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ORIGINAL PAPER

# Hydrological drought analysis of Mediterranean basins, Turkey

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**Abstract**

Drought is one of the most common natural disasters that have devastating effects on the economy and ecology. In terms of water resources engineering, it is very important to know the temporal and spatial change of hydrological drought in the design, planning, and operation of hydraulic structures on rivers. Accordingly, in today's world where the scarcity of water resources is of a vital importance, it is necessary to carry out temporal and spatial hydrological drought analysis for critical regions. This is expected to yield the provision of effective precautions to protect the existing water resources. In this study, hydrological drought analyses of 3-, 6-, and 12-month periods were performed by Streamflow Drought Index (SDI) method using the streamflow data of 29 streamflow-gauging stations (SGS) in the Mediterranean Basin which is located in the southern region of Turkey. Monotonic trends of the calculated drought indices are obtained by the nonparametric Mann–Kendall method, and the slope values were obtained by Sen's slope method. The temporal change of the drought index was handled for three different periods as 1960–1979 (first period), 1980–1999 (second period), and 2000–2015 (third period), and the severity of the drought has increased in the third period covering the years 2000–2015. It was determined that the occurrence percentages of extreme drought generally in the middle part of the basin are higher than the other parts of the basin. As a result of the trend analysis, a significant downward trend was determined between 13 and 35% of the stations for different timescales. It was observed that the stations with significant trends are in the western part of the basin.

**Keywords** Mediterranean basins · Spatial–temporal distribution · Trend analysis · Hydrological drought · Streamflow Drought Index

## Introduction

Drought can be defined as the period in which the amount of water needed by living beings cannot be met by existing water resources (Kundzewicz 1997; Dobrovolski 2015). In case of drought, environmental, agricultural, and socioeconomic problems may occur, and if it continues for a long time, nature may be damaged (Şen 1998; Mishra and Singh 2010). Drought, contrary to natural disasters such as earthquake, flood, and overflow, does not affect a specific region, but a wider area. Besides, it is more destructive compared to other natural disasters, and its effects are felt for many years on the nature, plants, and people.

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Drought is generally classified as meteorological, hydrological, agricultural, and socioeconomic drought (Wilhite and Glantz 1985; Heim 2002). Firstly, meteorological drought is defined as the period when precipitation is below normal for a long time (Hayes et al. 2011). Secondly, hydrological drought is defined as the reduction in runoff during periods of low rainfall (Liu et al. 2012). Thirdly, agricultural drought is expressed as not having enough moisture in the soil for the plants to vegetate (Botterill and Fisher 2003). Finally, socioeconomic drought is defined as the physical scarcity of water affecting people and the deterioration of the supply–demand balance of economic goods (Sırdaş 2002). Although, different variables are used in drought types, they are directly related to each other. Low precipitation, which is the main variable of meteorological drought, directly affects the streamflow, which is the main parameter of hydrological drought. Soil moisture, being one of the variables of agricultural drought, is completely related to both drought parameters. As a result, it is inevitable to experience socioeconomic drought due to meteorological, hydrological, and agricultural drought.

