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Analyzing and predicting drought in arid and semi-arid regions by using atmospheric general circulation model and RCP scenarios

M.Eftekhari [1*], S.A.Eslaminezhad [2], M.Ghaemi [3] , M.Ghorani [2], M.Akbari [4]

1, Ph.D. Student in Water Resources Engineering, University of Birjand, Birjand, Iran
2. Department of surveying and Geomatics Engineering, College of Engineering, University of Tehran,Tehran, Iran.
3. Allame Helli High school, Birjand Education Department, Birjand, Iran
4. Department of Civil Engineering, University of Birjand, Birjand, Iran

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ABSTRACT

Drought is a climatic phenomenon that almost happens in every climate situation, because Iran country is located in the arid belt of earth, the importance of drought and analyzing it in the past and future is important for us to programming and managing the water resources. In this research which was done in the study area of the watershed region of Kashfrud, the effect of climatic changes in the climatic precipitation parameter under two scenarios of RCP4.5 and RCP8.5 in the study period (19987-2016) was analyzed and surveyed. To analyze drought in the study region by using Standard Precipitation Index (SPI) and surface water supply index (SWSI), the occurrence and time of climatic and hydrological drought were analyzed. For predicting the future period precipitation by atmospheric general circulation model of MIROC5 and by using small scale (Delta) method under release scenarios RCP4.5 and RCP8.5, the future precipitation data were achieved, then standard precipitation index in the next 30 years' period (2019-2048) was calculated. Using the implemented calculations in standard precipitation index and analyzing the results in the next 30 years, the number of dry and very dry months; means index number less than - 1.5, in the study area was achieved. Based on the achieved results from the standard precipitation index (SPI) in the annual scale in Mashhad and Golmakan station, the first decades of the study period (1987-1996) and future periods (2019-2028) are the driest periods. Also, the results of hydrologic drought index in annual scale in Mashhad station indicates 19 dry years and in Golmakan station indicates 16 dry years.

1. Introduction

Drought indicates a long-term dryness that depends on different climatic and hydrologic processes (Kamali et al., 2017). In other words, drought not only depends on temperature or precipitation but also depends on other variables and it is feedback from the whole climate system (Trenberth et al., 2014). Drought is a slow phenomenon that is accompanied by precipitation and relative moisture decrease, temperature increase, and wind rate (Kew et al., 2009). Predicting drought helps to correct the management of the crisis and controlling the resulted damages from that, therefore the best time for managing the drought is the wet years (Moghimi et al, 2018). In this regard, for analyzing the rate and amount of drought, researchers have provided different indexes such as standard precipitation index (SPI).Drought indexes are usually expressed as a number, scientists believe that these indicators are more useful in decision making than raw data (Abdulrazzaq et al., 2019). Due to the simplicity of calculations, the precipitation data and the calculation ability for any desired time scale are applicable (Khan et al., 2020). McKay et al. have defined the SPI index as a suitable index for different schedules (1, 3, 6, 12, 24, and 48 months) with output values ranging from 2 to +2. SPI is the most favorable index for drought (Karabulut, 2015)

