

Impacts of Climate Change on Surface Water Resources of the Ziarat River Basin, Iran

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Abstract

Background/Objectives: To assess the impacts of climate change on water resources (Ziarat River basin) using appropriate model. **Methods:** A general atmosphere circulation model HadCM3 was used to study climatic change and in order to downscaling HadCM3 model outputs, ANFIS model was also used. After calculating minimum, maximum temperature and precipitation, the impact of climate on drainage basin of Ziarat was identified. In next step of research, the impact of this phenomenon on basin's runoff was assessed using HEC-HMS model. This model was first used for base period then the impacts of climate change and global warming on hydrology of basin in future periods were investigated. **Results:** Research results clearly showed that climate scenarios in all three future periods have equal impact on climate changes. So that an increasing in temperature and decrease in precipitation will occur in future. The volume of discharging Ziarat River will be associated with decreasing flow rate or discharge. So that the decrease will be gradual and continues and the lowest decrease in Horizon 2020 and the highest one will be also in period 2090. These results show that increasing temperature and consequently increasing evapotranspiration and soil moisture reduction will be effective on reducing the runoff.

Keywords: Climate Change, ANFIS, HEC-HMS

1. Introduction

Current generation of climate global models cannot be used in applied studies smaller than their dimensions because of low resolution. Climate global models accomplish fluids' dynamic calculations well in continental scale but parameterize small scale processes. Parametrization means replacing a small scale or complicated process with a modeled or simplified process in GCM. Due to this, downscaling was invented as a method for interpolating large-scale climate variables and meteorology small-scale data extraction. The basis for this method is this assumption that a relationship can be found between atmosphere processes and different scales. Since the beginning of 1990s, many such relationships were gained based on past studies about meteorology and hydrology. Big scale meteorology patterns have been used for modeling meteorology parameters such as rainfall modeling in Washington, space-time pattern of daily

rainfall in the Ruhr Basin and eastern Nebraska, average temperature and monthly precipitation in Oregon, the occurrence of heavy rain and drought in the Delaware River Basin, rare occurrence of rainfall on the islands of Great Britain, Winter rainfall in Abary and estimation of the rate of evaporation from pan in south Louisiana. The first use of regression in the field of climate changes was conducted in¹ found a relationship between monthly average of temperature and precipitation and the outputs of climate global models using linear regression. In² used artificial neural networks for calculating precipitation for the first time in 1993³. Forecasted precipitation in 2007 using neural networks and geographical information system and acquired an accurate model through combining these two methods. In⁴ also proposed a model for daily precipitation using neural networks in 2006, the used parameters in this model included concentration of pressure level from 500 hPa to 1000 hPa and the height of 500 hPa above sea level, and surface moisture of 700

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hPa in which the results showed accurate model of neural networks. In⁴ proposed the first computer model in 2006 for downscaling using multi-variable linear regression called SDSM. In⁵ predicted precipitation using fuzzy law. The results of created fuzzy model in⁵ show that the obtained method is better model than other downscaling methods⁵ also forecasted precipitation in St. Paul in Brazil using neuro-fuzzy algorithm. In⁶ calculated statistical downscaling and climate extremes using time neural network. In⁷ conducted precipitation modeling for climate changes through vector machine in which the method of vector machine is a trustworthy method for modeling precipitation. In⁸ created fuzzy model for monthly rainfall in Hungary using the patterns of atmosphere circulation and Southern Oscillation Index. In⁹ investigated climate changes in Greece through comparing two regression models and artificial neural network that based on their results, precipitation indexes had been modeled by neural networks less accurate than regression model. Common methods of downscaling include the method of using main cell or proportion method, statistical methods, dynamic method. Proportion method is of the simple methods in returning big scale data in which the difference between base and future data of GCM are added to observational amount through changing factor method¹⁰. To overcome the weakness of these models' low resolution, the outputs of these models are required to be downscaled before using them in assessing the impacts of climate change. Assessing the impacts of climate change on water resources is conducted within two steps. In first step, the changes in temperature, precipitation and other variables of climatology such as evapotranspiration will be investigated and in the second step, the changes of runoff will be investigated using the outputs of previous step. Hydrologic models provide a framework for assessing the relationship between meteorology, human activities and water resources. Therefore, as the first step, this research investigates climate change using HadCM3 model and downscale of ANFIS model. As the second step, using HEC-HMS model, the simulation of runoff flow and its impact on hydrology of Ziarat basin will be investigated within future periods.