As the effects of climate change and global warming on the world have become more evident and largely perceived, international broad projects are commenced by many countries on these issues. Similarly, especially in recent years, elaborate studies on drought have been widespread among a large number of researchers. There has been an increasing tendency in such studies to contribution to the issue (Wu et al. 2008; Zhou et al. 2019; Altın et al. 2020). Drought indices are generally used by researchers and scientists in the analysis of drought (Dracup et al. 1980; Wilhite and Glantz 1985). Various input parameters such as precipitation, streamflow, groundwater, and storage data are used in the calculation of these index values. To summarize some of these index values, the Standardized Precipitation Index (SPI) was used by McKee et al. (1993) in determining the meteorological drought based on monthly rainfall data. Effective Drought Index (EDI) was developed by Byun and Wilhite (1999). They used precipitation data similar to the SPI method in the analysis of drought. This method is very effective in monitoring both meteorological drought and agricultural drought (Lee et al. 2012; Wambua et al. 2018; Kamruzzaman et al. 2019). Palmer Drought Severity Index (PDSI) is an index developed by Palmer (1965) for using in the analysis of meteorological drought and can be benefited for different time periods. This index uses average temperature, total precipitation, and soil water–holding capacity observation values. Palmer Hydrological Drought Index (PHDI) is another result of drought analysis determined by the PDSI index. With the use of this index, the time when the drought will end can be calculated by using the moisture ratio required for the end of the drought, depending on the required rainfall. PHDI method requires monthly temperature and precipitation data; these data must be complete for time series to be absolute. The use of the PHDI method is beneficial because it considers droughts that may affect water resources for long periods. The water balance approach on which the method is based allows the evaluation of the total water system. The Standardized Runoff Index (SRI) method proposed by Shukla and Wood (2008) calculates index values in the same way as SPI, while flow data is used instead of precipitation data in SPI. Streamflow Drought Index (SDI) was developed by Nalbantis and Tsakiris (2009), and monthly surface streamflow values and historical time series are used as inputs for index values calculated like the SPI method.

As it is found out from the aforementioned information, there are various drought indices developed by many different researchers to analyze different drought types. Droughts have been evaluated using the methods mentioned above by different researchers around the world. For example, the meteorological and hydrological drought of Kasilian Basin in Northern Iran and the Vistula Basin in Poland were determined by Cheraghalizadeh et al. (2018) and Kubiak-Wójcicka and Bąk (2018), respectively. Pathak and Dodamani (2016) conducted hydrological drought using SDI and SRI methods in the Ghataprabha River Basin, while Meshram et al. (2018) examined Tons River Basin in India. Since the SDI method only needs streamflow data to calculate index values, the method is frequently preferred by researchers and scientists in recent years in determining hydrological drought (Nalbantis 2008; Nalbantis and Tsakiris 2009; Tabari et al. 2013; Hong et al. 2015; Jahangir and Yarahmadi 2020; Malik et al. 2020). Because of its advantages, this method was used to determine the hydrological drought in the present study.

In addition to analyzing the drought with different indices, determining the temporal trend (increasing or decreasing) of drought severity is very important for the operation and management of existing water resources and agricultural areas. The most frequently used method in determining the trend of time series is the Mann–Kendall method which is proposed by Mann (1945) and developed by Kendall (1975). This method is often used in determining the trend of drought, which is a time series, as well as determining the trend of hydrometeorological datasets. For example, Tosunoglu and Kisi (2017) evaluated the trend of the hydrological drought of the Çoruh Basin in Turkey using the Mann–Kendall method, Myronidis et al. (2018) determined the trend of the SDI values obtained in different time periods, and Yilmaz (2019) used Mann–Kendall with innovative Sen's methods to monitor the trend of meteorological drought in the Southeastern Anatolia region of Turkey. Sen's slope method, which determines the linear slope (the amount of change per unit time), is proposed by Sen (1968). This method is mostly used as a supportive test besides Mann–Kendall test to determine the linear slope of dataset. In the literature, it is mostly preferred to determine the trend slopes of drought indices (Abeysingha and Rajapaksha 2020; Gumus et al. 2021) as well as hydrometeorological data (Da Silva et al. 2015; Islam et al. 2021).

When studies on drought and drought trends in Turkey are examined, it can be found that Türkeş et al. (2009) determined the drought using the PDSI method and severity of Konya subregion in Central Anatolia; Türkeş and Tatlı (2009) carried out a general analysis of drought in Turkey with the SPI method; Tuna et al. (2009) examined the drought analysis of Çoruh Basin with the SPI method; Gumus and Algin (2017) analyzed meteorological and hydrological droughts of Seyhan and Ceyhan basins using the SPI and SDI methods, respectively; Güner Bacanli (2017) analyzed the drought with the SPI method and rainfall trend in the Aegean Region; and Özfidaner et al. (2018) investigated hydrological drought analysis of Seyhan Basin streamflow data with the SDI method. When these studies in the literature are taken into consideration, it is seen that the hydrological drought analysis of the Eastern Mediterranean, Antalya, and Western Mediterranean basins have not been studied. Therefore, in this study, hydrological drought analysis of the Eastern Mediterranean, Antalya, and Western Mediterranean basins is performed by the SDI method for different periods. Trend analyses of SDI values obtained for 3-, 6-, and 12-month periods were made, and the slopes of the significant trends were determined. In addition, the spatial distribution of different drought classes and trend slopes has been evaluated.

