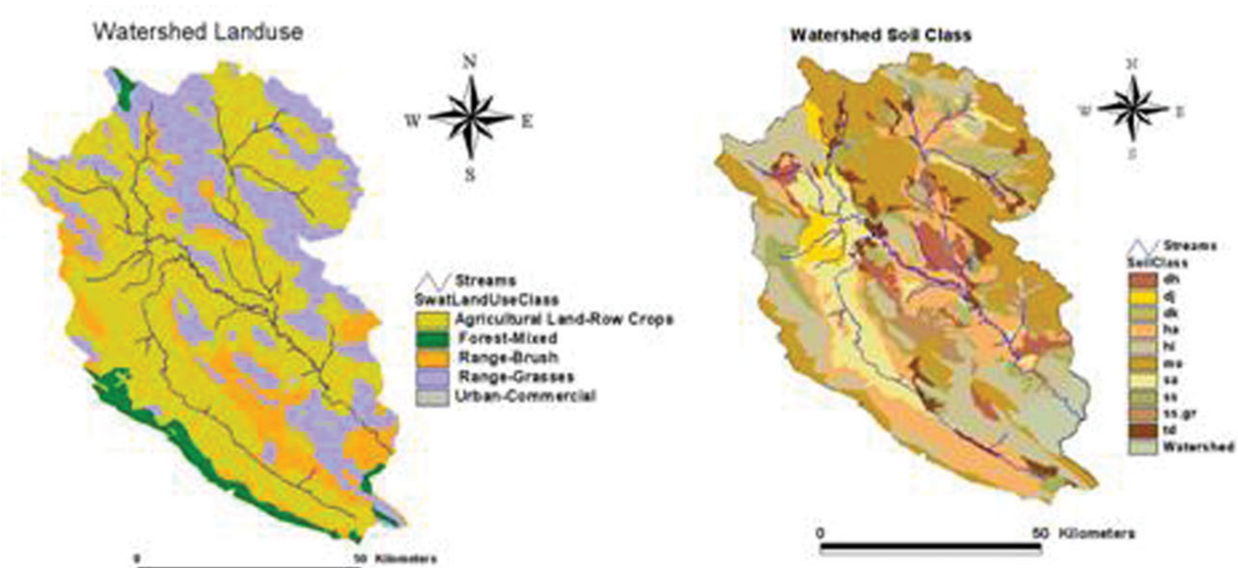

Figure 4. Land use map (left) and soil class map (right).

Table 2. Final values of applied parameters in the simulation

Parameter	Parameter definition	Range of changes	Optimized values
SMTMP	Snowmelt base temperature (°C)	±5	2.375
SMFMN	Minimum melt rate for snow during the year (mm/(°C day))	0–10	4.615
ESCO	Soil evaporation compensation factor	0.01–1	0.6418
ALPHA-BF	Base flow alpha factor (days)	0–1	0.01542
GW-REVAP	Groundwater revap. coefficient	0.02–0.2	0.1772
SOL_AWC(1)	Soil available water storage capacity (mm H_2O/mm soil)	0–1	*0.1225
CN_2	SCS runoff curve number for moisture condition II	20–90	−0.22*
CH_K_2	Effective hydraulic conductivity in the main channel (mm/h)	0–150	2.2625
REVAPMN	Threshold water level in the shallow aquifer for "revap" (mm)	0–500	105.875

* parameters CN2 and SOL_AWC were optimized as a multiplier of initial values.

Table 3. Model performance

	R^2	E_{NS}	$\overline{O}$ Mean observed	$\overline{S}$ Mean simulated	VARo Observed variance	VARs Simulated variance
Calibration 1992–1996	0.82	0.8	22.1	20.21	432.16	440.25
Validation 1998–2000	0.77	0.73	8.31	10.17	174.32	172.53

Nash–Sutcliffe (ENS) and coefficient of determination (R^2) were used to evaluate the performance of the hydrological model. The closer the model efficiency is to 1, the more accurate the model is.

$$R^2 = \frac{\left[\sum_{i=1}^{n}(O_i - \overline{O})(S_i - \overline{S})\right]^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2 \sum_{i=1}^{n}(S_i - \overline{S})^2} \quad (6)$$

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \quad (7)$$

In these equations, $\overline{O}$ and $\overline{S}$ are the mean observable and simulated discharge, respectively.

