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Investigation of climate change effect on drought characteristics in the future period using the HadCM3 model (Case study: Khoy station, northwest of Iran)

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Abstract

Investigation of drought event has a great importance in the natural resources and water resources management and planning. In this research, the effect of the climate change on drought characteristics in Khoy station was investigated using the HadCM3 model under B2 scenario. The statistical downscaling was executed using SDSM 4.2.9 and observed daily precipitation, observed predictors and large-scale predictors derived from the HadCM3 model. Afterwards the SPI was calculated for different time scales of 3, 12, 24, 48 months in the observed period of 1977-2006 and also three periods of 2007-2036, 2037-2066 and 2067-2096. The results show that the mean annual precipitation will decrease in the future periods, in the manner that the fourth and second periods respectively with the depletion of 48 mm (17%) and 34 mm (12%) than the observed period have maximum and minimum rate of the depletion. The results also show that the drought occurrence with more intensity, duration and frequency can occur in the future periods.

Keywords: Khoy; Drought; Large-scale predictors; Statistical downscaling; SPI

1. Introduction

Climate change and its consequences, as a threat to the Earth, influence natural and man-made environments. The emission of greenhouse gases and greenhouse effects cause the global warming and Climate change. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), over the 100-year period ending 2005, average global surface temperatures rose by 0.74 °C. According to the United Nations Framework Convention on Climate Change (UNFCCC, 1992), Climate change is defined as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. On the basis of future prediction of different climate change scenarios, temperature increase and its effect on water demand and moreover, the probable decrease in precipitation in some regions, cause to give notice to the drought event seriously. In recent decades, extreme drought events seem to be growing in frequency in many countries (Hoerling *et al*., 2012; Nandintsetseg and Shinoda, 2013; Spinoni *et al*., 2014). The future prediction of precipitation and drought characteristics has an important role in reducing drought effects through the adoption of the best methods. The Standardized Precipitation Index (SPI) was developed by

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McKee *et al*., (1993) to define and monitor the drought. The World Meteorological Organization (WMO) has suggested to all meteorological organizations the monitoring dry spells using SPI. This index is used in many organizations, like the Climatological Research Center in Iran and The Colorado Climate Center, The Western Regional Climate Center and The National Drought Mitigation Center in USA. Morid *et al*., (2005) introduced SPI and EDI (Effective Drought Index) as the best indices through the study of different drought indices in Tehran province.

Nowadays, the application of GCM (General Circulation Model) in projection of future climate has been become plentiful in many researches (Mohammadi and Taghavi, 2005; Lazar and Williams, 2008; Dastorani *et al*., 2011; Braga *et al*., 2013; Yu *et al*., 2014; Enyew *et al*., 2014; Babaeian *et al*., 2015; Lee *et al*., 2016). Mohammadi *et al*. (2010) investigated the precipitation and temperature of Iran using MAGICC SCENGEN. The results indicate the increase of future temperature and decrease of future precipitation in all over the Iran. Abbasi and Asmari (2011) investigated the future precipitation of Iran using the HadCM3 model. They stated that the precipitation will be decreased until 2100 to amount of 2.5 %. Loukas *et al*. (2008) studied the climate change effects on drought severity in Greece using CGCM2 and SPI. The results show that the drought severity has been increased. Golmohammadi and Massah Bavani (2011) investigated climate change impacts on drought intensity and duration at Gharasoo basin using HadCM3 and SPI during the period of 2040-2069 show that the drought intensity and duration will be decreased due to an increase in future precipitation. Lee and Kim (2013) in the multi-model assessment of the climate change effect on the drought severity-duration-frequency relationship showed that among the four types of GCMs used in study, the MRI model predicted the most severe future drought for the Seoul region, and the SDF curve derived using the MRI model also resulted in the highest degree of drought severity compared with the other GCMs. Salehpour Jam (2015) indicated that drought event with more intensity, duration and frequency than base period can occur in future periods under A2 scenario in northwest of Iran. Lee *et al*. (2016) investigated the future changes in drought characteristics under extreme climate change over South Korea. Changes in the frequency and the severity under climate change were evaluated through the drought spell analyses. Overall features of drought conditions in the future showed a tendency to increase (about 6%) in frequency and severity of droughts during the dry season (i.e., from October to May) under the climate change.

