Pure and Applied Geophysics

Drought Assessment in the Aegean Region of Turkey

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Abstract—Drought indices are commonly used to monitor the duration and severity of droughts. In this regard, the continuously changing climate regardless of its cause or effect pushes the limit of the water deficit through time and space. Izmir is a raising city in Turkey, which owns various water resources including but not limited to seashores, lakes, river streams, and groundwater aquifers. In this study, the long-term precipitation and temperature records from 14 meteorological stations between 1973 and 2020 (for 47 years) are used to investigate the drought characteristics in Buyuk Menderes, Kucuk Menderes, and Gediz basins located in the Aegean region of Turkey. For this, the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI), Percent of Normal (PNI), and the so-called Discrepancy Precipitation Index (DPI) are used with consideration to 1-, 3-, 6-, and 12-month moving averages to investigate the drought patterns. Results showed that the monthly indices depict very similar results for the entire region. However, in the 1980s and 2010s droughts were more severe than the rest of the historical records. When the moving average operator is implemented in the analysis (3-, 6- and 12-month periods), neither SPI nor the SPEI showed the same results at any stations. It is illustrated that the periods of severe and normal drought have occurred in the past, yet the indices that are obtained using average values are generally within the normal limits, but extreme values (extremely arid or extremely wet) occurred occasionally. It is also concluded that although there is a similarity between the implemented indices, the DPI and PNI depict the highest resemblance.

Keywords: Buyuk Menderes, drought analysis, Gediz, Kucuk Menderes.

1. Introduction

Droughts are among the biggest challenge in the production, safety, and resilience of food and agricultural goods. Regardless of the cause of droughts, the ever-changing climate raises serious concerns about water scarcity and energy generation. For this, the water, food, and energy nexus are getting more attention worldwide. Turkey is among the countries that have serious concerns regarding water scarcity (Sokollu, 2014). For instance, Izmir as Turkey's third-largest city (with over 4 million inhabitants) benefits from being a touristic destination, socio-economic hub, and agricultural zone owing to its water resources. Izmir district has great potential for the development of water resources including coastlines, lakes, streams, and groundwater reserves. For this, the monitoring and evaluation of historical drought events are of great importance in the planning and development of the region.

In this regard, Standardized Precipitation Index (SPI), Effective Drought Index (EDI), Decimal Index (DI), Percent Normal (PNI), Drought Area Index (DAI), Palmer Drought Severity Index (PDSI), China-Z Index (CZI), and the newly advanced Standardized Precipitation Evapotranspiration Index (SPEI) are among the effective indices in the evaluation of drought, while numerous studies have been conducted to investigate these indices (e.g., Amirataee et al., 2016; Azmi et al., 2016; Danandeh Mehr et al., 2021; Mehdizadeh et al., 2020; Morid et al., 2006; Svoboda et al., 2002; Vaheddoost & Safari, 2021; Yihdego & Webb, 2016; Yihdego et al., 2019; Terzi et al., 2019). The interested reader is also encouraged to evaluate other indices such as the joint deficit index (Mirabbasi et al., 2017; Temeliyeh et al., 2020), integrated agricultural drought index (Liu et al., 2020), and reconnaissance drought index

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(Tsakris et al., 2007) recently developed for evaluating the drought form different aspects.

As examples from the literature, Abarghouei et al. (2011) examined the linear trends in Iran using 3-, 6-, 9-, 12-, 18- and 24-month SPI indices. Yacoub and Tayfur (2017) evaluated the drought of the Trarza region, Mauritania, using 44 years of precipitation records. The normal Standardized Precipitation Index (normal-SPI), log normal Standardized Precipitation Index (log-SPI), Gamma Standardized Precipitation Index (Gamma-SPI), Percent Normal (PNI), China-Z index (CZI), and Decile were used in the analysis, while 1-, 3-, 6-, and 12-month timeframes were considered for the determination of drought condition. Umran Komuscu et. al. (1999) computed the SPI values for 40 stations including the Izmir station. SPI-3, SPI-6, SPI-12, and SPI-24 associated with precipitation time series between 1940 and 1997 were addressed, while results indicated several degrees of drought in the Izmir station. Pamuk et al. (2004) conducted a drought analysis between 1971 and 2001 in the Aegean region using the precipitation data recorded in 14 stations. It was concluded that there is no sign of droughts, including summer, associated with the monthly SPI values. However, when the stations are considered in the analysis, above the normal droughts, especially in July and August months were depicted. Danandeh Mehr and Vaheddosst (2020) studied 46 years of monthly precipitation and temperature records in six meteorological stations in Ankara, Turkey. They used the SPI and SPEI with 3-, 6-, and 12-month moving averages and performed a comparative analysis between the indices and potential trends associated with the data records in each station. Bhunia et al. (2020) implemented the SPI in pre-monsoon, post-monsoon, and monthly time steps in three relatively drought-prone regions of West Bengal (Purulia, Bankura, Midnapore) in India using 117 data records.

This study aims to evaluate the historical droughts across the Aegean region of Turkey between 1973 and 2020 by observing and comparison of the different drought indices. In this study, we have implemented the most recent precipitation time series of the Aegean region to conduct a spatio-temporal drought analysis using different drought indices for the first time. The quality of the data is examined by applying a double mass curve (consistency), run test (randomness), and linear trend analysis. The spatial and temporal behavior of drought in the Izmir and Aydin districts is investigated using SPI, SPEI, PNI and DPI. The study was carried out with the most updated data recorded in 14 meteorological stations scattered across the study area. In the following sections, the study area, methodology used in the analysis, results of the applied indices, discussion of the results, and the conclusion are given in detail.

2. Study Area and Data

The Izmir and Aydin districts located in the Aegean region of Turkey, own several urban and rural areas. This region is shared between three basins namely, Buyuk Menderes, Kucuk Menderes, and Gediz that are addressed in this study (Fig. 1). There are 20 sub-basins in total, five of which are located in the Kucuk Menderes, five in the Gediz, and 10 in the Buyuk Menderes basin. Therefore, a relatively large number of meteorological stations are needed to address the drought issue in the study area. Knowing this, the present study address the precipitation and temperature data in 14 meteorological stations between the years 1973-and 2020. The data records were acquired from Cesme, Denizli, Guney, Izmir, Yatagan, Kusadası, Manisa, Mugla, Nazilli, Salihli, Seferihisar, Selcuk, Sultanhisar, and Usak stations. Initially, the statistical properties of the time series including maximum (Max), kurtosis coefficient (K), skewness coefficient (S), arithmetic mean, and standard deviation (S_d) of the monthly-averaged precipitation (total precipitation at a month divided by the number of days) is investigated (Table 1). These time series together with the spatial and temporal properties of the data records are later used in the calculation and evaluation of the drought indices in the next section.

3. Methods

3.1. Data Analysis

The precipitation data are obtained from the General Directorate of Meteorology in the daily total
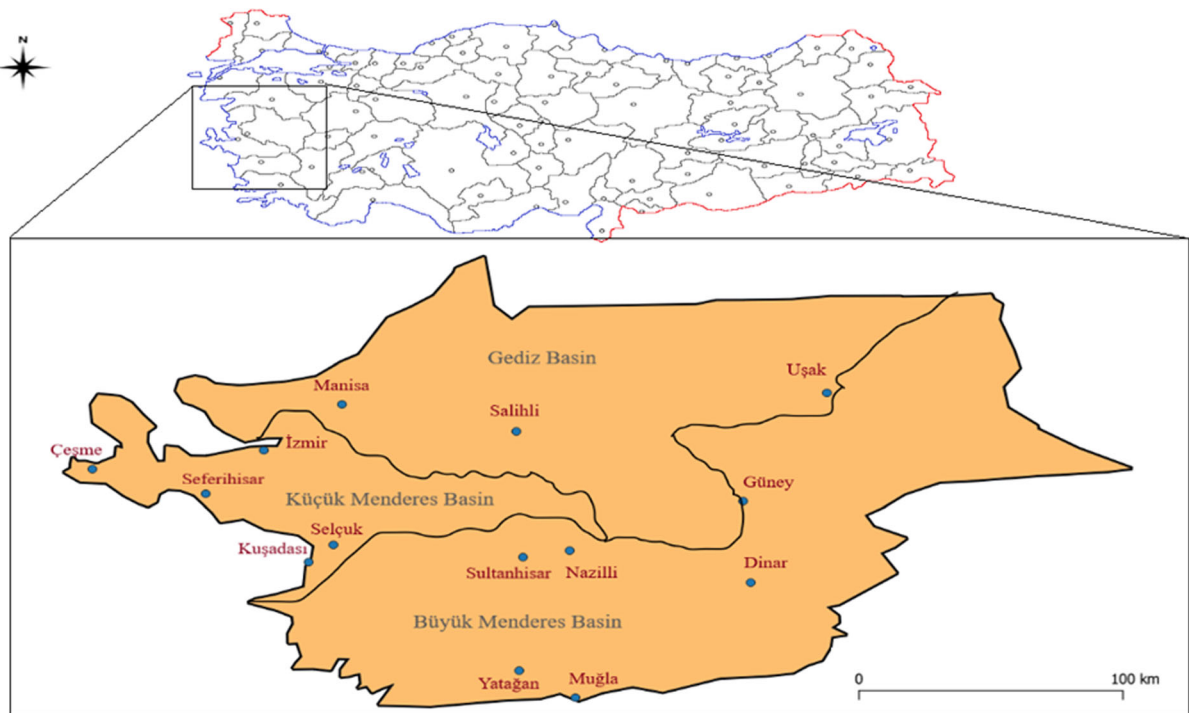
Figure 1
Basins and location of the meteorology stations

