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Drought Monitoring Based on the SPI and RDI Indices under Climate Change Scenarios (Case Study: Semi-Arid Areas of West Golestan Province)

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ABSTRACT Based on SPI and RDI indices, changes in droughts in the semi-arid areas of west Golestan Province was assessed in the GIS environment by incorporating data from Hashemabad synoptic station and 11 climatic stations. After evaluating the ability of LARS-WG5 in the simulation period (1984-2010), downscaling of HadCM3, IPCM, and GFC models was done as a group under scenarios of A1B, A2 and B1 to evaluate changes in meteorological values of precipitation, T_{max}, T_{min}, and evapotranspiration during 2011-2030.Model accuracy was studied using the coefficient of determination, index of agreement (D) and the mean error. The results showed that the highest mean values of T_{max} and T_{min} were related to the B1 and A2scenarios, with an increasing trend of 0.81and 0.91°C, respectively. The highest mean evapotranspiration (1.34 mm) changes were under group model of B1 and A2. For precipitation, these were related to B1 (1.49 mm) and A1B (1.36 mm) scenarios. Based on the regional interpretation of drought, the central, northern and eastern parts, in spite of the current droughts, are predicted to be hit harder in the upcoming period and for more prolonged period. In this study, performance of group models to simulate climate data and use of drought indices were shown.

Key words: *Simulation, Downscaling, General Circulation Models, Evapotranspiration*

1 INTRODUCTION

Drought is a natural and recurrent climatic phenomenon that has not been properly assessed due to the complexity of nature (UNEP, 2012).

About 11 percent of the world's natural disasters are related to the drought phenomenon (Boken, 2005). Drought is usually a temporary

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disturbance which happens due to the abnormal reduction of precipitation in an area that is not necessarily arid. Its continuous and iterative nature shapes the overall impacts on land degradation and desertification (Millennium Ecosystem Assessment, 2005). According to the Fourth Report of IPCC (Intergovernmental Panel on Climate Change) (2007), the average global temperature had increased more than 0.74 °C during 1906-2005. At the moment the global warming has intensified nearly twice that of the fifty years ago. This phenomenon has brought such negative economic and environmental effects as precipitation reduction, decline in agricultural production and adverse effects on freshwater ecosystems, vegetation, fish and birds in various parts of the world (European Commission, 2007).

Several studies have been carried out on the impact of climate change on various aspects of drought using various methods and indices (Nicholls, 2004; Burke *et al*., 2006; Burke and Brown, 2008; Spittlehouse, 2008; Tigkas, 2008; Wood, 2008; Asadi *et al*., 2011; Mahdizadeh *et al*., 2011; Dousti *et al*., 2013; Zare *et al*., 2015), most of which are based on the simulation of the upcoming period. The general circulation models (GCMs) have been frequently used for simulating changes in climatic parameters under different scenarios.

Determining a set of appropriate and precise indices is of great importance for drought monitoring and impact assessment. Precipitation and evapotranspiration are important factors for monitoring meteorological droughts and, therefore, the indices that consider these two parameters are suitable for monitoring drought changes (Zare *et al*., 2015). In this respect, Reconnaissance Drought Index (RDI) (Dubrovsky *et al.*, 2008) and Standardized Precipitation Index (SPI) (McKee *et al.*, 1995) can be mentioned.

The current study revolves around the notion that the alternations in drought parameters will manifest itself through higher desertification and land degradation rates. Hence, this study is important in the sense that most signification and pragmatic drought parameters have been considered.

To date, most studies investigating the impacts of climate change have solely focused on the simulation of climate parameters based on a separate set of climate scenarios. Yet, this study, by dwelling on the emphasis made by the IPCC, has incorporated an ensemble scenario, which will produce higher accuracy in the prediction of future's climatic state. Therefore, this study was aimed to monitor the drought for a 26-year base period (1984-2010) and a 20 year simulation period (2011-2030) through LARS-WG. The climatic parameters of precipitation, evapotranspiration and minimum and maximum temperatures for the next 20 years (2011-2030) will be simulated by running the atmospheric general circulation ensemble models of IPCM4, HADCM3 and GFCM21 under the scenarios of A1B, A2 and B1 at Hashemabad station. Changes in drought will be evaluated using RDI and SPI indices for the base period and simulation period and effects of climatic changes on drought in the area will be analyzed. In order to regionally analyze droughts, previous and predicted RDI values were interpolated in GIS with Kriging method.

2 MATERIALS AND METHODS

2.1 Study area

The study area, covering about 5101 km^2, is located in western part of Golestan Province (36° 37′ 57.51″- 37° 27′ 24.26″ N, and 53° 51′ 14.76″ - 54° 51′ 46.26″ E). The southern part of the area is mountainous and western and northern parts are covered with deserts and fine sediments of the Caspian Sea (Figure 1, Table 1).

Table 1 Physiographic features of the study area

Elevation from sea level			Weighted average slope (%)	Aspect
Minimum elevation (m)	Maximum elevation (m)	Weighted average elevation (m)		
-32	3088	254	9.5	Flat

