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Investigating Precipitation Changes and Meteorological Drought Characteristics with Climate Change Scenarios (Case Study: Sari-Qamish Sub-basin of Zarinehrood)

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Abstract

Drought is one of the most important problems that humanity is facing today with effects intensifying and causing many problems in different regions due to climate change and the gradual increase in global warming in recent years. Knowing this phenomenon and managing it correctly can reduce the damage caused by it to some extent. In this study, in order to quantify the rainfall changes in the region from the rainfall data of Bukan, Saqez and Takab stations and based on the Standardized Precipitation Meteorological Drought Index (SPI) in the basic statistical period (1959-2020) and the future period (2020-2100). The CanESM2 model was used under RCP2.6, RCP4.5 and RCP8.5 scenarios. The results of the survey in the basic statistical period showed that the change trend of SPI values is decreasing. Also, the average decrease of monthly rainfall in the future statistical period under the RCP8.5 scenario in Takab, Bukan and Saqez stations is about 18, 18 and 23%, respectively, and the change trend of the SPI index under the RCP4.5 and RCP8.5 scenarios is a significant decrease. And in the RCP2.6 scenario, it has an insignificant decrease. Obviously, with the current results and the lack of greenhouse gas management, more severe droughts will occur in the study area.

Keywords: Climate change release scenarios, Meteorological drought, SPI index, Zarinehrood.

1. Introduction

Drought is a general and complex phenomenon that occurs in all types of climates, but its intensity and frequency vary from one climate and region to another (Belal et al., 2014). In other words, it is difficult to determine the beginning time and end of this creeping and gradual phenomenon unlike other hydrological events such as floods (Wilhite et al., 2007). In addition, drought is one of the most important problems that humanity is facing today due to climate change and the gradual increase in global warming in recent years with effects that have intensified and led to great environmental effects worldwide. In addition, the intensity, duration, and frequency of droughts have increased in recent decades on a global scale, and the intensity of their occurrence is higher in arid and semi-arid regions than in other climatic regions (Saadat et al., 2013).

It is possible to investigate droughts and determine their temporal and spatial expansion by using drought indicators. The use of these indicators makes it possible to quantify climate change. The Standardized Precipitation Index (SPI) is a standardized drought index based on the transformation of the annual distribution of precipitation into a standard normal distribution. Due to its strong statistical basis, SPI can be easily used in different regions and allows comparison between locations and time windows. The investigation of this index has been investigated at different points and its characteristics have been analyzed. Until today, the SPI index has been used more than other drought indices in the world due to the need for less input data and flexibility in its calculation. For example, Huang et al. (2016) investigated meteorological drought indicators in the Langat River Basin in Peninsular Malaysia in the Kuala Lumpur Valley. They used two standard precipitation drought indices for a one-month, 6-month, and 12-month time scale period and effective drought (EDI) to evaluate the severity, duration, and frequency of drought events. The results indicated that by comparing the characteristics of droughts in different statistical periods, severe droughts will occur in the region in the future if the current trend continues.

Lee et al. (2017) analyzed the drought characteristics in North Korea's Hwanghae Plain using multiple time scales of SPI and Standardized Precipitation Evapotranspiration Index (SPEI) from 1981 to 2100. The results of their research showed that the probability of not exceeding one-month SPEI to less than -1 in the spring season of 1995 is only 1.1%, but it will increase to 24.4% in 2085. They also stated that severe drought is likely to occur in the future as a result of climate change in the study area, and seasonal drought conditions will also be significantly affected by climate change. In their research, it was found that the greatest decrease in SPEI occurred in late spring and early summer, both of which are important for rice growth. Jang (2018) reported that according to the analysis of the future drought index in South Korea using the RDI and SPI indices and the RCP8.5 scenario based on the SPI index, the climate of this region will be wetter and the trend of drought reduction will be observed; in contrast, the RDI index, which is based on evaporation and transpiration, will experience drier conditions for the studied area.

Jasim and Awchi (2020) aimed to analyze the meteorological regional drought in Iraq for the 1970–2013 period using the monthly rainfall data of 22 meteorological stations scattered throughout the country based on the drought classes of SPI and the drought area severity-frequency (SAF) curve. The results showed that the studied area suffers from repeated periods of drought and the most severe periods of drought were from 1997 to 2001 and from 2007 to 2010. In addition, most of the droughts were classified as dry (mildly dry) by SPI classification. Danandeh Mehr et al. (2020) analyzed meteorological drought across Ankara, the capital of Turkey, using RCP4.5 and RCP8.5 scenarios and the SPI index. The results of their research showed that Ankara experienced six severe drought events and two severe droughts from 1971 to 2000. Projections indicated that fewer drought events will occur for the near future period of 2016–2040 with no severe drought events. The RCP8.5 scenario predicted that dry periods would be evenly distributed throughout the near future period.

Won and Kim (2020) investigated the impact of climate change on future droughts through SPI and the Evaporative Demand Drought Index (EDDI). These two drought indicators with different characteristics were used to investigate future drought trends and a drought intensity-duration-frequency curve was extracted for quantitative analysis of future drought depth. The results of their research showed that future droughts using data generated from different climate models can show the effects of drought well. Bong and Richard (2020) used SPI to identify and monitor drought in the Sarawak River Basin. Using monthly rainfall data between 1975 and 2016 for 15 rain gauge stations in the studied basin, drought index values were estimated for three, six, and nine months. Their findings showed that there is generally a decreasing trend for SPI values for three-time scales, which indicates a greater tendency to increase drought events throughout the basin. They also stated that in the last decade, there has been an increase in the number of dry months compared to the last 30 to 40 years for most of the rain gauge stations, which can be caused by climate change. They also stated that the findings of their study are valuable for planning and formulating drought strategies to reduce the adverse effects of drought.

Javan (2021) investigated the impact of climate change on meteorological drought in Urmia station using rainfall, drought data of the base period (1365-1385), and future periods (2031-2050 and 2051-2070) for 3, 6, 12, and 24-month time scales. Precipitation for future periods was scaled using the fifth report model and SDSM model. The analysis of rainfall changes in their research showed that in the first future period based on RCP2.6 and RCP8.5 scenarios, the average rainfall will increase, but in the second future period, a very small decrease in rainfall will be observed. Also, SPI values in long-term time scales indicate higher drought severity, and among the studied scenarios, RCP8.5 showed a more severe drought severity than the base period compared to other scenarios. Nikbakht and Hadeli (2021) monitored drought using SPI, RDI, and SPEI indices and investigated the characteristics of this phenomenon (drought intensity, magnitude, and duration) in the conditions of climate change in Kermanshah station during the statistical period from 1963 to 2019. The results of their research showed that during the study period, the temperature and potential evaporation and transpiration values increased in Kermanshah station, while the precipitation values decreased. They also showed that in all 3 indicators and 12 and 24-month periods, the magnitude of drought in the period after 1994 increased compared to the period before that.

Onuşluel Gül et al. (2022) investigated the drought behavior in Thracian and Aegean in the river basin of Turkey. For this purpose, a series of spatial analyses were used to identify different aspects of flooding in the study area, including trends in the annual mean drought severity series, changes in the onset time of the most severe annual flood periods, and spatial variations. The results of their analysis showed that in two consecutive periods 1958-1980 and 1981-2004, the western and southern river basin systems of Turkey experienced completely different behaviors between the two periods in terms of drought severity, drought duration, and drought duration.

Azizi and Nejatian (2022) chose the EC-EARTH model from the report (AR5) to investigate the effect of climate change on meteorological drought in the next three decades of Varamin Plain, and the RCP scenarios were micro-scaled by LARS-WG software. In addition, they evaluated the characteristics (intensity-duration) and return period of SPI and standardized precipitation-evapotranspiration index (SPEI) in an annual time series. The results of their research showed that the seasonal rainfall pattern has changed and the average temperature has increased by 1.4 degrees Celsius compared to the base period. The drought assessment results showed that the future drought severity has increased by 8% and 28%, respectively, compared to the base period based on SPI and SPEI, which indicates that SPEI is more severe than SPI in all three scenarios. Various studies in the field of drought based on SPI have investigated its changes in the analyzed statistical periods. The combination of this index with climate scenarios can reveal the characteristics of drought and its changes for future periods. The best combination in this regard is climate scenarios in the coming period.