Table 2 shows the optimum parameters of the calibration stage. It should be noted that parameters CN2 and SOL_AWC were optimized as a multiplier of initial values. Model calibration had been done with correlation function value, simulation of monthly flow, Nash–Sutcliffe (ENS), coefficient of determination (R^2), average of monthly flow, and variance of monthly flow between 1992 and 1996. Model validation was done from 1998 to 2000, and the results are depicted in Table 3. Figures 5 and 6 depict the results of model calibration and validation.

3 Results and discussion

3.1 Downscaled climate variables during a future period

Table 4 shows the results of downscaling temperature and precipitation data output from HadCM3 according to 1 and 2 relationships. By adding these changes to the observed data, data were downscaled for the future period (2040–2069).

3.2 Evaluating changes in temperature, precipitation, and runoff

Since the temperature and precipitation variables (rather than the other climatic variables) have a significant effect on water resource systems, agriculture, environment, and so on, the primary studies

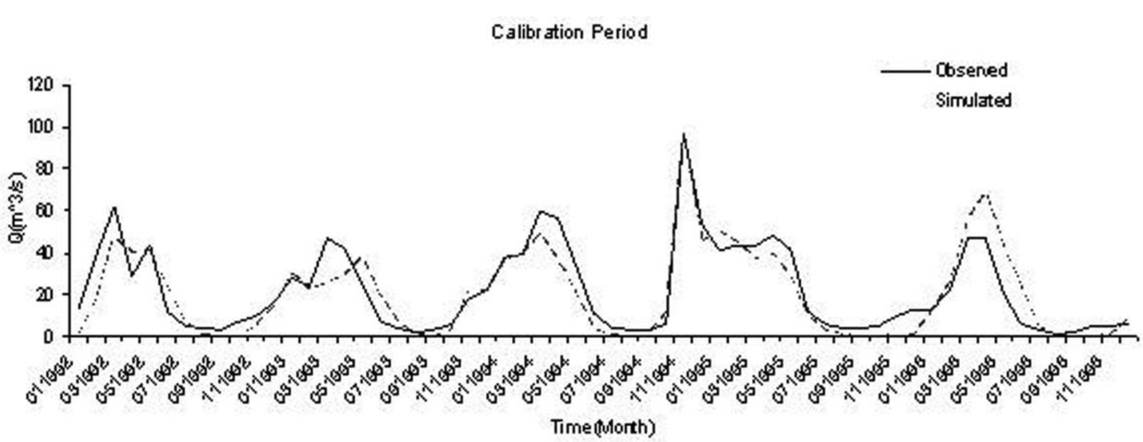

Figure 5. Observed and simulated (SWAT) stream flow (m^3/s) at Gharebaghestan station (1992–1996).

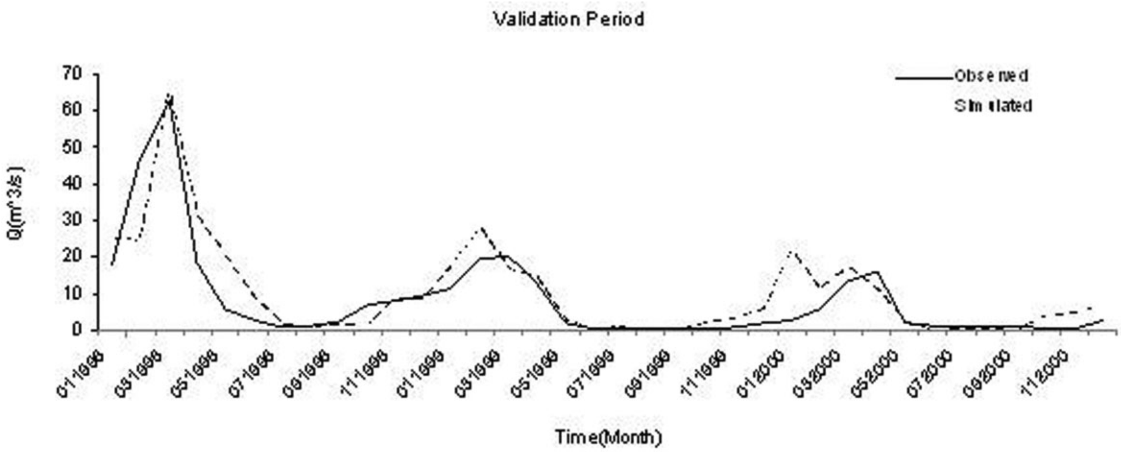

Figure 6. Observed and simulated (SWAT) stream flow (m^3/s) at Gharebaghestan station (1998–2000).

