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Identification of the trends associated with the SPI and SPEI indices across Ankara, Turkey

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Abstract

This study investigates the main characteristics (duration, severity, and trend) of meteorological drought events over Ankara Province, Turkey. We used 46 years of observed monthly precipitation and temperature series from six meteorological stations distributed across the study area to derive the well-known meteorological drought indices; the standardized precipitation index (SPI) and standardized precipitation evapotranspiration index (SPEI) both in 3-, 6-, and 12-month timescales. A comparative analysis between the indices, associated drought events, and potential trends at each station are presented. To explore the drought trends in each station, the well-documented Spearman rank-order correlation coefficient, innovative Şen's method, and innovative trend analysis are applied. The results showed that the province faced five extreme drought events during the period of 1971–2016, although temporal inconsistencies between the SPI and SPEI, particularly in 6- and 12-month timescales exist. Considering the SPEI, the results indicated a slight descending trend in the observed drought events; however, the SPI does not conform to the same pattern.

Keywords Drought · SPI · SPEI · Trend · Ankara

1 Introduction

Drought is a natural phenomenon, and its overall impact is determined based on its duration, severity, frequency, and areal extent. Drought monitoring is usually conducted under four categories of meteorological (precipitation deficit), hydrological (scarcity of surface and subsurface water resources), agricultural (shortage of water during growing and mature periods for crops), and socioeconomic droughts. Each of these categories needs its own indices and identifying variables. To date, numerous research articles have been addressed various drought indices at each category (e.g., Morid et al. 2006; Danandeh Mehr et al. 2014; Hesami Afshar et al. 2016; Montaseri and Amiratae 2017; Yacoub and Tayfur 2017; Tosunoglu et al. 2018; Myronidis et al. 2018; Terzi et al. 2019; Yihdego et al. 2019). To monitor meteorological

drought, various indices such as Standardized Precipitation Index (SPI), Deciles Index (DI), Drought Area Index (DAI), Percent of Normal (PN), Palmer Drought Severity Index (PDSI), China-Z index (CZI), Effective Drought Index (EDI), Reconnaissance Drought Index (RDI), and the most recently developed Standardized Precipitation Evapotranspiration Index (SPEI) are available. These indices are usually calculated using historical precipitation and/or temperature time series.

In view of global warming and its impact on regional climate, trend analysis of extreme events like drought has got more attention over the past decades (e.g., Chattopadhyay and Edwards, 2016; Cui et al. 2017; Wu and Qian 2017; Labudová et al. 2017; Shiru et al. 2018; Dong et al. 2019; Polong et al. 2019; Danandeh Mehr et al. 2019). For instance, Xu et al. (2003) studied the possible long-term precipitation trends in Japan using parametric and nonparametric approaches. Partal and Kahya (2006) used the well-documented Mann–Kendall and Sen's tests to investigate the trends associated with monthly and annual mean precipitations across Turkey. The study concluded that systematic approaches are critical in detecting the climatic change induced trends across the country. Abarghouei et al. (2011) studied the linear trends associated with 3-, 6-, 9-, 12-, 18-, and 24-month SPI indices

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across Iran. A 30-year time span was used, and it was concluded that the drought severity is increasing in the country. The Potential trend in annual precipitation and streamflow series of the Eastern Black Sea Region was investigated by Eris and Agiralioglu (2012) using the Mann-Kendall test. Yang et al. (2016) studied the SPEI in the Haihe River Basin from 1961 to 2010 and demonstrated that the basin drought frequency is increasing at both annual and seasonal scales. Cui et al. (2017) utilized the simple linear regression, Mann-Kendall, and innovative Şen (IŞM) methods to detect the seasonal and annual trends of temperature and rainfall in the whole Yangtze River Basin, China. The results indicated increasing trends in both temperature and rainfall series in the study area. Tosunoglu and Kisi (2017) employed Mann-Kendall, modified Mann-Kendall, and IŞM methods to investigate the trends in annual maximum duration (AMD) and severity (AMS) in the Coruh River Basin, Turkey. The authors showed inconsistency between the results of Mann-Kendall and modified Mann-Kendall tests. While the former indicated no trend, the latter presented a significant decreasing trend for AMS and AMD series. The IŞM also exhibited a clear decreasing trend in the AMS series. Recently, Nourani et al. (2018) utilized the integrated wavelet transform-Mann Kendall and IŞM techniques to determine potential trends in different hydro-climatological variables affected on the water level of Lake Urmia, Iran. The results indicated that the main factors influencing the lake level are: (a) a significant negative trend in the streamflow series and (b) an increasing trend in the observed temperature time series. Caloiero (2018) applied the Mann-Kendall and IŞM methods to investigate the potential trend in SPI over New Zealand and found increasing and decreasing trends in different regions. In a similar study, Jin et al. (2019) used Mann-Kendall and IŞM methods to investigate trends in of SPEI series at Zoige Wetland, China and showed that the majority of areas had drying trends. More recently, Şen (2019) has proposed a successive arithmetic

Table 1 Classifications of dry conditions using SPI and SPEI indices

| Classification	SPI threshold	SPEI threshold
Moderate drought	$-1.49 < SPI < -1.0$	$-1.42 < SPEI < -1.0$
Severe drought (SD)	$-2.0 < SPI < -1.5$	$-1.82 < SPEI < -1.43$
Extreme drought (ED)	$SPI \leq -2.0$	$SPEI \leq -1.83$

average method in studying trends associated with hydro-meteorological time series. The method was applied in seven geographical and climate regions of Turkey having superior results over the probabilistic, statistical, and stochastic approaches. Most recently, Wang et al. 2019 have applied Mann-Kendall and IŞM and Thiel-Sen Slope tests at the Yangtze River Delta, China to explore the trend of seasonal and heavy rainfall events. The authors demonstrated significant increasing trends during summer and winter as well as the decreasing trend in spring and fall seasons in the study area.