2. Materials and Methods

Ziarat River basin is geographically located in between the length of 24°-54° to 30°-54° and geographical width

of 36°-36° to 36°-42°. The area of this basin is 7791 square kilometers and the length of Main River to than place is about 16 kilometers. A major parts of this mountainous basin area involve some important mountain ranges such as Sarkooh, Talu, Marzang, Talder and Gardkooh. Ziarat headstream is from the zone steep heights. The vegetation is jungle and the weather of basin is cold. Figure 1 shows the location of Ziarat basin. Other required physiography parameters in simulating the flow have been shown in Table 1.

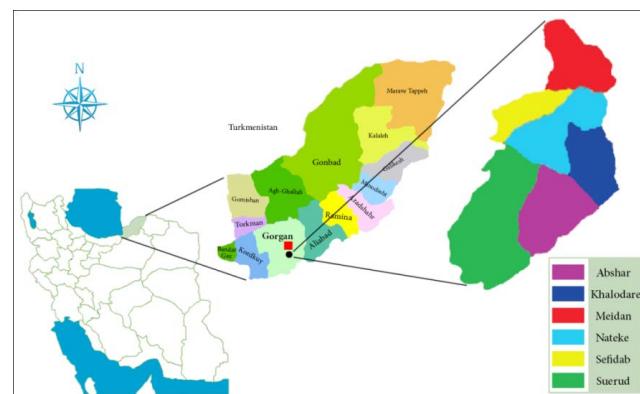


Figure 1. The map of Ziarat basin location in Golestan province, Iran.

Table 1. Physiography parameters of Ziarat basin

| | |
|---|---------|
| Area (square kilometers) | 77.91 |
| Maximum height in meters | 3300 |
| Minimum height (m) | 200 |
| The weighted average height (m) | 1915.45 |
| The weighted average slope of the basin (percent) | 54.47 |
| The weighted average slope of drainage (percent) | 9.41 |
| The main channel length (km) | 16.36 |
| Curve Number | 65.46 |

3. Climate Change of HadCM3

A general atmosphere circulation model known as HadCM3 was used in order to study climate change in this paper. HadCM3 is a type of paired ocean-Atmospheric General Circulation Models (AOGCM) which has been designed and developed in Hadley Center of the UK Meteorological Organization. Resolution power of this model is network with dimensions of 2.75 degrees of geographical width and 3.75 geographical lengths (IPCC, 2007). This model has been described In⁷ HadCM3 consists of two atmosphere and ocean components

named HadAM3 (atmosphere model) and HadOM3 (ocean model) that involves one model of ice-sea as well. This model doesn't require surface flux setting (additional artifacts flux for the surface of the ocean) for improving the simulation. The simulations are conducted based on 356-day year and 30-day months. High resolution power of ocean component is the most important advantage of this model.

In order to anticipate precipitation using ANFIS model, minimum, maximum temperature and radiation in daily scale (required by precipitation model-runoff) were used. Due to this, 70 percent of base data within the years 1982 to 2001 for calibration period and 30 percent of data within 2002 to 2010 for validation period were used. So that the number of membership functions was chosen within 2 to 5. Different types of membership function were also used which included triangular, trapezoidal, bell-shaped, Gaussian, Gaussian 2 and two sigmoid. To achieve the best prediction by this model and scenario, the criteria NSE and R² were utilized that following relations have been proposed for mentioned criteria:

$$NSE = 1 - \frac{\sum_{i=1}^N (O_i - S_i)^2}{\sum_{i=1}^N (O_i - \bar{O})^2} \quad (1)$$

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

In which,

O_i: observational data, S_i: estimated data, \bar{O} and \bar{S} the average of observational and estimated data and σ is variance.

4. The Results of Climate Change in Future Period's Rather Base Period

Table 2 shows the results of assessing ANFIS model prediction with different membership functions. The best performance in all types of membership functions has occurred in the number of 2 membership functions.

The results of table above show that bell-shaped membership function is better than other functions so this function was used in mentioned ANFIS model. Therefore, first ANFIS model was calibrated for base periods within statistical years if 1982-2010 then through re-executing calibrated model for base period, validation

was assessed.