The future prediction of precipitation and drought characteristics play a key role in reducing drought effects. In this research, the Climate change effect on drought characteristics at the Khoy station was investigated using the HadCM3 model under the B2 scenario and the Standardized Precipitation Index (SPI).

2. Materials and Methods

2.1. Study Site

The Khoy station is located at 44° 58′ east longitude and 38° 33′ North latitude in the West Azarbaijan province (Figure1). According to the method of Emberger and based on the 30 year period ending 2006, the Climate of this station is cold semi-arid. The specific location of the West Azarbaijan province causes that this province is influenced by north, northwest and west in the cold season of the year. It is also influenced by low pressure system producing rain in the summer.

2.2. Research Method

In this research, the statistical downscaling was executed after preparing observed data and quality control using SDSM 4.2.9, observed daily precipitation, observed predictors and large-scale predictors derived from the HadCM3 model under the B2 scenario in the Khoy synoptic station.

2.2.1. Preparing observed data

In this stage, sorting daily precipitation data was executed in the period of 1976-2001. The code of -999 was assigned to the missing data.

2.2.2. Downloading large-scale predictors

For downloading large-scale predictors of NCEP and HadCM3, the HadCM3 grid box covering the study site was identified through AutoCAD 2012 and ArcGIS 10 (Figure 2).