Following the abovementioned trend in drought studies, the main objectives of this study are (i) to screen meteorological drought events across Ankara during the period of 1971–2016 and (ii) to investigate the potential patterns in the drought indices. To this end, we first derived two meteorological drought indices, the well-established SPI and more recently developed SPEI, at different timescales using monthly rainfall and temperature measurements from six meteorological stations located in the study area. Then, the main characteristics of extreme and severe drought events are distilled from the areal average of each drought index. Eventually, the potential trends associated with the SPI and SPEI at each station are analyzed using three methods comprising Spearman's rank order correlation (SROC), IŞM, and innovative trend analysis (ITA). Although there are a few studies assessing trends in drought indices across Turkey (e.g., Sirdaş and Sen 2003;

Fig. 1 Difference between drought indices for a given probability (Danandeh Mehr et al. 2019)
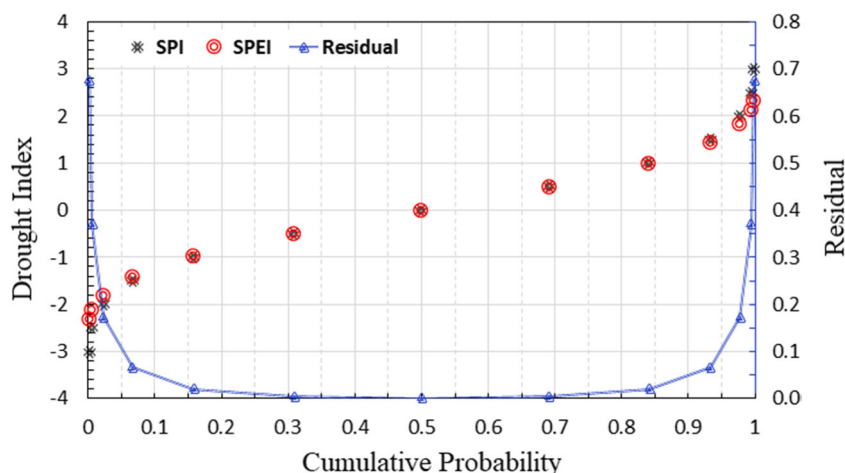
Fig. 2 Location of meteorological stations, Ankara, Turkey
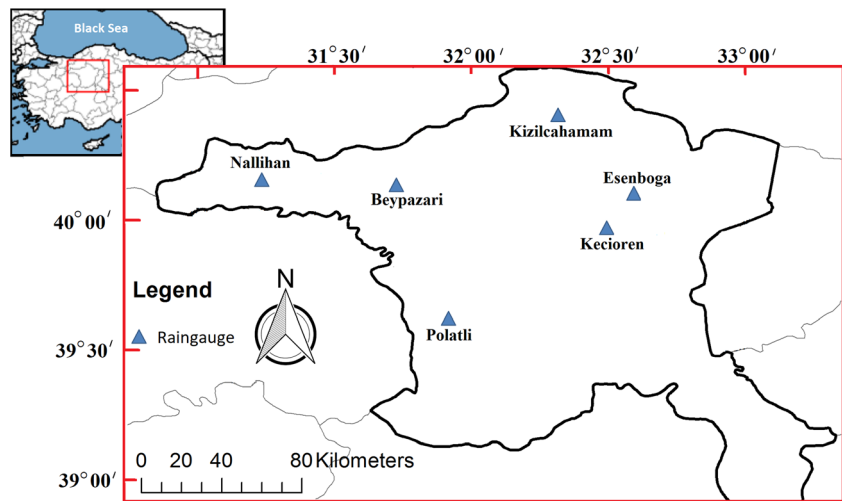
Sönmez et al. 2005; Tatli and Türkeş 2011), to the best of the authors' knowledge, this is the first study that applies SROC, IŞM, and ITA methods in studying the trends associated with both SPI and SPEI in Ankara, Turkey. Moreover, further comparison between the drought classes/thresholds in regard to SPI and SPEI has been accomplished. It is aimed that the results would be helpful for sustainable watershed management and decision-making in Ankara Province.

2 Methodology

2.1 Overview of SPI and SPEI

The SPI (McKee et al. 1993) is one of the most commonly used meteorological drought indices which is developed based on the normalization of precipitation probabilities. It defines the deficit in precipitation and allows drought monitoring at different timescales. Although SPI is generally produced using monthly precipitation data, it can be calculated with daily or weekly data. Owing to the simplicity of SPI and its utilities, the World Meteorological Organization (WMO) recommends the use of SPI as the most essential drought index compulsory in all countries in monitoring meteorological drought conditions. Regardless of the time interval at which precipitation values are presented (1-month time step is used in this study), the SPI calculation is started by fitting the desired distribution function to the accumulated time series of precipitation data and then the probabilities of accumulated precipitation observations are normalized using inverse CDF of the standard normal distribution function. Thus, the values of SPI are the corresponding Z scores of the fitted distribution. Different percentiles of the selected distribution represent different classes of precipitation conditions. The lower the SPI, the higher the drought intensity.

The SPEI (Vicente-Serrano et al. 2010) is another meteorological drought index that considers the variability of both precipitation and temperature to predict drought conditions in a region. The index has been used in the variety of drought-analyzing studios recently (Jiang et al. 2015; Jin et al. 2019; Wang et al. 2019). The first step to calculate the SPEI is the estimation of monthly potential evapotranspiration (PET). Then, the water balance equation is used to calculate the monthly deficit (D_i).

$$D_i = P_i - PET_i \tag{1}$$

where P_i is the total precipitation value at the month i.

