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Future Climate Conditions and Trend Analysis of Precipitation and Temperature in Bar Watershed, Iran

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: Climate change is one of the most important challenges for human society, which will affect ecological, social and economical systems. Because of water scarcity issues, studying the potential climate change and its impacts on climate variables and water resources is necessary. The study of climate variables and predict their changes in policy and planning is so vital. Between climatic variables, changes in precipitation and temperature patterns have important influences on the quantity and quality of water resources, especially in arid regions. Therefore, evaluating the trend of their values is one of the most important issues in the hydro climate studies.
Place and Duration of Study: Trend of maximum and minimum temperature and precipitation for observation period (1971-2010) and future periods (2010-2039, 2040-2069 and 2070-2099) has been studied by nonparametric Mann-Kendall test in Nayshabour Bar watershed, Iran.
Methodology: In this investigation the output of Hadcm3 and CGCM1 models under A1, A2 and B2 scenarios were downscaled by using Statistical downscaling model (SDSM). Then trend of these climate variables by using nonparametric Mann-Kendall test was

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analyzed.
Results: The results of the statistical parameters evaluating showed that the outputs of Hadcm[3] model under A2 scenario are more compatible with the study area. The results of Mann-Kendall test showed that during the observation period, the trend of precipitation and minimum temperature was decreasing. On the other hand, the trend of average and maximum temperature was increasing, but the trend of these variables at 95% confidence level was not significant. During the future periods, the trend of precipitation was decreasing, and the trend of average, maximum and minimum temperature was increasing that was not significant at 95% confidence level too.
Conclusion: Statistical downscale model is powerful tools for downscale climate variables. Also trend analyses of climate variable can help to mitigation and adaptation global warming issue.

Keywords: Mann-Kendall test; hadcm3 model; A2 scenario; SDSM; downscaling.

1. INTRODUCTION

Climate change is one of the most important challenges for human society, and effects of that will influence human life. The temperature of earth's surface has increased since the 19th century. The past three decades have been known as the warmest years during this period. All these data indicate that the average temperature of land and ocean rise about 0.89ºC from 1901 to 2012 [1]. Today, the most powerful tools to simulate future climate scenarios are atmospheric Global Circulation Models (GCM) [2-4]. The outputs of these models are used as the input of hydrological models after downscaling. The output of atmospheric global circulation models have low spatial resolution, so it is required to be downscaled by the certain procedures. Nowadays there are different methods of downscaling for the climatic data. Due to the facilities and accuracy of the statistical downscaling models, they are being used more than other downscaling models [5-8]. Precipitation and temperature affect many processes associated with the management of water resources [9]. So it's essential to present some methods for studying trend of hydrological processes. Assessment of trend can effectively help to interpret the relationship between environmental changes and hydrological processes [10]. Existence of trend in time series may be caused by gradual changes in natural climate or by human activities [11].The Mann-Kendall test is one of the most widely used non-parametric methods for analyzing the trend of data [12]. Many studies have been discussed the effects of climate change on the temperature and precipitation [13-17]. Regarding the most of these studies, results displayed rising temperature and reduced precipitation. Also, many researchers have checked trend of climatic variables by using statistical tests. [18-21] examined the trend of precipitation in different areas by using nonparametric Mann - Kendall test. The results showed a negative trend in precipitation. [22-29] have evaluated the trend of temperature by using nonparametric Mann - Kendall test. The results showed that there is an insignificant increasing in temperature.

According to these studies, researchers have focused on the trend of climatic variable during observation period in addition to studying the trend of observation period and climate change conditions under different scenario were also evaluated by using Mann - Kandall test. So, the planners and managers need to observe the future trend lines of the climate variables. This information assists them to understand the real threats that they will face in future years. The aim of present study was to simulate future climate conditions and then study the trend of mean, maximum and minimum temperature and also precipitation for observation and future climate conditions in the Bar Watershed, Iran.

2. MATERIALS AND METHODS

The present study was conducted for the Bar Watershed which located in the northwest of Mashhad, Khorasan Razavi Province, Iran. It covers an area of approximately 11.388 hectares. The study area is located in the southwest of Binalood Mountains, within 36º 27' to 36º 36´ N latitude and 58º 40´ to 58º 49´ E longitude (Fig. 1). The mean altitude of 2226m from sea level. The region exhibits distinctly mountainous topographical features. The mean annual precipitation is recorded as 330.4mm and mean temperature of 5.3ºC [30].