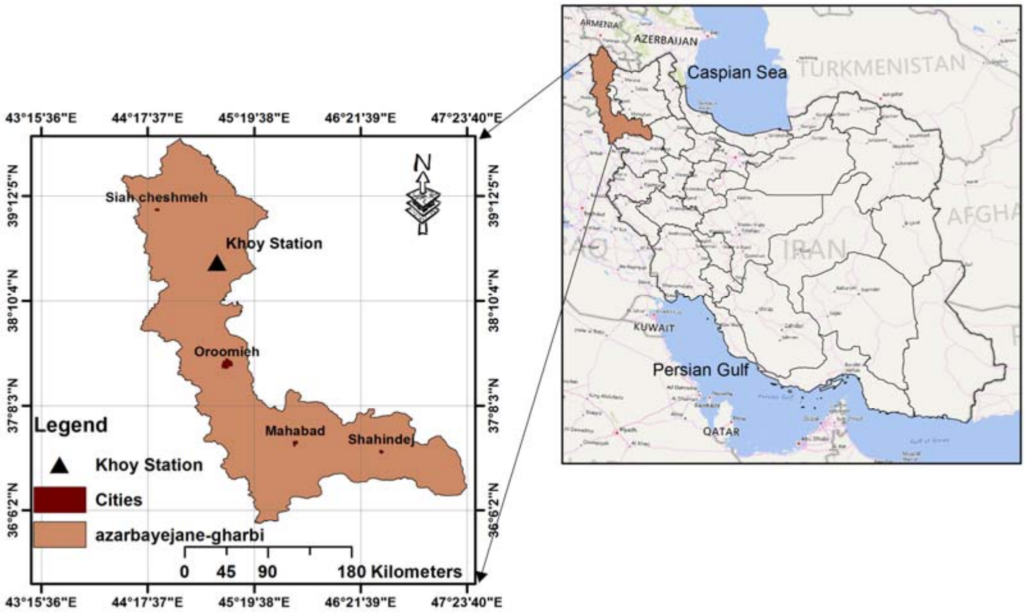

Fig. 1. The geographical location of Khoy synoptic station

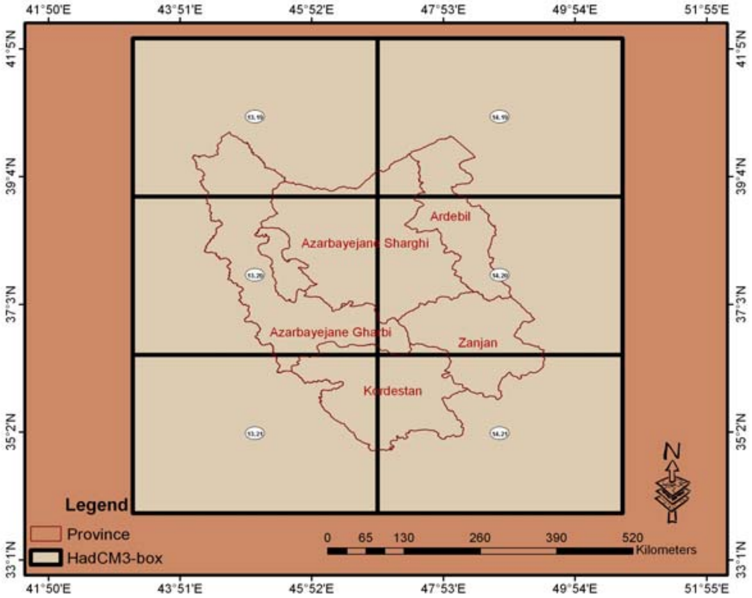

Fig. 2. The HadCM3 grid box covering the study site

2.2.3. Quality control and data transformation

In this step, input file was checked to recognize the missing data and/or suspect Values. Then code of -999 was assigned to missing data in all input series. Whenever SDSM encounters this code the value will be skipped. In addition, the fourth root transformation was applied to the predictand in conditional model.

2.2.4. Downscaling precipitation and evaluation of large-scale predictors

In this research, the statistical downscaling was executed after screening downscaling predictor variables using SDSM 4.2.9, observed daily precipitation, observed predictors and large-scale predictors derived from the HadCM3 model. The period of 1976-2001 was considered as the observed period.

Model calibration and validation were done respectively during periods of 1976-1995 and 1996-2001 based on downscaled data derived from observed predictors. The general circulation model was also validated for the period of 1976-2001 based on downscaling HadCM3 predictors under B2 scenario. The models were evaluated on the basis of the root mean squared error (RMSE) and coefficient of determination at the Khoy station (Equation 1).

$$RMSE = \left[\frac{1}{n} \sum_{i=1}^{n} (S_i - O_i)^2 \right]^{\frac{1}{2}} \qquad (1)$$

Where: S_i, is downscaled data, O_i, is observed data, and n is the sample size.

2.2.5. Calculation and analysis of the standardized precipitation index

In this research, SPI was calculated through ReDIM and DIP softwares for different time-scales of 3, 12, 24 and 48 months in the observed period of 1977-2006 and three periods of 2007-2036, 2037-2066 and 2067-2096. First, sorting monthly precipitation data was executed for the kinds of periods. Missing data were also constructed for Khoy station in the observed period based on Gilandeh station. Then, drought classification according to the limits of classes that have been released by the National Drought Mitigation Center was done using the calculated SPI (Table 1). Finally, obtained results were analyzed according to the frequency of dry months based on SPI ≤ -1 and SPI ≤ -1.5 and the maximum duration and intensity of drought periods.

Table 1. Drought classification according to the National Drought Mitigation Center

SPI	Class
2.00 ≥	Extremely wet
1.99 – 1.50	Very wet
1.49 – 1.00	Moderately wet
0.99 – 0.99-	Near normal
1.49 – -1.00-	Moderately dry
1.99 – -1.50-	Very dry
2.00- ≤	Extremely dry

3. Results

The results indicate models have a proper ability to simulate daily precipitation values on the basis of the root mean squared error and coefficient of determination at the Khoy station (Table 2).