precipitation format; while the temperature data are acquired in the daily average, daily maximum, and daily minimum format. Through hydrological studies, it is common to face the data irregularities such as data loss or deficiencies in precision errors, measurement failures, etc. To this end, usually, a data reconstruction method is used to re-obtain the information loss in the provided data. Therefore, in this study, the data deficiencies were completed using the homogeneity method, and afterward, the time series were converted to the monthly average format.

3.1.1 The Double Mass Curve

The double mass curve is a method that compares the consistency of the data from a single station against the remaining stations of the study area (Reddy, 2006). The method can also be used in the naturalization, and reconstruction of the allocated data based on the cumulative behavior of the data ensemble.

3.1.2 Run Test

The run test determines the temporal randomness in the time series. It is known that random behavior is troublesome due to hardship in predicting the future outcome of the phenomenon. It is a statistical procedure that examines whether a set of data within a given data set is derived by a random process or not. Thereby, the run test is applied to analyze the occurrence of similar events separated by different events. It is also important in determining if the outcome of an experiment is truly random, especially where random and sequential data have implications for subsequent theories and analysis. The following equations can be used for run test analysis,

$$E = \frac{H + 2H_a H_b}{H} \tag{1}$$

$$V = \frac{2H_a H_b (2H_a H_b - H)}{H^2(H - 1)} \tag{2}$$

$$Z = \frac{R - (E)}{(S_d)} \tag{3}$$

Table 1

Meteorology stations and monthly-averaged rainfall characteristics

Station	Basin	Subbasin	Location	Mean (mm)	S_d (mm)	Max (mm)	K (mm)	S (mm)
Denizli	B. Menderes	Çürüksu	37° 45′ 43.2″ N 29° 05′ 31.6″ E	1.49	1.40	7.58	1.64	1.25
Sultanhisar	B. Menderes	Aydın Söke	37° 53′ 03.5″ N 28° 09′ 01.4″ E	1.65	1.80	10.71	2.39	1.48
Salihli	Gediz	Gediz	38° 28′ 59.2″ N 28°07′24.2″ E	1.32	1.27	6.55	0.83	1.10
Selçuk	K. Menderes	K. Menderes	37° 56′ 32.3″ N 27° 22′ 00.8″ E	1.84	2.18	10.88	2.28	1.53
Çeşme	K. Menderes	Çeşme-Karaburun	38° 18′ 13.0″ N 26° 22′ 20.6″ E	1.59	2.02	9.79	2.4	1.61
Manisa	Gediz	Gediz	38° 36′ 55.1″ N 27° 24′17.6″ E	1.95	2.17	13.35	3.83	1.70
Uşak	B. Menderes	Banaz Çayi	38°40′16.4″ N 29°24′14.5″ E	1.45	1.20	5.56	0.38	0.92
Güney	B. Menderes	Buldan-Buharkent	38°09′05.4″ N 29° 03′ 31.3″ E	1.40	1.25	6.57	1.28	1.13
Yatağan	B. Menderes	Çine	37° 20′ 22.2″ N 28° 08′ 12.8″ E	2.98	3.49	20.82	2.71	1.58
Muğla	B. Menderes	Çine	37° 12′ 34.2″ N 28°22′00.5″ E	3.15	3.54	21.51	2.79	1.59
Kuşadası	K. Menderes	Kuşadası	37°51′34.9″ N 27°15′54.7″ E	1.71	2.07	11.22	2.70	1.59
Nazilli	B. Menderes	Nazilli Kuyucak	37° 54′ 48.6″ N 28° 20′ 37.3″ E	1.58	1.68	10.02	2.26	1.46
İzmir	K. Menderes	İzmir Körfez	38° 23′ 41.6″ N 27° 04′54.8″ E	1.93	2.27	13.66	2.94	1.62
Seferihisar	K. Menderes	Tahtali-Seferihisar	38° 11′ 35.0″ N 26° 50′ 27.5″ E	1.69	2.10	14.51	3.81	1.73

where E is the expected number of runs; S_d is the standard deviation of the number of the runs; H is the total number of the data; H_a is values falling below average, H_b is valued above the average, V is variance, R is the run number, and Z is the score of the test. To figure out the randomness of the data within a 95% confidence bound, the Z score must be within the $-1.96 \leq Z \leq +1.96$. If the Z score falls outside of the mentioned range, it shows that the data is not random.

3.1.3 Linear Trend Analysis

A trend is a temporal change in the expected values of a random variable that can be considered as increasing or decreasing. Therefore, a linear trend can be obtained using,

$$Y = aX + b \qquad (4)$$

where Y and X are input and output and, a and b respectively determine the slope and intercept of the line. Alternatively, a 95% confidence level, Student's test statistics values between -1.96 and 1.96, is used to determine if the slope of the trend line is significant enough to be considered a trend.

3.2. Drought Indices

Drought indices are numerical representations for the severity of drought calculated with help of climatic or hydro-meteorological inputs. These indices are usually evaluated for a given time to measure the qualitative status of droughts in different locations, while there exist lots of indices in the statement of art which was partially detailed above.

3.2.1 Moving Average (MA)

The moving average function smooth values and noise with the data stream resulting in a large-scale model. It is trending or lagging indicator as sudden temporal changes are smoothed out or neglected. Using the MA models has many advantages and the main one is that, they prove the cyclical trends within time series. Therefore, 3-, 6-, 9-, 12-, 24-, and 48-month MA can be used for cyclic or large-scale evaluations. Hence, in this study 3-, 6-, and 12-MAs are used to explore large-scale historical trends and cyclic behavior associated with the time series. The MA can be obtained as,

$$MA_n = \frac{\sum_{i=1}^{n} X_i}{n} \tag{5}$$

where, n is the period number for the MA, and equals the ith member of the MA.

3.2.2 SPI

Since SPI is based on fitting a proper distribution to the precipitation time series, the application of different types of probability distributions affects SPI values and results. Likewise, a 1-month SPI drought index is an indicator of meteorological droughts, while SPI with 3-, 6-, 9-, and 12-month MA respectively project soil moisture, effective precipitation over distinct seasons, and annual water deficit. The application of longer SPI (e.g. 18-, 24-, and 48-month SPIs) is alternatively can be used in the evaluation of groundwater stage, climate, or the water resources in the region (WMO, 2012). In this respect, Table 2 states the drought classifications for the SPI, while the selected precipitation data are fitted to the Gamma distribution using the following equation (Yacoub et al., 2017),

$$g(x) = \frac{p^{\propto-1}e^{\frac{-p}{\beta}}}{\beta^{\alpha}T(\alpha)} \tag{5}$$

in which,

$$\propto = \frac{1}{4A}\left(1 + \sqrt{\frac{4A}{3}}\right) \tag{6}$$

of which,

$$\beta = \frac{\overline{x}}{\alpha} \tag{7}$$

when,

$$A = \ln(\overline{x}) - \frac{\ln(\overline{x})}{n} \tag{8}$$

where, α is the shape parameter and β is the scale parameter, p is the precipitation amount, T is the Gamma-function by integration, and n is the number of observations.