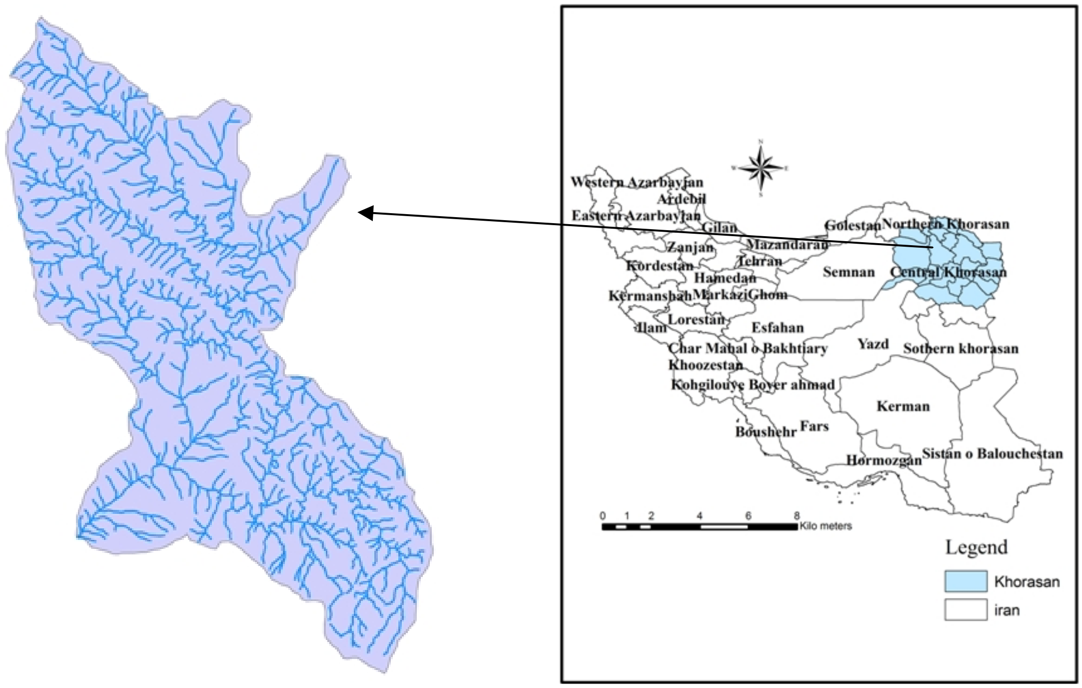


Fig. 1. The position of bar watershed

The mean, maximum and minimum temperature and precipitation were considered in this investigation. These data were collected from stations presented in the study area and some surrounding stations. The characteristics of these stations showed in Table 1.

After gathering the required information, the accuracy of them was evaluated in SPSS software. In order to fix the statistical imperfections of this information, the correlation method was used between stations. In order to specify the appropriate scenario and GCM model for subsequent studies, Canadian Centre for Climate Modeling and Analysis, Canada (CGCM1) and Hadley Centre for Climate Prediction and Research/Met Office, UK (Hadcm3) models were downscaled under A1, A2 and B2 scenarios for study area. The accuracy of these models has been proved in many studies for evaluating the effects of climate change on water resources [16-17]. For this purpose, at first climatic variables were simulated by two

GCM models for future periods and have been compared with the observed variables of study area, then the best model and scenario were selected.

Table 1. Characteristics of stations

Station	Latitude (°E)	Longitude (ºN)	Elevation (MSL)	Available data (years)
Mashad	36° 16'	59º 38'	990	1950-2010
Bar	36° 29'	58º 42'	1520	1951-2010
Marusk	36° 16'	58º 22'	1900	1990-2010
Karkhane ghand	36° 17'	58º 66'	1074	1986-2010

2.1 Downscaling the Climatic Data

One of the weaknesses of GCM models is that simulated climatic variables are large scale. Therefore, these variables do not have sufficient accuracy for hydrological and water resources studies. So it is vital to downscale them by different methods that exist for downscaling the climatic variables. In this investigation, SDSM model has been used to downscale the climatic variables. Finally, in order to select the appropriate GCM models and scenarios, downscaled data compared with observed data. For evaluating the function of models and comparing them, both graphical and statistical parameters such as RMSE, MAE, NSE, PBISE and R^2 were used [31].

3. SDSM

This model analyses and calibrates the predictable variables of National Center Enviroment Prediction (NCEP) and GCM Wilby et al. [8]. At first, the predictable variables such as temperature and precipitation were downscaled by using combined regression techniques and stochastic weather generator and then these variables were predicted at station-scale. The SDMS downscale the daily climatic variables by implementing the following steps (Fig. 2).

In this method, large-scale data were extracted from the simulated data by HadCM3 and CGCM1 model for the period 1971-2000. Then these data is introduced into the SDSM, the mean, maximum and minimum temperature and precipitation were downscaled under A1, A2 and B2 scenarios for study area. First, variables were simulated for the base period by the chosen predictors. Then these variables were anticipated under A1, A2 and B2 scenario for the periods of 1997-2010, 2069-2078 and 2070-2099 and changes of each variable were studied in various scenarios comparing to base period. After achieving the empowerment assessment to downscale the climatic data, these variables were predicted for future periods. The trend of variables for base and future periods were investigated at 95% confidence level by using the Mann-Kendall test and XLSTAT software [32,33].