*Corresponding author's email : mobineftekhari@yahoo.com
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and it is a known index for describing the monitor of climatic drought (Aghelpour et al., 2020; Deo, 2011). Surface Water Supply Index (SWSI) is one of the other indexes for measuring the intensity of drought (Keyantash, 2021). The calculation of this index is actually for purifying the abnormal values of surface water supply reservoirs; therefore, this index is a proper parameter to measure the effects of drought on river flow (Abdulrazzaq et al., 2019). The representative concentration pathways (RCP) are a greenhouse gas emission pathway approved by the IPCC in its Fifth Report (AR5) in 2014. The development of RCPs in the first stage enables climate model makers to accelerate the development of the overall scenario process in parallel with the development of publications and socio-economic scenarios (Shiru et al., 2020). Fadaei Kermani et al. (2014) studied the SPI index and the method to determine the drought period with the help of this index for Bam city over 30 years. The results of appropriate and acceptable values of Pearson correlation coefficient, average absolute error, average root square error, model efficiency, and residual mass indicated that the model provided acceptable predictions of the drought situation in the region and the current model is strong and acceptable. Jahangir et al. (2015) predicted drought based on SPI index and the neural network over 31 years in Alborz province and in this study, severe and very severe drought periods, the most severe drought calculated the lowest SPI for many stations in periods of 3, 6, 9, 12 and 24 months and also made predictions using the multilayer perceptron neural network method so that the result was very close to the observed values. Heidari and Haddadi (2015) monitored and predicted drought in Khuzestan province using drought index, SPI, and Markov chain. They showed that by analyzing plots, fluctuations in precipitations resulted in fluctuations in discharge and years that show SPI model of drought have shown discharge decrease in the average moving discharge in comparison with the average level and severe droughts of rainfall and its effect on discharge water caused a jump in the Kendall Man test and this model also shows a decrease in discharge. Montaseri and Amirataee (2015) used the SPI model and spearman correlation test to identify precipitation fluctuations and drought periods and the results of this study showed that both SPI and rainfall anomaly index (RAI) drought indexes can be used only to determine the trend of changes in drought and wet periods due to high correlation of the above two drought indexes, and they were used in assessing and determining the changing trend of drought and wet years. Touma et al. (2015) analyzed the relationship between drought and changes in temperature, rainfall and soil moisture using four evaluation indicators SPI, Effective Rain Fall Index (ERI), and soil moisture drought index (SMDI) in different regions of the world and they concluded that there is a possibility of exceptional drought increase and also stresses due to drought for natural and human systems that will occur due to the concentration of greenhouse gases. Hamzeh et al. (2017) in a study entitled "Temporal and spatial monitoring of agricultural drought using remote sensing data" compared drought indexes based on satellite data with SPI index and they inserted that the VCI index is the best agricultural drought index in the central region.

In the present study, which was conducted in the study area of Kashfarud catchment; the effects of climate change on climatic parameters of precipitation under two scenarios of RCP4.5 and RCP8.5 in the study period (1987-2016) were studied and evaluated. The data used were daily rainfall and discharge, which were obtained from Mashhad and Gol Makan stations (precipitation) and two hydrometric stations Kardeh and Moushang (Discharge), which were prepared from the Meteorological and Water Organization of Khorasan Razavi, respectively. For drought monitoring, the study area in two observation periods (1987-2016) and predicting period (2019-2048) by using standardized precipitation index (SPI) and surface water supply index (SWSI), the occurrence and the time of meteorological and hydrological droughts were studied. To predict future precipitation data with MIROC5 general atmosphere circulation model and using statistical exponential microscale method, determining the change factor method (Delta) under RCP4.5 and RCP8.5 scenarios, future precipitation data were obtained, then the precipitation index was calculated for the next thirty years (2019-2048). Plots were drawn for more detailed analysis. To verify and validate the work; Pearson correlation coefficients and mean error were calculated.

2. Materials and Methods

2.1. Study area

This research was done in the basin of Kashfrud, a section of Gharegom watershed in the eastern north of the Iran' country and the north of Khorasan Razavi province. This watershed is located between the geographical length of 58 degrees and 2 minutes to 60 degrees and 8 minutes and a geographical width of 35° 40′ to 36° 3′. The direction of western north flow is eastern south. The population center is located in the research area. The total area of the watershed is 995 km (Figure 1). the climate of two regions; Mashhad and Saangbast is intense semi-dry and the Aghdarband region and Narimani region have a desert climate, however, it should be mentioned that the researchers consider the Kashfrud watershed as the dry and cold climate. Also, it should be considered that the existence of various mountains and the vicinity of the Kashfrud watershed to the central **desert is very** important in the climate change of this region and results in various climates in that region. The maximum height of the watershed from the water surface is 3092 meters and the lowest point of that is 390 meters at the exit of thes Khatoon bridge.