Table 2. The obtained results of different membership functions in ANFIS method

| Test | Training | The best number of membership function | | Type of membership functions | |
|------|----------|--|----------------|------------------------------|-------------|
| | | NSE | R ² | | |
| 0.94 | 0.81 | 0.97 | 0.81 | 2 | Triangular |
| 0.94 | 0.87 | 0.97 | 0.87 | 2 | Trapezoidal |
| 0.95 | 0.93 | 0.96 | 0.93 | 2 | Bell-shaped |
| 0.93 | 0.90 | 0.97 | 0.90 | 2 | Gaussian |
| 0.93 | 0.91 | 0.95 | 0.91 | 2 | Gaussian2 |
| 0.92 | 0.91 | 0.95 | 0.91 | 2 | Two sigmoid |

The results of calibration and validation of downscaled and observational data of temperature and precipitation have been proposed in Table 3. Considering Nash-Sutcliffe coefficient of determination and capability indices, the model has generally good capability in downscaling climate data of temperature and precipitation of the area in future periods.

Table 3. Error statistics resulted by observational and modeled parameters by ANFIS model

| Period | Average monthly precipitation | | Minimum monthly mean temperature | | Maximum monthly mean temperature | |
|-------------|-------------------------------|----------------|----------------------------------|----------------|----------------------------------|----------------|
| | NSE | R ² | NSE | R ² | NSE | R ² |
| Calibration | 0.82 | 0.87 | 0.98 | 0.99 | 0.97 | 0.99 |
| Validation | 0.73 | 0.78 | 0.84 | 0.92 | 0.93 | 0.97 |

After ensuring the results of model simulation, temperature and precipitation variables (maximum and minimum) were forecasted for three future periods of 2011 to 2030, 2046 to 2065 and 2080 to 2099 by HADCM3 model within climate scenarios of SRA1B, SRA2 and SABI.

Through compared average values of minimum temperature in Figure 2. It is clear that minimum temperature in each three periods will be more than base period (increasing temperature within 0.31 to 1.78 centigrade degree in minimum temperature). In all three scenarios the most minimum temperature will occur in period of 2080 to 2099, this is while for all three future periods, the period of 2011 to 2030 will have less minimum temperature compared to two periods of 2046 to 2065 and 2080 to 2099.

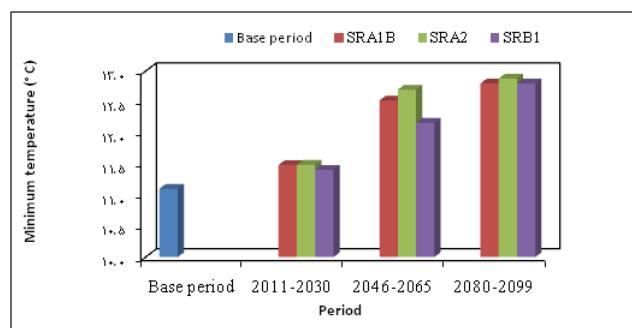


Figure 2. Long-term average of minimum annual temperature for base and future periods.

In Figure 3 through comparing average values of maximum temperature, it is clear that maximum temperature in each three periods will be more than base period (increasing temperature within 0.06 to 1.68 centigrade degree in maximum temperature). In all three scenarios the most maximum temperature will occur in period of 2080 to 2099, this is while for all three future periods, the period of 2011 to 2030 will have less maximum temperature compared to two periods of 2046 to 2065 and 2080 to 2099.

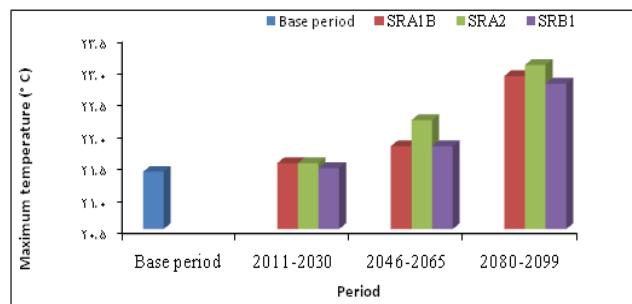


Figure 3. Long-term average of maximum annual temperature for base and future periods.

