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Assessment of Drought Characteristics and Trend Analysis in Antalya Basin, Turkey

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ABSTRACT

Drought is a phenomenon related to water scarcity due to decrease in precipitation over a long period of time. It is also identified as a natural and a recurrent feature of climate, although many erroneously consider it as a rare and random event. The understanding and trend analysis of historical drought is vital for the future development and management of water resources. In this study, the Standardized Precipitation Index (SPI) at SPI 1, 3, 6 and 12 month time scales was computed using long time series (1970-2007) of monthly precipitation data observed at 9 meteorological stations in Antalya Basin, Turkey. The computed SPI values were, then, subjected to the Mann-Kendall (MK) and Spearman's Rho (SR) statistical trend analyses. Based on the results of the study, most of the results of SPI determined for above indicated time-scales, were found to fall under "No Drought" and "Near Normal" drought intensity classes. Though there are variations in the values of the drought characteristics considered in the study, the values did not show spatial pattern. In addition, significant trend without spatial pattern was observed in the SPI 12 values determined for almost all of the stations considered in the study.

Keywords: Drought; SPI; Drought duration; Drought magnitude; Antalya basin

INTRODUCTION

Drought is a natural phenomenon that results from deficiency of water, usually as results of considerable shortage in precipitation, or as a result of mismatch between water supply and demand at a particular area and during a certain period of time (Zarger et al., 2011). It is often considered as a temporary condition as it takes place when the water demand of a system is more than the supply of water (Zolotokrylin, 2013). As indicated by Ye et al. (2016), drought is a widespread and frequently occurring climate-related hazard that occurs virtually in all climatic zones of the world.

According to Botterill and Cockfield (2013), drought is known to cause significant declines in crops and livestock productivity in various parts of the world. According to the South African National Disaster Management Center (Elliott et al., 2014), drought results in reduction in agricultural production and productivity by affecting quality and quantity of crops and animals. Drought also intensifies insect infestation, plant and animal disease, increases cost of irrigation and other surface and ground water development interventions (Vose et al., 2016). These, directly or indirectly, affect the economy of a region and the wellbeing of people living in that region.

Turkey is one of the countries in the Mediterranean Basin that have frequently been affected by drought in recent decades, mainly as a result of high temporal and spatial variability of precipitation (Caloiero et al., 2018). This has caused a significant loss in the agricultural sector. In addition, severe droughts are known to affect other economic sectors of the Country that use water as vital input (Kayam and Cetim, 2012).

The frequency, duration, spatial coverage and, level or intensity are variables that are used to characterize drought (Wilhite 1993; Savari et al., 2009). Identifying these characteristics and determining the level (intensity) of drought is crucial to reduce the damages caused by drought. According to Kogan (2000), drought characterization is essential as it enables operations such as drought early warning and, according to Hayes et al., (2004), drought risk analysis needs to be carried out as it allows improved preparation and contingency planning. Regional drought analysis is vital for designing efficient and sustainable water management strategies, both on the demand and supply side (Ziolkowska, 2016). As stated by Boudad et al. (2018), the characterization of drought plays a vital role in the planning of strategies with regards to resource mobilization and management of water resources.

Drought can be classified as meteorological, hydrological, agricultural and socio-economic depending on variables considered to determine its impacts (Edossa et al., 2010). Meteorological drought takes place when an area experiences precipitation below normal for a considerable period of time. Hydrological drought is a term used to describe the absence of the required amount of water supply expressed in terms of stream discharge, amount of water stored in a reservoir, and/or the depth of groundwater table, whereas agricultural drought describes the condition of soil moisture content. Apparently, meteorological drought appears before the other forms of drought and it affects the others (Zarger et al., 2011).

A number of methodologies have been developed to characterize drought. Among these methods, however, drought indices-based quantification of intensity and duration of droughts has been widely used (Keyantash and Dracup 2002; Jain et al., 2015). This is because drought indices are simple to determine and flexible, and can easily be used to compare changes from what was normal at various spatial and temporal scales (Marcos-Garcia et al., 2017). Among many drought indices, the Standardized Precipitation Index (SPI) is widely used in various regions of the world. In addition, SPI was selected in this study as it is recommended by the World Meteorological Organization (WMO) for meteorological drought analyses (WMO 2015).