3.2.3 SPEI

SPEI is a meteorological drought index that takes into account the variability of precipitation and temperature to predict drought conditions in a region. While calculating the SPEI, the first step is to determine the monthly potential evapotranspiration rate in the region (PET). Then, the water balance equation is then used to determine the monthly deficit (D_i) as

$$D_i = P_i - PET_i \tag{9}$$

where P_i is the total precipitation of ith month.

Finally, the developed explicit values are standardized and adapted to a log-logistics distribution function. The SPEI values for the ith month are the standardized values of the probability (p) of exceeding a given D_i and are calculated by Eq. (10) (Danandeh Mehr and Vaheddoost 2020), while Table 2 represents the drought categories for the SPEI.

$$SPEI_i$$
$$= W_i - \frac{2.515517 + 0.802853W_i + 0.010328W_i^2}{1 + 1.432788W_i + 0.189269W_i^2 + 0.001308W_i^3} \tag{10}$$

Table 2

Drought classification for SPI and SPEI indices (Barua et al., 2010)

Z-Index value	Category
More than 2	Extremely wet
From 1.99 to 1.5	Very wet
From 1.49 to 1	Moderately wet
From 0.99 to − 0.99	Near normal
From − 1 to 1.49	Moderately dry
From − 1.5 to − 1.99	Severe wet
Less than − 2	Extremely dry

while $W_i = \begin{cases} if\, p < 0.5, \sqrt{-2lnp} \\ if\, p > 0.5, \sqrt{-2ln(1-p)} \end{cases}$ where p is the exceedance probability of calculated D_i values.

3.2.4 Percent of Normal Index (PNI)

Percent Normal (PN) is a meteorological drought index that can be determined by dividing actual precipitation by normal precipitation. If 180% or more of normal rainfall occurred during the period means extremely wet. Likewise, 161–180% of normal rainfall signs are very wet, 121–160% of normal rainfall signs are moderately wet, 81–120% of normal rainfall signs are near normal, 41–80% of normal rainfall signs moderately drought, 21–40% of normal rainfall signs severe drought and 20% or less of normal rainfall signs extremely drought seasons.

3.2.5 Discrepancy Precipitation Index (DPI)

The drought index used is based on the inconsistency of precipitation data concerning the mean value. It is expressed in Eq. 11.

$$DPI = D_i = log\left(\frac{Pi}{P}\right) \qquad (11)$$

where D is the discrepancy value (D-score) for the ith precipitation, P_i is the ith precipitation in the data series, and P is the mean of the precipitation time series. According to this index, if any precipitation value is less than about 75% of the average value, there is extreme drought. For instance, by considering an average value of 1000 mm and precipitation of 250 mm (75% less than the average), the D-score is − 0.6, which indicates extreme drought. Similarly, if the corresponding D-score is − 0.4, then there is severe drought and finally 40% less precipitation than average, then the D-score is − 0.2, indicating moderate drought.

4. Results

4.1. Data Analysis

The consistency of the data set was checked by the double mass curve and found to be satisfactory.

Also, the Z-values of the run test, given in Table 3 for the rainfall and temperature, show that the data is not random. Likewise, Fig. 2 shows the linear trends, while the X and the Y-axis respectively represent time and precipitation values (the total precipitation of the allocated month divided by the days). Similarly, Fig. 3 demonstrates the linear trends associated with the temperature time series in the selected stations. As shown in Figs. 2, 3, in all stations the average temperature values increased, while the average precipitation experienced a decrease. Therefore, the reduction in precipitation and increase in temperature can naturally trigger drought events.

4.2. SPI

The SPI values for each month are calculated and evaluated by considering the average values of each month, while the iso-SPI lines are given on the maps of the study area using the Kriging interpolation method to reach a general conclusion on the patterns of SPI-1 (Fig. 4), SPI-3, SPI-6, and SPI-12 (Fig. 5) over the region. Finally, by applying the minimum and maximum of all SPI values, the spatial distribution of historical extreme events is also given on the maps (Fig. 6). Based on the conducted analysis, the area closer to the sea experienced wetter periods, while more severe droughts have been observed in the terrestrial areas. Based on Fig. 4, drought patterns

Table 3

Z-values of the run test for precipitation and temperature data

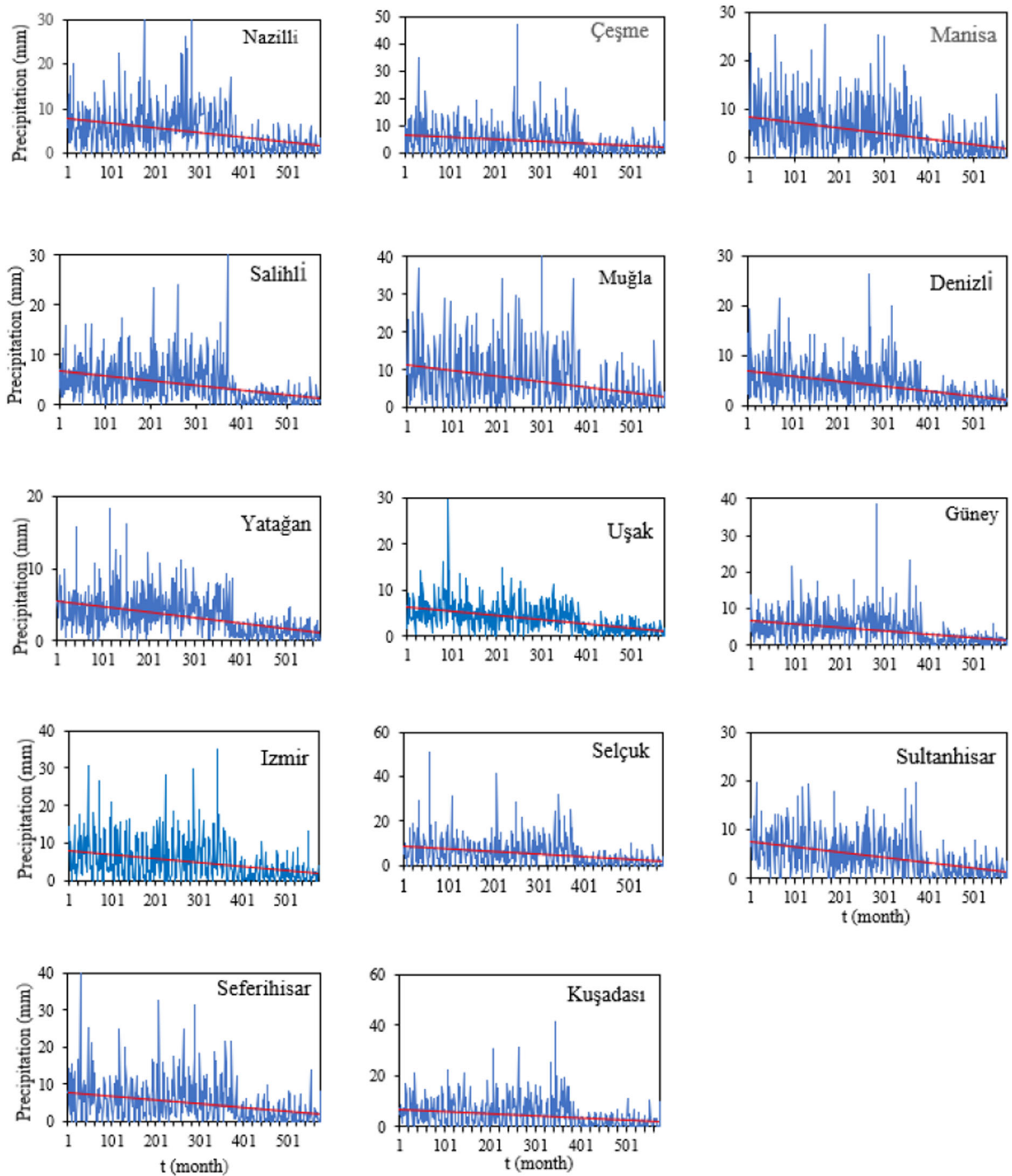| Station name	Precipitation	Temperature
Nazilli	− 60.40	− 63.99
Çeşme	− 61.32	− 63.99
Manisa	− 35.12	− 64.02
Salihli	− 58.27	− 63.98
Muğla	− 60.24	− 64.01
Denizli	− 34.18	− 63.98
Yatağan	− 58.11	− 63.99
Uşak	− 56.01	− 64.01
Güney	− 58.93	− 63.98
Izmir	− 60.01	− 64.01
Selçuk	− 62.16	− 64.02
Sultanhisar	− 58.18	− 63.99
Seferihisar	− 4.21	− 64.01
Kuşadası	− 10.73	− 64.02