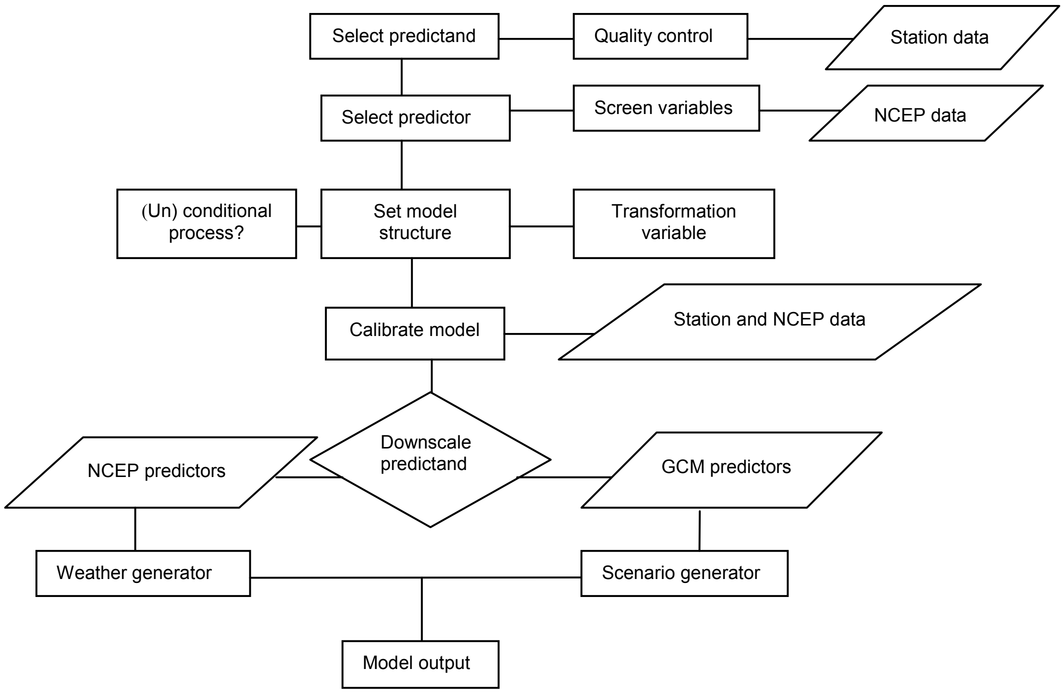


Fig. 2. Flowchart of SDSM climate scenario generation

4. RESULTS

4.1 Downscaling

In this section by using the large scale observed variables (NCEP) and SDSM, the chosen predictors of climate variables were selected. For this purpose, 12 final large scale parameters were selected from 26 large scale NCEP parameters and their various functions that were presented in Table 2.

4.2 Evaluation SDSM model

In this section observed data of average daily temperature and precipitation in the period 1971-2000 were studied and compared with the simulated temperature and precipitation data from GCMs and the model and scenario which has more statistical accuracy have selected. As explained, in this investigation to evaluate model, both graphical and statistical parameters were used. The results of the graphical method are shown in Fig. 3.

Finally, by comparing the results of downscaled data and observed data for period of 1971-2000, the accuracy of the Hadcm3 and CGMC1 models in predicting scenarios for the future years have evaluated. To make this evaluation, PBISE, NAE, MAE, RMSE and R^2 indicators were used (Table 3).

Table 2. Parameters to perform the downscale statistical analysis temperature and precipitation

Variable	Chosen predictor	*P* value	Partial correlation
Precipitation	500hPa Wind Direction	0.01	0.07
	850hPa Wind Direction	0.04	0.06
	Mean Temperature at 2m	0.04	0.06
Average temperature	Mean Sea Level Pressure	0.00	0.75
	850hPa Zonal Velocity	0.00	0.50
	850hPa Geopotential	0.00	0.46
Maximum temperature	Mean Sea Level Pressure	0.00	0.63
	850hPaMeridiona Velocity	0.01	0.43
	Near surface relative humidity	0.00	0.51
Minimum Temperature	Mean Sea Level Pressure	0.00	0.73
	Mean Temperature at 2m	0.00	0.54
	Surface Wind Direction	0.03	0.7

4.3 Climate Variable Generation

The results of downscaling in SDSM showed that among the Hadcm3 and CGCM1 models under A1, A2 and B2 scenarios, the Hadcm3 model under the A2 scenario gave the highest statistical accuracy in predicting the climate data (Table 3). By using the output of A2 scenario the desired variables for future period were predicted (Fig. 4).

4.4 Changes of Climate Variable in the Future Periods

After predicting the average, maximum and minimum temperature and precipitation for the periods 2010-2039, 2040-2069 and 2070-2099, the values were compared with the observed values in the period 1971-2000 (Fig. 5).

4.5 The Trend Analysis of Climatic Variables

By using the Maan-Kendall test and XLSTAT software, the trend of these variables at 95% confidence level for base and future periods were considered (Fig. 5).

The results of Maan-Kendal test were presented in Table 4.