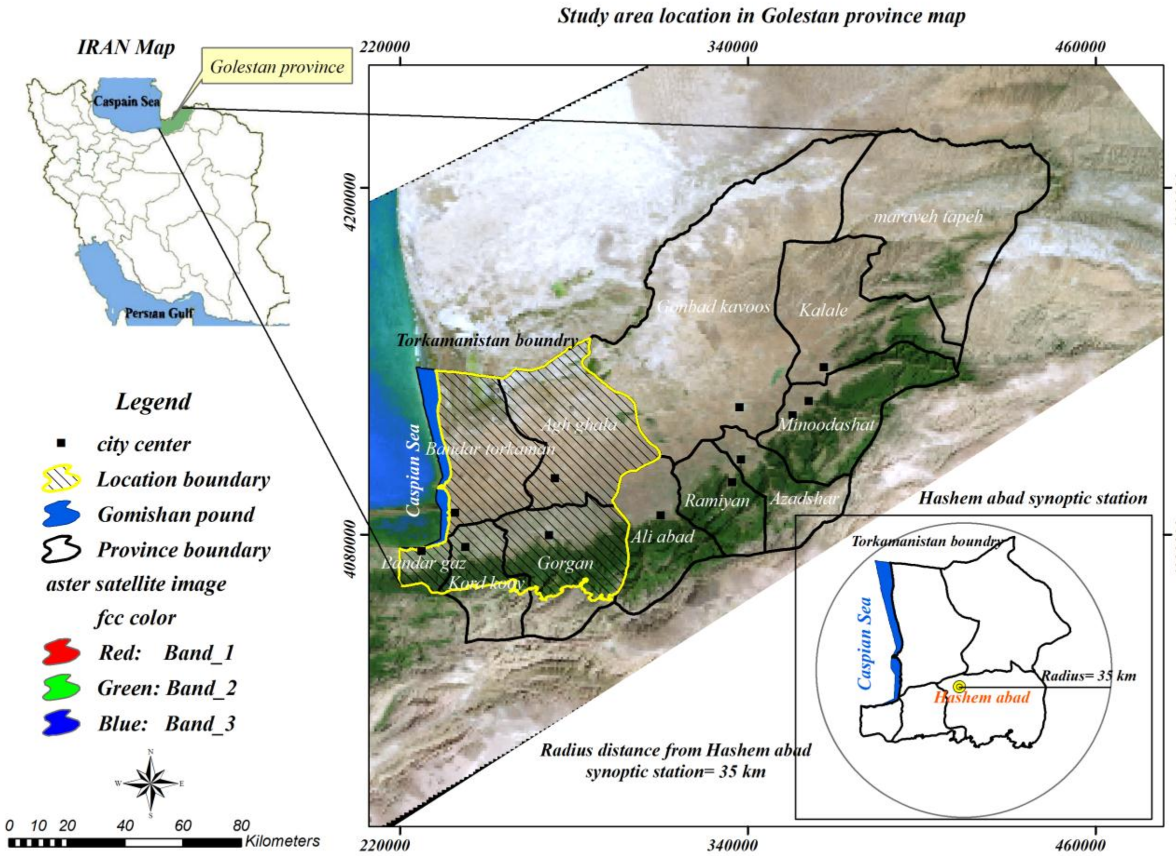

Figure 1 Location of the study area in the northern Iran and western part of Golestan province

2.2 Climatic parameters and models

The data, including minimum and maximum temperatures, evapotranspiration, and precipitation for a 26-year base period (1984-2010) and 20-year simulation period (2011-2030) were gathered from the Hashemabad's synoptic station (Table 2) and incorporated with 11 climatic stations in the GIS environment. Data were normalized in the Minitab software, version 17.1.0. Table 3 represents climate features of precipitation, minimum and maximum temperatures, and evapotranspiration.

Table 2 Specifications of Hashemabad station

Type	Longitude	Latitude	Elevation (m)	Established year	Coverage radius (km)
synoptic	54.27	36.85	13.30	1984	35

Table 3 The climate features (precipitation, minimum and maximum temperature, and evapotranspiration (± SD) for the base period (1984-2010)

Parameter	Variable	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Tmin	mean	8.9	13.6	18.4	22.5	23.7	21.7	16.1	10.9	5.9	3.4	3.1	5.2
	SD	1.1	1.2	1.0	1.1	1.0	1.1	1.7	1.2	1.4	1.8	1.5	1.4
Tmax	mean	19.8	24.6	30.6	32.1	33.3	31.5	27.5	21.5	15.6	12.8	12.6	14.8
	SD	2.1	2.0	1.6	1.5	1.5	1.6	1.7	2.0	2.1	1.9	2.0	2.4
Precipitation	mean	51.7	40.9	22.6	26.6	20.7	31.2	55.6	62.8	54.4	49.2	58.2	59.5
	SD	28.5	23.5	17.4	27.7	22.4	20.6	36.3	35.2	21.4	29.7	27.4	23.4
ETP	mean	8.6	9.5	18.3	44.5	90.6	157.1	203.4	210.2	158.0	88.4	38.6	15.1
	SD	3.2	3.1	4.8	7.5	7.9	14.5	14.9	18.5	12.1	13.6	6.0	4.2

The LARS-WG, a statistical downscaling model originally developed by Roscoe *et al*. (1991) and Semenov and Barrow (1997), was used here. This model has three main parts, including calibration, evaluation and simulation of future meteorological data. For calibration, the model needs a file that represents the climate behavior in the last period, which was provided with the daily precipitation, maximum and minimum temperatures and solar radiation data for the base period of the study. Then, the generated data by the model and actual data (observed) for the baseline period were verified using accuracy assessment indices. To evaluate simulation results and observational data for the base period, coefficient of determination, mean error and index of agreement were used in this study. Based on evaluation statistics, the model with the highest coefficient of determination value and the lowest statistic errors value or with the index of agreement near one was selected as the best model (Equation 1).

$$D = 1 - \left[\frac{\sum_{i=1}^{n}(Si - Oi)^2}{\sum_{i=1}^{n}(|S'i| + |O'i|)^2}\right] \quad (1)$$

$$S'i = Si - \bar{S} \; O'i = Oi - \bar{O}$$

where, Si and Oi are the simulated data by the model and the actual data. $\overline{\mathrm{S}}$ and $\overline{\mathrm{O}}$ are the total mean of data in S'i and O'i and n is the total number of evaluated samples.

After confirming the model capability in simulating the behavior of climatic variables in the base period, simulation of the meteorological data for the periods 2011-2030 was carried out, using the behavior of climatic variables for the base period and statistical downscaling of data in an atmospheric general circulation model (Maurer and Hidalgo, 2008). In this study, three models of IPCM4, HADCM3 and GFCM21 were ensembled under three scenarios of B1, A2 and A1B (Semenov and Stratonovitch, 2010; Nakicenovic *et al*., 2000). Table 4 represents the models' features used in the study.

The number of stations in the downscaling process is defined on the basis of the network cell size of these models, topographic features and the type of climate, the assessment of which provides the basis for the adaptation of the results to the regional scale. A although there are 7 synoptic stations in Golestan province, Hashemabad, Gonbad Kavous, and Maraveh Tappeh have the longest records.

So, according to Table 4, and given the required network cells for the model, spatial resolution, and the compatibility of the mode with the expansion of the area of interest (5101

km^2), one station (Hashemabad) was used. The reason why this station was selected is the homogeneity of topographic features, the area, ground cover and the relatively homogeneous atmospheric condition of the study area.

Table 4 Features of general climate model in LARS-WG (Maurer and Hidalgo, 2008; Semenov and Stratonovitch, 2010)

Research center	Country	Global climate model	Model acronym	Grid resolution	Emissions scenarios
Pierre Simon Laplace Institute	France	IPSL-CM4	IPCM4	2.5×3.75°	A1B, A2, B1
UK Meteorological Office	UK	HadCM3	HADCM3	2.5×3.75°	A1B, A2, B1
Geophysical Fluid Dynamics Lab	USA	GFDL-CM2.1	GFCM21	2×2.5°	A1B, A2, B1

2.2 Drought indices for monitoring climate change

To analyze drought, one or more indices are necessary to determine wet and dry periods. Different indices, such as the Palmer Drought Severity Index and the percentage of normality, etc. have been suggested for drought monitoring and its quantitative effects. Reconnaissance Drought Index (RDI) and the Standardized Precipitation Index (SPI) were used in this study.

2.3.1 Drought index of RDI

Designed by Tsakiris *et al.* (2005), RDI was based on the cumulative amount of precipitation and potential evapotranspiration (Equation 2):

$$\propto_0^i = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}} \quad i = 1{:}\,N \quad j = 1{:}\,12 \qquad (2)$$

Where, p_{ij} and PET_{ij} are precipitation values and potential evapotranspiration of month i and year j, respectively. If the scale of the study is based on year, then the value of j is from 1 to 12. Parameter N is the number of years with statistics. The proposed method for calculating evapotranspiration is Thornthwaite equation, because this equation in arid and semi-arid areas shows the evapotranspiration amounts less than the actual. In the second step, RDI values were calculated by $\alpha_0^{(i)}$ for different years (Eq. 2) and then were normalized (RDI_n) as Equation 3:

$$RDI_n^{(i)} = \frac{\alpha_0^{(i)}}{\bar{a}_0} - 1 \qquad (3)$$

where, $\bar{a}_0$ is the arithmetic mean of $\alpha_0^{(i)}$ values for different years that are equal to the Drought Index ratio provided by FAO. Then in the final step, standardized RDI values (RDI_{st}) were calculated using the $\alpha_0^{(i)}$ values for different years (Equation 4), assuming that the $\alpha_0^{(i)}$ values follow the log-normal distribution.