The present study aimed to investigate the basic and future droughts in the Sari-Qmish sub-basin of Zarineh River in the south of Lake Urmia from the SPI drought index using the large-scale outputs of the CanESM2 model and the small-scale model of multivariate regression with the selection of the best predictor among the 26 parameters based on the greenhouse gas emission scenarios of the Fifth Report optimistic (RCP[1]2.6), moderate (RCP4.5), and pessimistic (RCP8.5) rainfall values in Bukan, Saqez and Tekab stations in the future period 2020-2100 so that SPI changes can be monitored in the study area.

2. Materials and Methods

2.1. Case Study

In this research, the Sari-Qamish sub-basin with an area of about 7304 square kilometers and an area equal to 586 km, one of the sub-basins of the Zarinehrood watershed and in the south of Lake Urmia, has been investigated. Three meteorological stations of Bukan, Saqez, and Tekab were selected in this sub-basin to investigate the SPI index and its changes in the statistical period of 1959-2020. In Figure 1, the location of the studied sub-basin in Iran and Urmia Lake Basin, and in Table 1, the statistical characteristics of the investigated data in Bukan, Saqez, and Tekab stations are presented.

[1]- Representative Concentration Pathway

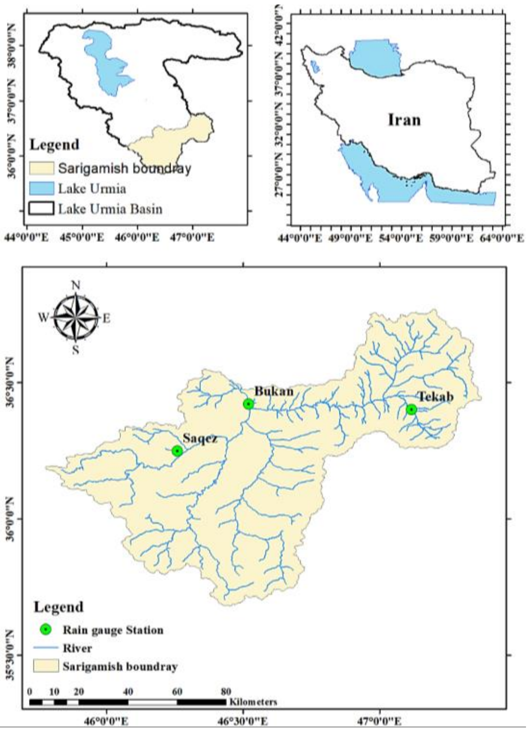


Fig. 1.The location of Sari-Qamish sub-basin and the studied meteorological stations

Table 1. Statistical characteristics of the investigated data in Bukan, Saqez and Tekab stations

station	average rainfall (mm)	maximum (mm)	minimum (mm)	standard deviation	Statistical period
Bukan	29.30	174.18	0	30.11	1959-2020
Saqez	40.22	235.49	0	41.43	
Tekab	27.51	140.48	0	27.71	

2.2. SPI and Extraction of Drought Characteristics

The SPI index is a powerful tool in the analysis of precipitation data in multiple time periods. By assigning a numerical value to the amount of precipitation, this index can compare areas with different climates. The SPI drought index was developed by McKee et al. (1993) as a replacement for the PDSI index and to quantify the lack of precipitation as a drought monitoring tool and an indicator of drought conditions for the state of Colorado, USA. To calculate the SPI index, the Gamma distribution density function and sometimes the Pearson function are used to fit the long-term rainfall data, which is finally transferred to the normal distribution. After performing the necessary calculations and determining the relevant parameters, the SPI index is expressed as positive and negative values. To extract and analyze the characteristics of drought in the region, a common method called the theory of drought was used (Mishra and Singh, 2010). By using this theory, three important characteristics of drought (continuity, severity, and magnitude) can be defined, which are shown in the figure 2. These specifications are shown considering the threshold level X_0 for the main variable X_t.

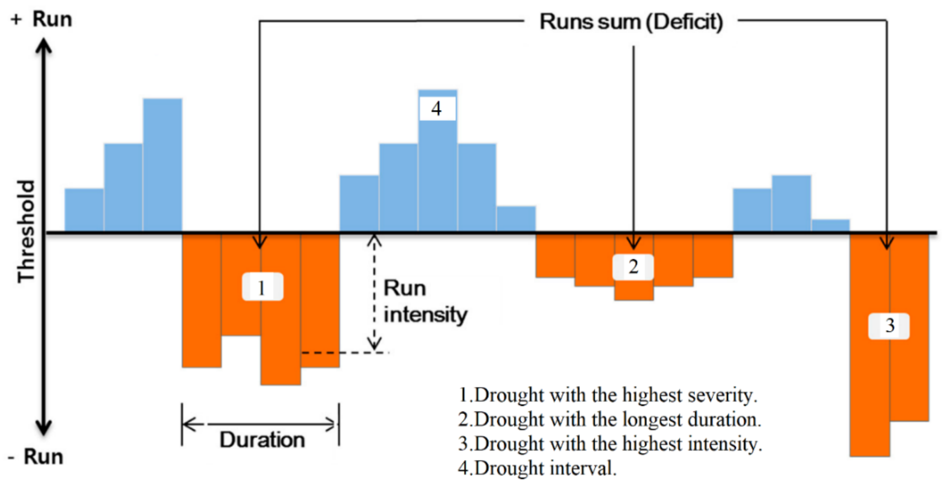


Fig. 2. Description of drought characteristics using Run theory considering the threshold level X_0

2.3. Emission Scenarios

Since the amount of greenhouse gas emissions in future periods is the most important input of atmospheric general circulation models and it is not possible to calculate and determine the emission of these gases in the future periods and on regional scales, and forecasting the regional climate under the phenomenon of climate change is difficult, different emission scenarios including emission scenarios have been presented for them. But it should be noted that a climate scenario is not a weather forecaster. RCP scenarios are associated with the possibility of large changes in human activities and greenhouse gas emissions in future. The RCP2.6 scenario was designed by the Integrated Assessment Modeling Framework Describing Global Environmental Change (IMAGE) modeling group from the Netherlands Environmental Assessment Institute, in which the concentration of carbon dioxide gas by the year 2100 is about 490 ppm, and the world population is about 7 billion people with the effect of greenhouse gases being up to 2.6 W/m^2 on radiative forcing. In the RCP2.6 scenario, technology growth and the amount of new energy used instead of fossil energy and fuel will increase, whereas the amount of production and emission of greenhouse gases will decrease.

The RCP4.5 scenario was designed by the MiniCAM modeling group, in which the concentration of carbon dioxide gas will be around 650 ppm by the year 2100, and the population growth rate will be lower than the RCP2.6 scenario, as well as the effect of greenhouse gases announced to be up to about 4.5 W/m^2 on radiative forcing. In the RCP4.5 scenario, technology growth and the use of new energy sources instead of fossil energy and fuels will decrease compared to the RCP2.6 scenario, whereas the amount of production and emission of greenhouse gases will increase. The RCP8.5 scenario was designed by the Model for Energy Supply Strategy Alternatives and their General Environmental (MESSAGE) modeling group and the International Institute for Applied Systems Analysis in Austria. In this scenario, the carbon dioxide concentration will be around 1960 ppm by the year 2100 and the population growth will be around 12 billion people along with the effect of greenhouse gases being up to 8.5 W/m^2 on radiative forcing. In the RCP8.5 scenario, technology growth will decrease due to the augmentation in gross domestic product compared to the RCP2.6 scenario.

In this study, by examining the 26 predictive parameters in Table 2, the effective parameters were selected despite the higher correlation with the observed rainfall data, and the rainfall values in the future periods were estimated according to the selected CanESM2 predictors using the multivariate regression method.