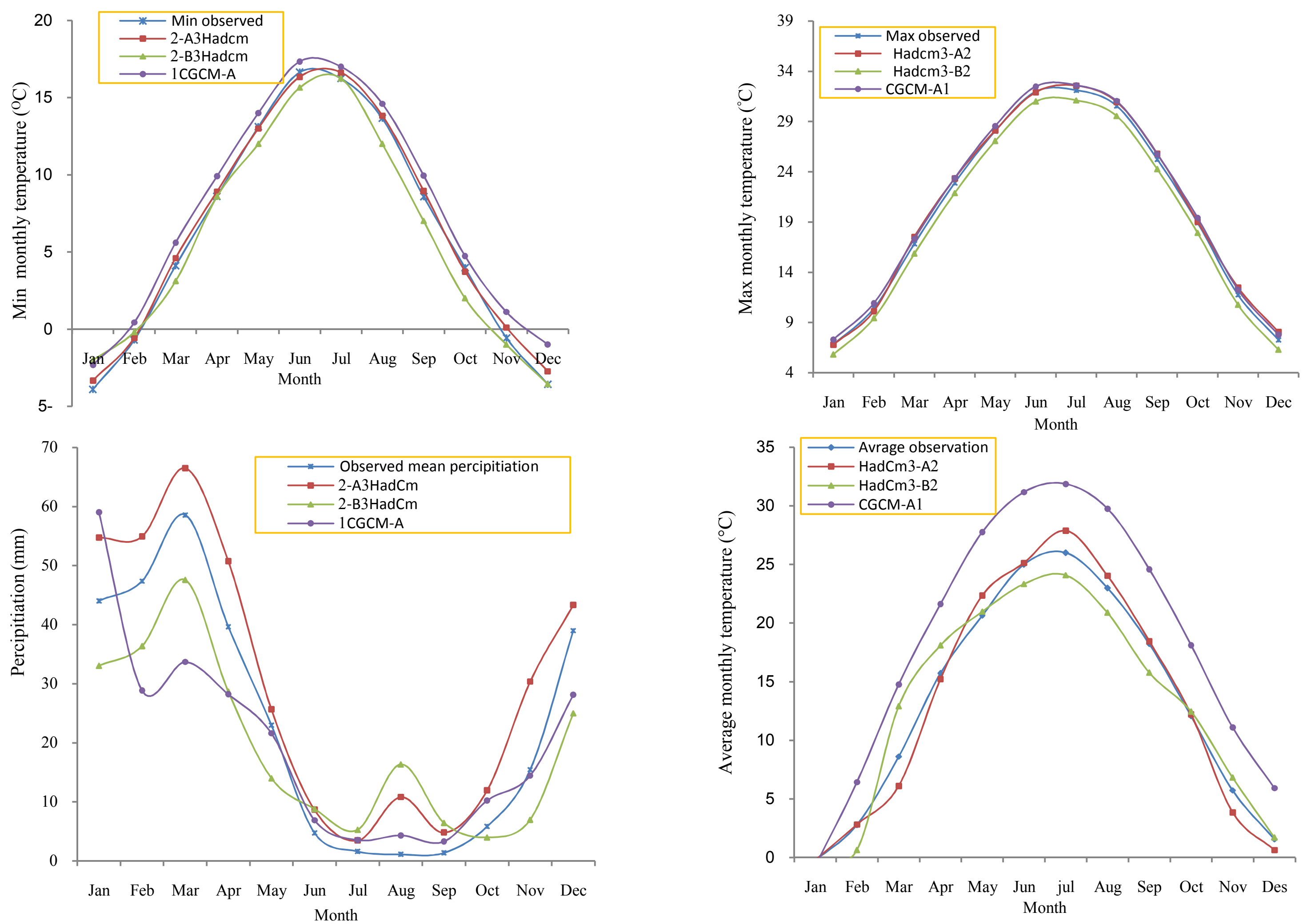


Fig. 3. The results of simulation and observed values in the period of 1971-2000

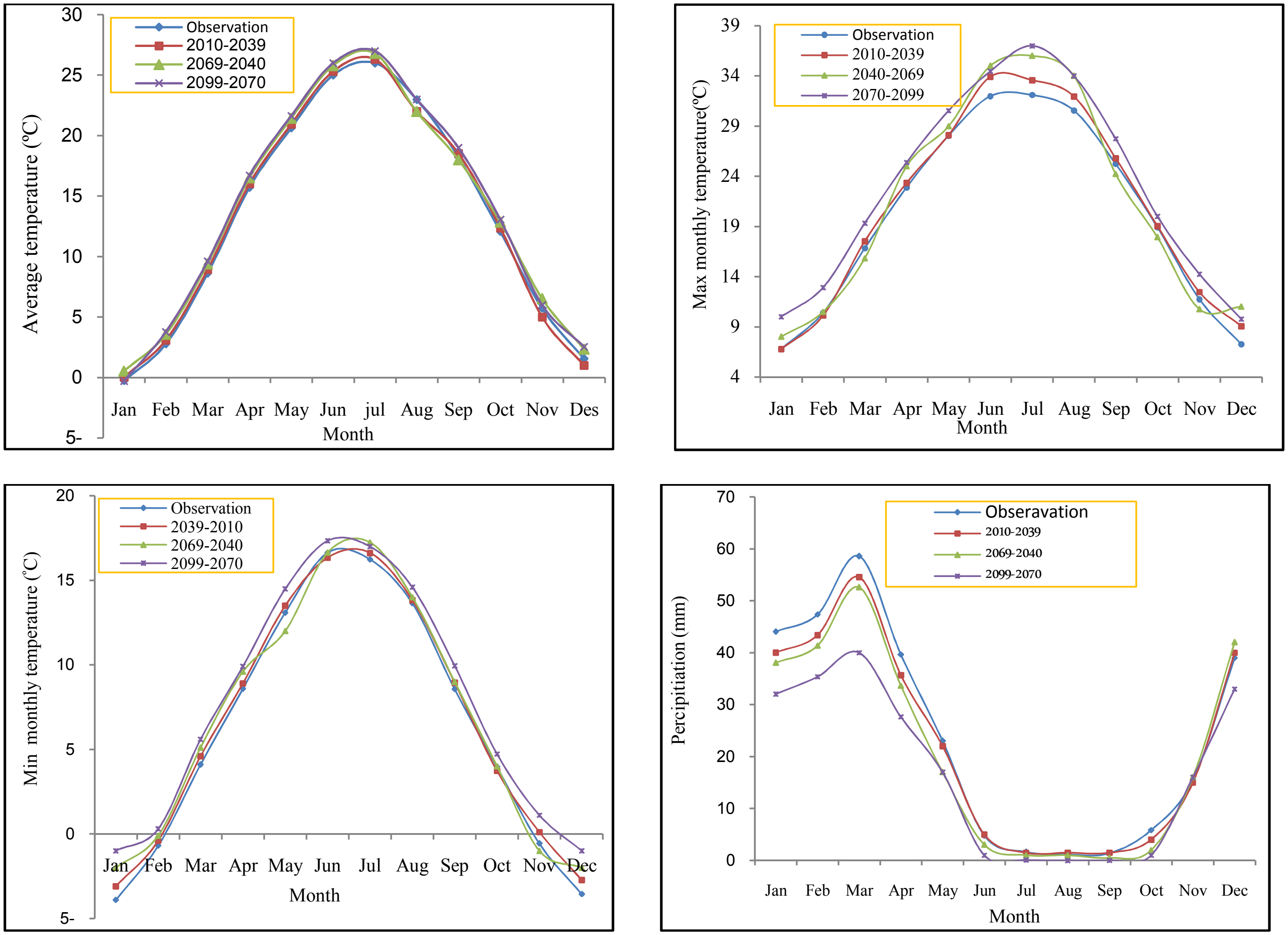


Fig. 4. The observed and predicted values for future periods by using Hadcm3 model under A2 scenario