## Study area and data

There are 26 basins in Turkey. The hydrological drought of the Eastern Mediterranean, Antalya, and Eastern Mediterranean basins, located at the south of Turkey, are investigated in this study. The basins are named as the Mediterranean Basin of Turkey. As stated in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2013), the Mediterranean Basin is one of the basins that are highly vulnerable to global climate change and will be highly affected by climate change (Selek and Aksu 2020). Therefore, it will be useful to investigate the effect of global climate change on streamflow in this region.

In this study, 29 streamflow-gauging stations (SGS) located in the basin are used for determining hydrological drought. These SGS are operated by the General Directorates of Electrical Power Resources Survey and Development Administration namely EIEI in Turkey (the stations designated with the letter E) and of State Water Works namely DSI in Turkey (the stations designated with the letter D). The information about the station number, station name, elevation, drainage area, mean streamflow, latitude, longitude, and measurement range of streamflow values of these SGS are given in the Table 1. D08A067-Söğüt Lake-Exit station has the highest altitude, while E09D018-Manavgat Stream-Waterfall station has the lowest altitude. The station with the largest drainage area is E17D014-Göksu River-Karahacılı, while the drainage area of D08A084-Değirmen Dere-Soda village station is the smallest. It is seen that E09D018-Manavgat Stream-Waterfall station with the largest drainage area has the maximum mean streamflow. According to Table 1, it is seen that the data measurement started between 1956 and 1990 mostly continue until 2015. The total drainage area of the SGS is 44,336.52 km$^2$, and the region is a mountainous territory (Fig. 1).

Greenhouse farming activities are highly developed in the Mediterranean Basin due to the high sunshine duration. Tourism, trade, and agriculture are the most important sources of income in the Mediterranean region of Turkey. In addition, enterprises are operating in this region, which are engaged in livestock and mining activities. All kinds of products such as wheat, corn, cotton, peanuts, oranges, bananas, and out-of-season vegetables are grown in the agricultural areas. Especially greenhouse production has been improved significantly in recent years. Eighty percent of the cultivated roses for rose oil is in this region of Turkey. Moreover, about 20% of the apple stocks produced in Turkey are grown here. Most of the water used in irrigation of agricultural lands and fruit trees in the region is provided from underground water sources (TUBITAK, 2013a; TUBITAK, 2013b; TUBITAK, 2013c). Additionally, the fill rate (% of full supply dam volume) of dams, which directly affects electricity generation capacity and agricultural irrigation, decreased for the three basins from 2012 to 2018. For example, it is decreased from 34.30 to 11.8% in the Western Mediterranean basin, from 40.40 to 13.40% in the Antalya Basin and from 93.30 to 64.00% in the Eastern Mediterranean basin (MAF 2020; Serdar 2020). Accordingly, the droughts that may occur in the region will adversely affect the production capacity of agricultural products, so the evaluation of the hydrological drought of the region emerges as an important issue. In addition, it will be inevitable to experience a socioeconomic drought, as the drought will harm the economy of the people of the region who are dependent on agriculture.

## Methods

### Hydrological drought analysis

The Streamflow Drought Index (SDI) method was developed by Nalbantis (2008). This drought index is calculated by using monthly streamflow data ($Q_{i,j}$). In $Q_{i,j}$, $i$ represents the hydrological year, and $j$ represents the month within the hydrological year defined as the time between October and September. The cumulative streamflow volume is calculated as given in Eqs. 1, 2, and 3 for 3, 6, and 12 months' periods, respectively.