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\hat{\sigma}_y} \qquad (4)$$

where, $y^{(i)}$ equals to ln(α_0^((i))), $\bar{y}$ and $\hat{\sigma}_y$ are arithmetic mean and standard deviation of $y^{(i)}$, respectively. In addition to precipitation, evapotranspiration values are required for RDI index; thus, the evapotranspiration values were calculated using mean temperature and based on Thornthwaite in this study.

2.3.2 Drought Index of SPI

Developed By McKee *et al*. (1995), Standardized Precipitation Index (SPI) is calculated for every time scale. To calculate the index, long-term time series of rainfall data recorded at each station is fitted by a probability distribution and finally the fitted cumulative function is converted to normal distribution. SPI index is calculated in several steps (Equations 5 to 10).

$$g(x) = \frac{1}{\beta^{\alpha}.\Gamma(\alpha)}.x^{\alpha-1}.e^{-x/\beta} \quad (5)$$

where, rainfall values, x, is greater than zero and Γ(α)is the gamma function which is equal to Equation 5.

$$\Gamma(\alpha) = \int_{0}^{\infty} y^{\alpha-1} e^{-y} dy \quad (6)$$

In the gamma function, parameters α and β are shape and scale parameters of gamma distribution function, respectively, which must be estimated for each station and timescale. To estimate α and β, first parameter A must be calculated.

$$A = \ln(\bar{x}) - \frac{\sum \ln X}{n} \quad (7)$$

In this equation, n is the number of rainfall observations and their mean. The values of α and β is then obtained by Eq. 7 and Equation 8.

$$a = \frac{1}{4A}\left[1 + \sqrt{1 + \frac{4A}{3}}\right] \quad a > 0 \quad (8)$$

$$\beta = \frac{x}{\alpha} \quad \beta > 0 \quad (9)$$

Equation 9 is the cumulative probability function:

$$G(x) = \int_{0}^{x} g(x).dx = \frac{1}{\beta^{\alpha}.\tau(\alpha)}.\int_{0}^{x} x^{\alpha-1}.\varepsilon^{-x/\beta}.dx \quad (10)$$

Positive SPI values indicate more rainfall than the average and negative values indicate less than the average rainfall e. According to this method, when SPI is continuously negative and reaches -1 or less, a drought period occurs and ends when SPI becomes positive. Edward and McKay (1997) was followed for the SPI based drought classification, while Tsakiris *et al.* (2008) was followed for the wet years classification based on the RDI (Table 5). In this study, DIP (Drought Indices Package) software version 2.0 was used to calculate the SPI.

Table 5 Classification of drought and wet status based on SPI and RDI (Zare *et al.*, 2015)

SPI and RDI values	Symbol	Classification of drought
≥ 2	EW	extremely wet
1/5 -1/99	SW	Severely wet
1 - 1/49	MW	moderately wet
+0/99 – (-) 0/99	N	Normal
(-)1/49 - (-) 1	MD	moderately drought
(-)1/99 – (-)1/5	SD	Severely drought
≤ -2	ED	Extremely drought

3 RESULTS AND DISCUSSION

According to the networking of LARS-WG model on a global scale (about 200 km), data downscaling in this study with a radial distance of 35 kilometers is appropriate (Figure 1).

3.1 **Evaluation and calibration of LARS-WG model**

First, with regard to the base period of 26 years (1984-2010), the required climatic parameters for the implementation of the model were analyzed. A baseline scenario for the base period was used for calibration and verification of the model. The model outputs, including minimum and maximum temperatures, evapotranspiration and precipitation were compared with the observed data for the same period. The change in the mean and standard deviation of the observed and simulated climate parameters for the base period (1984- 2010) is shown in the following figures2 to 4. According to some studies, mean values compared to the standard deviation values have high accuracy.

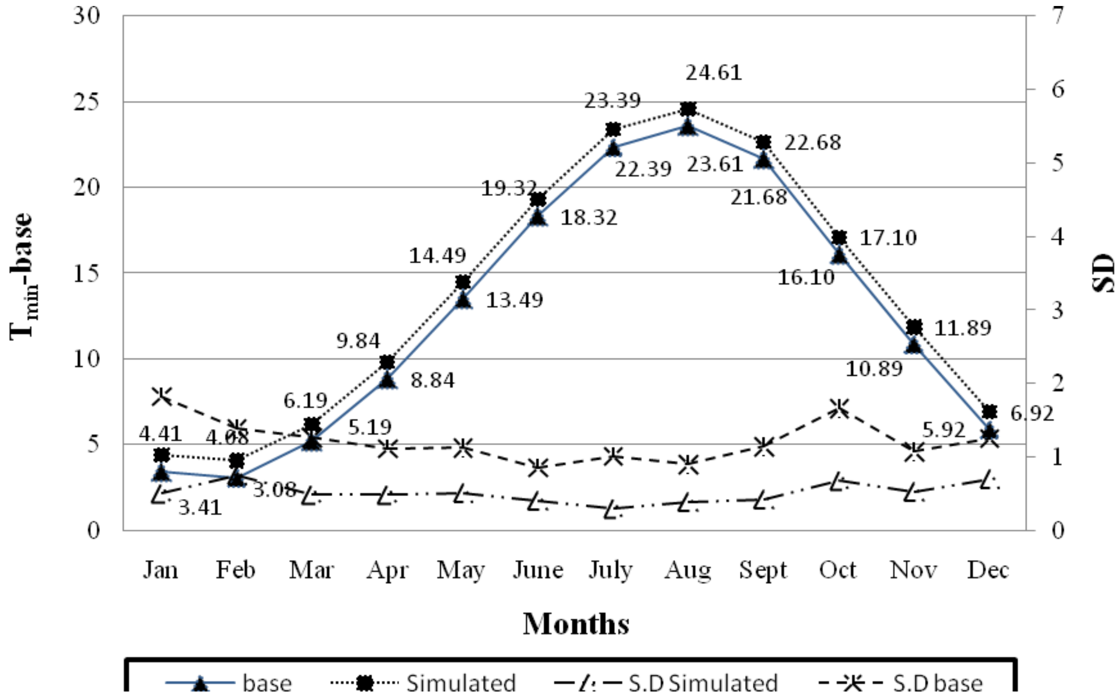

Figure 2 Mean and standard deviation of the observed and simulated minimum temperature for the base period (1984- 2010)