The comparisons between mean monthly amounts of observed and downscaled precipitation were illustrated in Figure 3 to 4 during the period of 1996-2001 and 1976-2001 relevant to the observed predictors and large-scale predictors derived from the HadCM3 model respectively. The variance inflations of 9 were used to generate downscaled data from large-scale predictors of NCEP and HadCM3.

Table 2. Evaluation indices of predictor models

NCEP		HadCM3 - B2	
R^2	RMSE	R^2	RMSE
0.84	2.05	0.88	2.81

The graphs of the standardized precipitation index are illustrated for the observed period in Figures 5 to 8.

Mean monthly distribution of the observed and downscaled precipitation under B2 scenario are illustrated in Figure 9.

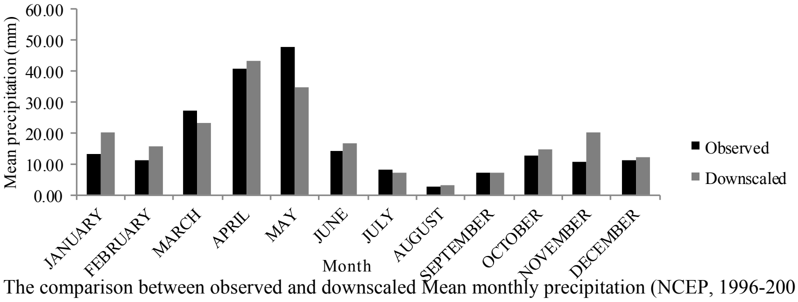

Fig. 3. The comparison between observed and downscaled Mean monthly precipitation (NCEP, 1996-2001)

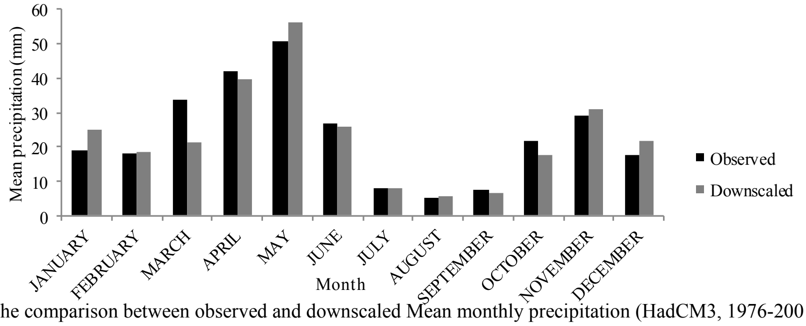

Fig. 4. The comparison between observed and downscaled Mean monthly precipitation (HadCM3, 1976-2001)