$$V_{i,j} = \sum_{j=3(k-1)+1}^{3k} Q_{i,j} \ , \quad k = 1,2,3,4 \tag{1}$$

$$V_{i,j} = \sum_{j=6(k-1)+1}^{6k} Q_{i,j} \ , \quad k = 1,2 \tag{2}$$

$$V_{i,j} = \sum_{j=1}^{12} Q_{i,j} \tag{3}$$

where $k$ denotes the reference period. For example, in Eq. 1, $k=1$ denotes Oct–Dec (SDI 3-Dec), $k=2$ denotes Jan–Mar (SDI 3-Mar), $k=3$ denotes April–June (SDI

**Table 1** Information about the stations used in the study

| Station no | Station name | Altitude (m) | Drainage area (km$^2$) | Mean streamflow (m$^3$/s) | Latitude (°) | Longitude (°) | Measuring range |
|---|---|---|---|---|---|---|---|
| D08A067 | **Söğüt Gölü-Çıkış** | 1390 | 444.99 | 0.839 | 29.7872 | 37.0556 | 1972–2015 |
| D08A084 | **Değirmen Dere-Soda Köy** | 665 | 17.13 | 0.091 | 28.4500 | 37.2000 | 1981–2015 |
| D08A101 | **Koca Çay-Epçe** | 25 | 70.90 | 0.427 | 27.7667 | 37.3667 | 1990–2015 |
| E08D008 | **Başgöz Çayı-Çatallar** | 342 | 770.00 | 3.292 | 30.0744 | 36.4908 | 1962–2015 |
| E08D009 | **Eşen Çayı-Kavaklıdere** | 1115 | 546.80 | 3.773 | 29.5619 | 36.8253 | 1956–2015 |
| E08D011 | **Dalaman Çayı-Suçatı** | 595 | 3890.60 | 14.071 | 29.1033 | 37.0939 | 1960–2015 |
| E08D012 | **Dalaman Çayı-Akköprü** | 128 | 4964.90 | 41.640 | 28.9344 | 36.9181 | 1963–2010 |
| E08D015 | **Eşen Çayı-Kınık** | 8 | 2448.00 | 37.566 | 29.3167 | 36.3564 | 1971–2015 |
| E08D018 | **Karaçay-Kayadibi** | 110 | 234.10 | 14.266 | 29.4033 | 36.4733 | 1977–2015 |
| D09A006 | **Dim Çayı-Batı Sahil Sulama Kanalı** | 38 | 195.00 | 0.946 | 32.1217 | 36.5494 | 1971–2015 |
| D09A011 | **Korkuteli Çayı-Salamur Boğazı** | 1190 | 130.70 | 1.755 | 30.0500 | 37.1333 | 1969–2015 |
| D09A039 | **Onaç Barajı-Giriş** | 835 | 217.70 | 0.534 | 30.3667 | 37.5167 | 1974–2015 |
| D09A088 | **Değirmen Deresi-Sütçüler** | 750 | 130.90 | 1.284 | 31.0000 | 41.8333 | 1991–2015 |
| E09D002 | **Köprüçay-Beşkonak** | 116 | 1942.40 | 85.642 | 31.1886 | 37.1417 | 1939–2015 |
| E09D012 | **Manavgat Çayı-Sinanhoca** | 245 | 625.60 | 70.074 | 31.6086 | 36.9794 | 1963–2015 |
| E09D017 | **Alara Çayı-Alarahan** | 28 | 875.50 | 30.090 | 31.7267 | 36.6969 | 1968–2015 |
| E09D018 | **Manavgat Çayı-Şelale** | 4 | 1324.40 | 130.211 | 31.4517 | 36.8167 | 1971–2015 |
| E09D019 | **Köprüçay-Bolasan** | 435 | 1538.40 | 22.645 | 31.1914 | 37.3061 | 1984–2010 |
| D17A007 | **Pamuk Deresi-Keşbükü** | 132 | 599.00 | 11.916 | 34.7683 | 37.0306 | 1977–2015 |
| D17A017 | **Göksu-Gördürüp Köprüsü** | 1241 | 364.00 | 5.076 | 32.3000 | 37.1167 | 1977–2015 |
| D17A033 | **Göksu-Aladağ Köprüsü** | 850 | 588.40 | 7.289 | 32.6000 | 37.0500 | 1986–2015 |
| E17D012 | **Göksu Nehri-Bucakışla** | 397 | 2689.20 | 27.007 | 33.0258 | 36.6353 | 1961–2014 |
| E17D014 | **Göksu Nehri-Karahacılı** | 24 | 10,065.20 | 106.294 | 33.8156 | 36.4036 | 1960–2015 |
| E17D017 | **Lamas Çayı-Kızılgeçit** | 975 | 1005.20 | 5.160 | 34.0056 | 36.6600 | 1965–2015 |
| E17D019 | **Ermenek Çayı-Kırkkavak** | 130 | 3631.00 | 50.711 | 33.3114 | 36.5736 | 1965–2010 |
| E17D020 | **Göksu Nehri-Hamam** | 127 | 4304.00 | 42.998 | 33.3694 | 36.6358 | 1965–2015 |
| E17D021 | **Anamur Çayı-Alaköprü** | 37 | 313.20 | 24.133 | 32.8956 | 36.1758 | 1967–2015 |
| E17D025 | **Göktepe Deresi-Günder** | 1028 | 192.60 | 3.690 | 32.6550 | 36.6172 | 1990–2015 |
| E17D033 | **Kadıncık Çayı-Bahçe** | 730 | 216.70 | 5.033 | 34.6392 | 37.2256 | 1995–2015 |