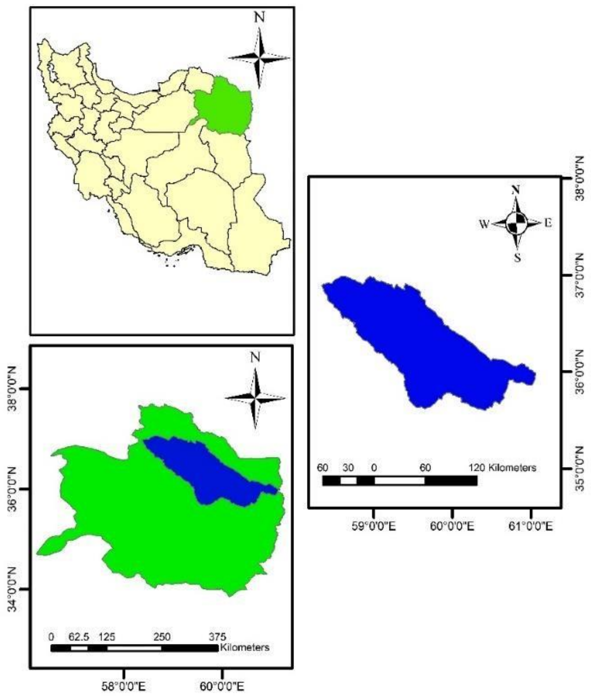

Fig 1. Location of the studied region

In the current research, two synoptic stations (Mashhad and Golmakan) and two hydrometric station (Kardeh and Mushang) were used. The reason for using these stations is their vicinity and their complete flow data from Kardeh and Mushang stations that we needed for calculating the SWSI and also, due to the accuracy of the flow data, the stations were selected that were not constructed before the construction of the station's site and they affect the flow. therefore, from two hydrometric stations, one around the Binalood mountains and another around the mountains of Hezar Masjed. The studied information and specifications of all four stations are presented in Figure 2 and Table 1.

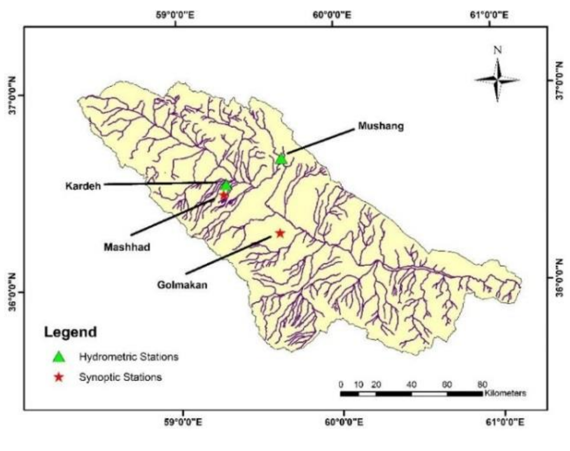

Fig 2. Watershed of Kashfrud (The studied region)

Table 1 specification of synoptic and hydrometric stations

Station name	Rainfall (mm)	Height (m)	Width (m)	Length (m)	Climate
Mashhad	256	999	26.36	63.59	Dry and cold
Golmakan	208	1569	44.36	13.59	Dry and cold
Kardeh	230	1322	65.36	66.59	Dry and cold
Mushang	243	1423	50.36	30.59	Dry and cold

2.2. Standardized precipitation index (SPI)

This index is one of the most popular indicators for calculating and monitoring meteorological drought based on precipitation, and also for calculating this index, the gamma distribution probability density function is used by Equation 1 (Raziei, 2021):

$$SPI = (P_i - \bar{P})/\delta \qquad (1)$$

In this Equation, Pi and $\bar{P}$ indicate rainfall during the statistical period and the long-term average of precipitation for the desired statistical period, respectively, and δ indicates the standard deviation. To calculate this index in the current project, the software (M.D.M) and data from two synoptic stations; Mashhad and Golmakan which have long-term statistics and appropriate dispersion in the watershed were used. For each station and each scenario, the standard precipitation index was calculated once monthly and once yearly. SPI and SWSI indexes were used for drought monitoring during the observation period (1987-2016). But, to predict drought in the next thirty years (2019-2048) due to the lack of flow data in the next thirty years, just the standard precipitation index has been used. The precipitation data of the studied stations were collected from Mashhad Regional Water Authority and a website[1].