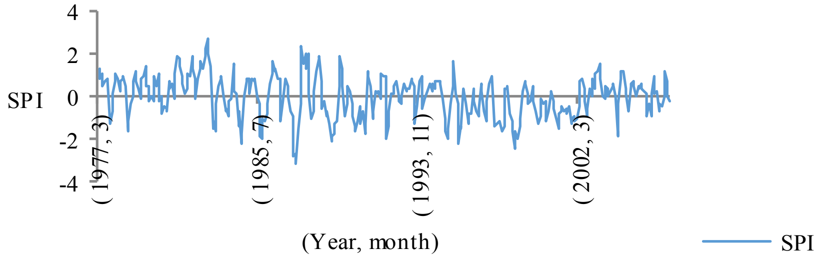

Fig. 5. SPI for time-scale of 3 months in the observed period

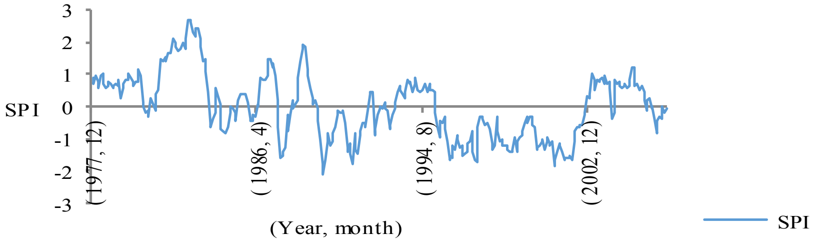

Fig. 6. SPI for time-scale of 12 months in the observed period

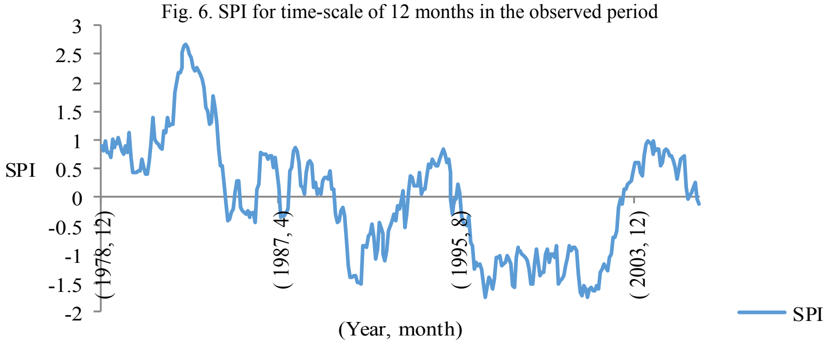

Fig. 7. SPI for time-scale of 24 months in the observed period

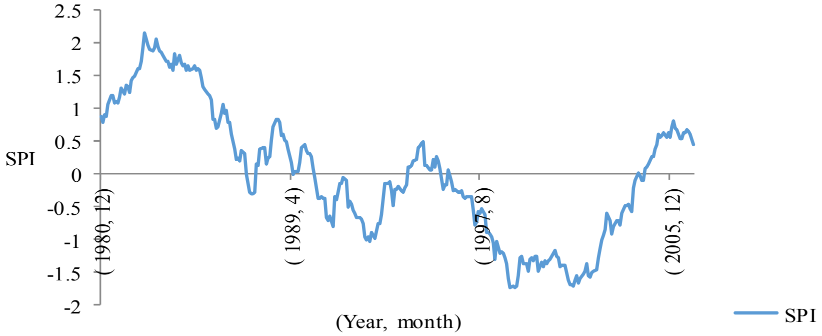

Fig. 8. SPI for time-scale of 48 months in the observed period

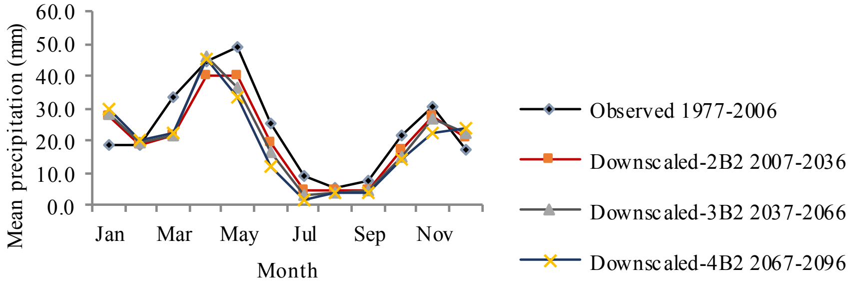

Fig. 9. Mean monthly distribution of observed and downscaled precipitation under B2 scenario

In this step, after calculating SPI values in different time-scales of 3, 12, 24 and 48 months based on the mean monthly precipitation of Khoy station in observed and future periods, drought characteristics were determined for different time-scales of each period (Table 3).