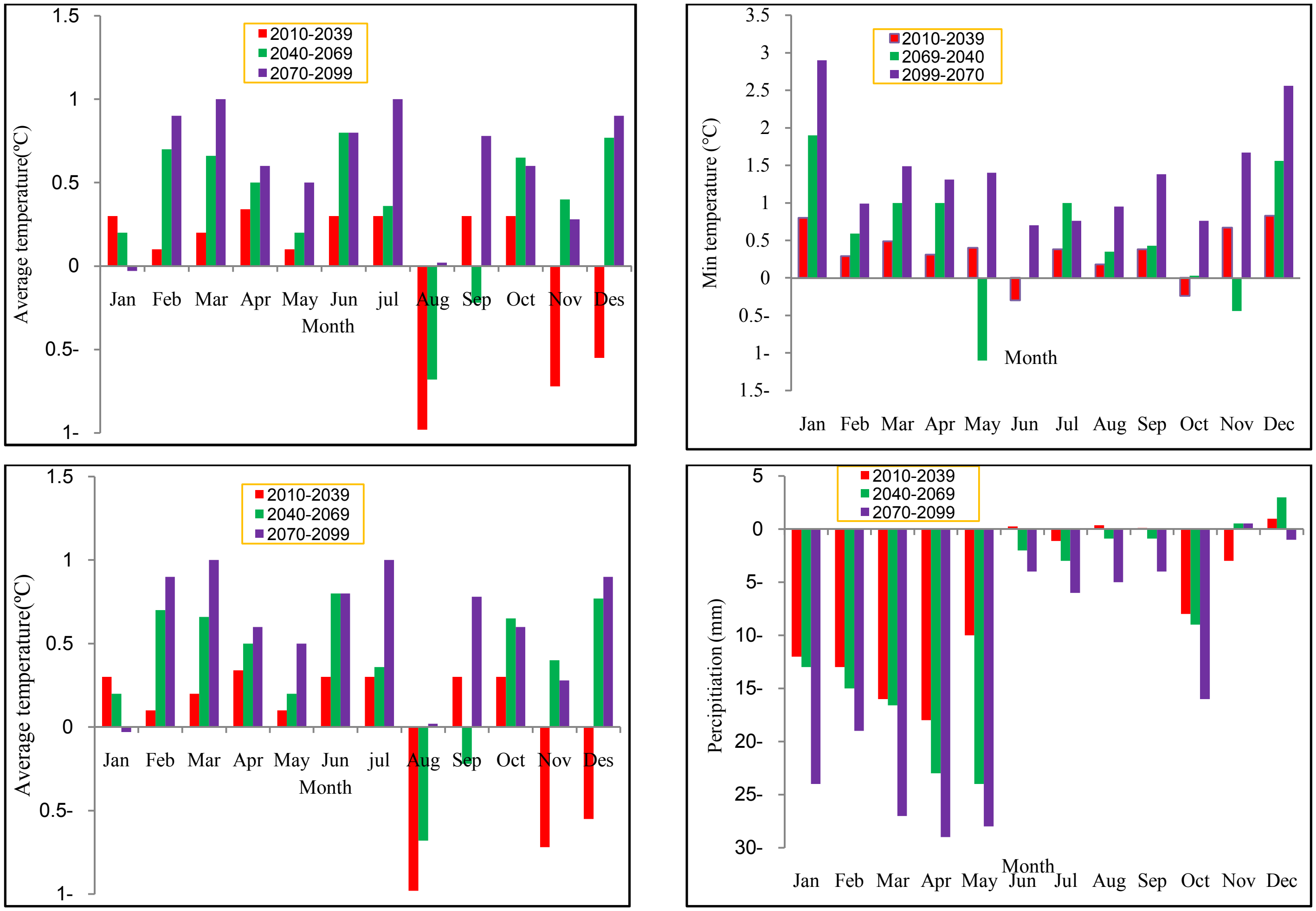
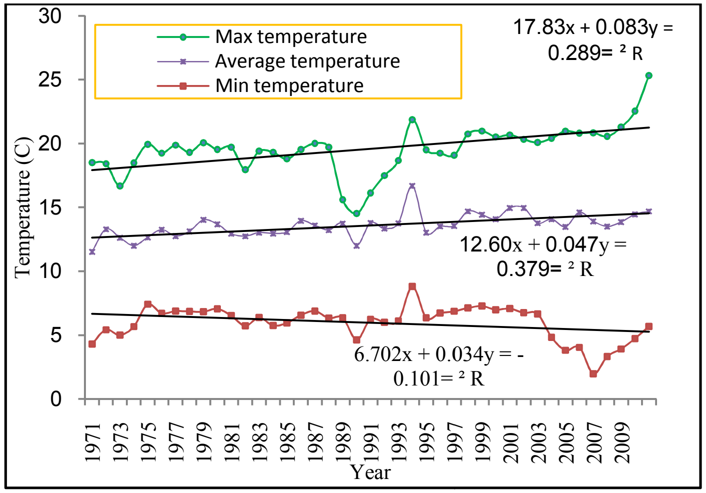
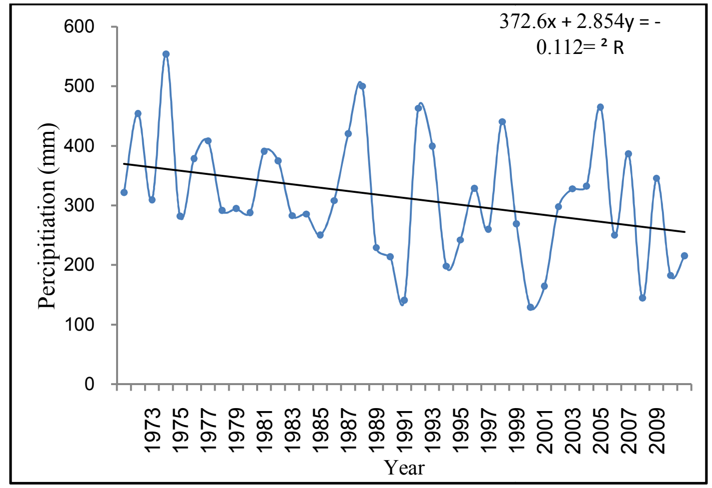