2.3. Surface water supply index (SWSI)

To calculate the hydrological drought index, the surface water intensity index (SWSI) was used. This index is calculated monthly according to Equation 2 (Janget al., 2020):

$$SWSI= (aP_{snow}+ bP_{prec}+ cP_{strm}+ dP_{resv}- 50)/12 \qquad (2)$$

[1] http://wrbs.wrm.ir

In Equation 2, variables a, b, c, d is considered the weight of each component and their sum is equal to one, P is also non-invasive probability in terms of percentage for snow (mm), rain (mm), water flows (m3/s) and water reservoirs (m3). The probability value of P is equal to the calculated probability from the probability distribution function fitted to the total series and volume of the reservoir in percentage. In this Equation, the difference of 50 for the symmetry of the index values is around zero and the number 12 for locating these values is between-4.17 and 4.17 (Wambua et al., 2017). Also, in Equation 3, the indirect effect of snow in the river flow is used, which is called the SWSI correction method (Wambua et al., 2017):

$$SWSI = \frac{P - 50}{12} \tag{3}$$

In Equation 3, P is equal to the probability calculated by the probability distribution function fitted to the total series in percentage. To predict the precipitation data in the future thirty-year period, at first marxim microscale model was used. In this model, a set of general circulation models of the atmosphere is embedded. For this study, among the existing models, the MIROC5 model was used. Precipitation information for this general circulation model under two scenarios RCP4.5 and RCP8.5 from the bellow database* was achieved.

2.4. Exponential small-scale

Due to the inadequacy of the appropriate output in the marxim model, to continue the research, the statistical exponential small-scale method, called "factor change" (Delta) was used. In this research, daily data were used for making small-scale, then, for more simple analysis, the data were converted to monthly scale.

$$P_{crpfut} = C_f * P_{rcpobs} \tag{4}$$

In the above Equation, the CF coefficient is the result of dividing the future period precipitation data (2019- 2048) into the raw data of the MIROC5 model. The raw data is so-called "Historical". The Prcpobs variable is the precipitation in the observation period from the desired station.

3.Results and discussion

3.1. The results of the evaluation of precipitation values in observation and predicting periods

In the current study, to investigate and display the future climate change, the precipitation diagram in the observation period (1987-2016) and future period (2019-2048) from Mashhad station has been drawn (Figure 3), future precipitation fluctuations or in other words the range of variations in precipitation values is less than the observed thirty-year period, and this indicates that precipitation will decrease in the next thirty years. In Figure 3, the years of 1991 (27.5 mm), 1992 (32.5 mm), 1993 (31.6 mm), 1998 (29 mm), and 2012 (26.5 mm) were the rainiest years, and 2008 (10.1 mm) had the least rainfall. Considering these interpretations, we expect the same results have the same trend with the standard precipitation index. Because the precipitation variable is the only input in the SPI index.

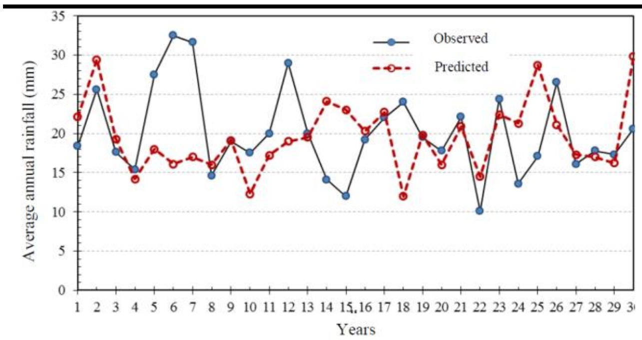

Fig 3. Thirty-year rainfall observed (1987-2016) versus RCP4.5 rainfall predicted (2019-2048) inMashhad station

Also, Figure 4 shows the current period (1987-2016) and the future period (2019-2048) of precipitation on Golmakan station to study and display changes in rainfall values. As can be seen in the Figure, future precipitation fluctuations are less and indicate that the precipitation will decrease in the next thirty years. Probably the highest average value of precipitation in the final decade (2039-2048) will be 24 ml. Moreover, it seems that with the small-scale results of the MIROC5 model, the minimum amount of precipitation will occur in the same decade. In Figure 4, the average results of precipitation value in the observation period indicate that 1991 (26.6 mm) and 2003 (26.1 mm) were rainy years and 1992 (11.2 mm) and 1993 (9 mm), 2000 (10.8 mm) and 2006 (11 mm) had the lowest precipitation. Considering these interpretations, it is expected that these results have the same trend as the standard precipitation index.