Finally, the evolved deficit values are standardized and fitted to a log-logistic distribution function. The SPEI value at the month i is the standardized values of the exceeding probability (p) of a given D_i and is calculated by Eq. (2).

$$SPEI_i = W_i - \frac{2.515517 + 0.802853W_i + 0.010328W_i^2}{1 + 1.432788W_i + 0.189269W_i^2 + 0.001308W_i^3} \tag{2}$$

While for $p \leq 0.5$, $W_i = \sqrt{-2\ln p}$ whilst, if $p > 0.5$, $W_i = \sqrt{-2\ln(1-p)}$, and the sign of the resultant $SPEI$ is reversed for $p > 0.5$ (Danandeh Mehr et al. 2019).

It is worthy to mention that the log-logistic model was suggested by Vicente-Serrano et al. (2010) in the original SPEI methodology. However, this recommendation is based on monthly historical observations from a limited number of sites (11 in total) and statistical fitness tests. Therefore, one can use any other probability distribution method to normalize the index bearing in mind that it would not be the same with the original SPEI. Following Vicente-Serrano et al. (2010), we applied log-logistic distribution in the present study; however, the application of generalized extreme value distribution has also been recommended (Stagge et al. 2015).
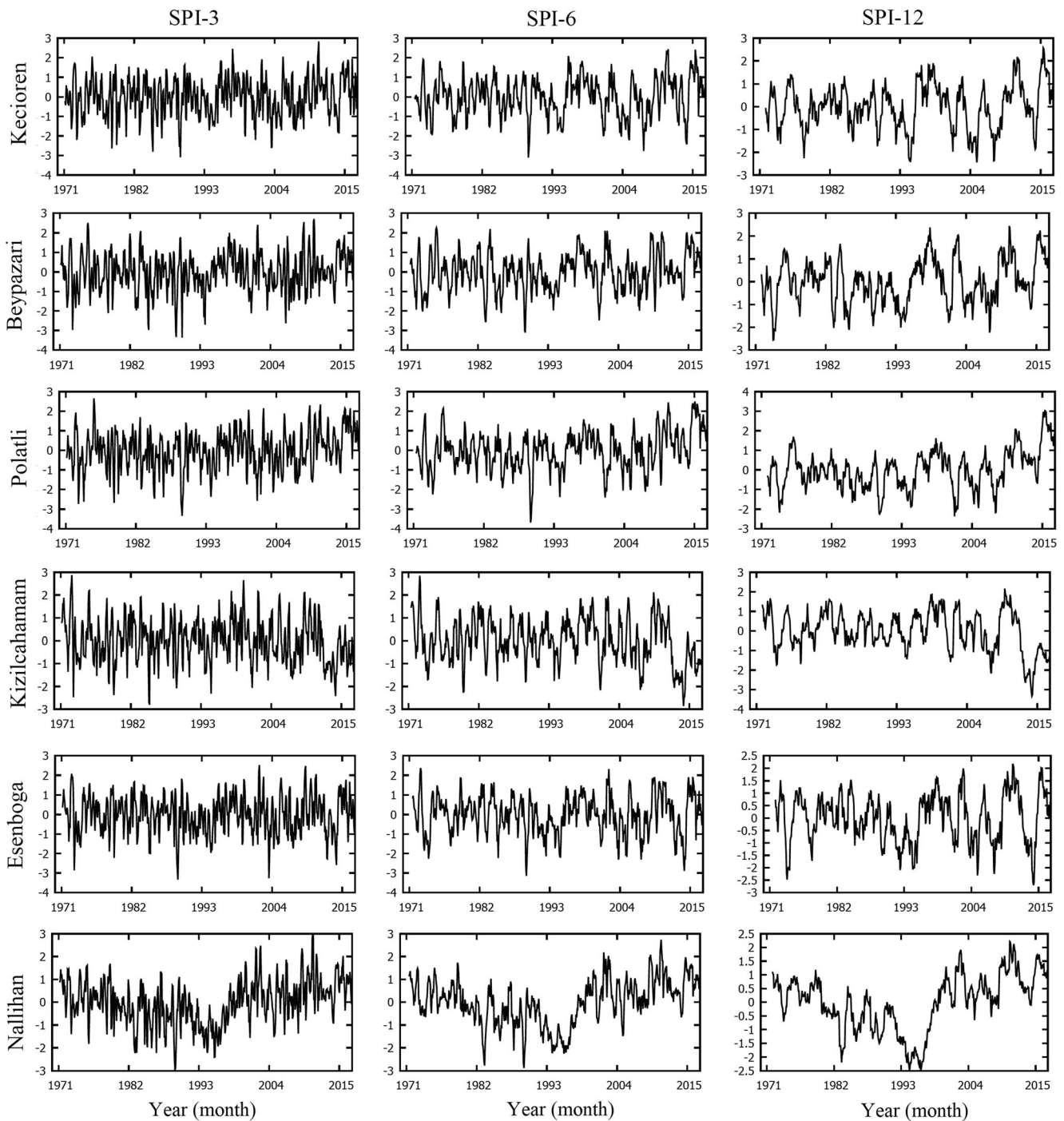
Fig. 3 Evaluation of 3-, 6-, and 12-month SPI at the meteorological stations during the reference period 1971–2016