Figure 2
Linear trend analysis results of precipitation data

were within the normal limits for an average of 1-month and 12- months of the year. In addition, 1-,

3-, 6-, and 12-month moving averages were found (Fig. 5) to be between − 1 and 1 in all stations, very

similar to those patterns observed in Fig. 4. Extreme value maps also have been used to understand the conditions of extreme (wettest and driest) periods that have occurred in the region (Fig. 6). In this context, the highest and the lowest SPI-1 were respectively

seen as 3.75 in Selcuk and − 4 in Denizli stations. Similarly, the wettest and driest SPI-3 records were respectively observed as 4.2 in Selcuk and as − 4.25 in Sultanhisar stations. The highest SPI-6 value was recorded as 3.95 at Selcuk station and the lowest SPI-
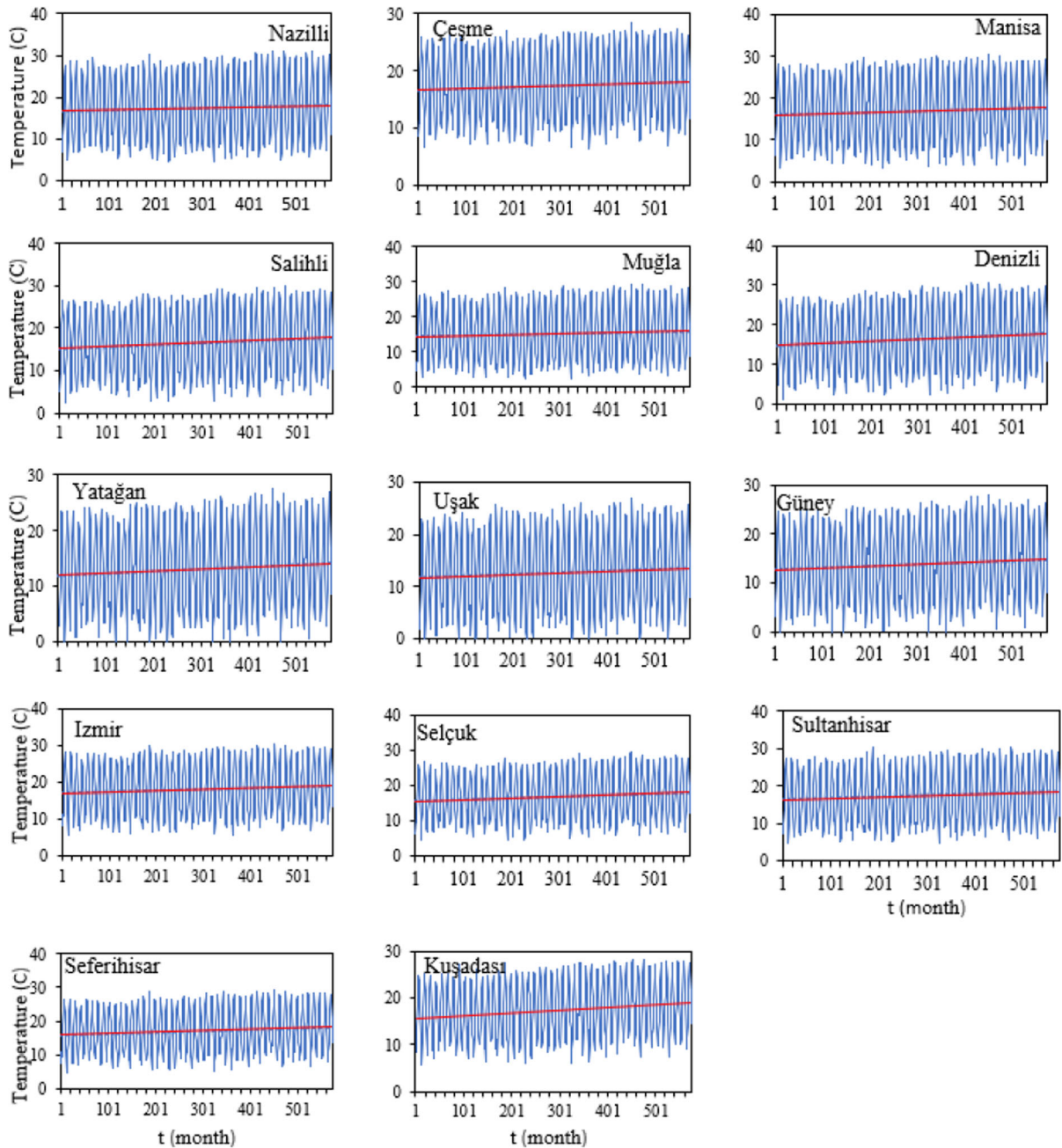
Figure 3
Linear trend analysis results of temperature data

6 value was observed as − 4.2 at Sultanhisar station. Finally, the highest SPI-12 value was 3.45 at Salihli station and the lowest SPI-12 value is − 3.25 at Sultanhisar station (Fig. 6). Therefore, for all MA values of all stations (1-, 3-, 6-, 12-month) based on general averages and for 1-month MA, no drought was detected, from 1973 to 2020, while several extreme dry and wet periods occurred in some stations.

4.3. SPEI

SPEI-1 values were also evaluated by considering the average values of each month and the iso-SPEI lines given on the map using the Kriging method (Fig. 7). Similar to the SPI, a general conclusion can be drawn for SPEI by taking the average values obtained for SPEI-3, SPEI-6, and SPEI-12 indices (Fig. 8). By considering the lowest and highest index values, it was concluded that several extreme drought events occurred in the past (Fig. 9). The SPEI-1 at all stations for July and August months showed moderate drought indices and remained at the normal limits for the remaining months. The meteorological drought (SPEI-1) at Mugla station showed moderately wet conditions, while the SPEI-3, SPEI-6, and

SPEI-12 maps representing agricultural and hydrological drought remained within the normal limits. Based on Fig. 7, drought was within the normal limits when 1-month MA in January, February, March, April, May, June, September, October, November, and December are on the focus. However, in July and August, all stations showed moderately dry values. Also, according to 1-, 3-, 6-, and 12-month MA given in Fig. 8 the SPEI patterns were within the − 1 to 1 limits.

The extreme value maps are given in Fig. 8 (wettest and driest) to understand the historical extremes that have been recorded in the stations. Accordingly, the wettest meteorological period recorded at Seferihisar station showed a 2.2 value. On the other hand, the driest period was observed at the Usak station with a − 2.7 value. According to the SPEI-3 results in which the agricultural drought was determined, the wettest season was recorded at Manisa station with a value of 1.8, while the driest season was observed at Usak station with an index value of − 2.75. When the SPEI-6 is considered, the highest index value recorded at Cesme station was 1.75, while the lowest record at Denizli station showed a − 2.8 value. Finally, the highest SPEI-12 value was measured at Mugla station as 1.9, but the
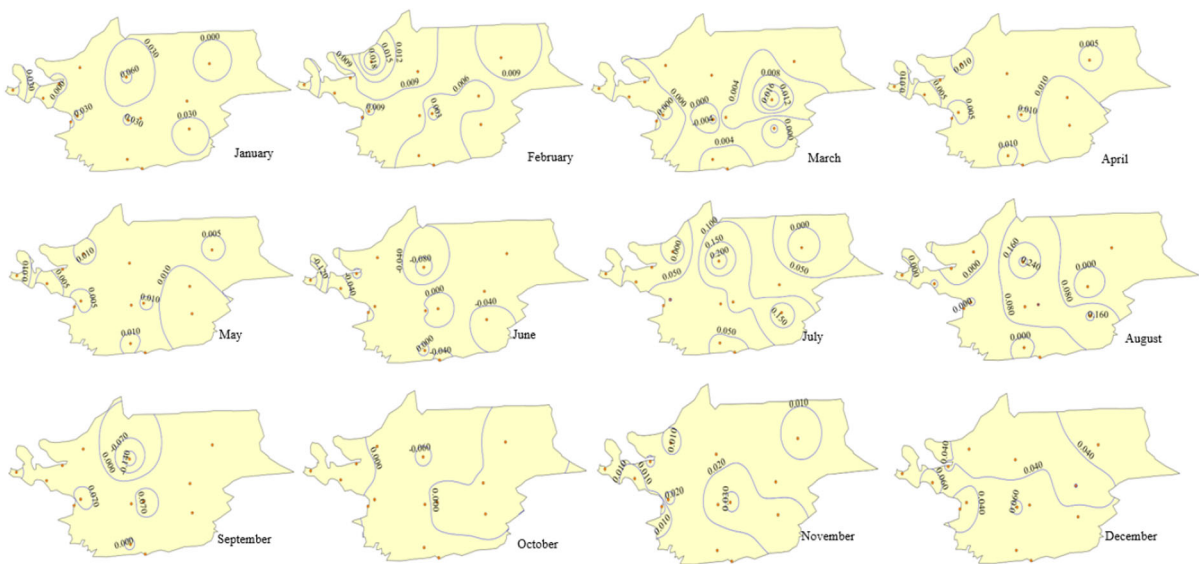