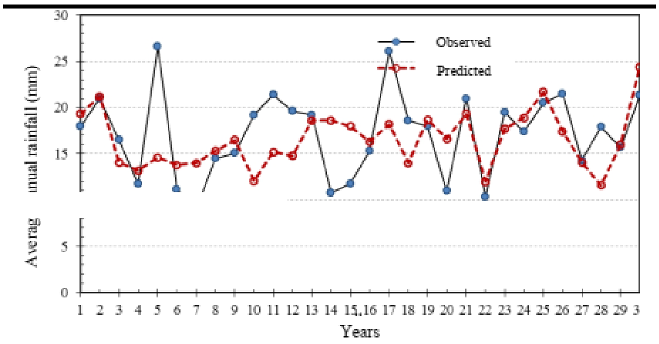

Fig 4. Thirty-year rainfall Predicted (1987-2016) versus RCP4.5 rainfall predicted (2019-2048 (inGolmakan station

By using the SPI index, we analyze the current and future droughts using two scenarios: RCP4.5 and RCP8.5 during the observation period (1987-2016) and prediction period (2019-2048). The standard precipitation index for Mashhad station and observation period (1987-2016) indicates that in a total of 30 years, 20 dry and very dry months and 13 wet and very wet months have occurred (Figure 5).

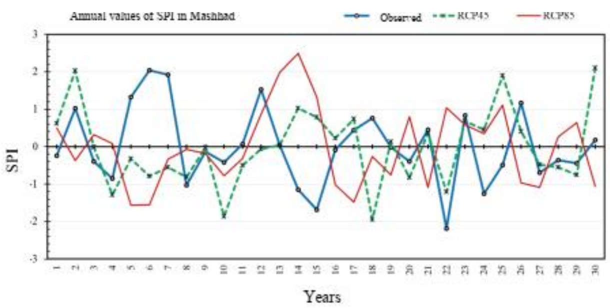

Fig 5. Annual values of SPI in Mashhad station in observation period (1987-2016) and prediction(2019-2048) under two scenarios RCP4.5 and RCP8.5

The results of calculating the standardized precipitation index in the annual scale of Golmakan station in the thirty-year observation period (1987-2016) and the prediction period (2019-2048) are shown in Figure 6, as it is clear from the figure, the driest year in the observation period had occurred at 1993, while by using the outputs of MIROC5 model, it seems likely to happen at the year of 2046 in the prediction period under the 4.5 scenario (Prediction by RCP4.5 scenario) and the prediction 8.5, at the year of 2023. In other words, drought will occur in the observational period in the first decade or with more confidence, it is expected to occur in the prediction period under scenario 4.5 in the third decade and the prediction period under scenario 8.5 in the first decade. Also, the wettest year in the annual SPI scale in the observation period of 1991 and the prediction period of 4.5, is the year 2048 and in the prediction period of 8.5, is the year 2032. In other words, the wettest years in the observation period in the first decade, in the prediction period of 4.5, are located in the third decade and the prediction period of 8.5, is likely to happen in the second decade.Like the mentioned descriptions, the results of the analysis of the SPI in the observation period (1987-2016) in Golmakan station indicate that in 360 months of the study period, there are 14 dry months and 18 wet months, and the years of 1993 and 2008 can be considered dry and the years of 1988 and 1991 are wet. Also, the results of the annual calculation of this index are presented that indicates the years 1993, 2000, and 2008 are dry years and 1991 and 2003 have been experienced as wet years. The annual results of the standard precipitation index are shown in Figure 6.

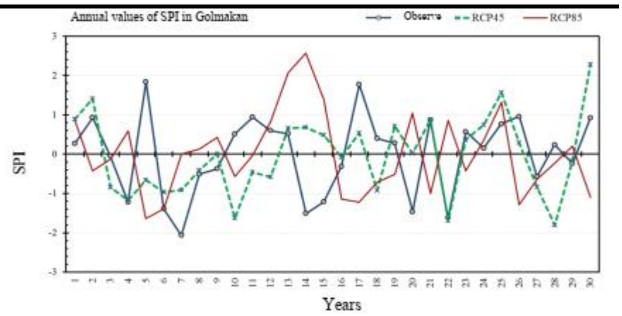

Fig 6. Annual values of SPI in Golmakan station in observation period (1987-2016) and prediction(2019-2048) under two scenarios RCP4.5 and RCP8.5

Also, according to the annual results of the standard precipitation index in Mashhad station, the results indicate that according to MIROC5 general atmosphere circulation model, results of 2028 and 2036 will likely dry years, and 2020, 2043, and 2048 will likely wet years.