Through comparing average precipitation in Figure 4 it is clear that precipitation in each three periods will be less than base period (decreasing precipitation within 1.61 to 31.47 mm) and the values of precipitation will decrease over time. In all three scenarios the minimum precipitation will occur in period of 2080 to 2099, this is while for all three future periods, the period of 2011 to 2030 will have more precipitation compared to two periods of 2046 to 2065 and 2080 to 2099.

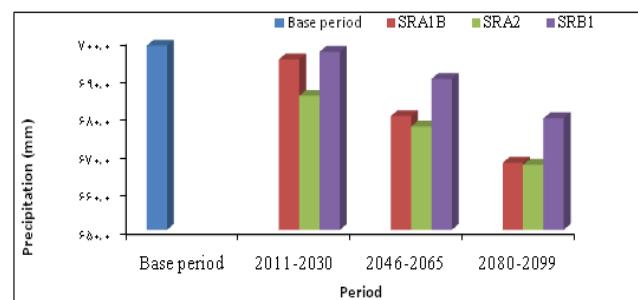


Figure 4. Long-term average of annual precipitation for base and future periods.

After calculating average, minimum and maximum temperatures as well as precipitation, climate impact on Ziarat basin was clarified. In another word the impact of climate scenarios on discharge of river flow was assessed. Hydrologic impacts on water resources management are determined through hydrologic methods. One of these methods is using HEC-HMS software. Hydrologic parameters of basin will be modeled in this software after assessing climate and their effectiveness. The aim of this level is investigating output hydrographs of Ziarat basin in the future to be able to analyze the impacts of climate change on the basin based on that.

The structure of drainage basin of Ziarat was created in HEC-HMS software environment first which is in accordance with Figure 5. This structure includes a basin and a connection (output). On this basis, the flow simulation was conducted for a twenty-year period of 1982-2001 as the base conditions Figure 6. Table 4 represents the properties of model elements and the values of model parameters and flow simulations for current conditions.

Table 4. Defined elements and parameters in HEC-HMS model in Ziarat drainage basin

| | |
|--|--------|
| The number of basins | 1 |
| Number of connections | 1 |
| Area (square kilometers) | 256.83 |
| Initial losses (mm) | 19.76 |
| Curve Number | 72 |
| Delay time (minutes) | 93.75 |
| Peak discharge (cubic meters per second) | 176.7 |
| Discharge volume (million cubic meters) | 3.318 |

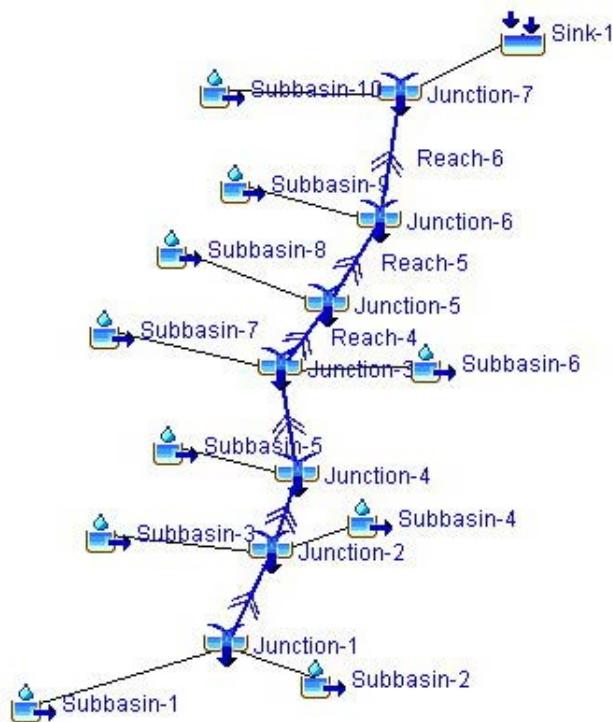


Figure 5. The structure of HEC-HMS model in Ziarat drainage basin.

In order to this, SCS was used to convert precipitation to runoff. For calculating precipitation losses, curve number method was also used. Then river flow was predicted for period of 1982-2001 as the base conditions as well as the scenarios of each one of future horizons.