Drought indices can be determined using historical and/or projected data. However, analyses of droughts using historical data is recommended as it provides real information on droughts so that future drought events can be monitored more effectively (Keyantash and Dracup 2002). This study was, therefore, initiated to investigate/characterize meteorological drought in Antalya Basin of Turkey using observed precipitation data of 1970-2007 by employing the Standardized Precipitation Index (SPI).

MATERIAL AND METHODS

Description of the study area

This research was conducted in Antalya Basin, Turkey. The Basin is located in the South West part of Turkey extending from 29.8696° E to 32.3028° E and from 36.2010° N to 38.4388° N geographic coordinates, and with an area of 19.58 km^2 (Figure 1). The basin drains surface runoff to the Mediterranean Sea and the total annual surface runoff is estimated to be 11.06 km^3 (Ministry of Agriculture and Forestry, 2016).

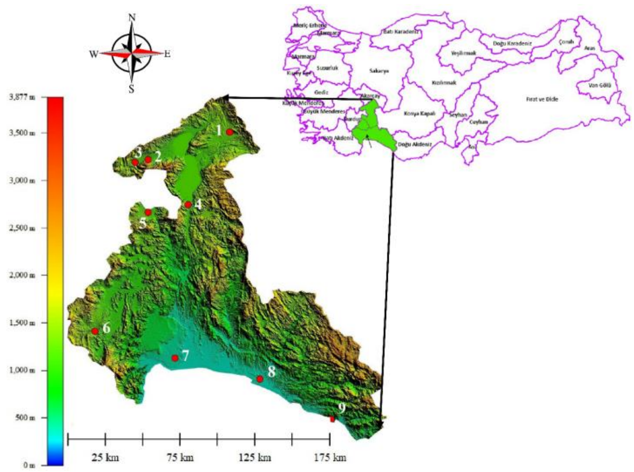

Figure 1. Locations of Antalya Basin and meteorological stations considered in the study.

Data collection and analyses

In order to meet the objective of the study, long time historical precipitation data of nine stations located in the study basin (Figure 1) were collected from the Turkish Meteorological Services. The names and locations of these stations are given in Table 1. These stations were selected based on the presence of long, continuous data at these stations. A total of 38 years of monthly rainfall data (1970-2007) were used in this study.

Table 1. Names and locations of the meteorological stations considered in the study.

Rain gauge station	Latitude (°)	Longitude (°)
1	38.2830	31.1778
2	38.1047	30.5577
3	38.0860	30.4582
4	37.8377	30.8720
5	37.7848	30.5679
6	37.0565	30.1910
7	36.9063	30.7990
8	36.7895	31.4410
9	36.5507	31.9803

Description of Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is one of the most widely used precipitation data-based meteorological drought indices. It was developed by McKee et al. (1993) to analyze and evaluate drought events. This method is based on only precipitation data. It is also known to be a simple index that allows checking not only drought periods, but also wet periods (Edwards and McKee 1997). According to Edwards and McKee (1997), this method is determined to compare precipitation within a certain period time to the long-term mean precipitation of a particular time step observed at the same site. Mathematically, it is given as:

$$SPI = \frac{X_i - \overline{X}}{\sigma},$$

where SPI X_i is precipitation at time i, $\overline{X}$ is mean precipitation of a particular time step and σ is standard deviation.

The mathematical computation of this index, for any time scale, at any study area is carried out using long-term precipitation data (longer than 30 years). The long-term precipitation data is fitted to Gamma Probability Density Function, which is then transformed into a normal distribution (Edwards and McKee, 1997). The SPI can be calculated for any time scale and this is done by comparing the precipitation for the period of interest (usually 1 month, 3 months, 6 months, 9 months and 12 months) to the mean of the same period over the historical record. Based on the values of this index, the intensity of drought can be classified as depicted in Table 2 (McKee et al., 1993).

Table 2. Drought intensity classification based on SPI.

SPI	Drought intensity class
-2 and less	Extreme
-1.5 to -1.99	Severe
-1 to -1.49	Moderate
0 to -0.99	Near normal
Above 0	No drought

Once the SPI 1, SPI 3, SPI 6 and SPI 12 values are determine at the selected stations, the values are further analyzed to characterize drought in a study area based on duration, intensity and trend.

Determination of drought duration and magnitude

As stated by Spinoni et al., (2014), Drought Duration (DD) is determined as the number of months between the start and the end of drought. According to McKee et al. (1993), drought event starts when the SPI is continuously negative and reaches an intensity of -1.0 or less and it ends when the SPI becomes positive. Thus, these definitions were used to determine the maximum Drought Duration at every station under the considered SPIs in this study. Thompson (1999) defined Drought Magnitude (DM) as the cumulative values of drought index over a drought period. In this study, MD was determined as the sum of SPI values within the maximum DD. DM divided by DD gives the Average Drought Intensity (ADI).