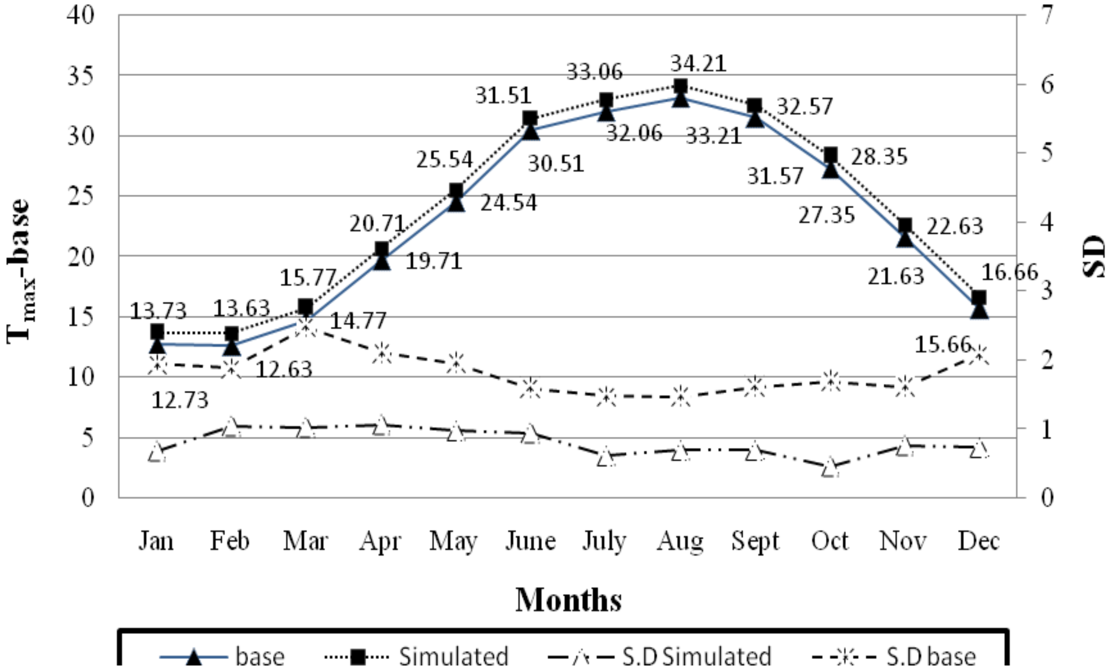

Figure 3 Mean and standard deviation of the observed and simulated maximum temperature for the base period (1984- 2010)

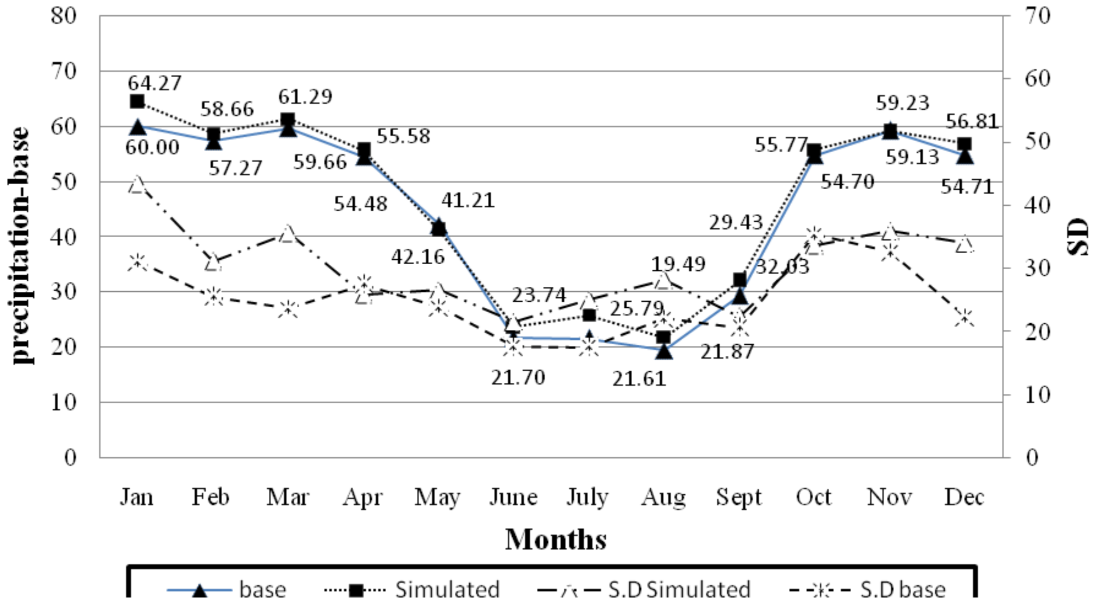

Figure 4 Mean and standard deviation of the observed and simulated precipitation for the base period (1984- 2010)

The results of the observed values for the base period (1984-2010) and values simulated by LARS-WG model based on verification statistics indicted that the mean of simulated values for the concerned parameters were in good agreement with the observed values for the base period (Table 6). Index of agreement (D) for all parameters is close to 1.

Table 6 The evaluation results of the simulated and observed values for the base period (1984-2010) by LARS-WG model based on the verification statistics

(Variable)	(Statistic error)		
	R^2	D	ME
Precipitation	0.673	0.907	- 0.06
Minimum temperature	0.783	0.939	- 0.07
Maximum temperature	0.835	0.995	0.20
Evapotranspiration	0.996	0.993	- 0.47

The statistical evaluation indicated high accuracy of LARS-WG model in simulating climate variables data of the Hashemabad's synoptic station for the base period. The LARS-WG was also applied to simulate precipitation, evapotranspiration, minimum and maximum temperatures for 20-year period (2011-2030) using three models of HADCM3, IPCM4 and GFCM21 ensemble under three scenarios of A1B, B1 and A2. The mean precipitation values for the next 20 years under three simulated scenarios of A2 (1.31 mm), B1 (1.49 mm) and A1B (1.36 mm) showed a difference over the base period (Figure 5), the highest of which was related to the group model B1 (had-Ipcm-Gfc) and A1B (had-Ipcm-Gfc) in the cold months, while the lowest changes (sometimes unchanged) were related to A2 in the warm months. The results corresponded to Spittlehouse (2008), Dousti *et al*. (2013), Mahdizadeh *et al*. (2011).