Table 2. Predictive values extracted from CanESM2 in the studied stations

Predictor title	Predictor	Predictor title	Predictor
Wind speed at 800-hPa	p8-fgl	Average sea level pressure	MSLPGL
Orbital velocity component at 800-hPa	p8-ugl	Wind speed at 1000-hPa	p1-FGL
Meridional velocity component at 800-hPa	p8-vgl	Orbital velocity component at 1000-hPa	p1-Ugl
Vorticity at 800-hPa	p8-zgl	Meridional velocity component at 1000-hPa	p1-Vgl
Wind direction at 800-hPa	p8-thgl	Vorticity at 1000-hPa	p1-zgl
Divergence at 800-hPa	p8-zhgl	Wind direction at 1000-hPa	p1thgl
Relative humidity at 500-hPa	p500gl	Divergence at 1000-hPa	p1zhgl
Relative humidity at 850-hPa	P850gl	Wind speed at 500-hPa	p5-fgl
Total precipitation	prcpgl	Orbital velocity component at 500-hPa	p5-ugl
Specific humidity at 500-hPa	s500gl	Meridional velocity component at 500-hPa	p5-vgl
Specific humidity at 850-hPa	s850gl	Vorticity at 500-hPa	p5-zgl
Specific humidity near surface	shumgl	Wind direction at 500-hPa	5-thgl
Average temperature at 2 m	tempgl	Divergence at 500-hPa	5-zhgl

2.4. Investigating the Trend of Precipitation Changes

In this research, the changing procedure of the SPI index in Bukan, Saqez, and Tekab stations was investigated using the modified Mann-Kendall non-parametric test. In time series, especially climate data time series, the need for trend analysis is felt. This test is one of the best methods for revealing and determining data trends, which has been widely used in hydrology, climatology, and meteorology studies (Man, 1945; Kendall, 1963; Khalili et al., 2016; Khozeymehnezhad and Tahroudi, 2019; Ahmadi et al., 2018; Tahroudi et al., 2019). Although the necessary condition for using this test is the absence of autocorrelation in the data time series, the data may have significant autocorrelation.

Therefore, the autocorrelation effect of the data should be removed first to be able to use the Mann-Kendall test (Nazeri Tahroudi and Shahidi, 2017). The World Meteorological Organization recommends the Mann-Kendall test to investigate and detect trends in time series (Kundzewicz and Robson, 2000; Behzadi et al., 2020). The steps to calculate this index are provided in the following:

A) The statistic S is considered as the following:

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}\left(x_j-x_i\right) \quad (1)$$

In which the x_j is the consecutive data values, n is the length of the data set and $\operatorname{sgn}(\theta)$ is the sign function which is defined as follows:

$$\operatorname{sgn}(\theta)=\begin{cases}1 & if \quad \theta>0\\ 0 & if \quad \theta=0\\ -1 & if \quad \theta<0\end{cases} \quad (2)$$

Mann (1945) and Kendall (1963) showed that when $n\geq 8$, the statistic S is approximately normally distributed and its mean and variance are as follows:

$$E(S)=0 \quad (3)$$

$$V(S)=\frac{n(n-1)(2n+5)-\sum_{i=1}^{m}t_i(t_i-1)(2t_i+5)}{18} \quad (4)$$

where t_i is the number of identical data in i^th^ category and m is equal to the number of paired groups. The statistics of the standardized test score Z is calculated as follows:

$$Z=\begin{cases}\dfrac{S-1}{\sqrt{Var(S)}} & S>0\\ 0 & S=0\\ \dfrac{S+1}{\sqrt{Var(S)}} & S<0\end{cases} \quad (5)$$

The Z standardized MK1 test statistic follows the standard normal distribution with mean=0 and variance=1. The null hypothesis is accepted on the condition that it $-Z_{1-\alpha/2}\leq Z\leq Z_{1-\alpha/2}$ is placed (Khozeymehnezhad and Tahroudi, 2019).

The slope value is calculated using the method provided by Theil and Sen with the following relationship (Theil, 1950; Sen, 1968):

$$\beta=Median\left(\frac{x_j-x_i}{j-i}\right) \qquad \forall i<j \quad (6)$$

where β is the estimator of the slope of the trend line, and x_i, x_j are the observed values are of i^{th} and j^{th} respectively. Positive values of β indicate an increasing trend and its negative values indicate a decreasing trend. In order to check and eliminate the effect of autocorrelation in the studied data, the following method is used. In this method, the effect of the first order autocorrelation coefficient (r_1) is calculated and if it is significant, it is removed from the data series. For this, the following steps are performed (Kumar et al., 2009):

$$r_k=\frac{\frac{1}{n-k}\sum_{i=1}^{n-k}(x_i-\bar{x})(x_{i+k}-\bar{x})}{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2} \quad (7)$$

The data series are assumed to be independent of each other (at a significance level of 10%) if:

$$\frac{-1-1.645\sqrt{n-2}}{n-2}\leq r_1\leq\frac{-1+1.645\sqrt{n-2}}{n-2}$$

Then the slope of the trend line or β for the data series is calculated from equation 6 and a new series is obtained as follows:

$$S=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\operatorname{sgn}\left(x_j-x_i\right) \quad (8)$$

In the next step, the r_1 coefficient of the new data series is recalculated. The first-order autocorrelation coefficient component AR(1) is removed from the new series as follows, and the residual series (y_i') is obtained from the following equation:

$$y_i'=x_i'-r_1\times x_{i-1}' \quad (9)$$

Finally, once again, the trend value $(\beta\times i)$ was added to the last series and the final series (y_i) is obtained as follows:

$$y_i=y_i'+(\beta\times i) \quad (10)$$

Now, by applying the Mann-Kendall test to the composite data series, the existence of a trend in them is investigated.

3. Results and Discussion

At first, by using monthly rainfall values in Tekab, Bukan, and Saqez stations in the statistical period of 1959-2020, the SPI index was extracted in time windows of 6, 12 and 24 months. The results of extracting SPI values in the studied stations were presented in figures 3 to 5. During the observation period, Bukan, Saqez, and Tekab stations had SPI values less than zero in about 46, 47, and 45 percent of the months, respectively, which indicates drought in the study area.

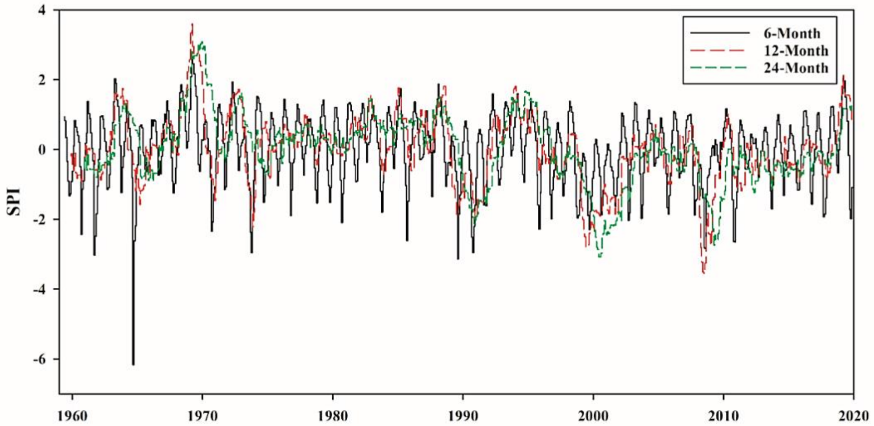


Fig. 3. SPI index changes in Tekab meteorological station in the statistical period of 1959-2020