3-Jun), and $k=4$ denotes July–September (SDI 3-Sep) periods. In Eq. 2, $k=1$ and $k=2$ denote the first 6 months (SDI 6-Mar) and last 6 months (SDI 6-Sep) periods, respectively, and Eq. 3 denotes the annual drought index value (SDI 12).

SDI for the reference period $k$ and $i$, hydrological year is calculated as follows.

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V}_k}{S_k}, \quad k = 1,2,3,4 \tag{4}$$

Here, $\overline{V}_k$ and $S_k$ represent the mean and standard deviation of cumulative streamflow volumes, respectively. SDI values were expressed by Hong et al. (2015) in four different classes ranging from mild to extreme drought (Table 2).

## Trend detection tests

Trend analysis is used to determine a statistically significant increase or decrease in a time series. Parametric or nonparametric tests can be used for trend analysis (Helsel and Hirsch 1992). Nonparametric tests (distribution-free) are frequently used in the analysis of hydrometeorological data (Yenigün et al. 2008). The Mann–Kendall trend test (Mann 1945; Kendall 1975) is one of the widely used nonparametric tests for detecting monotonic trends in hydrometeorological time series (Türkeş and Sümer 2004; Wu et al. 2008; Dogan et al. 2015; Forootan 2019; Naz et al. 2020). Details of the method can be found in Yenigün et al. (2008).

The serial correlation of the data should be removed before the Mann–Kendall test is applied (Von Storch and