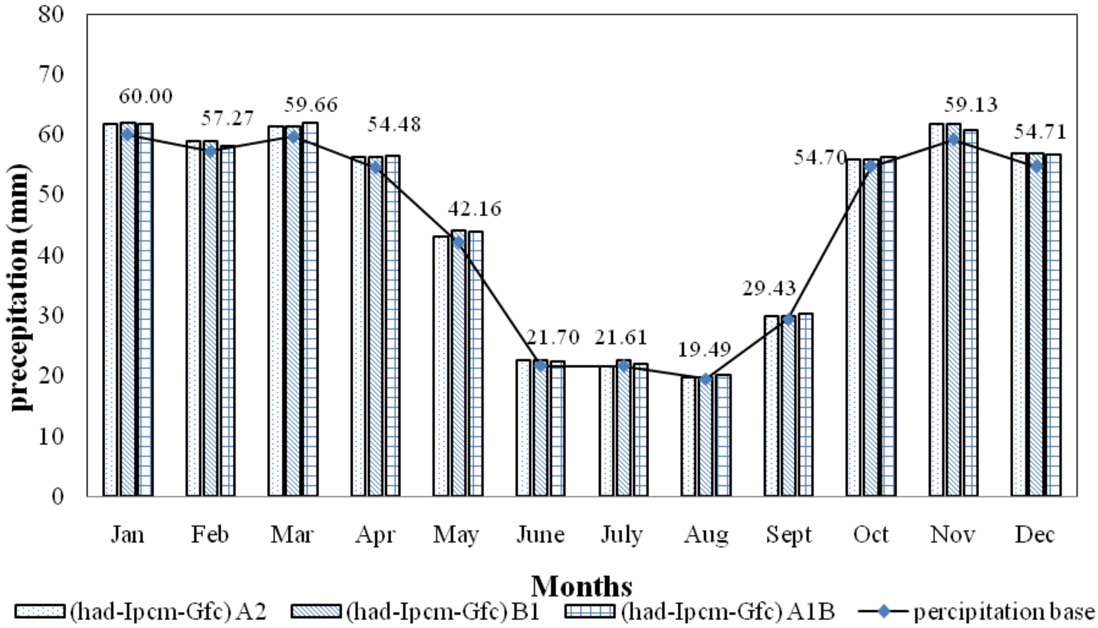

Figure 5 Mean monthly precipitation for the period 2011-2030 based on group performance of models under three scenarios of A2, B1 and A1B with the base period

The mean maximum temperature for the next 20 years, under three simulated scenarios of A2 (0.79°C), B1 (0.81°C) and A1B (0.80°C) showed a difference over the 20-year base period (Figure 6), the highest of which was related to the group model B1 (had-Ipcm-Gfc) and A2 (had-Ipcm-Gfc).

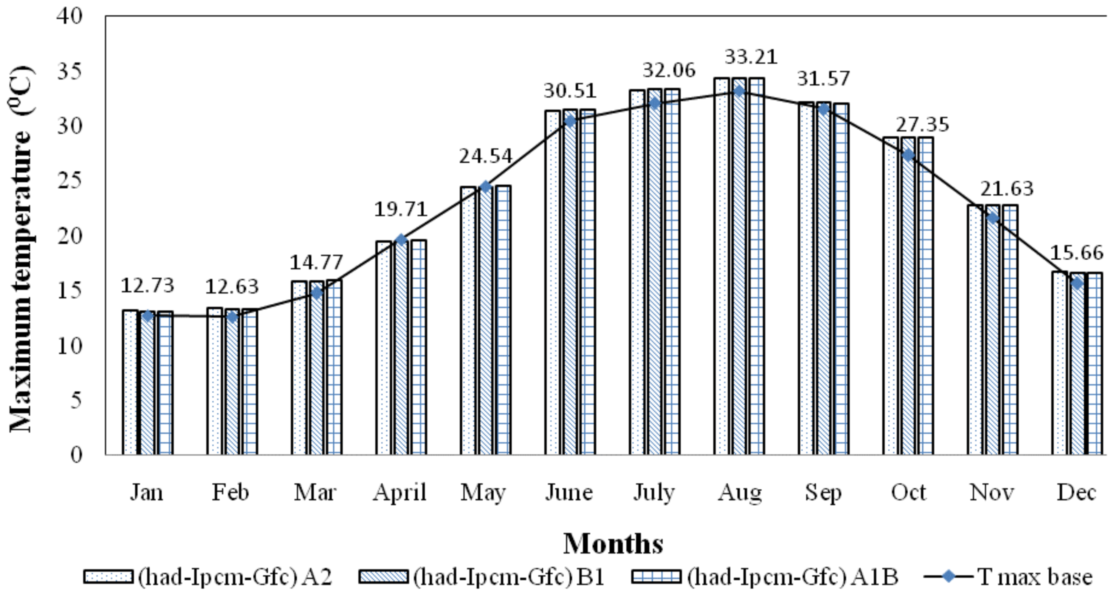

Figure 6 The mean monthly maximum temperature for the period 2011-2030 based on group performance of models under three scenarios of A2, B1 and A1B with the base period

The mean minimum temperature for the next 20 years under three simulated scenarios of A2 (0.88 °C), B1 (0.91°C) and A1B (0.88 °C) showed a difference over the 20-year base period (Figure 7). The results of this study are consistent with the ones for Dousti *et al*. (2013) and Nicholls (2004).

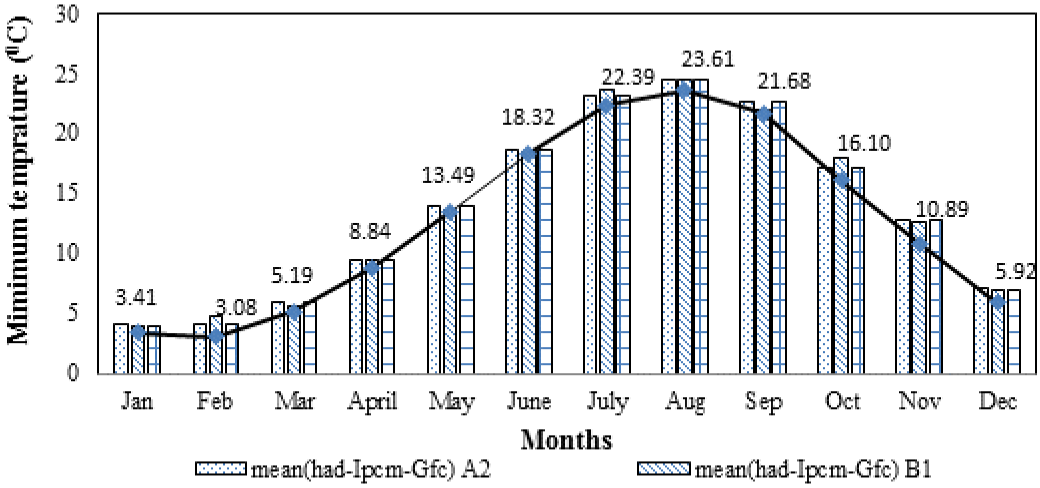

Figure 7 The mean monthly minimum temperature for the period 2011-2030 based on group performance of models under three scenarios of A2, B1 and A1B with the base period

The mean values of evapotranspiration for the next 20-year under three simulated scenarios of A2 (1.30mm), B1 (1.34mm) and A1B (1.31 mm)showed a difference over the 20-year base period, the highest of which was related to the group model B1 (had-Ipcm-Gfc) and A2 (had-Ipcm-Gfc) in July, August and September (Figure 8). Increase in simulated evapotranspiration values for the period 2011-2030 by the general circulation model and under climate change scenarios are in accordance with Zare *et al.* (2015) and Sheffield and Wood (2008).