Danandeh Mehr et al. (2019) have recently compared the residuals between SPI and SPEI for a set of cumulative probabilities and showed that rainfall and deficit do not possess an identical cumulative probability of occurrence, particularly in rare drought conditions (Fig. 1). Therefore, classification thresholds must be derived independently for each index. However, our review showed

that a number of recent studies (e.g., Meresa et al. 2016; Rhee and Im 2017; Abbasi et al. 2019; and Polong et al. 2019) classified the drought events with identical thresholds for SPEI and SPI regardless of the existing conflict. To overcome the inconsistency between the CDFs, the SPEI thresholds determined for a set of given probabilities (see Table 1) are used in this study.
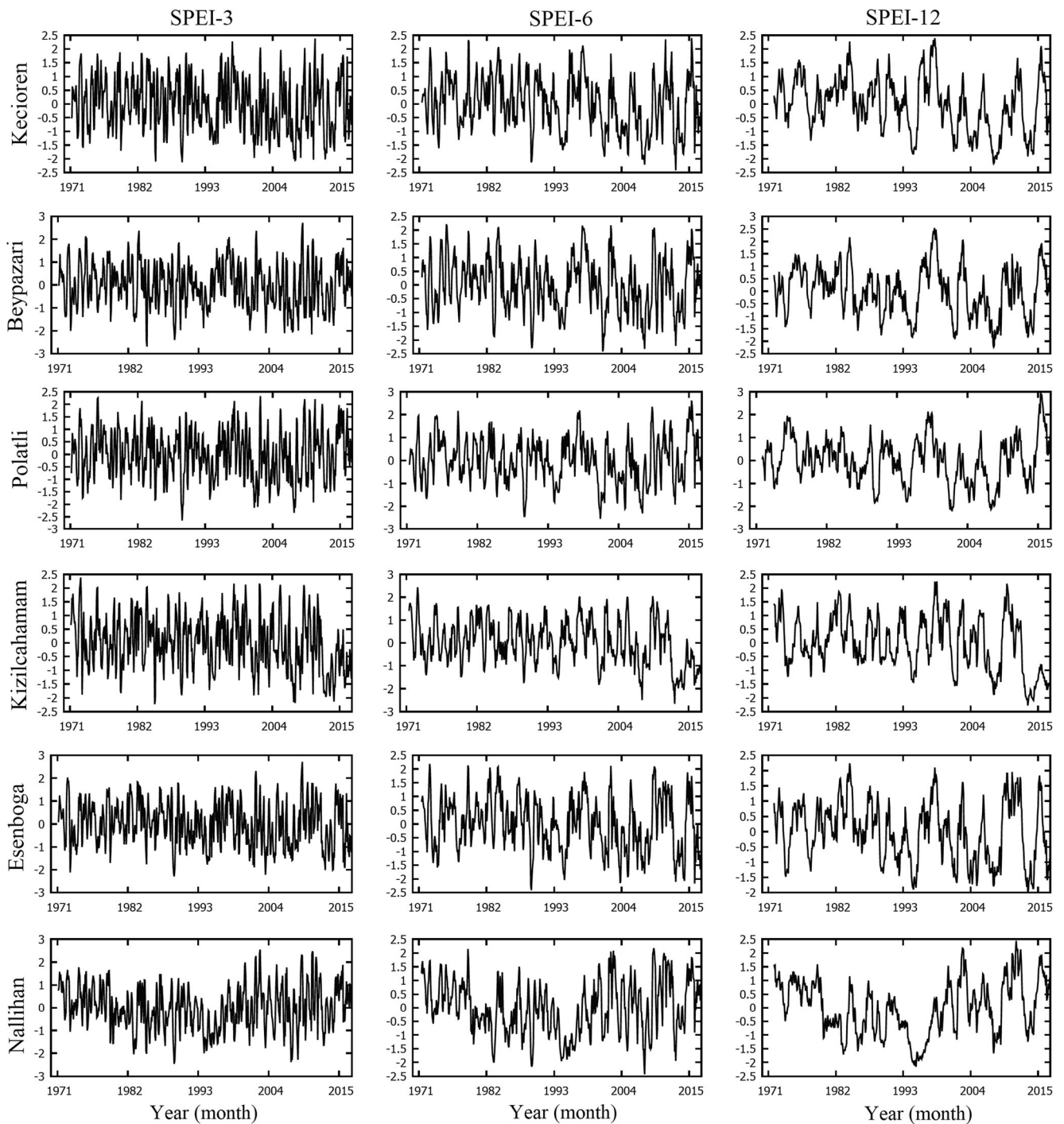
Fig. 4 Same as Fig. 2 but for SPEI

2.2 Trend analysis using Spearman rank order correlation (SROC)

This method is supported by WMO and is a nonparametric test to monitor long-term trends (Adeloye and Montaseri, 2002). McGhee (1985) explained the procedure of SROC as:

i) Consider time series of variable X_t.

ii) Arrange the values, x_t, in descending order and give them ranks.

iii) Calculate the difference between given rank and time step, t as $d_t = R_{Xt} - t$.

iv) Derive the trend coefficient as, $r_s = 1 - \frac{6\sum_{t=1}^{n} d_t^2}{n(n^2-1)}$

v) Considering the null hypothesis, as there is no trend, $t = r_s \sqrt{\frac{n-2}{1-r_s^2}}$

Fig. 5 Mean SPI and SPEI values at Ankara Province
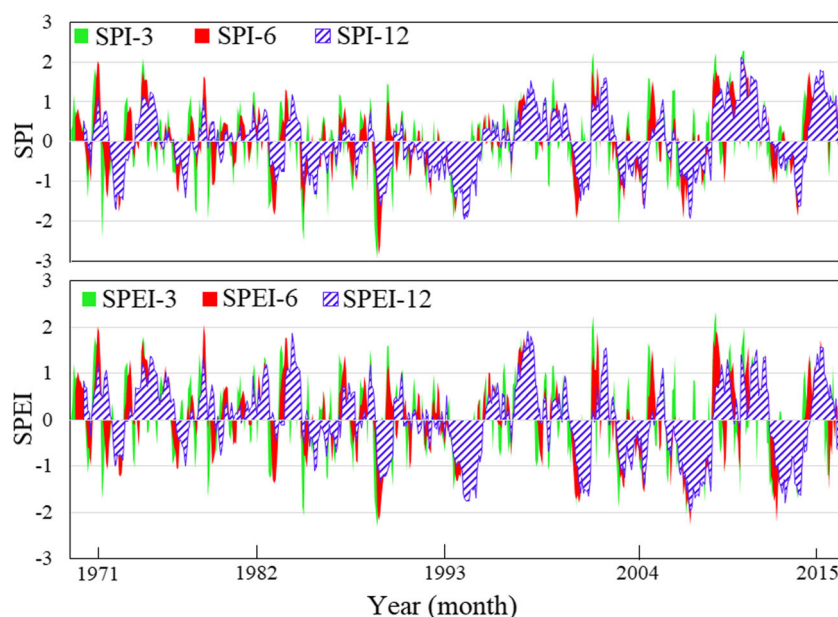
vi) This *t*-value can be compared with a Student's *t*-distribution of *n*-2 degrees of freedom.