Figure 4
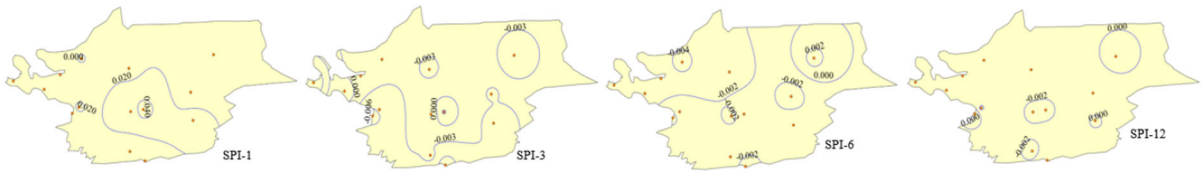Monthly average SPI-1 maps

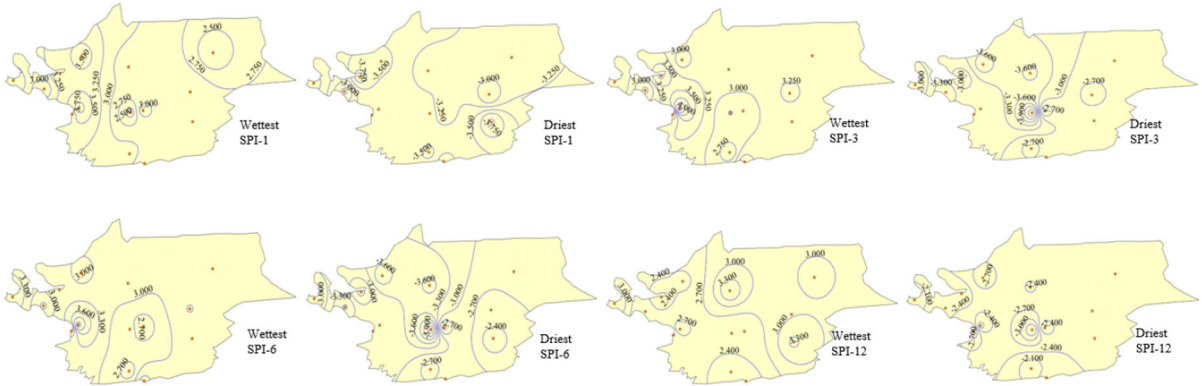Figure 5
Maps of the average of SPI-1, SPI-3, SPI-6, and SPI-12

Figure 6
The wettest and driest seasons of SPI-1, SPI-3, SPI-6, and SPI-12

Figure 7
Monthly average SPEI-1 maps

lowest was determined as − 2.65 at Mugla station. Thus, the SPEI values for all MA values of all stations (1-, 3-, 6-, 12-month) on the basis of general averages, showed no sign of continuous drought, but in the period 1973–2020, some exceptional dry and wet conditions were observed in all stations.
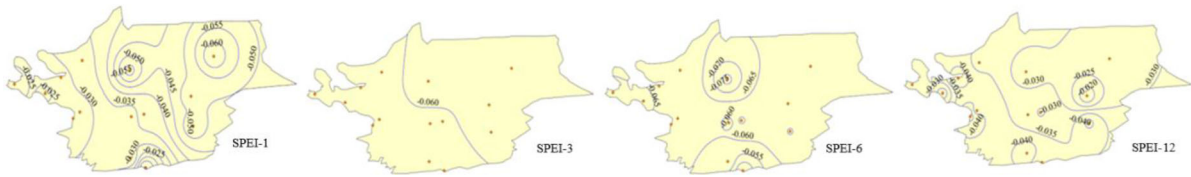
Figure 8
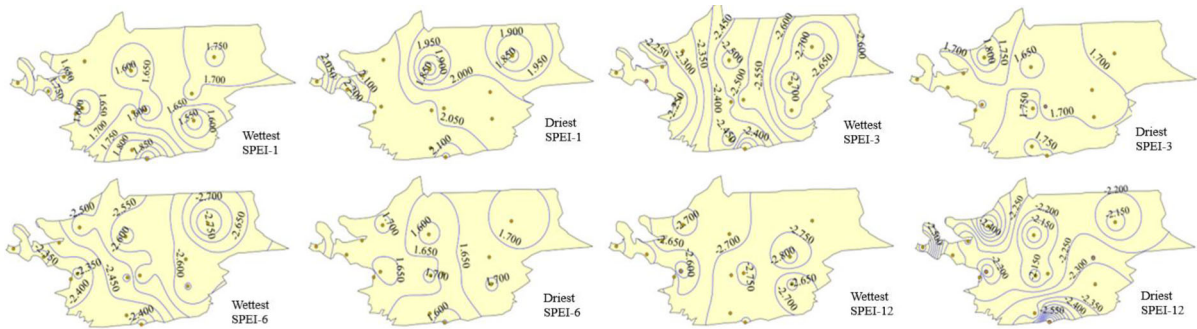Maps of the average of SPEI-1, SPEI-3, SPEI-6 and SPEI-12

Figure 9
The wettest and driest seasons by SPEI-1, SPEI-3, SPEI-6 and SPEI-12

4.4. Comparison of SPI and SPEI Results

To compare the results obtained by SPI and SPEI, Figs. 10–13 are given to show the drought conditions in all stations (red dot-line represent the SPEI and a straight blue line indicates the SPI). When 1-month MA is considered for the analysis (Fig. 10), although the recorded values were generally compatible with each other, moderate and severe dry periods for SPEI were observed in all stations between 1980 and 1990, but SPI values remained within the normal limits. In addition, although SPI values have been at moderate to severe drought state since 2010, SPEI values in Izmir and Kusadası stations remained within normal limits. SPEI values with 3-month MA were generally similar to each other, while SPI results showed a very wet period record in the 1990s at all stations, whereas SPEI remained within normal limits. Apart from this, SPI values showed a severe dry period between 2000 and 2010, while SPEI values were still within the normal limits. While the 6-month SPEI values for all stations showed severe drought between 1983 and 1993, the SPI values in the 1990s refer to a severe wet period. In the early 2000s, SPI values show a severe drought.

In the comparison made using the 12-month moving average, while the SPI values between 1973 and 1985 show moderate droughts across all stations, the SPEI values, on the contrary, indicate a moderately wet condition. Between 1990-and 2000, just like previous MA evaluations, SPI values are within normal limits, although the SPI values are severely wet. Likewise, while SPI was moderately and severely dry from 2000 to 2010, SPEI was within normal values. After 2010, although both indices followed a similar pattern, SPEI values remained lower than SPI values.