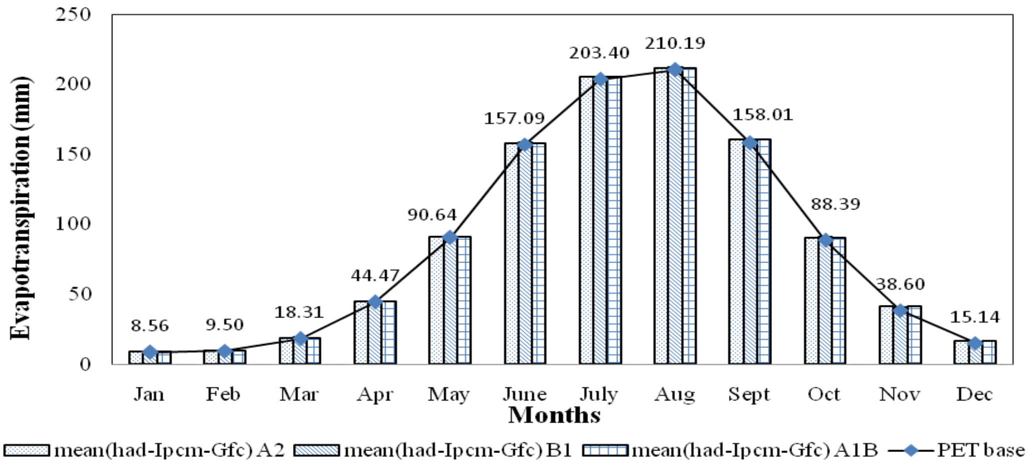

Figure 8 The mean monthly evapotranspiration for the period 2011-2030 based on group performance of models under three scenarios of A2, B1 and A1B with the base period

3.2 Drought indices of SPI and RDI for the base and simulation periods

After determining the values of SPI and RDI for the base and simulated period by ensemble models under scenarios of A2, B1 and A1B, correlation coefficients and index of agreement, D, were determined between indices (Table 7).

Table 7 Comparison of coefficient of determination and index of agreements for SPI and RDI for the base and simulated periods

period	Scenario	Index	R2	D
Base (1984-2010)		SPI and RDI base	0.916	0.99
Simulated (2011-2030)		SPI and RDI simulated	0.917	0.99
	(had-Ipcm-Gfc) A2	SPI and RDI	0.914	0.99
	(had-Ipcm-Gfc) B1	SPI and RDI	0.897	0.99
	(had-Ipcm-Gfc) A1B	SPI and RDI	0.914	0.99

Coefficients of determination and index of agreement (D) for various scenarios were very close to each other, of which the determination coefficients of SPI and RDI for the group model (had-Ipcm-Gfc) and the scenario B1 were less than 0.9 compared to other scenarios. Results of SPI index based on the precipitation values and RDI index based on the precipitation and evapotranspiration values for both base and simulations periods were calculated by the group model for 2011-2030 (Table 8).

Table 8 Simulation results of SPI and RDI indices based on group models under three scenarios of A2, B1 and A1B

Month	Base (1984-2010)		Simulated (1984-2010)		(had-Ipcm-Gfc) A2		(had-Ipcm-Gfc) B1		(had-Ipcm-Gfc) A1B	
	RDI	SPI	RDI	SPI	RDI	SPI	RDI	SPI	RDI	SPI
Jan	0.03	0.00	-0.02	-0.02	0.85	0.64	2.10	0.58	0.97	0.9
Feb	-0.08	-0.05	0.00	0.00	1.41	0.81	0.64	0.72	1.38	0.68
Mar	0.01	0.02	0.02	0.01	-0.25	-0.54	-0.42	-0.61	-0.59	-1.13
April	0.00	0.00	0.02	0.02	-0.68	-0.47	-0.54	-0.52	-1.66	-2.05
May	-0.07	-0.07	-0.05	-0.06	-1.35	-2.22	-1.51	-2.18	-0.52	-0.99
June	-0.03	-0.02	0.03	0.03	-1.73	-1.57	-1.35	-1.53	-1.13	-0.53
July	0.02	0.01	-0.06	-0.09	-0.67	-0.14	-0.77	-0.18	-0.38	0.53
Aug	-0.04	-0.06	0.00	0.00	-0.20	1.28	-0.11	1.31	-0.58	0.43
Sep	0.07	0.10	0.00	0.02	0.07	0.86	0.37	0.96	0.09	0.96
Oct	-0.02	-0.01	0.02	0.03	0.51	0.59	0.61	0.63	0.59	0.75
Nov	0.00	-0.01	0.01	0.01	0.78	0.47	0.62	0.47	0.21	-0.73
Dec	-0.06	-0.02	-0.04	-0.05	0.26	0.4	0.36	0.42	0.62	0.23

Drought monitoring of simulated values by RDI index and by the ensemble model under three scenarios of A2, B1 and A1 indicated that drought conditions in temperate and warm months fluctuated from moderate to severe relative to the group model A1B (had-Ipcm-Gfc) for spring, group models of A2 (had-Ipcm-Gfc) and B1 (had-Ipcm-Gfc) for summer, respectively(Figure 9). For cold months like January and February, moisture conditions were mostly average to intense, while, for the other months of the year, wet-period and drought conditions varied within the normal range. According to RDI, percent changes for the simulated compared to the base period showed 2% to 8.33% increase. These results are consistent with studies of Sheffield and Wood (2008) as well.

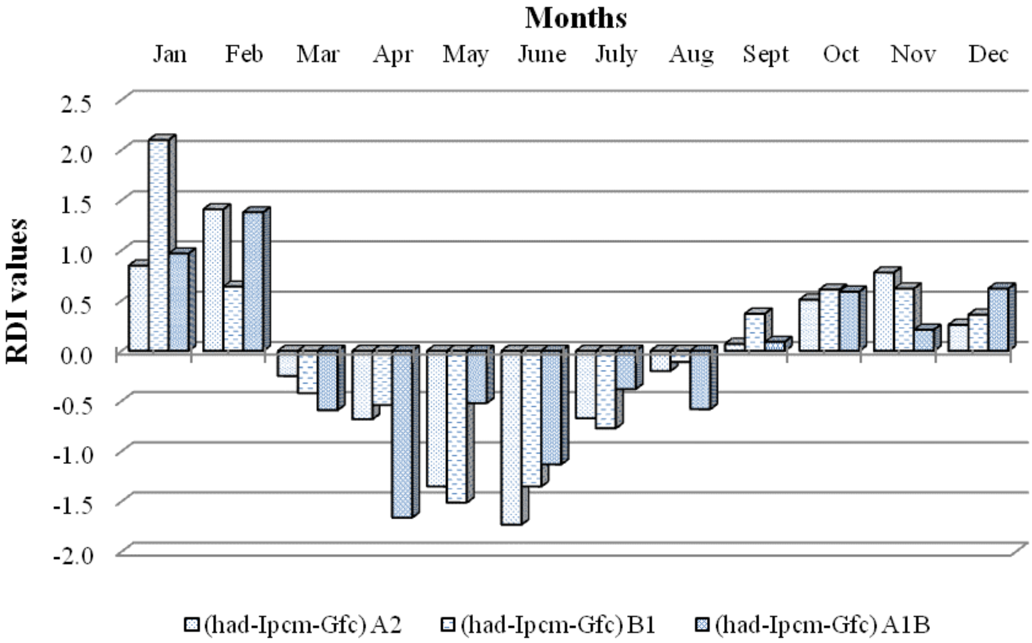

Figure 9 Drought monitoring based on RDI index in the period 2011-2030 under three scenarios A2, B1 and A1B

Based on changes in SPI, drought conditions showed fewer changes than RDI (Figure 10). Therefore, drought conditions during March to July ranged from moderate to very severe. These changes were seen for A2 and B1 scenarios in hot months and for A1B scenario in colder months of spring. In addition, except in August which more favorable conditions existed, the other months had normal conditions.