vii) Then, obtain the $t_{critical}$ using *t*-distribution table at α significance level with *n*-2 degrees of freedom.

viii) Reject the H_0 when $t > t_{critical\ (\alpha/2,\ n-2)}$ or $t < -t_{critical\ (\alpha/2,\ n-2)}$.

2.3 Trend analysis using innovative Şen's method (IŞM)

The innovative Şen's method is based on the graphical interpretation of the first- and second halves of a hydrological time series projected on a scatter plot (Şen, 2012, 2014). Some of the recent applications of ISM include Ay and Kisi (2015), Dabanlı et al. (2016), Nurani et al. (2018), and Güçlü et al. (2019). The step-by-step approach for using the IŞM is as described below:

i) First, the time series is divided into two halves, and each half is ordered ascendingly to be used on a scatter plot interpretation technique.

ii) First-half of the time series is projected on the *x*-axis, while the second-half is projected on the *y*-axis.

iii) The graphical interpretation of the method suggests that classifications of these trends can be categorized as no-trend (NT), monotonic increasing (MI), monotonic decreasing (MD), non-monotonic increasing (NMI), and non-monotonic decreasing (NMD).

2.4 Innovative trend analysis (ITA)

The innovative trend method (ITA) is somehow a revised version of the IŞM. Fully described by Wu and Qian (2017), the difference between the two methods is based on the rate of an increasing or a decreasing trend. In this respect, time series with different magnitudes must be normalized first. Then, a trend indicator is used to evaluate each time series. This indicator can be obtained using:

$$D = \frac{1}{n} \sum_{i=1}^{n} \frac{10(y_i - x_i)}{\bar{x}} \qquad (3)$$

while *D* is the trend indicator, *n* is the number of data in the time series. A positive *D* indicates an increasing trend, whereas a negative *D* indicates to decreasing trend.

3 Data

The SPI and SPEI were calculated using long-term (1971–2016) observed precipitation and temperature data in six meteorological gauging stations, namely, Polatli, Kizilcahamam, Esenboga, Nallihan, Kecioren, and Beypazari distributed across Ankara Province, Turkey (Fig. 2). The total geographical area of Ankara Province is approximately 25,000 km², located in 39° 00' N to 40° 35' N (latitudes), and 30° 40' E to 33° 20' E (longitudes). The province has an arid and semiarid climate with a mean annual rainfall of about 390 mm. The monthly precipitation and temperature data at the stations were obtained from the Turkish General Directorate of Meteorology (www.mgm.gov.tr).

Table 2 Observed severe drought events with respect to the areal average of SPEI and SPI indices over Ankara

	SPEI				SPI			
Timescale	Year	Dry month(s)	LD	S	Year	Dry month(s)	LD	S
3-month	1973	1	1	1.72	1978	7–8	2	1.76
	1979	4	1	1.69	1979	4	1	1.97
	1989	2	1	1.68	1982	11–12	2	1.65
	1990	3	1	1.44	1983	1	1	1.5
	1993	10	1	1.53	1986	5	1	1.88
	1994	5–6	2	1.45	1989	5	1	1.9
	2001	8	1	1.48	1990	3	1	1.79
	2007	8	1	1.51	1993	10–11	2	1.74
	2008	8	1	1.78	2003	8	1	1.63
	2010	9	1	1.61	2014	1–2	2	1.67
	2012	6–11	6	1.55	–			
	2013	6	1	1.57	–			
	2014	1–2	2	1.61	–			
6-month	1989	7	1	1.67	1974	1–2	2	1.65
	1994	6–9	4	1.52	1983	2–4	3	1.74
	2000–2001	12–4	5	1.67	1984	12	1	1.82
	2003	11	1	1.48	1989	7	1	1.87
	2004	12	1	1.44	1993	11–12	2	1.72
	2005	1	1	1.57	1994	7–8	2	1.65
	2006	8	1	1.45	2001	1–2	2	1.85
	2007	5	1	1.63	2004–5	12–1	2	1.59
	2007	8	1	1.7	2007	4–7	4	1.67
	2012	9–12	4	1.61	2014	1–2	2	1.75
	2014	2–4	3	1.53	–			
	2015	12	1	1.52	–			
12-month	1994–1995	5–2	10	1.62	1973	10–11	2	1.67
	2001	4–10	7	1.57	1989	6–7	2	1.56
	2007	7	1	1.53	1994	5–9	5	1.84
	2007–2008	12–6	7	1.58	2001	4	1	1.5
	2008	12	1	1.54	2005	1	1	1.69
	2013	2–6	5	1.62	2007	9–10	2	1.88
	2014	1–4	4	1.55	2014	2–4	3	1.6

Details about the stations and quality of measurements are available in Hesami Afshar et al. (2016).