4.5. PNI and DPI Results

As mentioned before, DPI and PNI are similar in terms of calculation. While PNI is obtained by dividing the precipitation of each period by the normal precipitation of the same period, DPI an be calculated by applying a logarithm function to the PNI. Table 4 details the extreme, severe, and moderate droughts of the PNI and DPI for all the
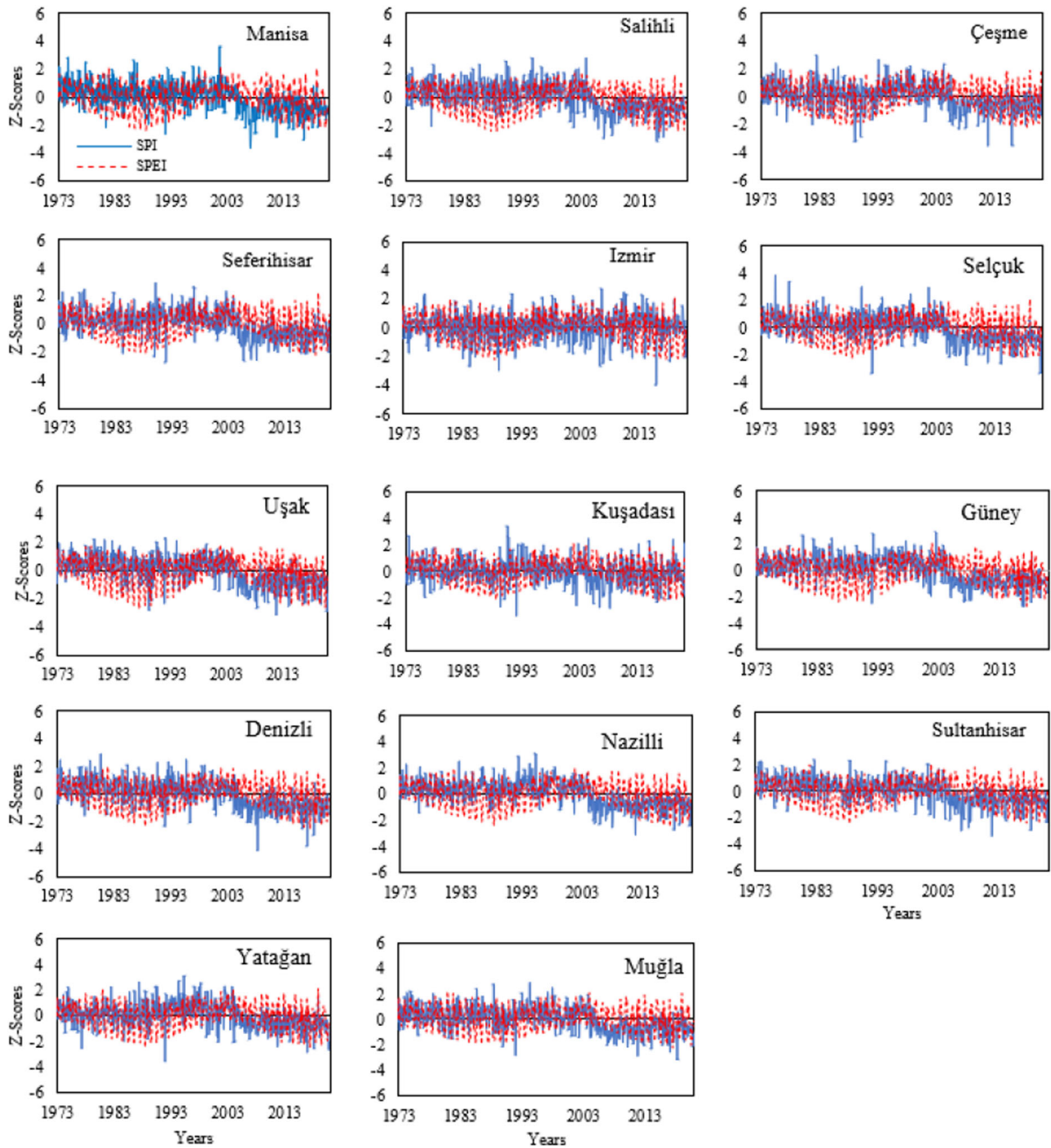
Figure 10
SPI-1 and SPEI-1 comparison graphs

allocated stations. In Table 4, stations are indicated by numbers (1 = Cesme, 2 = Denizli, 3 = Guney, 4 = Izmir, 5 = Kusadasi, 6 = Manisa, 7 = Mugla, 8 = Nazilli, 9 = Salihli, 10 = Seferihisar, 11 = Selcuk, 12 = Sultanhisar, 13 = Usak, 14 = Yatagan). According to Table 4, the results of the DPI and

PNI are almost the same, while there exist changes in drought severity in some stations (for example, Manisa station was seen as extremely dry in 1989 according to PNI-12, while severe drought was found according to DPI-12).
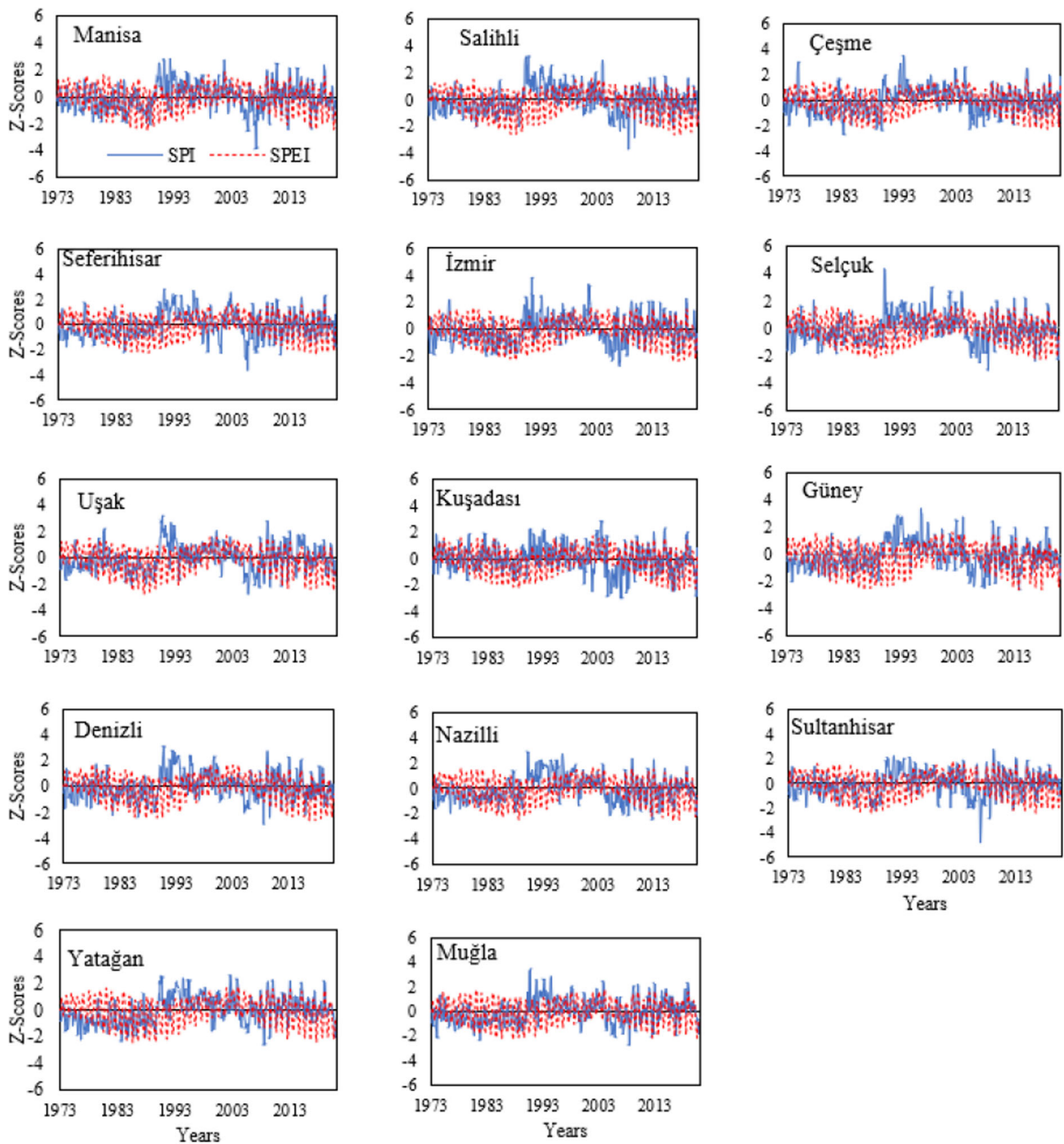
Figure 11
SPI-3 and SPEI-3 comparison graphs