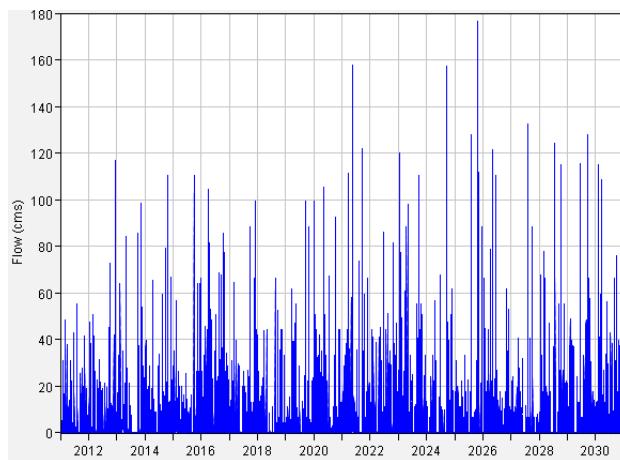


Figure 6. The graph of simulating flow for conditions of 1982-2001 base periods.

5. Simulating the Flow of Scenarios in Period of 2011-2030

Considering the developed model HEC-HMS for Ziarat drainage basin, flow simulation for three scenarios of SRA1B, SRA2 and SRB1 was conducted in the period of 2011-2030 and was compared with the base flow. Figures 7 to 9 shows the hydrograph of each simulation against base flow. The properties of flow status in this period for each one of scenarios have been shown in Table 5. Considering these results, it can be seen that in all three scenarios of 2020 horizon, peak discharge and flood volume have decreased so that the most decrease is related to SRA2 scenario in which peak discharge -1.92% and discharge volume decreases -1.93.

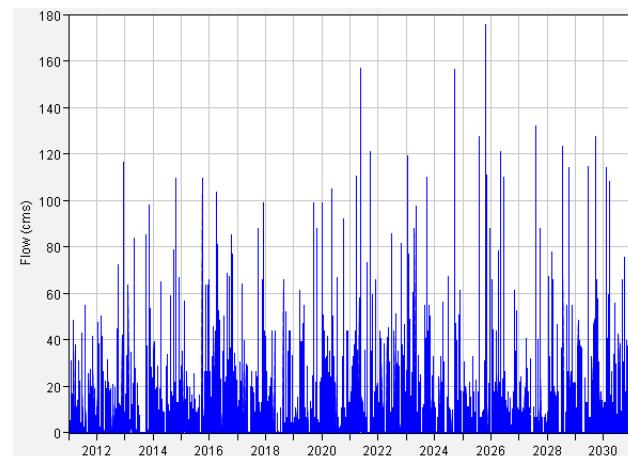


Figure 7. The graph of simulating flow for scenario SRA1B in the period of 2011-2030.

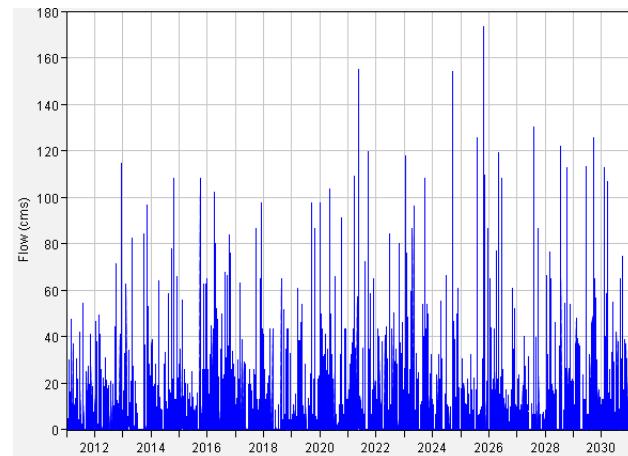


Figure 8. The graph of simulating flow for scenario SRA2 in the period of 2011-2030.