4 Results and discussion

4.1 Drought characteristics during the period of 1971–2016

In this study, the SPI and SPEI time series calculations are evolved using SPEI Package (Beguería and Vicente-Serrano 2017) in R environment. By default, the package uses Gamma and log-logistic distributions to standardize the SPI and SPEI values, respectively. The monthly PET is estimated using Thornthwaite method. Figure 3-4 shows the SPI and SPEI time series at 3-, 6-, and 12-month timescales calculated using rainfall and temperature measurements in the period 1971–2016 at all the meteorological stations. It is seen from the figures that wet and dry spells did not necessarily occur in the same months at each station. Likewise, the frequency of different drought events is not identical. For example, while the SPI-3 pattern at Beypazari station shows 12 extreme drought events, the SPEI-3 pattern indicates 16 extreme drought events during the same period. The SPI uses solely precipitation whereas the SPEI is based on both precipitation and temperature. Hence, it must be considered before making any decision.

Using the SPI and SPEI patterns in six meteorological stations, the mean SPI and SPEI patterns for Ankara province have been calculated and presented in Fig. 5. The main characteristics of historical severe and extreme drought events

Table 3 Observed extreme drought events with respect to the areal average of SPEI and SPI indices over Ankara

|	SPEI				SPI			
Timescale	Year	Dry month(s)	LD	S	Year	Dry month(s)	LD	S
3-month	1984	11–12	2	2.04	1973	1	1	2.44
	1989	3–5	3	2.08	1984	11–12	2	2.35
	2001	1	1	1.88	1989	2–4	3	2.53
	2003	7	1	1.91	2001	1	1	2.02
	2007	7–10	4	1.98	2003	7	1	2.11
6-month	1989	4–6	3	2.03	1989	4–6	3	2.51
	2007	7–10	4	2.03	–			
	2012	11	1	2.21	–			
12-month	2007	9–11	3	1.91	–			

including the year, months, length of drought (LD), and drought intensity (S: average severity) were summarized in Table 2 and Table 3, respectively.

Based on both SPI-3 and SPEI-3 pattern, Table 3 indicates that five extreme drought cases occurred within the 46 years of the investigation period. However, there are temporal differences between the indices. Considering SPI-3, the first and the last extreme drought occurred in 1973 and 2003, respectively. But from the SPEI-3 points of view, there is no extreme drought in 1973 and the last extreme drought tool place in 2007 lasting 4 months (beginning in July and termination in

November). Such long-lasting extreme drought in 2007 can also be recognized using SPEI-6 and SPEI-12 indices. A marked difference between the indices is also observed for a 1-month-lasting extreme drought event in November 2012 which is recognized only by SPEI-6.