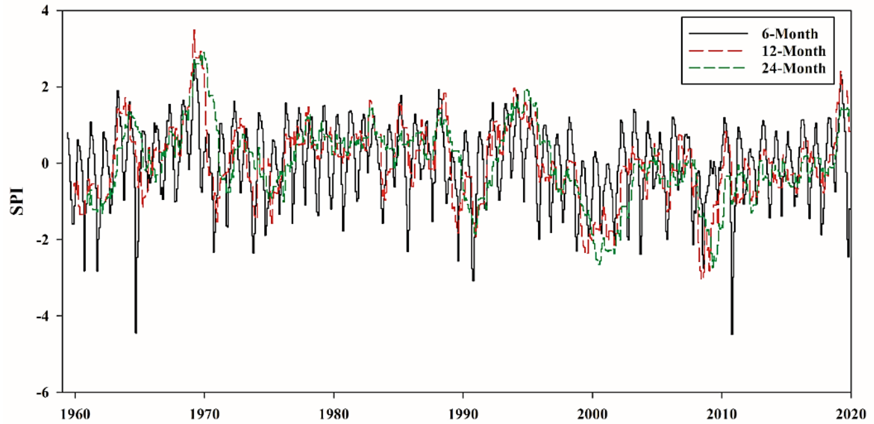


Fig. 4. SPI index changes at Bukan weather station in the statistical period of 1959-2020

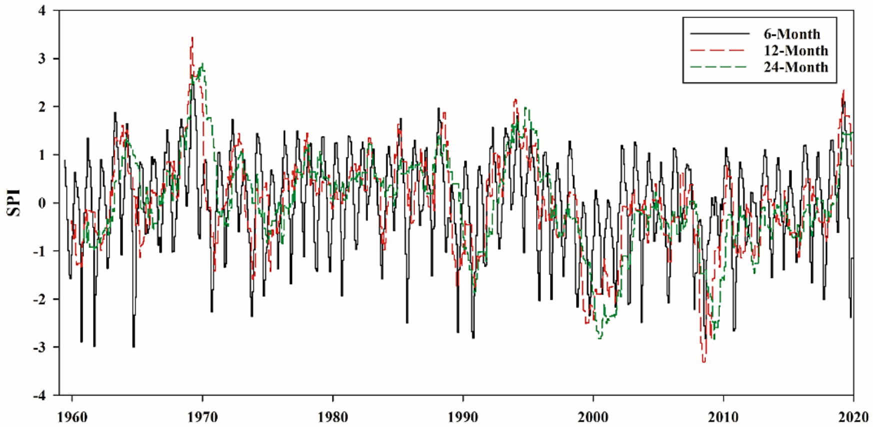


Fig. 5. SPI index changes in Saqez meteorological station in the statistical period of 1959-2020

The decrease of SPI values in the studied stations can be seen since 1995, but in the whole studied area, according to the results of the modified Mann-Kendall test, the trend of SPI values has been decreasing. A decrease in SPI values will indicate an increase in droughts in the study area. The results of examining the change of SPI values in the studied stations using the modified Mann-Kendall test are presented in Figure 6. The numbers in figure 6 will be multiplied by -1. These numbers show the decrease of SPI values in the study mode area. There is a decreasing change trend of SPI values in the studied stations in the 6 months and a significant level of 5%. At a 5% significant level, there is an insignificant and decreasing trend of changes in SPI values in the 24-month window and 12-month window in Bukan and Tekab stations, but significant and decreasing in Saqez station. Drought changes have increased in all studied stations. Using the Run theory, drought characteristics were extracted in the studied stations. The duration of drought and the intensity of drought in the studied stations (Tekab, Bukan, and Saqez) have been extracted and presented in figures 7 to 9.

According to the presented figures (7 to 9), it can be seen that the duration of drought has increased in recent years. So that a severe lack of precipitation has been observed in almost all the studied stations. Also, the severity of drought has decreased in recent years, which shows the decrease in SPI values. The trend of changes in the intensity and duration of meteorological drought extracted from the SPI index was analyzed using the modified Mann-Kendall test. The results of examining the trend and the slope of the trend line are presented in Table 3.

The results of studying the trend of meteorological drought intensity changes showed that the trend of changes in the drought intensity values in the studied stations is a non-significant decrease at the level of 5% significant level. The trend of changes in the duration of drought during the statistical period under investigation in the studied stations is incremental and insignificant at a significant level of 5%.

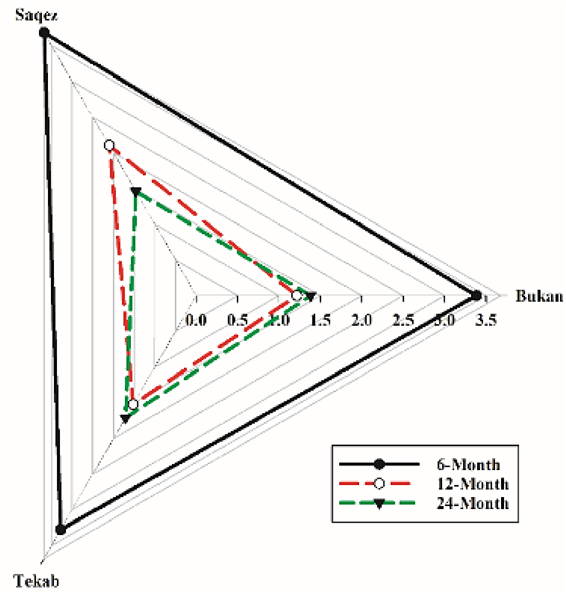


Fig. 6. Modified Mann-Kendall statistic in the study of the change of SPI values in the study area in the basic statistical period (1959-2020) (values should be multiplied by -1)

The increasing trend of drought duration in the studied area shows that the lack of rainfall is increasing in all the studied stations. The decreasing intensity of drought in the statistical period under review means that the intensity values have become more negative, which includes the increase in dry months.

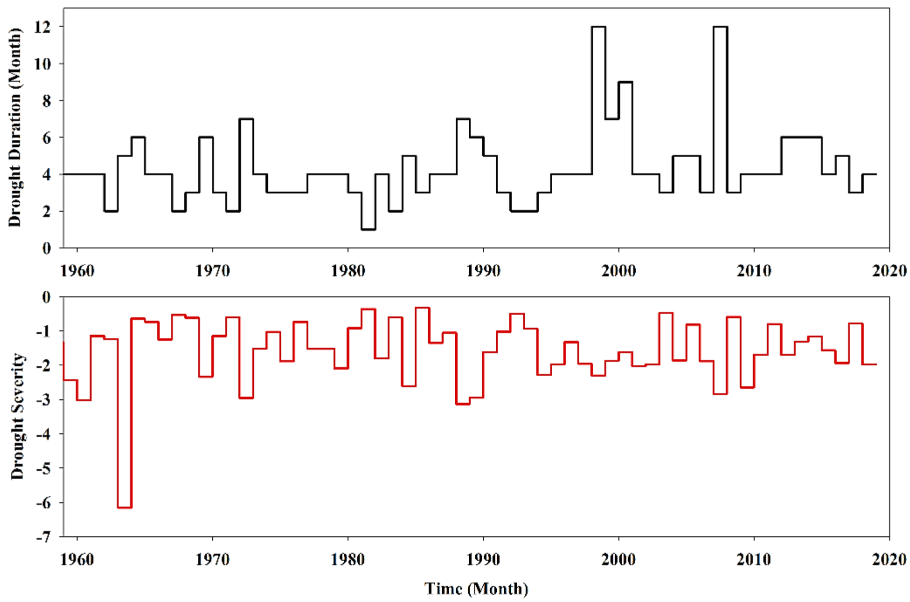


Fig. 7. Changes in duration and severity of meteorological drought SPI index in Tekab station