3.2. The results of discharge value evaluation in the observation period\

As mentioned before, calculation of SWSI index is only done for the observation period, because it needs flow data and implementing or modeling flow data for the future is itself an independent process requiring time and other meteorological variables. After calculating this index in Matlab software, to more accurate analysis and better expression, its results are monthly and according to the graph seen in Figure 7. This graph shows the SWSI index values monthly in the Mashhad station. In the bottom section, the passing discharge values and in the upper part SWSI index are shown and indicates that among 360 months in the observational period, we will have 302 dry and very dry months (< -2) and only one wet month (>+ 2).

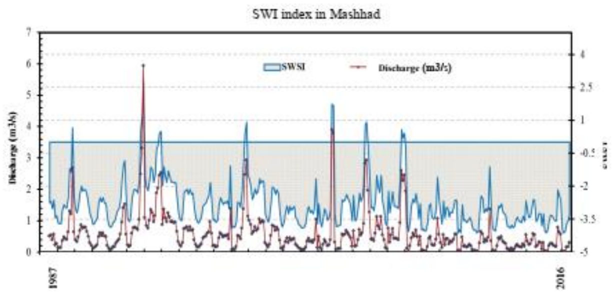

Fig 7. Monthly values of SWSI in Mashhad station in the observation period (1987-2016)

The results are shown in Figure 8, which indicates 218 dry and very dry months (< -2) and 36 wet months (>+2).

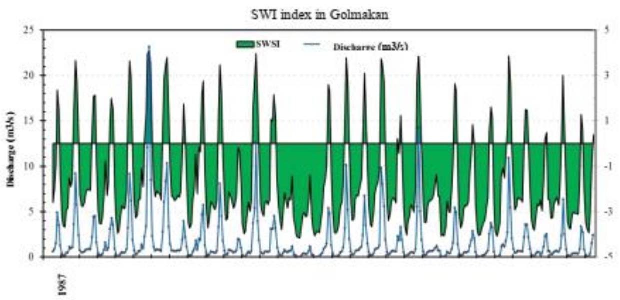

Fig 8. Monthly values of SWSI in Golmakan station in the observation period (1987-2016)

The MIROC5 model is taken under two RCP scenarios, but to verify the future generated data, it is necessary to perceive which scenario (RCP4.5 or RCP8.5) is closer and more accurate to the real data and the analysis will be done based on that data. For this regard, Pearson's correlation coefficient has been calculated using SPSS software. The results of the correlation coefficient are based on tables 2 and 3, that table 2 shows the correlation between Mashhad and RCP8.5 and RCP4.5 stations, and table 3 shows the correlation between Golmakan and RCP8.5 and RCP4.5 stations. It can be concluded that for both the studied stations (Mashhad and Golmakan) RCP4.5 has more accurate analysis than RCP8.5.

Table 2 Correlation of Mashhad station and RCP4.5 and RCP8.5

		RCP4.5	**Mashhad**
RCP	Pearson Correlation	1	0.678**
	Sig. (2-tailed)		0.0
	N	84	84
Mashhad	Pearson Correlation	0.678**	1
	Sig. (2-tailed)	0.0	
	N	84	84
		RCP8.5	**Mashhad**
RCP	Pearson Correlation	1	0.669**
	Sig. (2-tailed)		0.0
	N	84	84
Mashhad	Pearson Correlation	0.669**	1
	Sig. (2-tailed)	0.0	
	N	84	84

Since the output of the Marxim model was not useful in calculating the drought index, hence, for continuing the research, the statistical exponential micro-scale model "Delta" or "Change Factor" has been used to make the MIROC5 precipitation outputs in micro-scale under the two mentioned scenarios. Then, to verify and validate, the data of the statistical exponential model of factor change (Delta) are provided and it will provide data about which scenarios (RCP4.5) and (RCP8.5) provide a more appropriate analysis of the future data. Again, the correlation coefficient, the absolute error average, etc. was calculated that which is observed in Table 5. In this method, similar to the previous method, it seems that the

RCP4.5 scenarios has more relation with the observed period data.