4.2 Drought characteristics in the 1971–2016 in regard to SROC, IŞM, and ITA

As already mentioned, three methods were used to explore potential trends associated with the SPI and SPEI drought
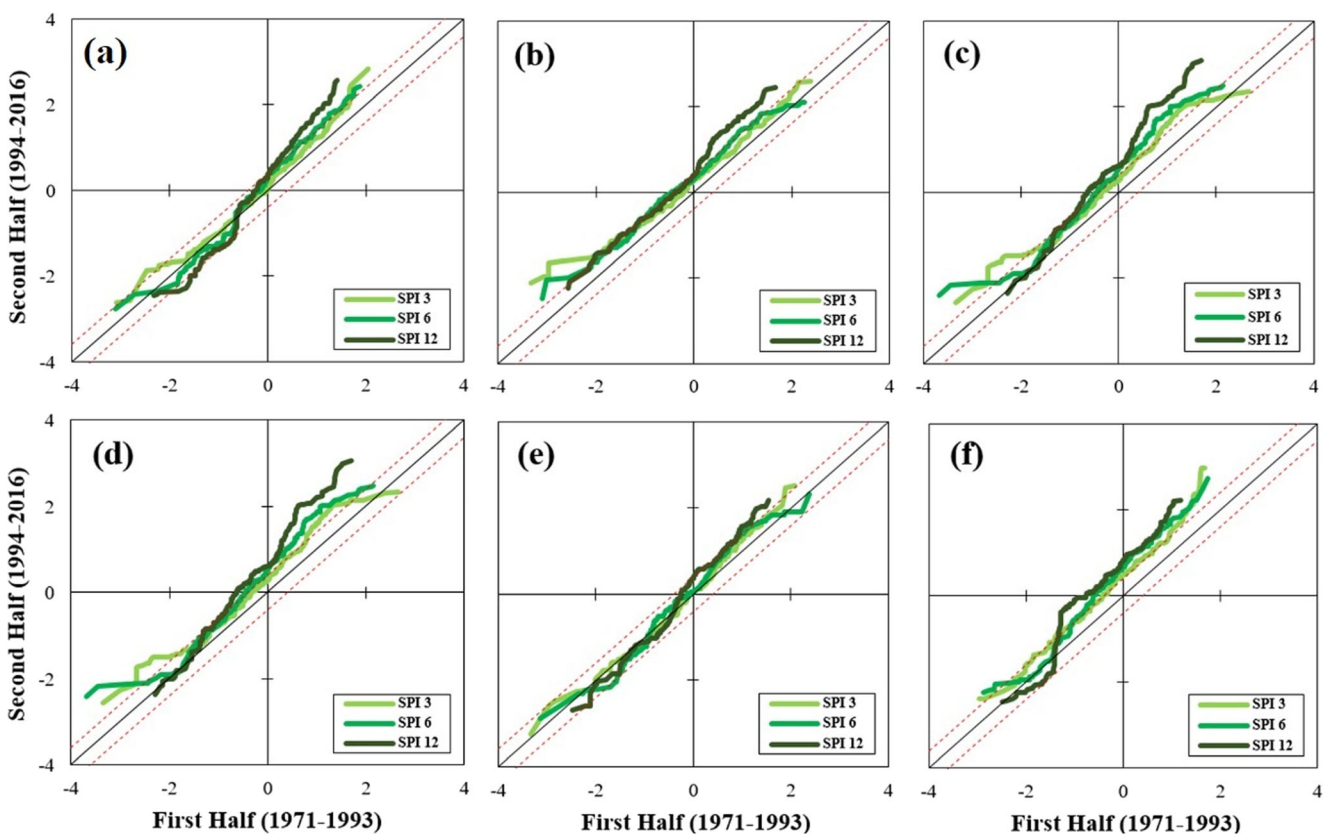
Fig. 6 Classification of trends associated with the SPI index in (**a**) Kecioren, (**b**) Beypazari, (**c**) Polatli, (**d**) Kizilcahamam, (**e**) Esenboga, and (**f**) Nallihan stations
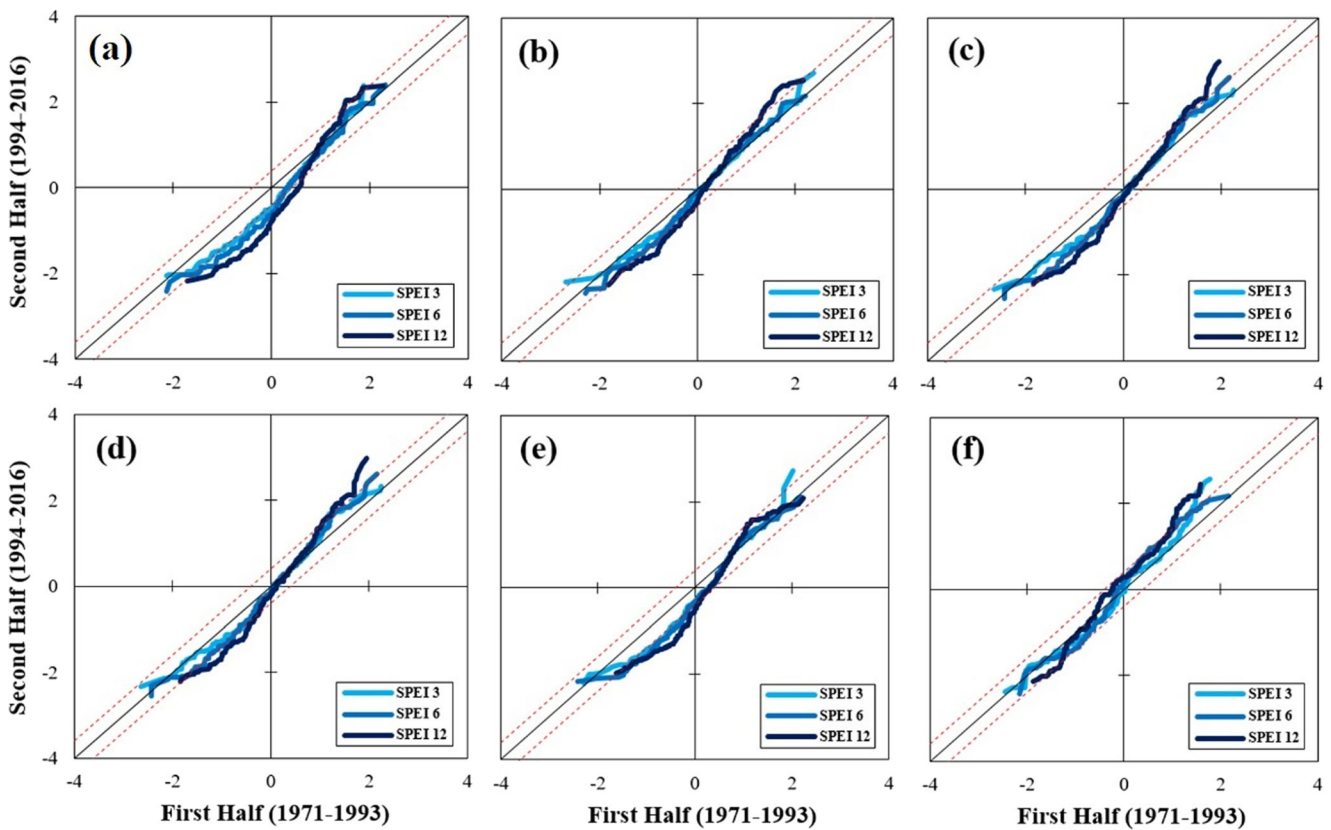
Fig. 7 Same as Fig. 6 but for SPEI

classification indices and to recognize possible differences between them. The results were given in Table 3. In this table, each time span associated with the allocated drought index is detailed based on the criteria used in the method. The graphical interpretation of the IŞM was also illustrated in Figs. 6 and 7, and both of the halves associated with the time run of the data series is drawn against a 90% significant band based on methodology suggested by ITA.

Table 4 suggests that most of the stations have an NMI trend with a decreasing acceleration rate. In Nallihan station, however, the rate of increase in nonsignificant SPEI is increasing. While comparing the results of SPI against SPEI, the patterns showed the degree of significance in trends associated with SPEI method is high which may indicate more attention to the difference between SPEI and SPI. Since the SPEI series reflect the effect of both rainfall and potential evaporation, they are more reliable signals for a long-term drought classification in practice.

According to Fig. 6 in all the stations except Esenboga, the SPI-3 patterns show an increasing trend with a descending acceleration rate (see Table 4). Such an increasing trend, but with higher magnitudes is also seen in SPI-6 and SPI-12 series indicating that the study region is getting drier trough the time. This implies that the changes in drought pattern in seasonal

and annual scales are not recognizable while there are evidences for a developing drought in interannual scale. This alteration can particularly be observed at Kecioren, Polatli, Kizilcahamam, and Nallihan stations. In Beypazari, however, the difference between small-scale (i.e., SPI-3) and large-scale indices (i.e., SPI-6 and SPI-12) are slight. When the effect of temperature is also considered, the results obtained for SPEI (see Fig. 7) do not necessarily match with the results obtained for SPI. For example, while a significant difference between SPI-6 and SPEI-6 patterns in Polatli, Kizilcahamam, and Nallihan stations are seen, there is no significant trend in the other stations (i.e., Kecioren, Beypazari, and Esenboga). Considering the location of Polatli, Kizilcahamam, and Nallihan stations, it is obvious that the central part of Ankara is more vulnerable to the long-term droughts. Since the degree of significance of SPEI patterns (see Fig. 7) and their acceleration rates (see Table 4) are smaller than the SPI, it is concluded that the temperature, slowly but surely, affects the drought patterns in the region. This can be an early warning for future droughts as the temperature rises or precipitation occurs less frequently.