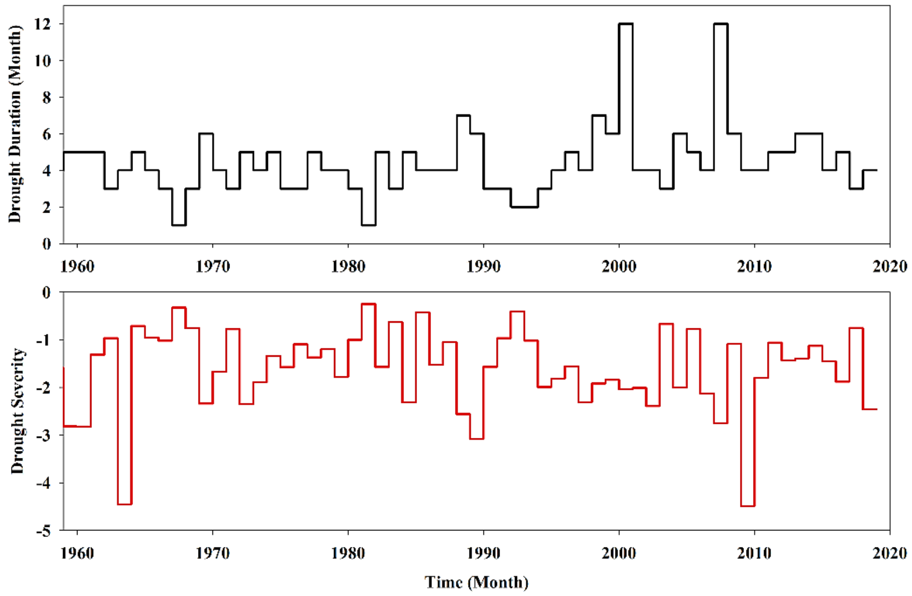


Fig. 8. Changes in duration and intensity of meteorological drought of SPI index at Bukan station

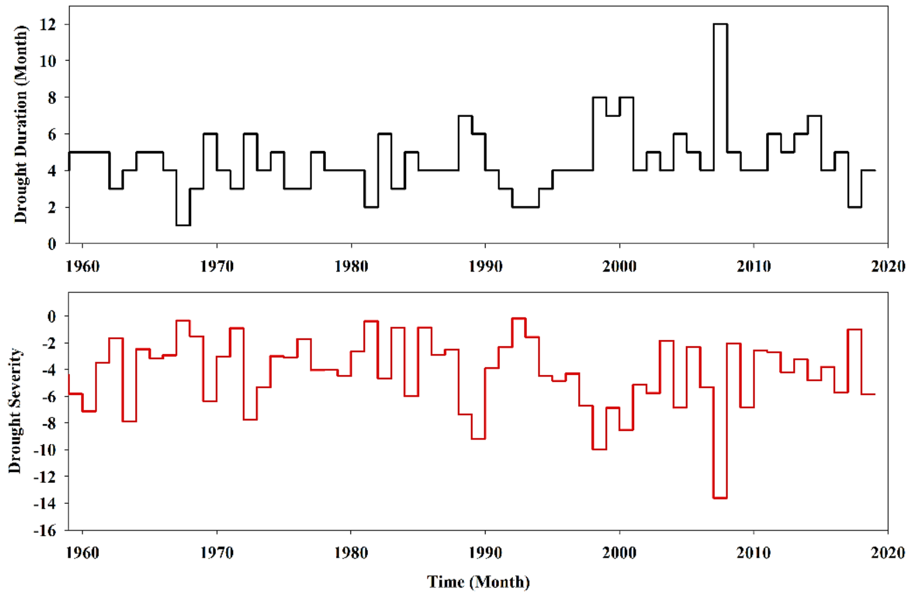


Fig. 9. Changes in duration and severity of meteorological drought of SPI index at Saqez station

Table 3. The results of examining the changes in the intensity and duration of drought in the studied stations

station	trend statistics	Drought period	drought severity
Bukan	Z statistic	1.62	-0.94
	slope of the trend line	0.001	-0.006
Saqez	Z statistic	1.40	-0.95
	slope of the trend line	0.001	-0.006
Tekab	Z statistic	1.68	-0.49
	slope of the trend line	0.001	-0.003

3.1. Extracting Predictive Values Based on Climate Change Scenarios

By extracting predictive values in two basic statistical periods (1961-2006) and the future period (2006-2100) obtained from CanESM2 values in three optimistic (RCP2.6), moderate (RCP4.5) and pessimistic (RCP8.5) scenarios), the correlation of 26 predictor parameters with monthly rainfall values in the studied stations was investigated and based on the appropriate correlation, 6 predictors were considered as the best predictors. Selected predictors and existing correlation values can be seen in Table 3. By selecting the best predictors according to Table 4, using multivariable regression, the simulation of rainfall amounts on a monthly scale in Tekab, Bukan, and Saqez stations in the future period was done. The results of the simulation of precipitation values on a monthly scale in the basic statistical period were analyzed based on the error values and the Nash-Sutcliffe statistic. The results of checking the error values (RMSE) and model efficiency coefficient (NSE) in the simulation of rainfall of the studied stations are presented in Table 5 and Figure 10.

Table 4. The results of the correlation between the values of the selected predictors and the rainfall of the studied stations in the basic statistical period (1961-2006)

Predictor title	Correlation values (Tekab)	Correlation values (Bukan)	Correlation values (Saqez)
Wind speed at 1000-hPa	0.47	0.47	0.48
Orbital velocity component at 1000-hPa	0.55	0.56	0.56
Wind speed at 800-hPa	0.49	0.49	0.50
Orbital velocity component at 800-hPa	0.55	0.56	0.56
Relative humidity at 500-hPa	-0.55	-0.58	-0.60
Average temperature at a height of 2 meters	-0.53	-0.57	-0.59

Table 5. Error values and model efficiency coefficient in rainfall simulation based on selected predictors on a monthly scale (total monthly rainfall (mm))

Synoptic station	RMSE (mm)	NSE
Tekab	9.5	0.89
Bukan	9.8	0.90
Saqez	14.3	0.89

Based on the results presented in Figure 10 and Table 5, it can be seen that the accuracy of the multifunctional regression model in the simulation of monthly precipitation values in the study area is acceptable and the multifunctional regression model has good performance in this field. Figure 10 also shows that due to the 95% confidence interval, most of the simulation cases are located in this range. The efficiency of more than 89% was observed at all stations under study. The lowest error rate is for Tekab station with 9.5 mm and the highest is for Saqez station with 16.3 mm.

Table 6. The average rainfall of the studied stations in two basic and simulated statistical periods in millimeters

Station	Base period (1959-2020)	Simulated period (2020-2100)		
		RCP 2.6	RCP 4.5	RCP 8.5
Tekab	27.51	21.87	21.11	17.71
Bukan	29.30	22.80	22.20	18.24
Saqez	40.22	30.63	29.32	23.63

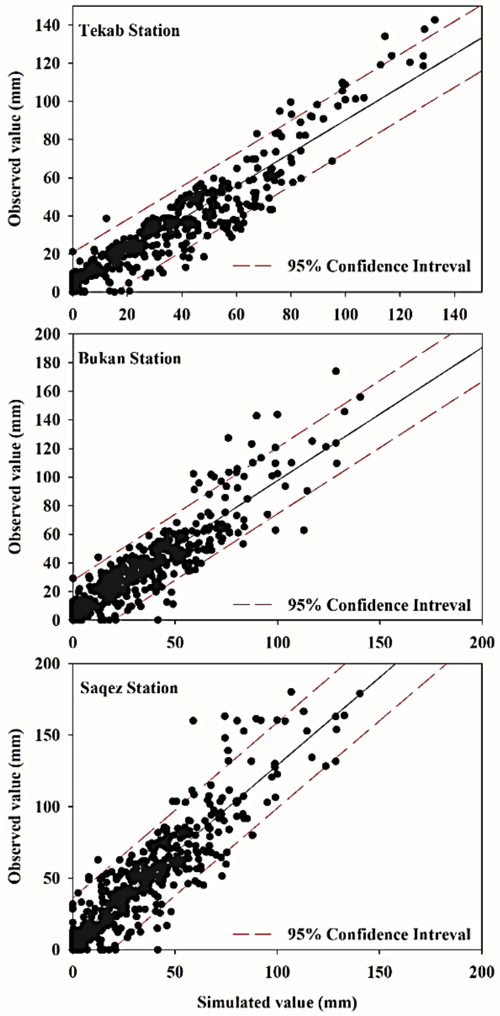


Fig. 10. Simulation results of monthly rainfall values of the studied stations using multivariable regression and selected CanESM2 predictive values