Trend analysis

In this study, the non-parametric Mann-Kendall (MK) and Spearman's Rho (SR) statistical tests were used in detection of drought trend in Antalya Basin. These tests identify the presence of significant trend in the values of the SPIs calculated during the study period.

A) Mann-Kendall (MK) test

Mann-Kendall test is a test for correlation between a sequences of pairs of values. The testing of trends is made at a specific significance level α, which is usually taken at 0.05. For the time series x_1, .., x_n, the MK test statistic is calculated using the formula:

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

$$sgn\left(x_j - x_i\right) = \begin{cases} +1 & if \quad \left(x_j - x_i\right) > 0 \\ 0 & if \quad \left(x_j - x_i\right) = 0 \\ -1 & if \quad \left(x_j - x_i\right) < 0 \end{cases}$$

The application of trend test is done to a time series x_i that is ranked from i = 1, 2 …n-1 and x j, which is ranked from j = i+1, 2 ….n.

The sample size n ≥ 10, the mean and variance of S are given as follows:

$$Var(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18},$$

where T_i is the number of data in the tied group and m is the number of groups of tied ranks. The test statistics Z is computed as:

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

The standardized MK statistic Z follows the standard normal distribution. Positive values indicate an increasing trend and negative values indicate a decreasing trend. To test for either an increase or decrease monotonic trend at α level of significance, H_0 is rejected if $|Z| > Z_{1-\alpha/2}$. At the 5% significance level (α =0.05), the null hypothesis is rejected if |Z|> 1.96.

B) Spearman's Rho test

Another rank-based non-parametric statistical test is the Spearman's rho test that used for trend analysis. In this test, assuming that the time series data are identically distributed and independent, the null hypothesis (H_0) and alternate hypothesis (H_1) indicate that there is no trend and the trend exists, respectively. The test statistics R_{SP} and standardized statistics Z_{SP} are calculated as follows (Yue et al., 2002):

$$R_{SP} = 1 - \frac{6\sum_{i=1}^{n}(D_i - i)^2}{n(n^2-1)}$$

$$Z_{SP} = R_{SP}\sqrt{\frac{n-2}{1-R_{SP}^2}} \quad ,$$

where n is the length of the time series, D_i is the rank of the i^{th} observation x_i in the time series and Z_{SP} is student's t-distribution with (n-2) freedom degree. The positive values of Z_{SP} indicate upward trend in hydrological time series, while negative Z_{SP} indicate downward trends in hydrological time series. The null hypothesis (H_0) is rejected and a significant trend exists in the hydrologic time series if $|Z_{SP}| > t_{(n-2,1-\alpha/2)}$.

RESULTS AND DISCUSSION

SPI values determined at various stations

The SPI1, SPI3, SPI6 and SPI12 values determined at the stations considered in the study were further analyzed to assess corresponding frequencies of the various drought levels. The values of this analysis are presented in Figure 2. As can be seen from the figure 2, a significant majority of the determined SPI values (SPI1, SPI3, SPI6 and SPI12) fall under "No drought" class, followed by "Near Normal" class. "Extreme" drought level was found to be the least frequent drought level at every station and for all SPIs.

Again, the SPI values were further analyzed to determine the most extreme values of SPIs determined for each station and identify the months and years corresponding to these values (Figure 3).