Table 3. Drought characteristics of the observed and future periods

Time -scale	Period	Scenario	SPI ≤ -1		SPI ≤ -1.5		Max duration of drought period (Month)	Max magnitude of drought period		Cum. SPI of period
			Number	%	Number	%		Cum. magnitude	Month	
3	1	-	66	18.44	24	6.70	7	11.25-	7	99.21-
	2	B2	58	16.20	23	6.42	5	9.12-	5	85.98-
	3		52	14.53	21	5.87	4	8.00-	4	77.82-
	4		53	14.80	22	6.15	6	10.97-	6	79.29-
12	1	-	72	20.63	20	5.73	16	22.82-	16	97.19-
	2	B2	66	18.91	10	2.87	17	24.59-	17	86.68-
	3		54	15.47	28	8.02	13	23.14-	13	84.34-
	4		51	14.61	22	6.30	25	40.47-	25	77.48-
24	1	-	75	22.26	22	6.53	24	30.82-	24	99.49-
	2	B2	62	18.40	37	10.98	24	46.05-	24	100.44-
	3		64	18.99	16	4.75	23	35.59-	23	91.50-
	4		41	12.17	19	5.64	26	47.27-	26	65.54-
48	1	-	60	19.17	18	5.75	58	81.50-	58	83.55-
	2	B2	48	15.34	14	4.47	23	39.98-	23	70.57-
	3		59	18.85	22	7.03	23	36.70-	23	89.03-
	4		54	17.25	23	7.35	47	70.45-	47	78.40-

The results from analysis of SPI in different time scales of 3, 12, 24 and 48 months in observed and future periods are:

In the time-scale of 3 months, the frequency of dry months based on SPI ≤ -1 and SPI ≤ -1.5 has been decreased in all periods than the base period, in the manner that the observed and third periods have a maximum and minimum frequency of dry Months respectively. The base period has also the maximum duration and intensity of drought period between different periods, respectively, including a drought period of 7 months and cumulative SPI of -11.25.

In the time-scale of 12 months, the frequency of dry months based on SPI ≤ -1 has been decreased in all periods than the base period, in the manner that the observed and fourth periods have a maximum and minimum frequency of dry Months respectively. The frequency of dry months based on SPI ≤ -1.5 has been increased in third period than the base period. The fourth period has also the maximum duration and intensity of drought period between different periods, respectively, including a drought period of 25 months and cumulative SPI of -40.47.

In the time-scale of 24 months, the frequency of dry months based on SPI ≤ -1 has been decreased in all periods than the base period, in the manner that the observed and fourth periods have a maximum and minimum frequency of dry Months respectively. The frequency of dry months based on SPI ≤ -1.5 has been increased in second period than the base period. The fourth period has also the maximum duration and intensity of drought period between different periods, respectively, including a drought period of 26 months and cumulative SPI of -47.27.

In the time-scale of 48 months, the frequency of dry months based on SPI ≤ -1 has been decreased in all periods than the base period, in the manner that the observed and second periods have a maximum and minimum frequency of dry Months respectively. The frequency of dry months based on SPI ≤ -1.5 has been increased in the third and fourth periods than the base period. The base period has also the maximum duration and intensity of drought period between different periods, respectively, including a drought period of 58 months and cumulative SPI of -81.50.

4. Discussion

Investigation of drought event has a great importance in the watershed and water resources management. In this research, obtained results based on observed and downscaled data under B2 scenario indicate that the mean annual precipitation will be decreased in the future periods, in the manner that the fourth and second periods respectively with the depletion of 48 mm (17%) and 34 mm (12%) than the observed period have maximum and Minimum rate of the depletion. This result corresponds with the results of Mohammadi *et al*. (2010), Abbasi and Asmari (2011) and Salehpour Jam *et al*. (2015). Salehpour Jam *et al*. (2015) indicated that the mean annual precipitation will be decreased in the future periods under A2 scenario in the northwest of Iran, in the manner that the mean annual precipitation at the Synoptic weather stations of Ardebil, Khoy and Oroumieh will be decreased.

Obtained results from the comparisons between Mean monthly amounts of observed and downscaled precipitation during the period of 1996-2001 and 1976-2001 show that the HadCM3 model is a proper model for Iran which is similar with the results of Dastorani *et al*. (2011), Salehpour Jam *et al*. (2015), zehtabian *et al*. (2016) and Salajegheh *et al*. (2016).