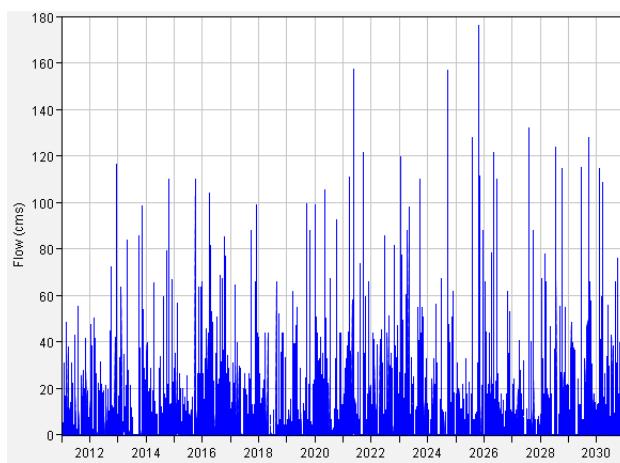


Figure 9. The graph of simulating flow for scenario SRB1 in the period of 2011-2030.

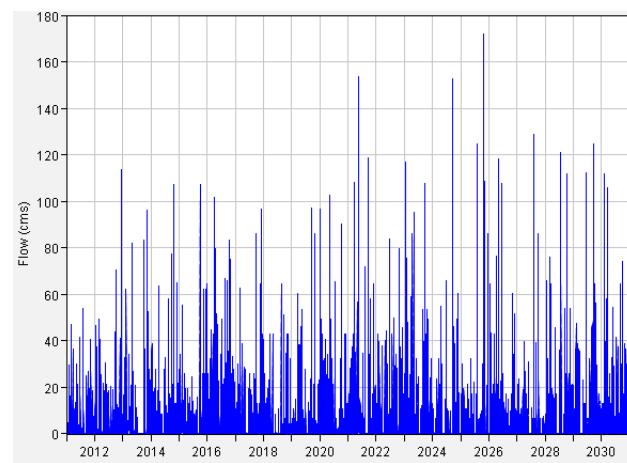


Figure 10. The graph of simulating flow for scenario SRA1B in the period of 2046-2065.

6. Simulating the Flow of Scenarios in the Period of 2046-2065

Figures 10 to 12 shows the hydrograph of each simulation against base flow. The properties of flow status in this period for each one of scenarios have been shown in Table 6. Considering these results, it can be seen that in all three scenarios of 2055 horizon, peak discharge and flood volume have decreased so that the most decrease is related to SRA2 scenario in which peak discharge -3.06% and discharge volume decreases -3.07.

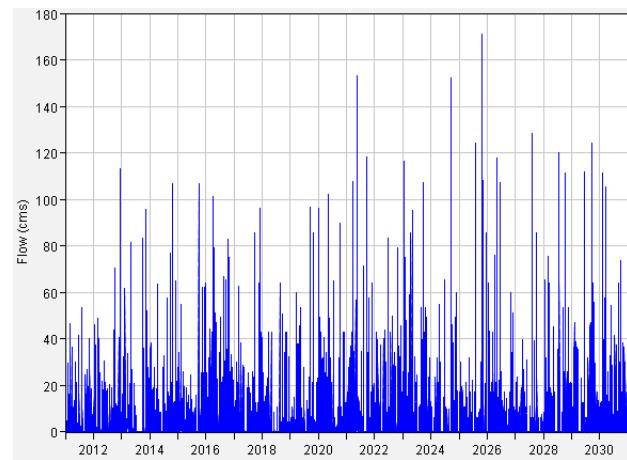


Figure 11. The graph of simulating flow for scenario SRA2 in the period of 2046-2065.

Table 5. The properties of flow status in period of 2011-2030 for each one of scenarios

| Mode | Peak discharge (Cubic meters per second) | Flood volume (billion cubic meters) | Percentage of variations compared to base conditions | |
|----------------|---|--|---|--------------|
| | | | Peak discharge | Flood volume |
| SRA1B scenario | 175.8 | 3.300 | -0.51 | -0.54 |
| SRA2 scenario | 173.3 | 3.254 | -1.92 | -1.93 |
| SRB1 scenario | 176.3 | 3.310 | -0.23 | -0.24 |

Table 6. The properties of flow status in period of 2046-2065 for each one of scenarios

| Mode | Peak discharge (Cubic meters per second) | Flood volume (billion cubic meters) | Percentage of variations compared to base conditions | |
|----------------|---|--|---|--------------|
| | | | Peak discharge | Flood volume |
| SRA1B scenario | 172 | 3.229 | -2.66 | -2.68 |
| SRA2 scenario | 171.3 | 3.216 | -3.06 | -3.07 |
| SRB1 scenario | 174.4 | 3.275 | -1.30 | -1.30 |