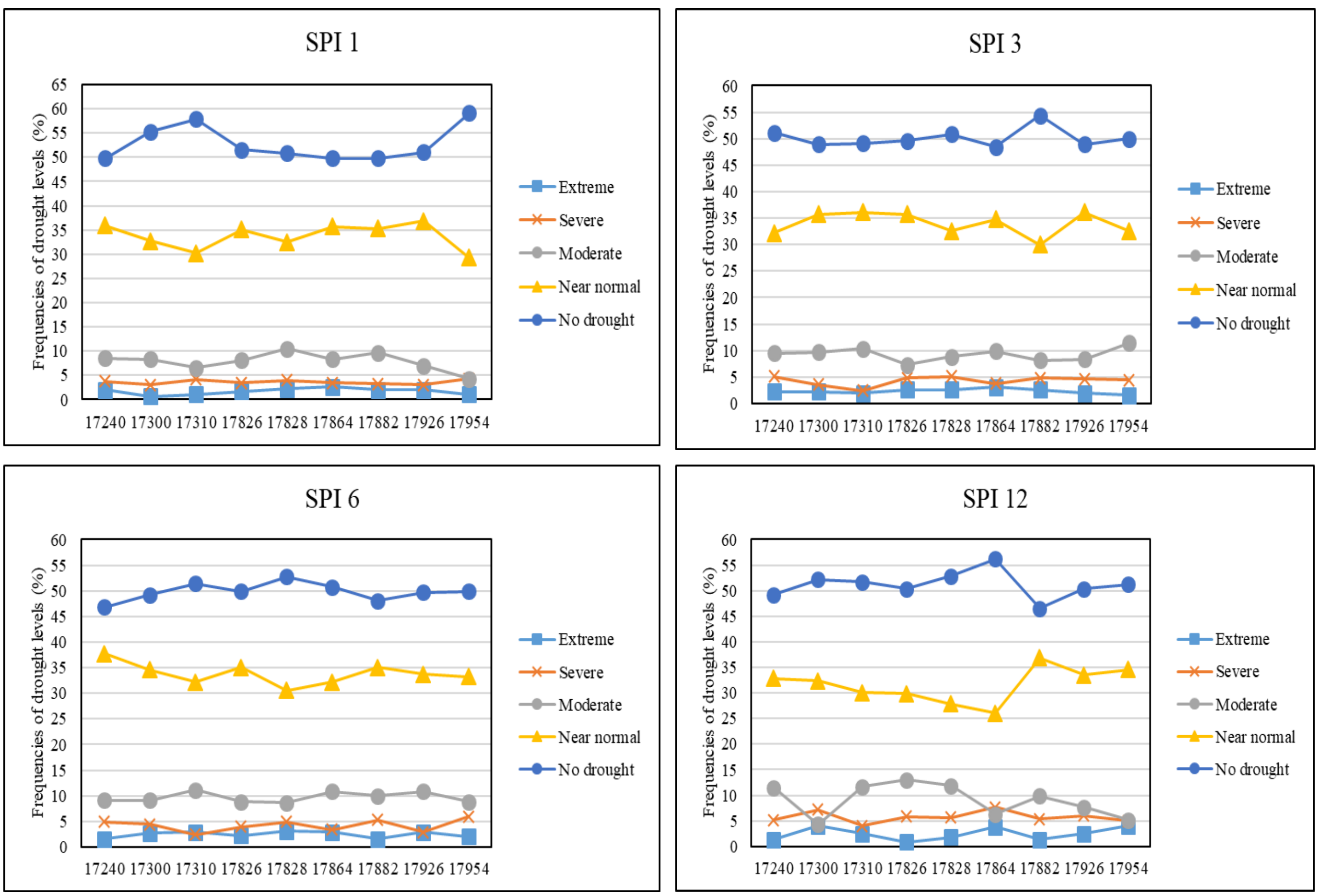

Figure 2. Frequencies of various levels of droughts (%) calculated at various stations.

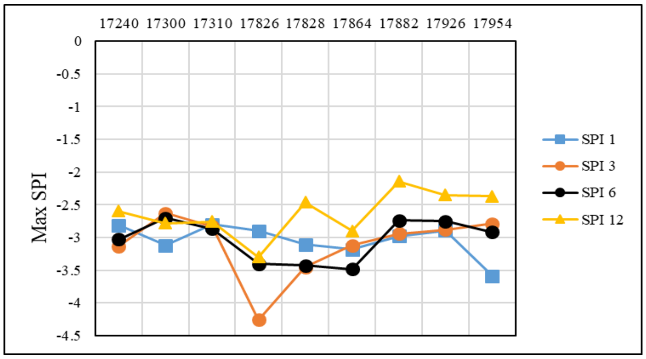

Figure 3. The most extreme values of SPIs together with the months and years for each station.

As depicted in the figure 3, the largest SPI 1 value of -3.59 was obtained at Station 17954 and it was calculated for the month of March of 1986. The largest SPI 3, SPI 6 and SPI 12 values were obtained at Stations 17826 (with value of -4.26), 17864 (with value of -3.48) and 17826 (with value of -3.3), respectively. One can also notice that, based on the maximum SPI 3, SPI 6 and SPI 12 values presented in the table, the maximum SPI values calculated at stations located in the northern part of the study are more intense than the maximum SPI values calculated at stations located in the southern part of the study area.