In this research, the variance inflations were used to generate the downscaled data from large-scale predictors of NCEP and HadCM3, like Salehpour Jam *et al*. (2015), and Salajegheh *et al*. (2016).

Obtained results indicate that drought event with more intensity, duration and frequency than base period can occur in future periods. This result corresponds with the results of Labedzki (2006), Loukas *et al*., (2008) and Salehpour Jam (2015). Salehpour Jam *et al*. (2015) indicated that drought event with more intensity, duration and frequency than base period can occur in future periods under A2 scenario in the northwest of Iran. On the other hand, Golmohammadi and Massah Bavani (2011) in investigation of climate change impact on drought intensity and duration at Gharasoo basin using HadCM3 and SPI during the period of 2040-2069 showed that the drought intensity and duration will be decreased due to an increase in future precipitation.

5. Conclusion

The emission of greenhouse gases and greenhouse effects cause the global warming and Climate change. In this study, climate change effects on drought characteristics in the Future Periods were investigated using the HadCM3 model under B2 scenario. The results indicate that the mean annual precipitation was decreased in the future periods of 2007-2036, 2037-2066 and 2067-2096. The mean monthly precipitation was also decreased in the future periods except January and December in all periods, and February and April in the third and fourth periods. Therefore, water scarcity is a crucial issue for future periods in the region. Because of the drought occurrence with more intensity, duration and frequency in the future periods, it is necessary to manage water resources and land uses in the study area.

The SDSM has a proper ability to simulate daily precipitation values using observed predictors and large-scale predictors derived from the HadCM3 model under the B2 scenario on the basis of the root mean squared error and coefficient of determination.

The authors suggest that the other models of GCM to be applied to show the effect of the climate change on drought characteristics in the future period.

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References

Abbasi, F., M. Asmari, 2011. Forecasting and assessment of climate change over Iran during future decades using MAGICC-SCENGEN model. Water and Soil, 25; 70-83.

Babaeian, I., R. Modirian, M. Karimian, M. Zarghami, 2015. Simulation of climate change in Iran during 2071-2100 using PRECIS regional climate modelling system. Desert, 20; 123-134.

Bootsma, A., S. Gameda, D.W. McKenney, 2005. Impacts of potential climate change on selected agroclimatic indices in Atlantic Canada. Canadian Journal of Soil Science, 85; 329-343.

Braga, A.C.F.M., R.M. da Silva, C.A.G. Santos, G.C. de Oliveira, P. Nobre, 2013. Downscaling of a global climate model for estimation of runoff, sediment yield and dam storage: A case study of Pirapama basin, Brazil. Journal of Hydrology, 498; 46-58.

Dastorani, M.T., A.R. Massah Bavani, S. Poormohammadi, M.H. Rahimian, 2011. Assessment of potential climate change impacts on drought indicators (case study: Yazd Station, Central Iran). Desert, 16; 159-167.

Golmohammadi, M., A. Massah Bavani, 2011. Investigation of climate change impact on drought intensity and duration. Water and Soil, 25; 315-326.

Hoerling, M., J. Eischeid, J. Perlwitz, X. Quan, T. Zhang, P. Pegion, 2012. On the increased frequency of Mediterranean drought. Journal of Climate, 25; 2146-2161.

IPCC, 2007. Summary for policy makers. In: IPCC. Climate change: The physical Science basic. Contribution of working group first to the Fourth assessment report of the intergovernmental panel on climate change. 1th ed., Cambridge university press, Cambridge.

Labedzki, L., 2006. Estimation of local drought frequency in central Poland using the standardized precipitation Index (SPI). Irrigation and Drainage, 56; 67-77.

Lazar, B., M. Williams, 2008. Climate change in western ski areas: potential changes in the timing of wet avalanches and snow quality for the Aspen ski area in the years 2030 and 2100. Cold Regions Science and Technology, 51; 219-228.