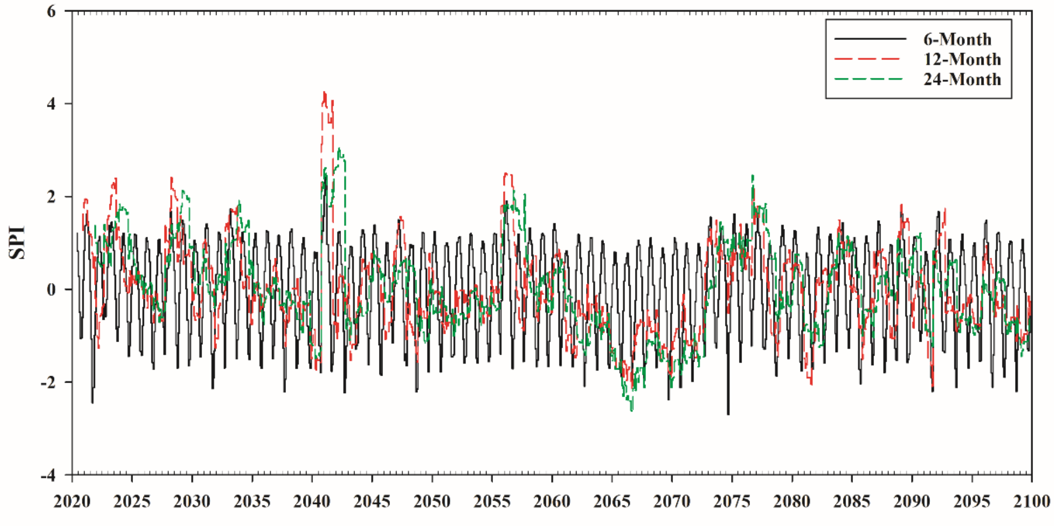
According to the results presented in Table 5 and Figure 10, the simulation of precipitation amounts in the studied stations in the statistical period of 2020-2100 was carried out under RCP2.6, RCP4.5 and RCP8.5 scenarios.

According to Table 6, by examining the average values of precipitation in the basic statistical period and the simulated statistical period, the results showed that the average values of precipitation in the studied stations in different scenarios have a decreasing trend. In addition, in the RCP8.5 scenario, a significant decrease in average monthly precipitation is observed in the study area.

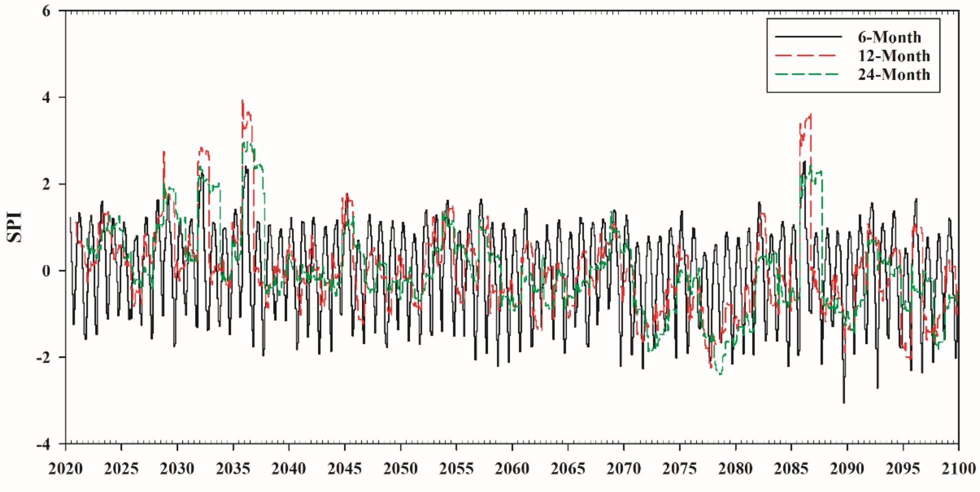
By simulating monthly precipitation values based on the aforementioned scenarios and CanESM2 predictors, the SPI meteorological drought index for the statistical period of 2020-2100 was estimated in 6, 12, and 24-month time windows. The results of the estimation of the SPI values in Figures 11, 12, and 13 are presented for Tekab, Bukan, and Saqez stations, respectively. Considering the form presented, we can see the slope of SPI values in each scenario. Changes of SPI values in the RCP2.6 scenario will be paved according to Figures 11-A, 12-A, and 13-A, and according to CanESM2 predictors of severe droughts over 2060 to 2075 under the RCP2.6 scenario will occur. According to RCP4.5 CanESM2 predictors, the slope of SPI values in the Bukan, Saqez, and Tekab stations following Figures 11-B, 12 B, and 13-B have been intensified and negative values of SPI have also increased. In the meantime, 12 and 24-month droughts have a further decrease in the 6-month SPI. Figures 11-C, 12-C, and 13-C indicate changes in SPI values in the 2020-2100 statistical period under the RCP8.5 scenario. The trend of severe decreases in the SPI values in this scenario is observed in the aforementioned shapes. The 6-month SPI meteorological drought in the form of 11-C, 12-C, and 13-C is more frequently visible than modes of 12 and 24-month, and the annual alternation is visible during the decline. From 2072 onwards, the alternation of SPI values in 12 and 24-month mode has also increased. Severe droughts as well as several severe wet at the end of the 2020-2100 statistical period are observed in the study area due to RCP8.5 and CanESM2 predictors. According to the RCP8.5 scenario, SPI values are less than -2 at the end of the statistical period in the studied stations.

The occurrence of several severely wet at the end of the statistical period can occur based on the increase in values that indicate the irregular distribution of the precipitation pattern. According to Figure 12, we can see a sharp decrease in SPI values in the 2075-2085 period. In the historical-statistical period (1959-2020), 46, 47, and 45% of the months had SPIs less than zero in Bukan, Saqez, and Tekab stations compared to other scenarios.

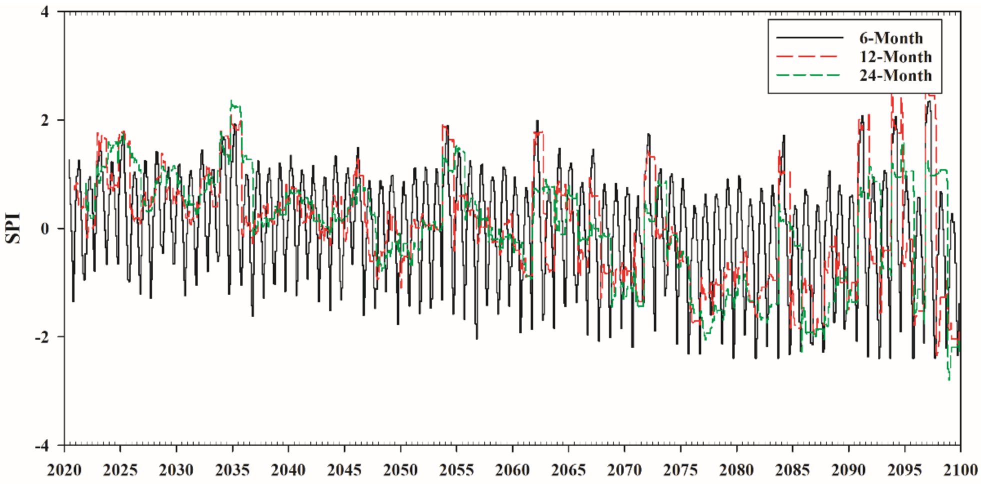
In the RCP2.6 scenario, 48, 46, and 46% of the months have SPIs less than zero in Bukan, Saqez, and Tekab stations in the 2020-2100 statistical period. This percentage in the studied stations is 52, 51, and 52% in the RCP4.5 scenario and 53, 52, and 53% in the RCP8.5 scenario respectively. In the RCP4.5 and RCP8.5 scenarios, droughts will cover more than half of the statistical period despite the lack of greenhouse gases in the 2020-2100 statistical period. This lack of rainfall and drought in the study area, despite Lake Urmia, will have many problems in the management of water resources, which can also affect the water level of Lake Urmia.