Table 3 Correlation of Golmakan station and RCP4.5 and RCP8.5

	RCP4.5	Mashhad
RCP Pearson Correlation	1	0.643**
Sig. (2-tailed)		0.0
N	84	84
Golmakan Pearson Correlation	0.643**	1
Sig. (2-tailed)	0.0	
N	84	84

	RCP8.5	Golmakan
RCP Pearson Correlation	1	0.623**
Sig. (2-tailed)		0.0
N	84	84
Golmakan Pearson Correlation	0.623**	1
Sig. (2-tailed)	0.0	
N	84	84

Table 4. micro-scale model validation

RMSE	Spearman	Pearson	MAE (mm/year)	
0.75	0.665	0.481	0.5	Mashhad (RCP4.5)
0.77	0.661	0.469	0.51	Mashhad (RCP8.5)
0.61	0.615	0.481	0.4	Golmakan (RCP4.5)
0.61	0.615	0.481	0.4	Golmakan (RCP8.5)

4. Conclusion

Drought is a natural phenomenon that causes a lot of damage to its region. Since the occurrence of drought is inevitable, especially in recent years that its rate has increased dramatically, a proper management system will be necessary to deal with this natural disaster and create a risk management system and it will be essential to provide proper and timely informing and correct information at any time scale. In this study, by studying the precipitation of the Marxim model under the two mentioned scenarios and with the MIROC5 model, it was found that this model is not capable of predicting the micro-scale data of precipitation, as the trend of monthly precipitation changes in the region is negligible and using these values in the drought phenomenon as a limiting event is incorrect. Also, the study of drought by the marxim method has high uncertainty and it is incorrect. Therefore, it was decided to use the Delta method for the exponential micro-scale outputs of the MIROC5 model under the two mentioned scenarios, the results of precipitation trend by MIROC5 model with statistical micro-scale method under two scenarios RCP4.5 and RCP8.5 showed that RCP4.5 outputs provide a more accurate analysis of future precipitation in the Kashefrud watershed. The analysis in the MIROC5 model indicates the accuracy and practicality of this model in predicting climate change and obtaining rainfall flow outputs by the statistical exponential micro-scale "Delta" method in the Kashfrud watershed. For Mashhad and Golmakan stations, the MAE were 0.5 and 0.4 mm per year and Pearson's correlation coefficients were 0.481,

0.481 and RMSE were 0.75, 0.61, respectively. The calculations of the mentioned index (standard precipitation index) and evaluation of the future thirty years result under the model of dry and very dry months, i.e. less than

-1.5, were achieved in 28 months of the study area. Also, the study of the surface water supply index (SWSI) of both stations indicates possible severe drought in the study period (1987-2016). Evaluation of the results in the climatic models for the next 30 years showed that rainfall in the KashfRud watershed in general decreased compared to the observation period of 30 years (1987-2016). This declining trend has not been the same in the studied three decades, so that in the first decade it shows an increase of 12% compared to the base period, 30% in the second decade and 8% in the third decade. Drought monitoring was carried out for the observational period with SPI and SWSI in the watershed area. For the future thirty years (2019-2048) the SPI was calculated that shows the significant changes in the incidence of drought in the statistical period. These changes showed that the intense dry and very intense dry classes will increase in the next thirty years, in other words, the amount of drought in the watershed area will not reduce in the next 30 years.Compared to the researches of other researchers such as Ansari et al. (2014), Aghakhani Afshar et al. (2017) and Hassanzadeh and Aghakhani Afshar (2019) similar results have been expressed, which indicates the emphasis of the current study. There is a lot of evidence on global climate change such as time change and the place of precipitation, which affects the ecosystem and health of humans, on the other hand, changes in rainfall increase environmental problems, so the existing information in this research has been collected to help managers and planners to better management of the water resources in the Kashfrud area.

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