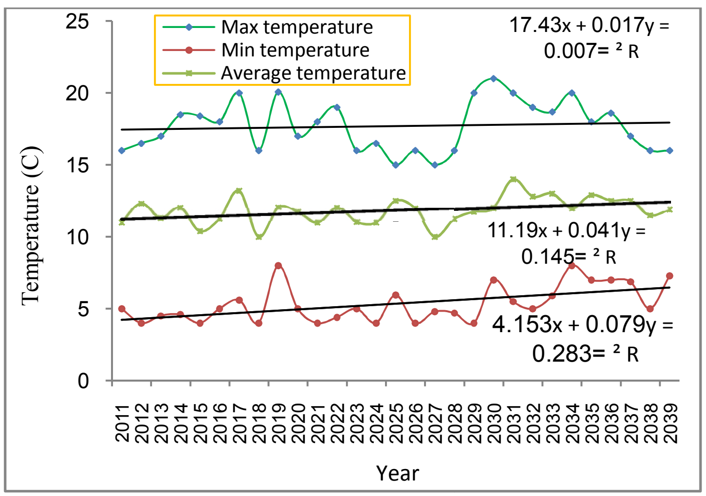
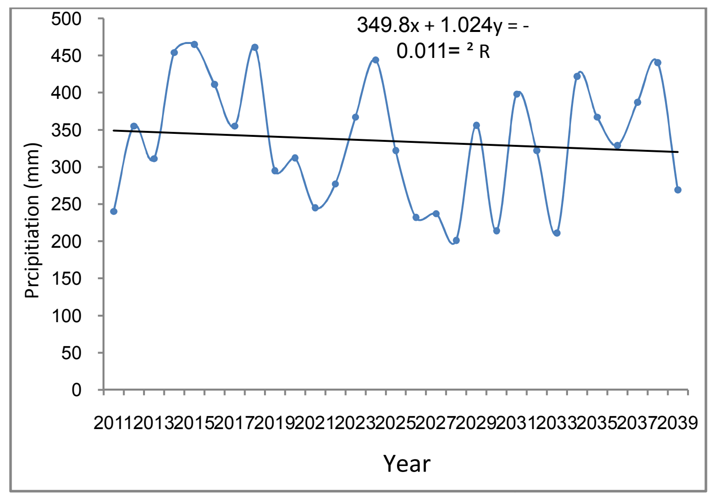