As ways of characterizing the drought in the study area, the maximum durations (DR) and the corresponding magnitudes (MM) of the various SPI values were determined, and the average duration of drought intensity (ADI) values were determined as ratios of MG to DR values. The values of these characteristics are presented in Figure 4.

Considering the values of DR of SPI1 presented in Figure 4, one can see that the longest drought duration of the stations located in the northern part of the study area was observed at Station 17240 (11 months), followed by Station 17828 (10 months). Whereas, the longest duration of the stations located in the southern part of the study area was observed at Station 17310, with a value of 8 months. The mean DD of the stations located in the northern part of the basin was found to be 8.6 months and the corresponding value of the stations located in the southern part of the basin was found to be 6.75 months. Thus, it can be said that the maximum DD values in the northern part of the basin are longer than the DD values at the southern part of the basin. With regards to the DM values under SPI 1, the largest drought intensity was observed at Station 17864 (9.92) followed by Station 17310 (8.61).

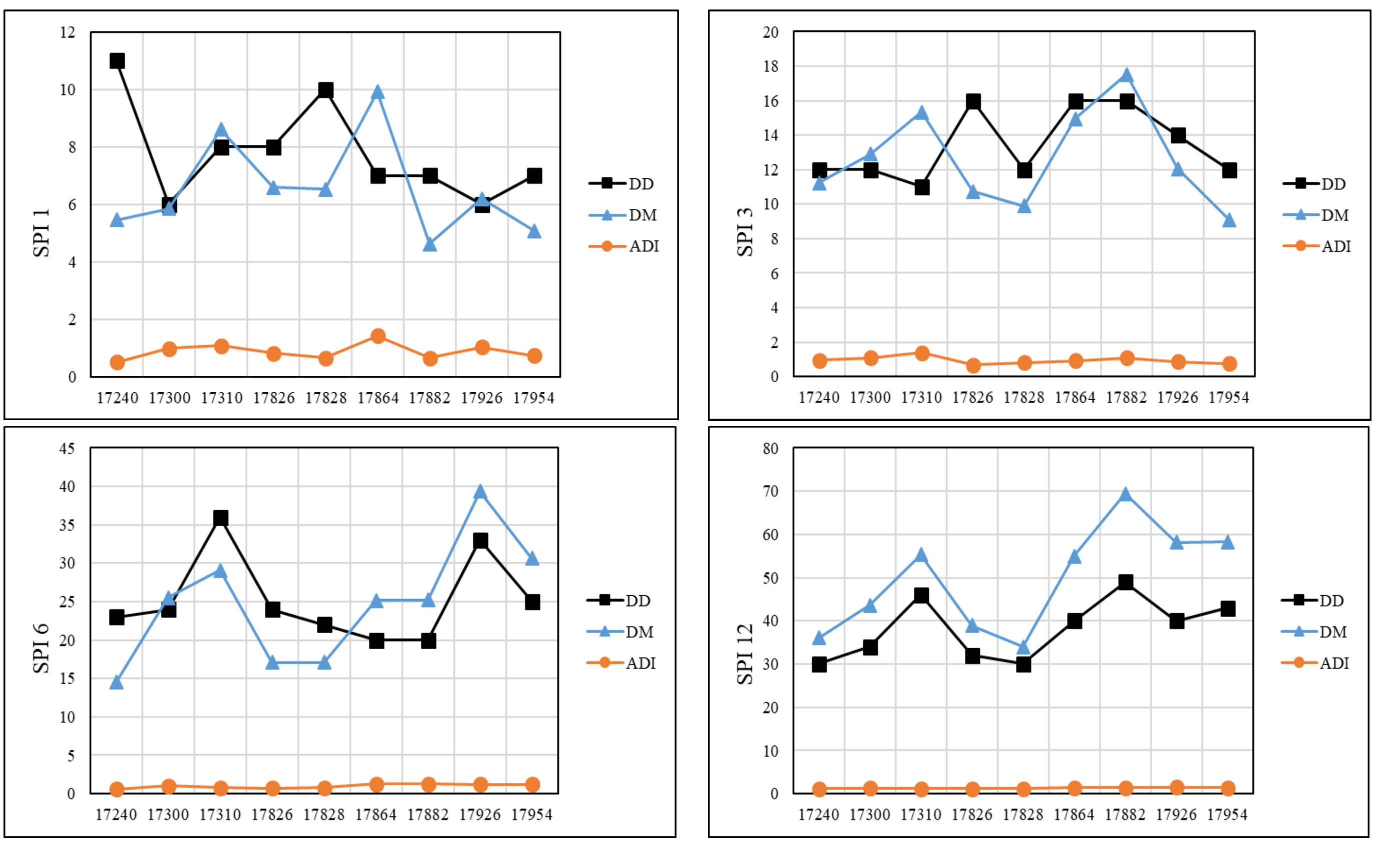

Figure 4. Drought characteristics (DD, DM and ADI values) of the stations for various SPI values.