(A)



(B)



(C)

Fig. 11. SPI Index of Tekab Meteorological Station in the 2020-2100 statistical period (A: RCP2.6, B: RCP4.5 and C: RCP8.5)

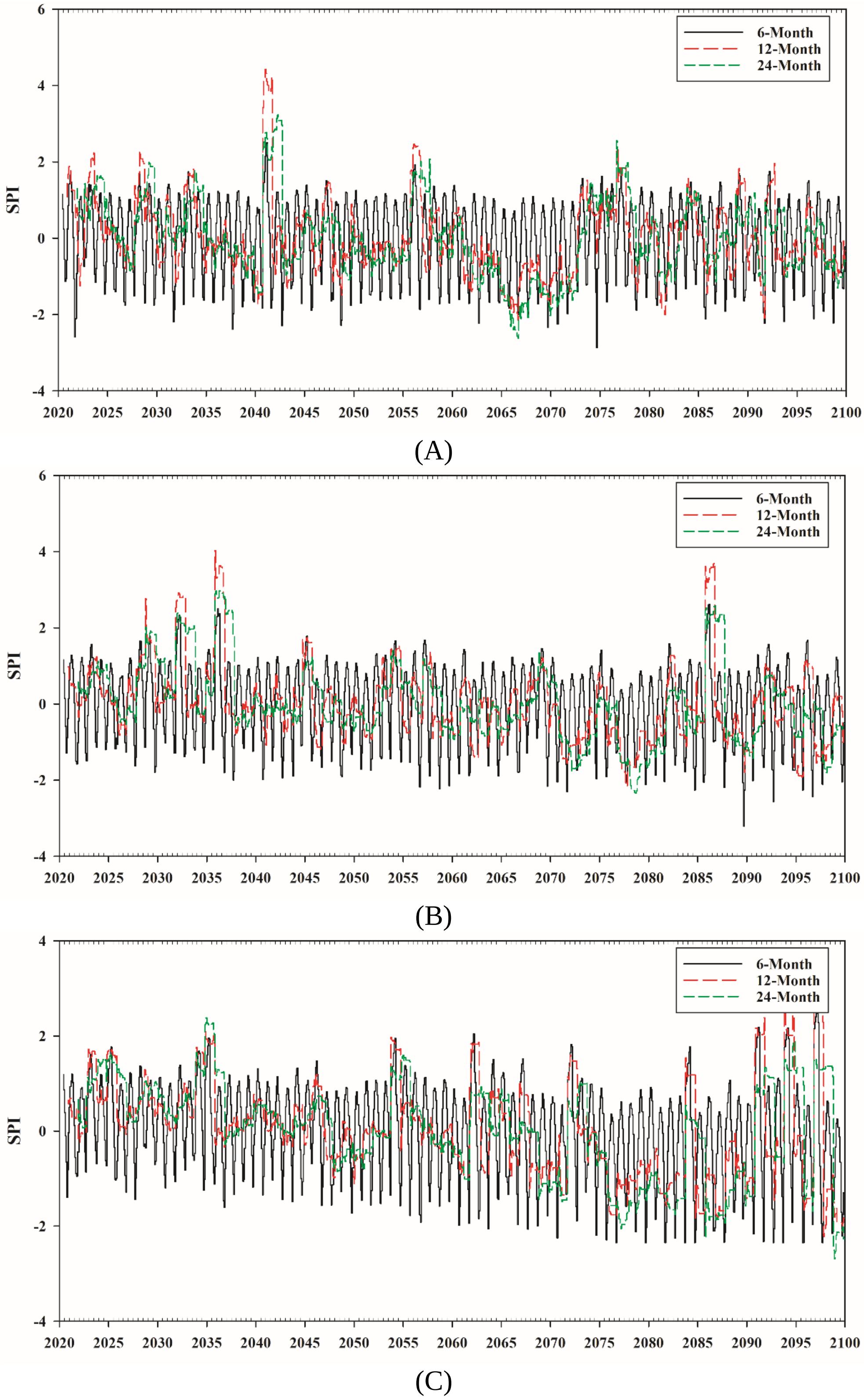
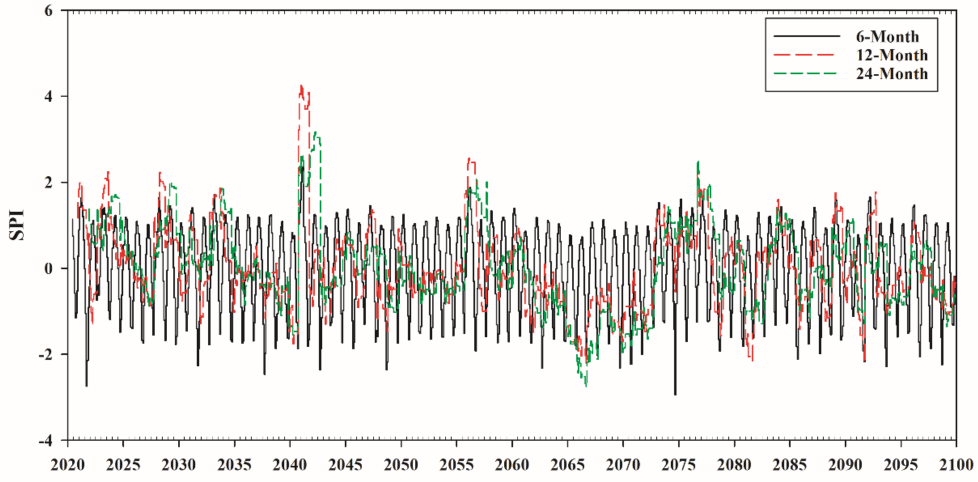
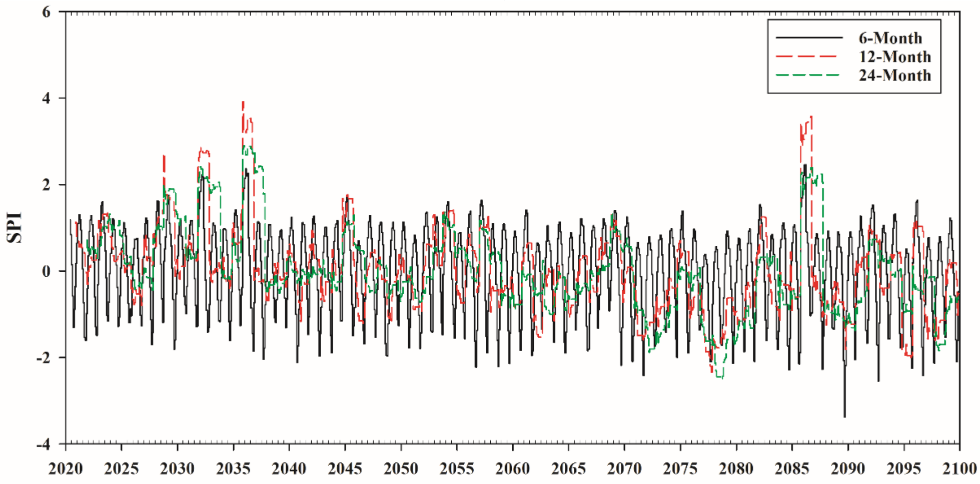