Fig. 5. Changes of the predicted variables compared with the observed variables


Max temperature
Average temperature
Min temperature
17.83x + 0.083y =
0.289= ² R
12.60x + 0.047y =
0.379= ² R
6.702x + 0.034y = -
0.101= ² R
Temperature (C)
Year


372.6x + 2.854y = -
0.112= ² R
Percipitiation (mm)
Year


Max temperature
Min temperature
Average temperature
17.43x + 0.017y =
0.007= ² R
11.19x + 0.041y =
0.145= ² R
4.153x + 0.079y =
0.283= ² R
Temperature (C)
Year


349.8x + 1.024y = -
0.011= ² R
Prcipitiation (mm)
Year

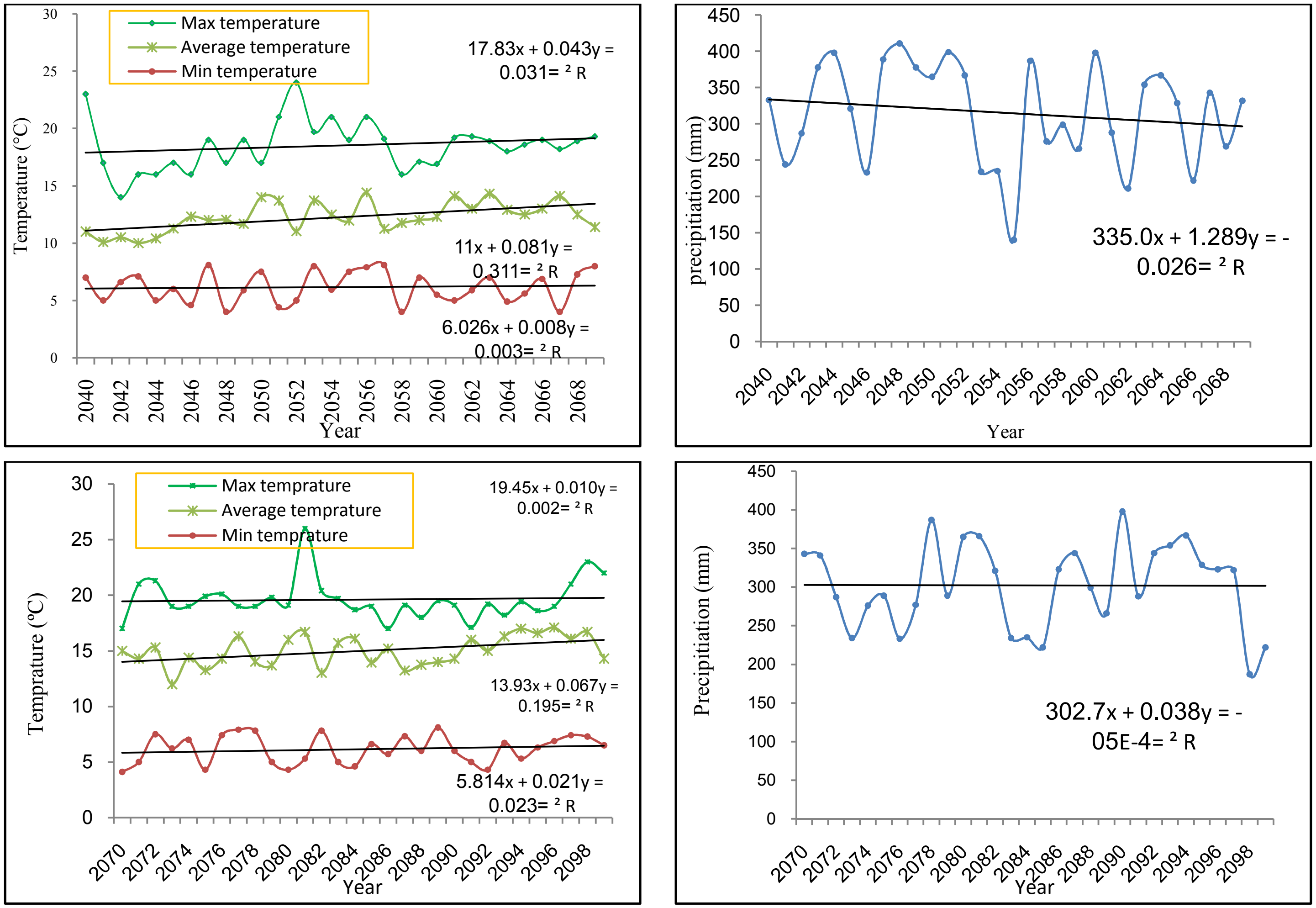


Fig. 6. Trend of studied variables in the observed and predicted periods

Table 3. SDSM validation by using statistical parameter

		Global circulation models		
		Hadcm3		**CGCM1**
		A2 Scenario	**B2 Scenario**	**A1 Scenario**
Average temperature	RMSE	4.04	4.2	4.52
	R^2	0.84	0.82	0.73
	Nash	0.99	0.94	0.79
	MAE	0.33	0.1	0.06
	PBIS	-0.24	-0.78	-0.51
Max temperature	RMSE	3.11	4.1	3.22
	R^2	0.94	0.81	0.89
	Nash	0.53	0.11	0.33
	MAE	0.14	0.78	0.41
	PBIS	-0.36	0.32	0.1
Min temperature	RMSE	3.44	4.54	3.67
	R^2	0.97	0.87	0.94
	Nash	0.12	0.34	0.45
	MAE	0.43	0.32	0.76
	PBIAS	0.03	-0.21	-0.2
Precipitation	RMSE	3.56	4.11	4.13
	R^2	0.02	0.01	0.09
	Nash	0.01	-0.32	-0.45
	MAE	0.83	0.23	0.35
	PBIS	9.44	-23	-0.44

Table 4. The results of the Maan-Kendall test

Periods	Variable	Minimum	Maximum	Average	SD	Kendalτ	Significant level
1971-2010	Precipitation (mm)	129	554	319	108	-0.212	0.05
	Max temperature (ºC)	14.5	21.1	18.5	1.3	0.039	0.29
	Min temperature (ºC)	1.9	7.9	5.9	3.2	-0.009	0.94
	Average temperature (ºC)	10.5	13.5	13.56	2.1	0.013	0.54
2010-2039	Precipitation (mm)	210	465	334	87	-0.196	0.12
	Max temperature (ºC)	15	5.21	17.6	2.6	0.07	0.54
	Min temperature (ºC)	4	8	5.3	1.4	0.03	0.32
	Average temperature (ºC)	10	14	11.8	1.1	0.021	0.71
2040-2069	Precipitation (mm)	141	411	314	95	-0.09	0.78
	Max temperature (ºC)	14	24	18.6	1.3	0.04	0.08
	Min temperature (ºC)	4	8.1	6.3	2.1	0.01	0.92
	Average temperature (ºC)	10	14.4	12.2	1.6	0.06	0.21
2070-2099	Precipitation (mm)	178	398	302	101	0.11	0.65
	Max temperature (ºC)	17	26	19.6	1.8	0.006	0.08
	Min temperature (ºC)	4.1	8.1	6.3	1.9	0.01	0.54
	Average temperature (ºC)	12	17.1	14.3	1.1	0.008	0.83