5. Discussion

The study aims to determine the meteorological, agricultural, and hydrological droughts of the Buyuk Menderes, Kucuk Menderes, and Gediz basins in the historical process using the SPI, DPI, PNI, and SPEI indices and also to compare the difference between these indices. Preliminary analysis showed that time series has a constant slope and can be considered consistent; and not random as well. There is an increasing trend in temperatures and a decreasing trend in precipitation, which already indicates an
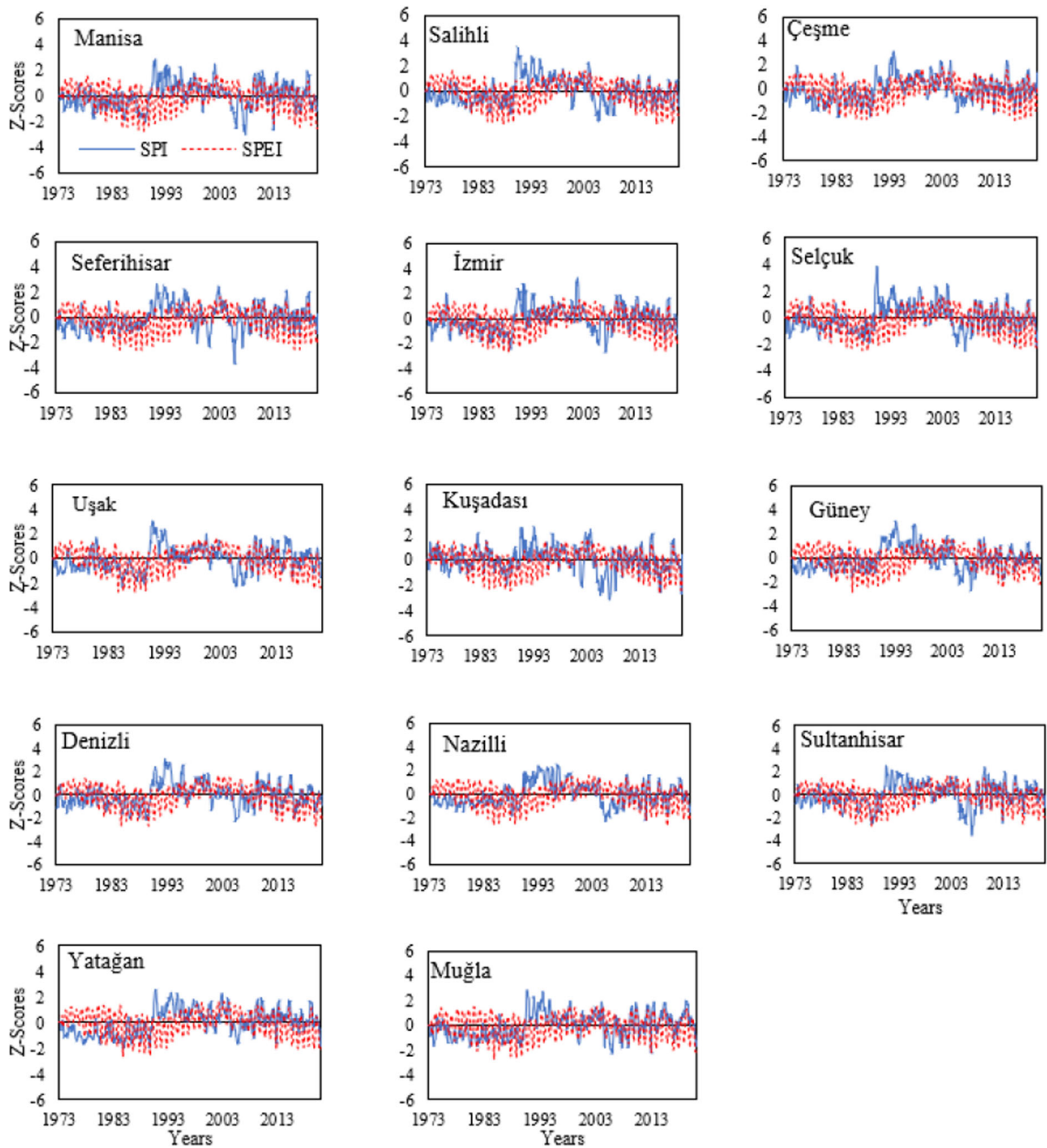
Figure 12
SPI-6 and SPEI-6 comparison graphs

ongoing drought pattern. For all months (January to December), the average SPI-1 values of those months have been determined, while there is a little sign of meteorological drought in the region which is aligned with the results of Pamuk et al. (2004). However, there exist some signs of agricultural and hydrological droughts, which could be depicted by the applied drought indices detailed in this study.

SPI and SPEI values were compared with each other with consideration of similar MA patterns.
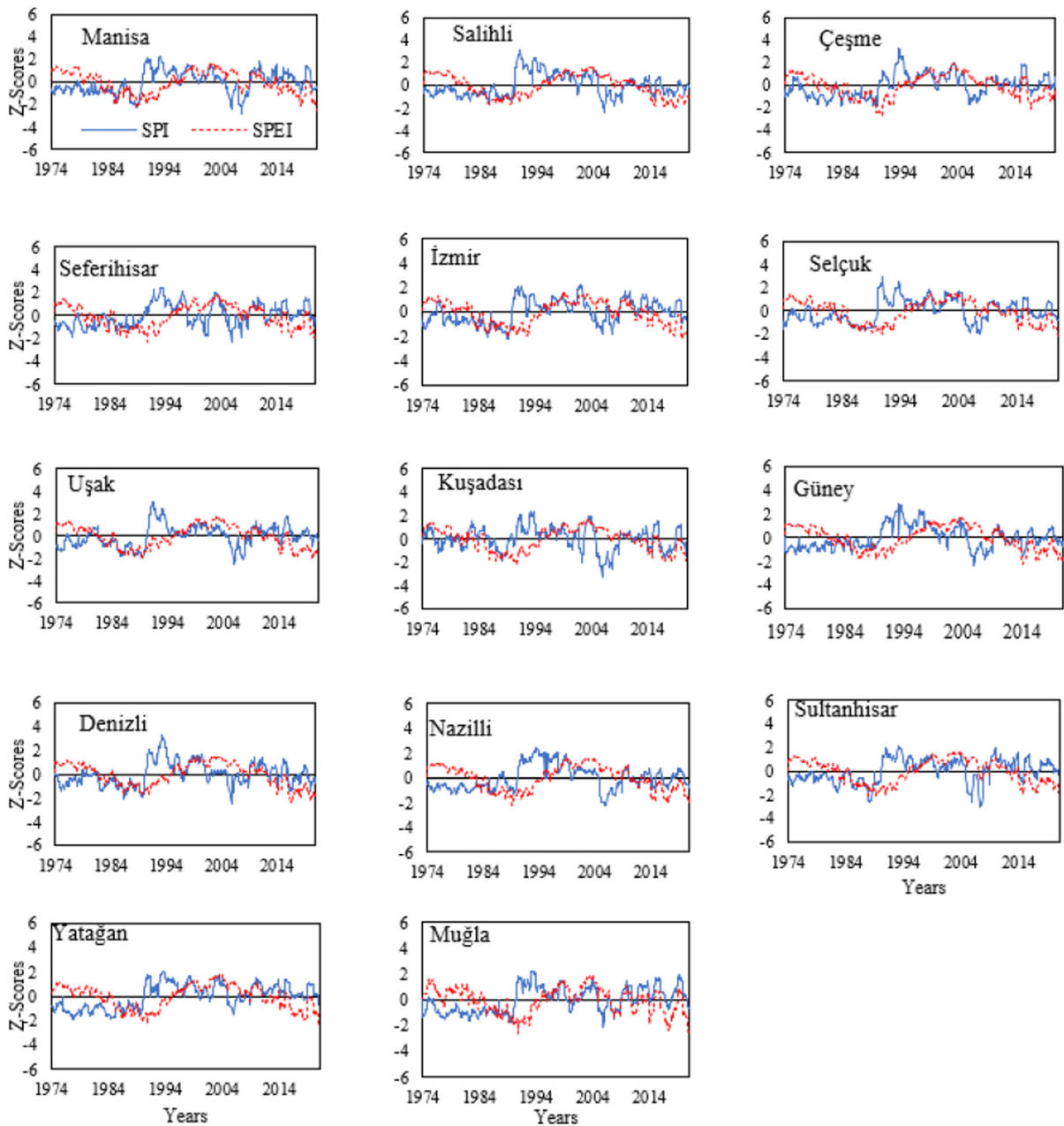
Figure 13
SPI-12 and SPEI-12 comparison graphs

Although some similarities were detectable, the most notable differences between the selected indices within the specified time frame can be summarized as,

- Severe meteorological drought (SPI-1) were observed in 1985–1990 and 2005–2012 periods at Selcuk, Sultanhisar, Manisa, Denizli, Usak, Kusadası, Sultanhisar and Denizli stations. However, SPEI-1 also depicted a moderate wet season for the 2007–2014 period.