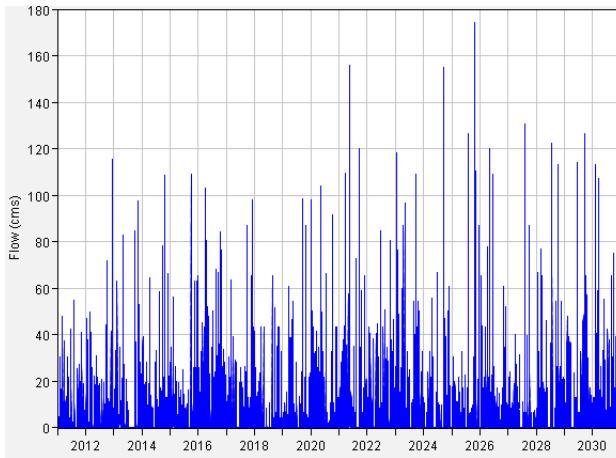


Figure 12. The graph of simulating flow for scenario SRB1 in the period of 2046-2065.

7. Simulating the Flow of Scenarios in Period of 2080-2099

Considering the developed model HEC-HMS for Ziarat drainage basin, flow simulation for three scenarios of SRA1B, SRA2 and SRB1 was conducted in the period of 2080-2099 and was compared with the base flow. Figures 13 to 15 show the hydrograph of each simulation against base flow. The properties of flow status in this period for each one of scenarios have been shown in Table 7. Considering these results, it can be seen that in all three scenarios of 2090 horizon, peak discharge and flood volume have decreased so that the most decrease is related to SRA2 scenario in which peak discharge -4.53% and discharge volume decreases -4.58.

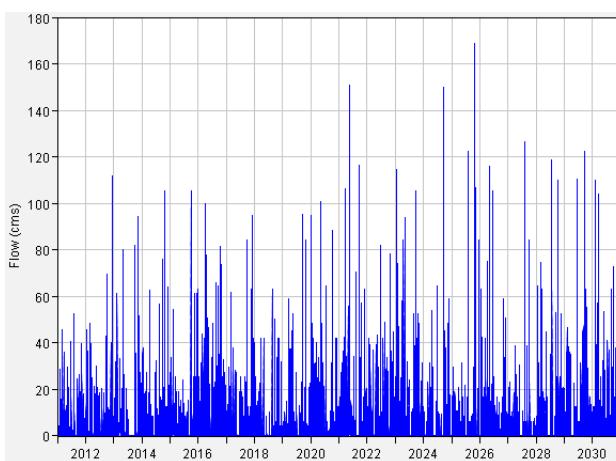


Figure 13. The graph of simulating flow for scenario SRA1B in the period of 2080-2099.

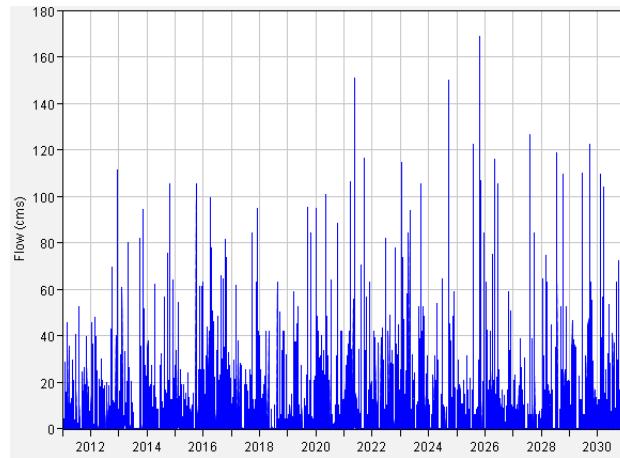


Figure 14. The graph of simulating flow for scenario SRA2 in the period of 2080-2099.