The DD values under SPI 3 exhibited similar characteristics to the ones under SPI 1. When it comes to SPI 6 and SPI 12, the longest DD values were observed at Station 17310 with values of 36 months and 46 months, respectively. In general, taking into consideration the values of DD, DM and ADI determined under SPI3 and SPI6, there is no considerable difference among stations located in the northern and southern parts of the study area, though DR values of SPI3 and SPI6 ranged from 4-7 months and from 7-10 months, respectively. The longest duration and the largest drought magnitude were obtained at Station 17864 with values of 27 months and 49.25, respectively, taking into consideration SPI 12. For SPI 12, the shortest duration and the smallest drought magnitude were obtained at Station 17828.

Trend analyses in the SPI values

The values presented in Table 3 are MK statistical values for identification of significant trend in the SPI values. Depending on the values of MK and SR values presented in Table 3, it can be seen that all stations did not exhibit significant trends in their SPI 1 and SPI 3 values. Out of all the stations considered in this study, it is only Station 17882 that showed a significant increasing trend in its SPI 6 value. As can be seen from Table 3, the SPI 12 values of all stations, but Station 17240, exhibited the presence of significant trend at various levels of significance. Among these stations, Stations 17826, 17864, 17882, 17926 and 17300 showed significant increasing trends in their SPI 12 values considering both MK and SR values. As opposed to this, Stations 17828 and 17310 exhibited decreasing trends in their SPI 12 values. Based on these values and the locations of these stations, one can tell that there is not difference in the presence of trends of SPI 12 values at stations located in the northern and southern parts of the study area.

Table 3. Mann-Kendall (MK) and Spearman's Rho (SR) values for identification of significant trend (Critical values at the 0.1, 0.05 and 0.01 significance levels are 1.645, 1.96 and 2.576, respectively).

Stations	SPI-1		SPI-3		SPI-6		SPI-12	
	MK	SR	MK	SR	MK	SR	MK	SR
17828	-0.67	-0.68	-0.87	-0.94	-1.23	-1.26	**-2.59 (S, 0.01)**	**-2.57 (S, 0.05)**
17826	0.03	0.02	0.25	0.23	0.57	0.56	**1.84 (S, 0.1)**	**1.79 (S, 0.1)**
17864	0.16	0.18	0.68	0.67	1.24	1.21	**1.91 (S, 0.1)**	**1.73 (S, 0.1)**
17240	-0.09	-0.05	0.24	0.28	0.61	0.56	1.34	1.51
17882	0.57	0.64	1.11	1.15	**1.80 (S, 0.1)**	**1.77 (S, 0.1)**	**3.78 (S, 0.01)**	**4.02 (S, 0.01)**
17926	0.19	0.24	0.88	0.89	1.40	1.34	**2.06 (S, 0.05)**	**2.13 (S, 0.05)**
17300	0.38	0.76	0.80	0.86	1.54	1.54	**4.50 (S, 0.01)**	**4.53 (S, 0.01)**
17954	0.01	0.58	0.14	0.22	0.47	0.54	0.44	0.87
17310	-0.55	0.05	-0.68	-0.60	-0.74	-0.69	**-2.61 (S, 0.01)**	**-2.32 (S, 0.05)**

CONCLUSION

Based on the SPI values of the various time scales considered in this study, significant proportions of the SPI values at all stations fall within the "Near Normal to No Drought" classes. In addition, though some characteristics of drought in the study basin were found to be larger at stations located in the northern part of the study area, it is very difficult to conclude that the values exhibit spatial pattern. Moreover, all stations, but one, showed the presence of significant trend in the values of SPI 12. However, this result was not found to be location related. With regards to SPI 12 values, a significant trend was observed at all stations, but one. Thus, conducting a study on the drought characteristics of SPI 12 considering future climate change in the study area is of paramount importance.

DECLARATIONS

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Conflict of interest

The authors hereby confirm that there is no conflict of interest.

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