In fact, Figures 9 and 10 are not showing the mean comparison for the two indices, but instead, they are showing the moisture and dryness of different months and seasons of the year for the predicted periods (2010-2030) based on the RDI and SPI indices under grouped scenarios of climate change. Based on these two figures, it was clarified that the SPI index shows fewer months but with more drought intensity (the maximum intensity) while the RDI has a more effective range (the longest duration) in the study area.

Based on the results of the simulation of SPI and RDI by ensemble models, drought conditions for A2 and B1 scenarios showed severe trend in hot months of the year compared to the A1B.In all studies, increasing trend of climatic parameters such as temperature, evapotranspiration and in some cases, precipitation variability in future long-term periods caused an increase in drought intensity and climate change. According to the results, it was found that the average predicted values during the next 20 years compared to the average values of the base period were greater. The values obtained for RDI index were closer to drought conditions than SPI index. These results are concordant with the results of Sheffield (2008), Nicholls (2004) and Kirono *et al.* (2011).Tables9represents comparison of mean values of climatic parameters for the next 20 years compared to the base period under the three climate change scenarios.

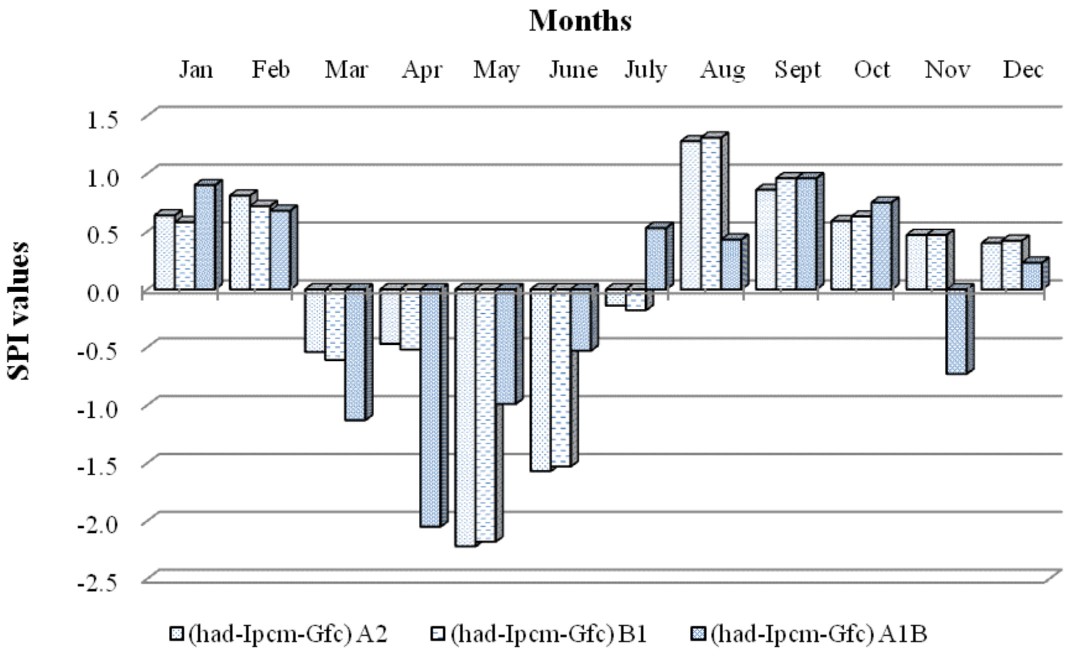

Figure 10 Drought monitoring based on SPI index in the period 2011-2030under three scenarios A2, B1 and A1B

Table 9 Comparison of mean values of climatic parameters for the next 20 years with the base period

index	Base (1984-2010)	Simulated (2011-2030)		
		(had-Ipcm-Gfc) A2	(had-Ipcm-Gfc) B1	(had-Ipcm-Gfc) A1B
T_{min} (°C)	12.74	13.63	13.65	13.62
T_{max} (°C)	23.03	23.83	23.84	23.83
Precipitation (mm)	534.34	550.05	552.24	550.62
PET (mm)	1042.30	1058.01	1058.40	1057.98

Table 10 and Figure 11 show clear interpretation that the central, northern and eastern parts, in spite of the current droughts, are predicted to be hit harder in the coming period and for more prolonged period, which could be thought of as the early warning signals for drought management. In Figure 11, the regional effect of drought is shown on the basis of the RDI index, where RDI values are lower in the western regions due to their dependency on evapotranspiration. These findings are consistent with several other studies (Tsakiris *et al.*, 2007; Tigkas, 2008; Asadi Zarch *et al.*, 2011; Kirono *et al.*, 2011; Asadi and Vahdat, 2013; Zare *et al.*, 2015; Hatefi, 2016).

Table 10 The detailed RDI values for the baseline and predicted periods (using the predicted variables of the LARS model), based on the regression equations established in Minitab

Stations	Equations	R-Sq %	RDI 1984-2010 base	RDI 2010-2030 simulated
Arazkooseh	-1.07+0.011142 rain-0.00571 ETO +0.0232 t_{min}-0.0346 T_{max}	99.4	-0.12	-1.58

Aq-Qala	-0.187 + 0.009424 rain - 0.002677 ETO + 0.05314 t_{min} - 0.0029 RH	99.7	-0.04	0.54
Behleki Dashli	0.582 + 0.014366 rain - 0.006505 ETO + 0.0540 t_{min}	99.5	-0.08	-0.10
Ramiyan	-0.959 + 0.00611 rain - 0.00780 ETO + 0.0177 t_{min} + 0.0073 RH	98	-0.08	-0.74
Kosar dam	-0.753 + 0.013241 rain - 0.008275 ETO + 0.0251 T_{max} + 0.0057 RH	99.5	0.01	-0.16
Gorgan dam	-1.098 + 0.012942 rain - 0.00736 ETO - 0.0405 T_{max}	98.4	-0.14	-2.07
Ghafar Haji	0.737 + 0.011304 rain - 0.00302 ETO + 0.0154 t_{min} - 0.0107 T_{max}	99	-0.09	0.70
Fazelabad	-1.397 + 0.007659 rain - 0.00452 ETO + 0.0406 t_{min} + 0.0211 RH	99.3	-0.04	-0.85
Upper Kordkoye	0.411 + 0.006239 rain - 0.005161 ETO + 0.0154 t_{min} - 0.0170 T_{max} + 0.0034 RH	99.8	0.04	0.81
Laleh Bagh	-0.685 + 0.013107 rain - 0.005565 ETO - 0.0628 t_{min}	99.7	-0.10	-1.54
Water Office of Gorgan	0.78+0.10227 rain- 0.004223 ETO +0.0171 t_{min} -0.0357 T_{max}	98.8	-0.05	-0.30