Table 4

Summary of drought indices

Indices	Drought Intensity	Stations													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
SPI	SPI-1	1989-90	1989-90	1989	1989	1989	1993	1989	2004-05	1998	1989	1989	2000-10	1989	1976
		2008	2008	2005-10	2004-05	1992	2005	2005	2008	1976	2005-08	2005-08	2015	2000-10	1989
		2015	2015		2015	2003-10	2010	2015		2005-10		2020	2020	2020	2000-10
	SPI-3	1983	1973-1980	1973-1980	1974	1974-1976	2004-2010	1974	1974	2004-2010	1998	1974	1978	1975-1980	1975-1983
		1989	2005	2005	1985-90	2003	2008	1982	1982	2008	2000	1978-80	2008	2005-08	2005
		2004-2008	2008	2008	2005-2008	2005-08		2005-2008	2005-2008		2005	2005-2008	2010		2008
	SPI-6	1978-1983	2005	1978-1983	1974	2005-08	1978-1983	1975-1983	2005	1998	1978-1983	2005	1985	1983-90	1975-85
		2005	2006-08	2005	2005		2005-08	2005	2008	2005-08	1996 1998	2008	2005-08	2005-08	2005
				2008	2008		2012				2005				2012
	SPI-12	1978	1985	2005	1989	2002	1989	1989	2005	2005	1977	2005	1989	1989	1974-1990
		1984	2005	2008	2005	2005	2005	2005		2008	2001	2008	2005	2005	1978
		2005	1988		2008	2008	2008				2005		2008	2008	
SPEI	SPEI-1	1985-90	1985-88	1985-90	1985-90	1985-90	1985-90	1985-90	1985-88	1985-88	1985-90	1985-89	1985-89	1985-89	1985-90
		2008-15	2008-15	2008-15	2010-20	2008-15	2008-15	2008-15	2008-15	2008-15	2008-15	2008-15	2008-15	2008-15	2008-15
			1989						1989						
	SPEI-3	1985-90	1985-90	1985-1990	1985-90	1985-90	1985-90	1985-90	1985-90	1985-90	1983-1990	1983-1990	1983-1990	1983-1990	1983-1989
		2005-15	2005-13	2005-13	2005-13	2006-15	2006-15	2005-13	2005-13	2005-13	2008-2013	2008-2013	2005-13	2005-13	2008-13
	SPEI-6	1985-90	1985-90	1985-90	1983-90	1983-90	1985-90	1985-90	1985-90	1983-90	1983-90	1983-90	1983-90	1983-90	1983-90
		2008-20	2008-20	2008-20	2008-20	2008-20	2008-2017	2008-2010	2013-2020	2015-2020	2013-20	2013-20	2015-20	2015-20	2013-20
	SPEI-12	1984	1985-90	2015	2017	1989	1989	1989	1989	2017	1989	1987-90	1987-90	1987-90	1987-90
		2015	2015	2017	2020	2015	2005	2017	2015		2015	2015	2015	2015	2015
			2020	2020		2020	2008	2020	2020			2017	2017-20	2017	2017-20
PNI	PNI-1	1989	1990	1989	1989	1989	1989	1989	2005	2005	1989	1989	2008	1989	1989
		2008	2008	2005	2005	2005	2005	2008	2008	2008	2005	2005	2015	2008	2005
		2015	2015	2008	2015	2018		2015			2008	2020	2020	2020	2008
	PNI-3	1989	1975-80	1975-80	1974-80	1974-80	2004-2010	1974-1975	1974-1982	2004-2010	1998-2000	1974-80	2008-2010	1974-80	1974-1980
		2005	2005	2005	1985-90	2003-08		2005-2010	2005-2008		2015	2005-2008		2005-2008	2005 2008
			2008	2008	2008										
	PNI-6	1978	2005	1978-1983	2005-2008	2005-2008	1978-1983	1974-83	2005	2005	1978-1983	2005	2005	2005	1974-1983
		1983	2008	2005			2005-2008	2005	2008	2008	2005	2008	2008	2008	2005
		2005		2008											2012
	PNI-12	1978	1985	2008	1989	2002	1989	1989 1998	2005	2005	1978	2005	1992	2005	1989
		1989	1989	2020	2005	2005	2008	2005		2008	2001		2005	2008	
			2005		2008			2020			2005		2008		
DPI	DPI-3	1989	1978 2005	1975-80	1974-1980	2003	2004 2006	1974 1975	1974-1982	2004 2006	1998 2000	1974-1980	1974-1980	1974-1980	1974 1977
		2005	2008	2005 2008	1985-90 2008	2005 2008	2008 2010	2005-2010	2005-2008	2008 2010	2015	2005 2007	2005 2007	2005 2007	2005 2008
	DPI-6	1978 1983	2005	1978-83	2005	2005	1978-1983	1978-1983	2005	2005	1978-83	2005	2005	2005	1974-83
		2005	2008	2005 2008	2008	2008	2005 2008	2005	2008	2008	2005	2008	2008	2008	2005 2012
	DPI-12	1978 1984 1989	1989	2008	1989 2005	2002	1989	1998	2005	2005	1978	2005	1992	2005	1989
		2005	1985 2005	2020	2008	2005	2008	2020		2008	2001		2008	2008	

	Color Indicators
Moderately Dry	
Severely Dry	
Extremely Dry	

- In the Izmir station, the results of SPI-1 showed moderately wet conditions for the study period, but according to the results of SPEI-1, moderate and severe dry periods were dominant during the 2000–2010 years.

- SPEI-3 values showed moderate and severe drought in all stations during 1985–1993 and after the year 2010. But, in the first half of the 1990s, all stations showed wet conditions compared to the SPI-3 patterns. Apart from this, there were generally normal or moderately dry/wet periods instead.

- The hydrologic drought assessment, using a 6-month MA showed similar behavior in all of the stations. Yet, between 1973–1990, SPI-6 values in all stations indicate moderate and severe drought. While severe dry seasons were determined during the 1990–2000 years. Also, during the 2000–2010 years, moderate and severe droughts similar to those between 1973 and 1990 were observed. However, after 2010 the general behavior of the precipitations was near normal.

- SPEI-6 values showed severely dry at all stations between 1983 and 1993 and after 2010. But in the remaining periods, it was within normal or moderately wet limits.

- When a 12-month MA is considered, all stations showed a similar pattern, very similar to those detailed for 6-month MA. Considering the SPI-12 values between 1973 and 1993, a moderately dry period was experienced. Between 1993 and 2004, it followed a moderately and extremely wet period.

- While SPEI-12 values followed a normal course in 1973–1985, moderately dry between 1985 and 1995, moderately wet between 1995 and 2010, and moderately dry after 2010 even towards the last years (in the last half of the 2010s) sometimes severe drought is observed.

- DPI-1 values could not be calculated due to the zero precipitation values that deviate from the results of the logarithm operator.

- According to the results of DPI-3 and PNI-3, a moderate and severe drought from 1974 to 1980, and a severe drought from 2003-to 2010 were dominant. Results of DPI-6 and PNI-6, showed moderate and severe drought in 1978, 1983, 2005, and 2008. While, the DPI-12 and PNI-12 showed severe drought in 1978, 1984, 1989, 2005, 2008, and 2020 years.

6. Conclusions

In this study, the drought patterns of the Aegean region in Turkey as a home for several metropolitan cities such as Izmir, Manisa, and Aydın are addressed. 47 years of precipitation and temperature records from 14 meteorological stations in Buyuk Menderes, Kucuk Menderes, and Gediz basins were used to calculate the SPI, DPI, PNI, and SPEI drought indices on 1-, 3-, 6- and 12-month time scales. It has been determined that there is a tendency to decrease in precipitation with increasing temperatures in general.

Results obtained for SPI-1 were almost within normal limits. Short-term extreme droughts have also been observed in the study period. Although, short-term drought indices showed near-normal values, long-term indices such as 3-, 6-. And 12-month MA showed many severe conditions indicating the changes in the micro-climate of the region. It was also observed that the nearshore regions experienced moderate droughts when the eastern parts of the region in the same period experienced more severe droughts. Therefore, the mountainous area in the eastern parts of the region and the corresponding socio-economical activities are more vulnerable to drought, and yet not the meteorological drought but the long term hydrological drought is the main concern for the agricultural, industrial, energy, and food security of the region. Since the concept of drought depends on environmental conditions such as relative humidity, temperature, and topography, the values calculated with the SPEI index were found to be more sensitive compared to those of SPI. In addition, the rainfall-based indices used in this study, DPI and PNI, showed very close results.

Funding

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Code Availability

None.

Declarations

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