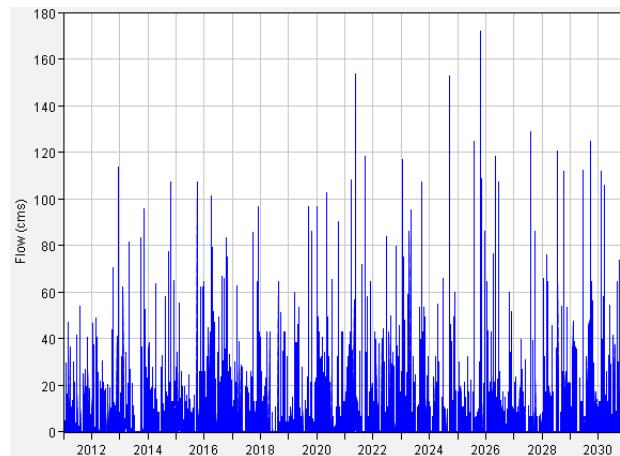


Figure 15. The graph of simulating flow for scenario SRB1 in the period of 2080-2099.

8. Conclusion

A general atmosphere circulation model known as HadCM3 was used in order to study climate change in this paper, and in order to downscaling HadCM3 model outputs, ANFIS model was also used. After calculating minimum, maximum temperature and precipitation, the impact of climate on drainage basin of Ziarat was identified. In next step of research, the impact of this phenomenon on basin's runoff was assessed using HEC-HMS model. Considering the methodology of the research, ANFIS model was calibrated for base periods within statistical years if 1982-2010 then through re-executing calibrated model for base period, validation was assessed. So that

Table 7. The properties of flow status in period of 2080-2099 for each one of scenarios

| Mode | Peak discharge (Cubic meters per second) | Flood volume (billion cubic meters) | Percentage of variations compared to base conditions | |
|----------------|--|---|---|--------------|
| | | | Peak discharge | Flood volume |
| SRA1B scenario | 168.8 | 3.170 | -4.47 | -4.46 |
| SRA2 scenario | 168.7 | 3.166 | -4.53 | -4.58 |
| SRB1 scenario | 171.8 | 3.227 | -2.77 | -2.74 |

the number of membership functions was chosen within 2 to 5. Different types of membership function were also used which included triangular, trapezoidal, bell-shaped, Gaussian, Gaussian 2 and two sigmoid. After modeling, the results were assessed using the indexes of NSE and R², this is while⁷ mentioned the efficiency of fuzzy model compared to downscaling models. Considering confirmed model of ANFIS, climate changes were investigated for three future periods of 2011 to 2030, 2046 to 2065 and 2080 to 2099 within climate scenarios of SRA1B, SRA2 and SRB1 separately for variables of minimum, maximum temperature and precipitation.

- Through comparing average values of minimum temperature, it is clear that minimum temperature in each three periods will be more than base period (increasing temperature within 0.31 to 1.78 centigrade degree in minimum temperature). In all three scenarios the most minimum temperature will occur in period of 2080 to 2099, this is while for all three future periods, the period of 2011 to 2030 will have less minimum temperature compared to two periods of 2046 to 2065 and 2080 to 2099.
- Through comparing average values of maximum temperature, it is clear that maximum temperature in each three periods will be more than base period (increasing temperature within 0.06 to 1.68 centigrade degree in maximum temperature). In all three scenarios the most maximum temperature will occur in period of 2080 to 2099, this is while for all three future periods, the period of 2011 to 2030 will have less maximum temperature compared to two periods of 2046 to 2065 and 2080 to 2099.
- Through comparing average precipitation, it is clear that precipitation in each three periods will be less than base period (decreasing precipitation within 1.61 to 31.47 mm) and the values of precipitation will decrease over time. In all three scenarios the minimum precipitation will occur in period of 2080 to 2099, this is while for all three future periods, the period of 2011 to 2030 will have more precipitation

compared to two periods of 2046 to 2065 and 2080 to 2099.

- Through comparing long-term average values of annual discharge, it is clear that in all three future periods, the discharge will be less than base period so that in all three scenarios of 2020 horizon, peak discharge and flood volume have decreased. The most decrease is related to scenario SRA2 in which peak discharge -1.92% and discharge volume decreases -1.93%. Considering these results, it can be seen that in all three scenarios of 2055 horizon, peak discharge and flood volume have decreased so that the most decrease is related to SRA2 scenario in which peak discharge -3.06% and discharge volume decreases -3.07. Also in all three scenarios of 2090 horizon, peak discharge and flood volume have decreased so that the most decrease is related to SRA2 scenario in which peak discharge -4.53% and discharge volume decreases -4.58.

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