Table 4. results of down scaling temperature and precipitation data

Dec	Nov	Oct	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	HADCM3
4.46	9.48	15.98	21.92	26.75	27.37	22.94	17.48	13	7.61	3.19	1.48	T_{obs} (°C)
1.31	1.91	2.83	3.26	3.64	4	4.38	3	1.8	1.92	1.8	2.12	ΔT
79.67	65.73	28	0.54	0.22	0.76	1.27	29.4	62.63	101.48	72.39	70.37	P_{obs} (cm)
1.21	0.96	0.93	0.62	0.46	0.38	0.61	0.7	0.92	0.98	1.09	1.29	ΔP

conducted in the context of the effect of the climate change phenomenon were mainly focused on these two variables.

Figure 7 shows that the average of long-term monthly temperature increase during the period 2040–2069 for all months, and the annual average increase is about 2.6°C. The maximum increase is 4.5°C in June and the minimum increase is 1°C in December.

In season comparison, summer has the maximum increase in temperature than the other seasons. This increase is 4°C, whereas in winter, the average temperature increase is 1°C.

Figure 8 depicts the monthly precipitation during the base period (1971–2000) and the percentage of rainfall changes during the future period 2040–2069 in comparison to the base period. The figure also depicts a precipitation increase of 19% in winter, whereas during the remaining months, the rainfall decreases. However, by eliminating the months with no precipitation in a year, a 9% increase of precipitation in the annual average of future periods can be expected.

After introducing the downscale time series of precipitation and temperature to the Hydrological SWAT model, the runoff time series of the Gharesou Basin was produced for the period 2040–2069.

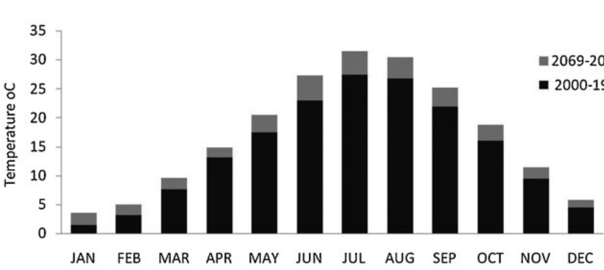

Figure 7. Temperature increase in the period 2040–2069, compared to the base period.

Figure 9 shows the percentages of long-term monthly runoff changes during the future period compared with the observed period. Annual average trends show that the runoff will increase by 4% in the future period. The maximum increase is 120% in

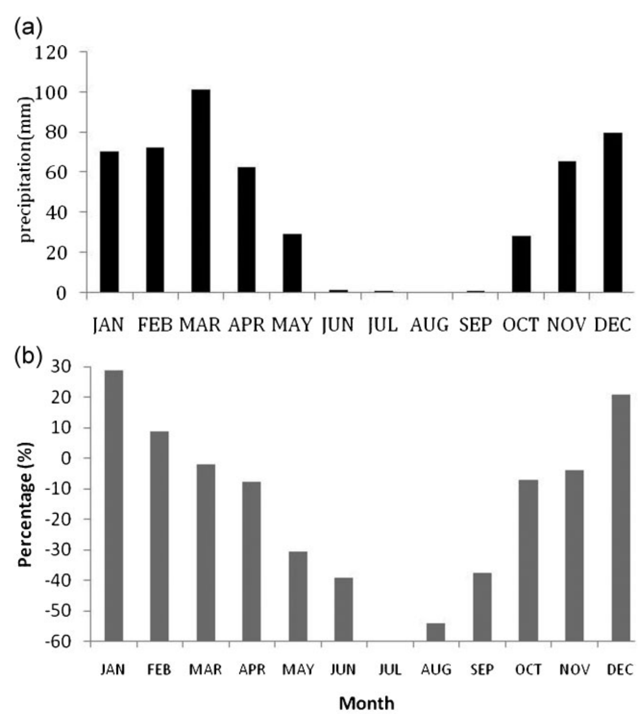

Figure 8. (a) Monthly precipitation in the base period (1971–2000), (b) Percentage monthly rainfall during 2040–2069 compared to the base period.