Lee, J.H., C.J. Kim, 2013. A multimodel assessment of the climate change effect on the drought severity–duration–frequency relationship. Hydrological Processes, 27; 2800-2813.

Lee, J.H., H.H. Kwon, H.W. Jang, T.W. Kim, 2016. Future Changes in Drought Characteristics under Extreme Climate Change over South Korea. Advances in Meteorology, 2016; 1-19.

Loukas, A., L. Vasiliades, J. Tzabiras, 2008. Climate change effects on drought severity. Advances in Geosciences, 17; 23-29.

McKee, T.B., N.J. Doesken, J. Kleist, 1993. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology, Anaheim, USA. pp. 179-183.

Mohammadi, H., M. Moghbel, F. Ranjbar, 2010. The study of Iran's precipitation and temperature changes using the MAGICC-SCENGEN model. Journal of Geography, 8; 125-142.

Mohammadi, H., F. Taghavi, 2005. Trend of extreme indices of temperature and precipitation in Tehran. Geography Researches, 53; 151-172.

Morid, S., M. Moghaddam, Sh. Paymozd, H. Ghaemi, 2005. Design of Tehran province drought monitoring system. Water Resources Management Co. (WRMC-Iran), Report number: 1, 196p.

Nandintsetseg, B., M. Shinoda, 2013. Assessment of drought frequency, duration, and severity and its impact on pasture production in Mongolia. Natural Hazards, 66; 995-1008.

Salajegheh, A., E. Rafiei Sardooei, A. Moghaddamnia, A. Malekian, Sh. Araghinejad, Sh. Khalighi Sigaroodi, A. Salehpour Jam, 2016. Prediction of climatic variables using statistical downscaling model (SDSM) in Future under Scenario A2. Desert Management, 4; 12-25.

Salehpour Jam, A., M. Mohseni Saravi, J. Bazrafshan, Sh. Khalighi Sigaroudi, 2015. Investigation of Climate Change Effect on Drought Characteristics in the Future Period using the HadCM3 model, Case Study: Northwest of Iran. Journal of Range and Watershed Management, 67; 537-545.

Sayari, N., A. Alizadeh, M. Bannayan, A. Farid Hossaini, M.R. Hesami Kermani, 2011. Comparison of two GCM models (HadCM3 and CGCM2) for the prediction of climate parameters and crop water use under climate change (case study: Kashafrood Basin). Water and Soil, 25; 912-925.

Schoof, J.T., S.C. Pryor, 2001. Downscaling temperature and precipitation: A Comparison of regression-based methods and artificial neural networks. International Journal of Climatology, 21; 773-790.

Spinoni, J., G. Naumann, H. Carrao, P. Barbosa, J. Vogt, 2014. World drought frequency, duration, and severity for 1951-2010. International Journal of Climatology, 34; 2792-2804.

Enyew, B. D., H. A. J. Van Lanen, A. F. Van Loon, 2014. Assessment of the impact of climate change on hydrological drought in Lake Tana catchment, Blue Nile basin, Ethiopia. Journal of Geology & Geosciences, 3; 174-185.

Wilby, R.L., T.M.L. Wigley, 2000. Precipitation predictors for downscaling: Observed and general circulation model relationships. International Journal of Climatology, 20; 641-661.

Yu, P.S., T.C. Yang, C.M. Kuo, H.W. Tseng, S.T. Chen, 2014. Climate change impacts on streamflow drought: a case study in Tseng-Wen reservoir catchment in southern Taiwan. Climate, 3; 42-62.

Zehtabian, Gh R., A. Salajegheh, A. Malekian, N. Boroomand, A. Azareh, 2016. Evaluation and comparison of performance of SDSM and CLIMGEN models in simulation of climatic variables in Qazvin plain. Desert, 21; 155-164.