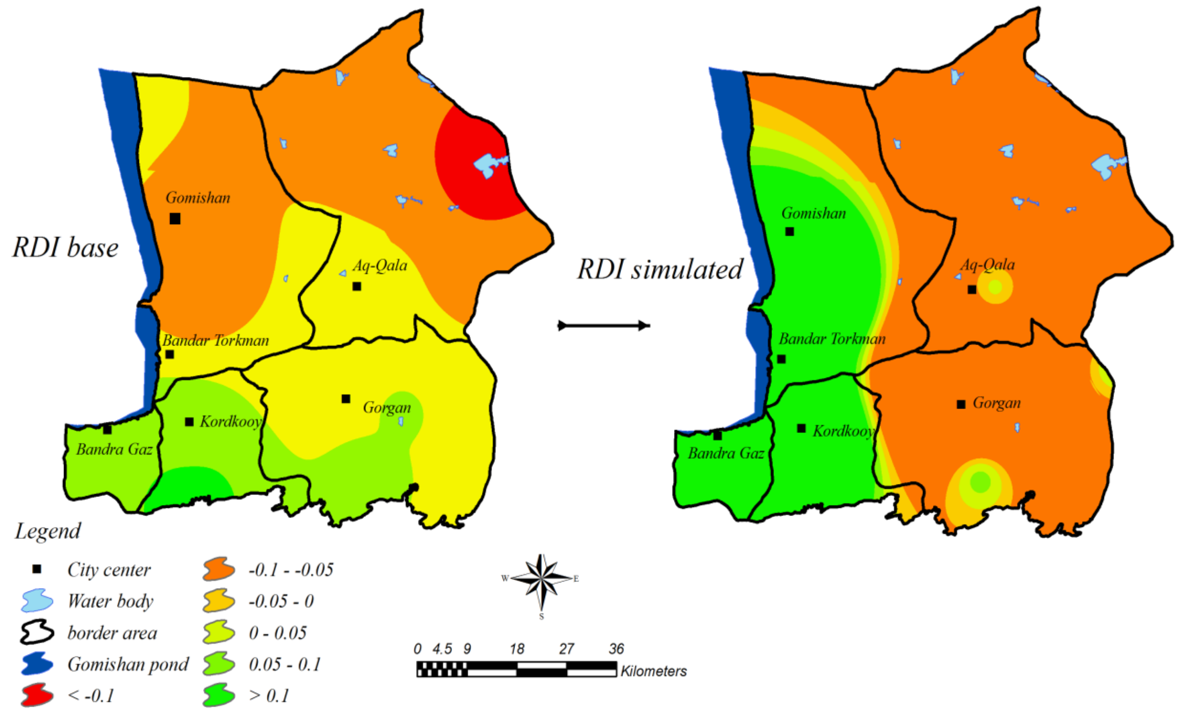

Figure 11 Regions affected by drought, based on the RDI index in the baseline and predicted periods

4 CONCLUSIONS

In this study, the climate data in a base period of 20 years (2011-2030) was simulated by the general circulation modelLARS-WG5under three scenarios of A2, B1 and A1B. Drought monitoring was performed by RDI and SPI indices to assess the changes in influential parameters on droughts. The results showed that LARS-WG5 model could simulate the climatic parameters such as precipitation, temperatures and evapotranspiration over a period of 20 years (2011-2030) compared to the base period (1984-2010).

The mean precipitation values for the next 20 years under three simulated scenarios of A2 (1.31mm), B1 (1.49mm) and A1B (1.36 mm) showed a difference over the base period, the highest of which was related to the group model B1 (had-Ipcm-Gfc) and A1B (had-Ipcm-Gfc) in the cold months, while the lowest changes (sometimes unchanged) were related to A2 in the warm months. Changes of mean maximum and minimum temperatures were 0.81 and 0.91, respectively, that showed an increase over to the average 20-year base period. Regarding changes of mean evapotranspiration values, the highest increase was seen for the group model of B1 (had-Ipcm-Gfc) (1.34 mm) during July to September.

In drought monitoring analysis, simulated values by RDI index and group models under three scenarios of A2, B1 and A1B suggest that drought conditions during the warm months ranged from moderate to severe and moisture conditions ranged from moderate to very severe during the cold months. By examining the changes trend by RDI index, the drought conditions had a longer time interval than the SPI. Since the SPI is only calculated based on precipitation data and RDI depends on precipitation and evapotranspiration values, calculated values of simulating changes in RDI would be notable.

The central, northern and eastern parts, in spite of the current droughts, are predicted to be hit harder in the upcoming period and for more prolonged period which could be thought of as the early warning signals for drought management.

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پایش خشک‌سالی براساس شاخص‌های SPI و RDI تحت سناریوهای تغییر اقلیم (مطالعه موردی: مناطق نیمه بیابانی غرب استان گلستان)

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چکیده با استفاده از داده‌های اقلیمی ایستگاه سینوپتیک هاشم‌آباد گرگان و یازده ایستگاه هواشناسی، پایش و بررسی روند تغییرات خشک‌سالی بر مبنای شاخص‌های بارش استاندارد (SPI) و شاخص خشک‌سالی (RDI) در منطقه نیمه بیابانی غرب استان گلستان در محیط GIS انجام گردید. پس از ارزیابی توانایی مدل گردش عمومی جو LARS-WG5 در شبیه‌سازی دوره (۲۰۱۰-۱۹۸۴) براساس سناریو پایه، ریز مقیاس‌سازی مدل‌های HadCM3، IPCM و GFC به صورت گروهی و تحت سناریوهای A1B، A2 و B1 جهت بررسی تغییر مقادیر اقلیمی بارش، دمای حداکثر، دمای حداقل و تبخیر و تعرق و اثر آن‌ها بر روی خشک‌سالی منطقه، در دوره (۲۰۳۰-۲۰۱۰) صورت گرفت. ارزیابی و صحت مدل‌ها نیز با استفاده از آمارهای ضریب تبیین (R2)، شاخص توافق (D) و میانگین خطا (ME) انجام گردید. نتایج نشان داد که مدل LARS-WG در شبیه‌سازی متغیرهای اقلیمی، دارای توانایی بالایی است. با مدل‌سازی دوره ۲۰ سال آینده نسبت به دوره پایه، بیشترین تغییر میانگین مقادیر دمای حداکثر و حداقل مربوط به سناریو B1 و A2 به ترتیب دارای روند افزایشی به مقدار ۰/۸۱ و ۰/۹۱ درجه سانتی‌گراد بود. بیشترین میانگین تغییرات تبخیر وتعرق مربوط به مدل گروهی B1 و A2 به میزان ۱/۳۴ میلی‌متر بود. در ارتباط با تغییرات مقادیر بارش، بیشترین میانگین تغییر مربوط به سناریو B1 و A1B به مقدار ۱/۴۹ و ۱/۳۶ میلی‌متر بود. براساس تحلیل منطقه‌ای خشک‌سالی، مناطق مرکزی، شمالی و بخش‌های شرقی، با وجود خشکسالی‌های موجود، در آینده با شدت و مدت بیشتری دچار خشک‌سالی خواهند شد. در این تحقیق، کارایی مدل‌های گروهی جهت شبیه‌سازی داده‌های اقلیمی و همچنین استفاده از شاخص‌های خشک‌سالی، جهت پایش خشک‌سالی، نشان داده شده است.

کلمات کلیدی: تبخیر و تعرق، شبیه‌سازی، کوچک مقیاس‌سازی، مدل‌های گردش عمومی