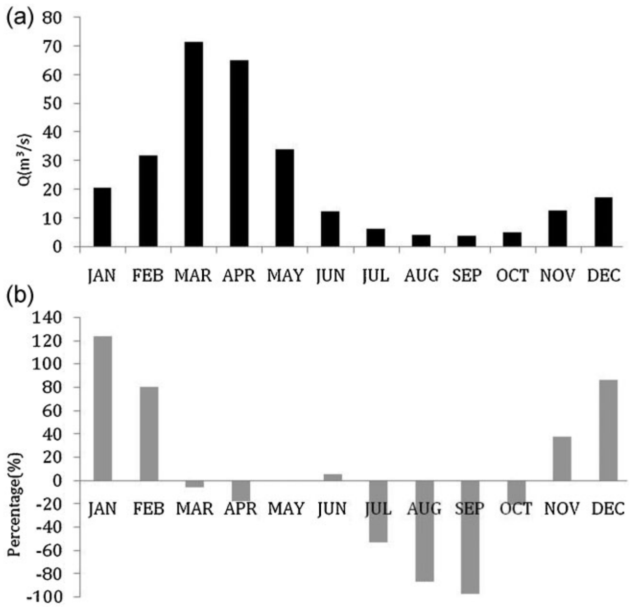

Figure 9. Monthly runoff in the base period (1971–2000) and the percentage change in future (2040–2069) runoff compared to the base period.

January, and the maximum decrease is 97% in September. The season scale showed a 96% increase in winter and a 44% decrease of runoff in summer.

Zarghami et al. [27] evaluated the effect of climate change on surface stream flow in the east of the Azarbaijan Province. They showed that changes in precipitation and temperature patterns have a serious impact on the quality and quantity of runoff, especially in the arid regions. They used LARS-WG tools to downscale the HADCM3 model output under the A1B, A2, and B1 scenarios in six synoptic stations. Our study results showed an increase of 2.6°C in the annual average temperature as compared with 2.3°C provided by Zarghami et al. [27].

A comparison of the results of precipitation variables with the help of the findings by Zarghami et al. [27] shows that they had decreased in their studied region; whereas ours represent an increase in winter and a decrease during the other seasons.

Abbaspour et al. [7] studied the effect of climate change on the water resources in Iran. They used the SWAT Hydraulic model in their research to investigate the future climate effect on Iran's water resources. The future climate was produced for the A1B, B1, and A2 scenarios during the periods 2010–2040 and 2070–2100 by using the CGCM3.1 general circulation models that were downscaled in the case of 37 stations. They applied the hydrological model with the aim of analyzing the effects of future climate during various periods on blue and green water, precipitation, and the wheat yield in different parts of the country. They found that generally, in future, wet areas will receive more precipitation, whereas dry areas will receive less precipitation [7]. Considering that our study area is located in the wet regions, the results depicted greater precipitation in those regions.

Our results for the runoff variable depicted a 96% runoff increase during winter and a >44% run off decrease in summer; whereas Zarghami et al. [27] showed a high rate of runoff decrease and Abbaspour et al. [7] showed severe floods in the wet regions and harder droughts in the dry regions.

4 Conclusions

Climate change has important effects on water resources (IPCC 2007, USEPA 2004). Acquiring data in regard with the effect of global warming is very limited. A regional evaluation of this effect is crucial for understanding hydrological changes. In this study, the effect of climate changes on the outflow of the Gharesou Basin during the period 2040–2069 using the HadCM3 model, from the AOGCM model set under the A2 scenario, has been analyzed. Furthermore, the continuous simulation rainfall-runoff model was applied to study the hydrology of the basin under conditions of climate change. The results of temperature, the precipitation scenarios of the HadCM3 model, from the fourth IPCC report, and the time series of simulated runoff by the SWAT model (rainfall-runoff model) indicate that the climate and hydrological variables of the Gharesou Basin will experience significant changes in the future.

The comparison of observable and simulated climate variables with the help of the climate model during the period 2040–2069 shows that during different months, the temperature region will grow warmer by 1–4°C than the base period. Precipitation will witness a change between −30 and +30 in all months expect those without rainfall, which can affect the total available water, peak time, and external events. Since temperature and precipitation exhibit the most effects on the hydrology of the basin, simulations indicate a change from −11 to 25 m^3/s in the basin runoff.

The obtained results of this research provide close estimations of temperature, precipitation, and runoff changes regardless of the uncertainties. Certainly, more accurate results would be obtained in case of considering the uncertainties such as land cover change under climate change, downscaling methods, the hydrological simulation model, and so on; these effects of some of these uncertainties are considered as our next research study.

The subsequent research with regard to the effect of climate change on the watershed ecology can provide appropriate data for investigating these effects. Thus, to reach this aim, land cover dynamic studies due to climate change and its consequences on regional water resources is required.

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