5. DISCUSSION AND CONCLUSION

Climate change is one of the most important challenges for human society, which will affect ecological, social and economical systems. The Bar Watershed be confronted with many water scarcity problems. The study indicated that the temperature values compared to the precipitation values have better correlation with observed values that it is consistent with the results of [17]. This is due to the fact that the temperature has less time variations compared to the precipitation and it is a continuous variable and is less affected by the time irregularities, but precipitation is a discrete variable and is affected by many different variables. The results of downscaling SDSM showed that among the Hadcm3 and CGCM1 models under A1, A2 and B2 scenarios, Hadcm3 model under A2 scenario has the highest statistical accuracy in predicting the climate data (Table 3). Base on the Fig. 5 the average, minimum and maximum temperature increased compared to the base period which is consistent with the results of [13,34], but in contradiction with results of [17] who did their study in the southwest of Iran. Maybe this opposition is due to the differences of weather conditions. For example, the Bar Watershed have affected by the weather conditions of Siberia, but the southwest of Iran have affected by the weather conditions of Sudan and Red Sea. The results of this investigation showed that the long term annual precipitation of study area has decrease trend, however it is not significant at 5% confidence level that indicate instability in climate and its variations [35,36]. The report of Russia’s national academy of sciences showed that the increase in temperature caused melting in ices in Siberia and affected the discharge of rivers. These conditions have affected the climate of Iran, because one of the most important air mass entering Iran is coming from Siberia. Regarding the results of recent researches, the surface earth temperature has increasing trend [37] that caused weaknesses in dynamic low pressure systems and decrease of precipitation in the Bar Watershed. Climate change can affected the amount and temporal distribution of precipitation. It can be concluded from Figs. 4 and 5 that generally the precipitation will decreases over the 21st century. The point of this study was the temporal distribution of precipitation pattern. For example, by approaching the end of the 21st century, there will be less precipitation in the winter and more precipitation in the autumn. The trend of base period variables have evaluated and the result showed that the trend of minimum temperature and precipitation were decreasing. On the other hand, the trend of average and maximum temperature was increasing, but they were not significant at 5% confidence level. In addition, the trend of periods (2010-2039), (2040-2069) and (2070-2099) variables have evaluated and the result indicated that the trend of average, minimum and maximum temperatures were increasing, but they were not significant at 5% confidence level. Also, in these periods the average temperature increases, respectively, by 0.01, 0.3 and 0.6, the minimum temperature increases by 0.3, 0.5 and 1.4 and the maximum temperature increases by 0.7, 1.4 and 2.7 centigrade degree compared to the based period (1971-2000). On the other, the precipitation showed a not significant decreasing trend at 5% confidence level. Also the results showed that the average annual precipitation decreases by 6, 10 and 17 mm compared to the base period respectively.

Based on the A2 scenario, the amount of greenhouse gasses will increase during the 21st century. A possible cause for the rise in temperature across the region under study is the increase in the amount of greenhouse gasses. As temperature rises, the low pressure systems in the region are weakened, which in turn leads to less precipitation there. These changes will have significant impacts on the ecosystems. Base on the mentioned results, in the future the Bar Watershed will face with more water scarceness issues. This result forces the government to find new and sustainable adaptation strategies to rescue the future of the water resources. The water management in this region should be more flexible to cope with climate change and its serious impacts. Given the results it was observed that the climate in the province will change from semi-arid to arid, and that makes it of utmost importance that we seek ways to face the climate change and adapt to it. This adaptation would require international and extensive measures to be taken, which is out of the scope of this study; therefore, here a number of adaptation strategies concerning effects on water resources in the region, will be introduced, in order to be used in the water sector. As the main goals of this research comprise studying the trends of temperature and precipitation in the region under study, we need to adopt a scenario-based approach in studying the effects of climate change on the system and to provide proper adaptation strategies. For the particular area, given the climate situation of the country, the strategies could come under the three categories of watery supply, saving, and optimized system management.

5.1 Supplying More Water

The first solution could naturally be supplying more water from new resources. If the situation in the region allows, inter-catchment water transfer could be the right strategy, but it is also necessary to investigate the potential of the source catchment for transferring water under the climate change conditions.

5.2 Wastewater Treatment

Another common strategy worldwide is to use water resulting from wastewater treatment. Also, using watershed and appropriate use of rain water, we can reduce vaporization and save the water in fountains and aqueducts for the hot season, so that the base flow is preserved in rivers. It's worth noting that the measure is vital considering tourism and environmental demands.

5.3 Demand Management

The strategy can be divided into two types, the saving strategies and water evaluation strategies. As most of the available water in Iran goes to the agriculture sector, and saving on potable water as juxtaposed to saving on agricultural needs will be negligible, it is important to pay special attention to saving in the agriculture sector. International experience shows changing water fees and receiving the final cost from the consumers is a success, and therefore an optimized pricing policy needs to be analyzed. One of the most important strategies widely used in the agriculture sector is to modernize the irrigation systems in use. Furthermore, changing crop types is also among the most common methods employed vis-à-vis climate change, in order to preserve the area under cultivation [16].

5.4 Optimized Exploitation Policies

One of the most prominent policies for adaptation to climate change is to optimize exploitation of water from dam reservoirs and underground water resources. Another strategy could be to create a water market and strictly control fees in the water bills, so that the minimum environmental need of rivers is not ignored due to the current status of consumption of water resources.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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