Referring to the earlier studies in the Ankara region, Sönmez et al. (2005) showed 7%–9% moderate, 6%–7% severe, and 2%–3% extreme meteorological drought events

Table 4 Trend analysis at the selected stations (value for SROC is *t*, and for ITA is *D*)

Station	Method	SPI-3		SPI-6		SPI-12		SPEI-3		SPEI-6		SPEI-12	
		Value	Sign	Value	Sign	Value	Sign	Value	Sign	Value	Sign	Value	Sign
Kecioren 17,130	SROC	1.31	NS	2.30	S	2.73	S	3.80	S	5.08	S	7.61	S
	IŞM	–	NMI	–	NMI	–	NMI	–	NMI	–	NMI	–	NMI
	ITA	− 21.2	NSD	− 20.6	NSD	− 20.4	SD	− 19.8	NSD	− 20.3	NSD	− 20.5	SD
Beypazari 17,680	SROC	2.08	S	3.21	S	4.02	S	2.13	S	2.41	S	3.84	S
	IŞM	–	MI	–	MI	–	MI	–	NMI	–	NMI	–	NMI
	ITA	− 21.8	NSD	− 20.4	NSD	− 20.2	SD	− 18.1	NSD	− 19.2	NSD	− 20.5	NSD
Polatli 17,728	SROC	4.07	S	5.91	S	7.82	S	1.21	NS	1.17	NS	2.30	S
	IŞM	–	MI	–	MI	–	MI	–	NMI	–	NMI	–	NMI
	ITA	− 20.0	NSD	− 20.2	NSD	− 20.1	SD	− 18.9	NSD	− 20.1	NSD	− 20.9	NSD
Kizilcahamam 17,664	SROC	3.52	S	4.27	S	4.92	S	5.78	S	6.61	S	7.03	S
	IŞM	–	NMI	–	NMI	–	NMI	–	NMI	–	NMI	–	NMI
	ITA	− 17.5	NSD	− 19.5	NSD	− 20.3	NSD	− 19.2	NSD	− 20.0	NSD	− 20.9	SD
Esenboga 17,128	SROC	0.46	NS	0.30	NS	0.52	NS	3.39	S	3.76	S	4.76	S
	IŞM	–	NMI	–	NMI	–	NMI	–	NMI	–	NMI	–	NMI
	ITA	− 23.1	NSD	− 20.1	NSD	− 20.2	NSD	− 19.5	NSD	− 20.2	NSD	− 20.6	NSD
Nallihan 17,679	SROC	5.10	S	7.01	S	8.72	S	0.20	NS	0.76	NS	1.57	NS
	IŞM	–	MI	–	MI	–	NMI	–	NMI	–	NMI	–	NMI
	ITA	− 20.5	SD	− 19.9	NSD	− 19.8	NSD	27.7	NSI	− 20.7	NSD	− 19.3	NSD

NS not significant; *S* significant; *MI* monotonic increasing; *NMI* non-monotonic increasing; *NSD* nonsignificant decreasing; *SD* significant decreasing; *NSI* nonsignificant increasing

during the 1930–2002 period. Türkeş and Tatlı (2009) reported a decreasing trend in extreme drought conditions in Polatli and Ankara stations for the period 1929–2006. Bacanli et al. (2009) developed adaptive neuro-fuzzy models to forecast SPI-1, 3, -6, -9 and -12 indices in the Central Anatolia and Ankara district and showed that moderate drought events occurred more frequently. Regardless of the scenarios that were foreseen for the SPI patterns in these studies, it is obvious that these results, especially at large scales, are along with the results obtained in our study.

5 Conclusion

The 46 years of precipitation and temperature records associated with six meteorological stations located across Ankara Province were used to calculate SPI and SPEI drought indices at 3-, 6-, and 12-month timescales. In the first step, the spatial mean of historical SPI and SPEI patterns were obtained individually to determine drought events in the province with respect to each index. The results indicated similar events for the 3-month timescale. By contrast, significant differences were obtained at higher timescales. Regarding the inconsistencies in the CDF of each index, the results implied that the use of identical thresholds for SPI and SPEI, as done in Rhee

and Im (2017), may increase the level of uncertainties associated with drought classes, particularly in higher timescales. To overcome such a problem, the use of the SPEI thresholds (Table 1) is strongly suggested. In the second step, three different trend analysis including SROC, IŞM, and ITA methods were used to evaluate the long-term patterns in the SPI and SPEI at each meteorology station. The results generally showed that most of the stations have an NMI trend with a decreasing acceleration rate. However, the SPI-born values are not in full agreement with those obtained by SPEI.

Since the results obtained for SPI-3 are not significant, trends associated with the inter-annual drought patterns were negligible. However, based on the increasing rates of the ascending trends associated with the SPI-6 and SPI-12, precipitation over distinct seasons (i.e., SPI-6), the formation of the streamflow(s) and available water at reservoirs (i.e., SPI-12) in the Ankara region are expected to experience a deficit.

This study was limited to historical meteorological drought indices. To make an informed decision for sustainable watershed planning and management and optimize the operation rules of available water resources, trends in drought indices would be extended to the future periods based on projected outputs of global climate models. The findings would be more beneficial if hydrologic, agricultural, and socioeconomic droughts are considered in future studies.

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