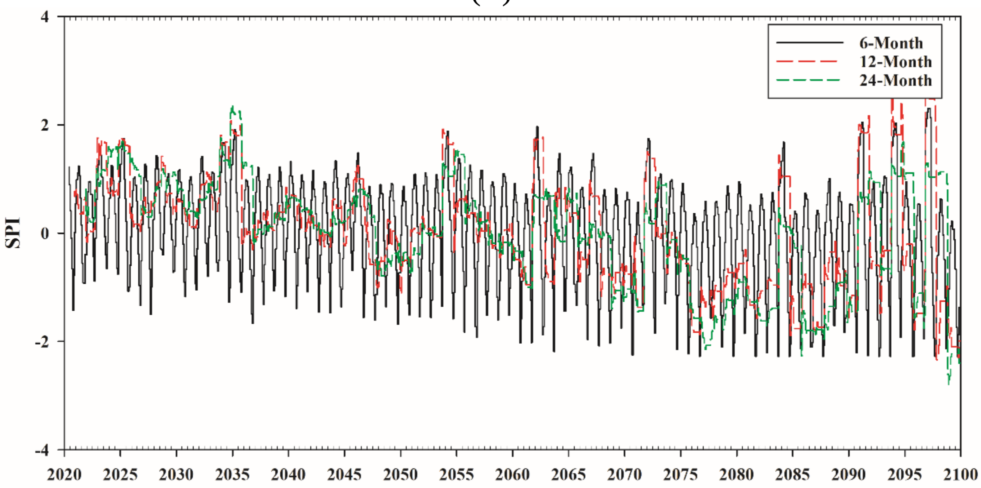
Fig. 12. SPI Index of Bukan Meteorological Station in the 2020-2100 statistical period (A: RCP2.6, B: RCP4.5 and C: RCP8.5)



(A)



(B)



(C)

Fig. 13. SPI Index of Saqez Meteorological Station in the 2020-2100 statistical period (A: RCP2.6, B: RCP4.5 and C: RCP8.5)

The modified Mann-Kendall (MK) Test was used to evaluate the changes in the SPI values in the 2020-2100 statistical period by eliminating the effect of internal correlation. The results of the process of changes in SPI values in different scenarios are presented in Figure 11. The numbers presented in Figure 14 must be multiplied by -1. The trend of SPI values in all scenarios studied in the 2020-2100 statistical period is reduced. At the significant level of 5%, the decrease in SPI values in the RCP4.5 and RCP8.5 scenarios is significant. The RCP2.6 scenario is an optimistic scenario that will not be expected.

However, the results of the trend of changes to SPI values in the RCP2.6 scenario indicate a decrease in SPI values in this scenario, which will decrease the SPI and indicate an increase in drought. The Z values of the modified MK test in the RCP2.6 scenario in the studied meteorological stations are non-significant at 5%. The SPI slope values in 6-month mode in Bukan, Saqez, and Tekab stations are -0.0001, -0.0001, and -0.0002 in the RCP2.6 scenario, -0.0004, -0.0004, and -0.0004 in the RCP4.5 scenario, and -0.0008, -0.0008, and -0.0008 in the RCP8.5 scenario each year. The slope of SPI values in the RCP8.5 scenario is greater than in the other two scenarios. The MK statistics in the RCP8.5 scenario are also more severe than the other two scenarios. If greenhouse gases are not reduced and the current conditions are not managed worldwide, the expected RCP8.5 scenario will occur and lead to more droughts. But if the greenhouse gases are controlled and managed, the process of changes to the SPI values will be non-significant. Reducing SPI values, in addition to increasing the negative amounts of SPI, will also reduce the positive values of SPI, which will reduce the wet years in the study area. According to Figure 14, it can be seen that RCP8.5 is associated with more decreasing severity of the SPI values compared to the other two scenarios.

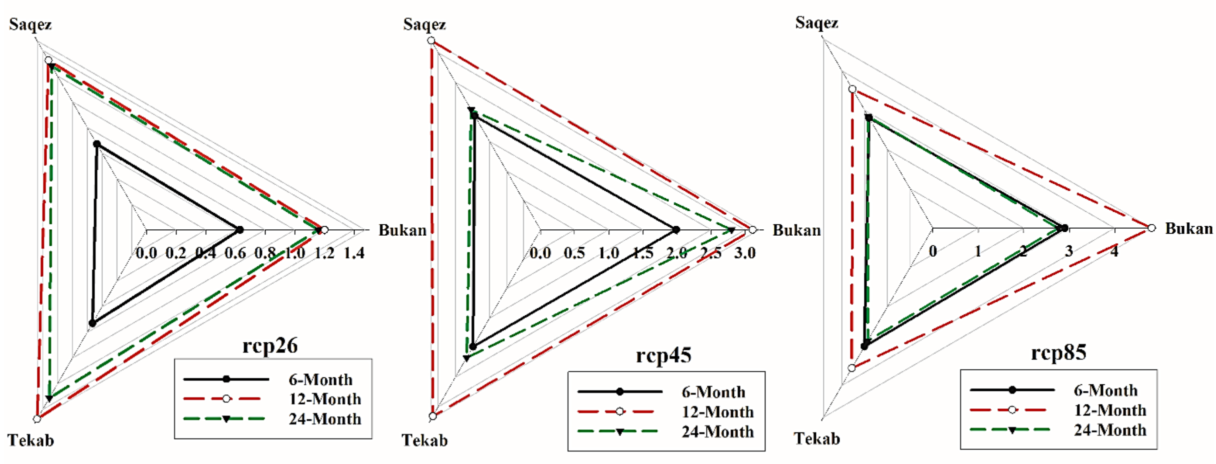


Fig. 14. Results of MK statistics review in the changing process of SPI values in the study area (Values must be multiplied by -1)

The decrease in SPI values in both statistical periods showed that the study area was susceptible to drought and that these changes would increase in the future. The results showed that the decrease in SPI values in the future would be significant according to the current conditions, which match the Javan (2021) in the study area. Also, based on studies such as Javan (2020), it can be acknowledged that the Standard Precipitation Index (SPI) is the most popular logical tool for drought analysis.

4. Conclusion

In this study, by using the rainfall values of Bukan, Saqez and Takab stations in two basic statistical periods (1959-2020) and future (2020-2100) precipitation changes in the Sari-Qamish sub-basin in the south of Lake Urmia under the influence of climate change and pre- CanESM2 forecasters were analyzed under three optimistic RCP2.6, moderate RCP4.5 and pessimistic RCP8.5 scenarios. The results of SPI values in the basic statistical period (1959-2020) showed the decreasing trend of SPI values in the analyzed statistical period in three time windows of 6, 12 and 24 months. Also, the increase of drought changes in all three studied stations has had significant changes since 1995 and has increased strongly in recent years in the 6-month mode. The results of the correlation between the observed values and the CanESM2 predictor values indicate the acceptable accuracy of the 95% confidence limits of the multivariate regression model in the simulation of precipitation according to the best CanESM2 predictors. Also, on a monthly scale, the efficiency of the model had an acceptable accuracy of simulating precipitation values of more than 89%. According to the simulated values, the SPI index in the statistical period of 2020-2100 in three time windows of 6, 12 and 24 months and under the three scenarios RCP2.6, RCP4.5 and RCP8.5 showed that the SPI values are increasing and This increase has been moderately and pessimistically significant. By examining each of the stations, the results showed that at Bukan station, the number of months with negative SPI increased from 46 months in the base period to 48 months in the future period under the RCP2.6 scenario and to 52 months under the RCP4.5 scenario increased to 83 months under the RCP8.5 scenario. This increase for Saqez station is from 47 months in the base period to 46, 51, and 52 months in the statistical period of 2020-2100 under RCP2.6, RCP4.5, and RCP8.5 scenarios, respectively. In Takab station, the number of months with negative SPI has increased from 45 months in the basic statistical period to 46, 52 and 53 months in the 2020-2100 statistical period under the mentioned scenarios. The average changes in precipitation values at Bukan station in the basic statistical period (1959-2020) compared to the predicted statistical period (2020-2100) under RCP2.6, RCP4.5, and RCP8.5 scenarios are about 22, 24, and 38, respectively. The percentage will decrease. The same decrease percentage in Takab station is about 21, 23 and 36% respectively and in Saqez station it is about 24, 27 and 41% respectively. In addition, based on the pessimistic scenario of RCP8.5, severe droughts are observed at the end of the predicted statistical period due to the lack of management of greenhouse gases and the increase of fossil fuels.

5. Disclosure Statement

No potential conflict of interest was reported by the authors.

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