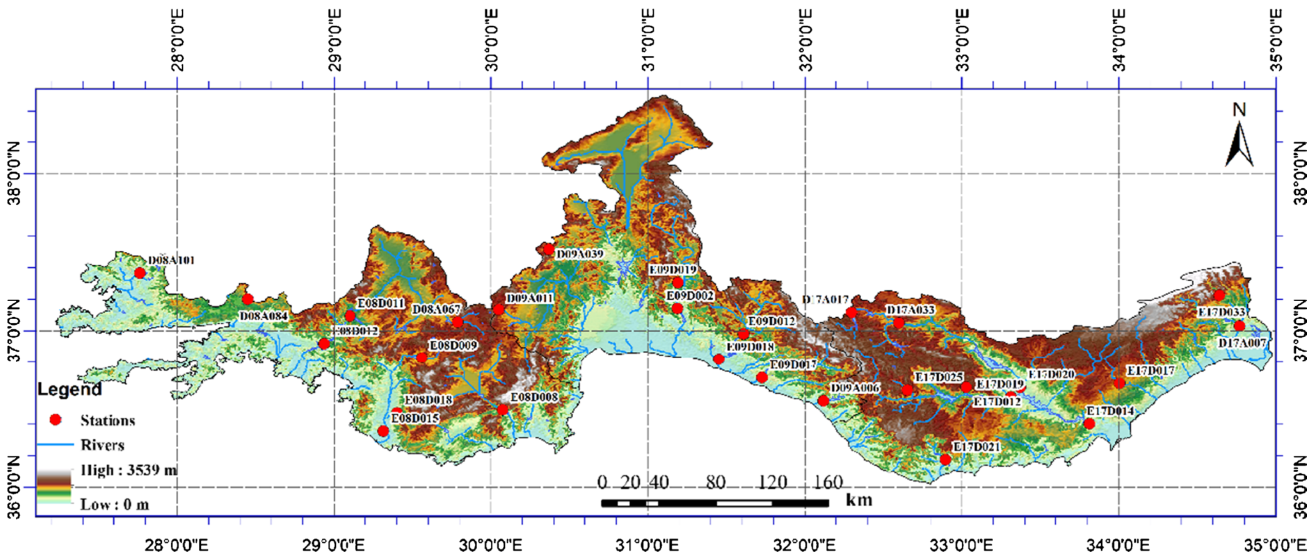


**Fig. 1** Study area

**Table 2** Classification of SDI values (Hong et al. 2015)

| SDI values | Classification |
|---|---|
| SDI ≤ −2 | Extreme drought (ED) |
| −2 < SDI ≤ −1.5 | Severe drought (SD) |
| −1.5 < SDI ≤ −1 | Moderate drought (MoD) |
| −1 < SDI ≤ 0 | Mild drought (MD) |

Navarra 1995). Therefore, the method, proposed by Salas et al. (1980) and adopted by different researchers (Xu et al. 2010; Gocic and Trajkovic 2013), is applied to control serial correlation. In this study, if time series datasets are determined to be serially correlated, the pre-whitened time series are obtained (Partal and Kahya 2006; Gocic and Trajkovic 2013). Details of the method are given by Gumus (2019).

The true slope of data (change per unit time) is determined with Sen's slope method. This method proposed by Sen (1968) is a nonparametric method used to determine the linear slope of the data and is widely preferred by researchers to calculate slope of hydrometeorological data also including drought indices ((Da Silva et al. 2015; Gumus et al. 2021; Islam et al. 2021). The slope estimation of $N$ pairs of data is calculated using the following equation:

$$Q_i = \frac{x_j - x_k}{j - k} \qquad i = 1,2, \ldots\ldots, N \tag{5}$$

where $x_j$ and $x_k$ are the data values at time steps of $j$ and $k$ ($j > k$), respectively. The median of these $N$ values of $Q_i$ is defined as linear slope of data.

Finally, the Mann–Kendall rank correlation test is used to calculate initial years of the significant trend. This test does not take differences of magnitude of the values into account; it only counts the number of consecutive values where the value increases or decreases compared to the prior values. Details of the method are given by Yenigün et al. (2008).

The spatial distribution of drought and trend slopes was prepared using the inverse distance weighting (IDW) method, which works with the spatial interpolation of the results. The method is employed in this study to produce spatial distribution maps for the studied area and was fulfilled using a commercially available software named ArcGIS 10.1. The most important feature of this method is that it provides ease of interpretation, and its calculation is relatively fast (Shepard 1968; Lu and Wong 2008). Details of the method are given by Gumus and Algin (2017).

## Results and discussion

### Drought analysis

As a result of the analyses made with the SDI method, the index values obtained for the 3-, 6-, and 12-month periods of 29 stations are determined, and their temporal distribution is given in Fig. 2. To evaluate the periodic changes of SDI values, the dataset is divided into three different time intervals. The periods are defined as the first period from 1960 to 1979, the second period from 1980 to 1999, and the third period from 2000 to 2015. The mean value of all stations given with red line on the graph (Fig. 2). According to the SDI 3-Dec values, in the first period, moderate drought (MoD), severe drought (SD), and extreme drought (ED) do not occur; however, in 1973, 1974, and 1978, at only a few stations (2 in 1973, 4 in 1974, 8 in 1978), MoD

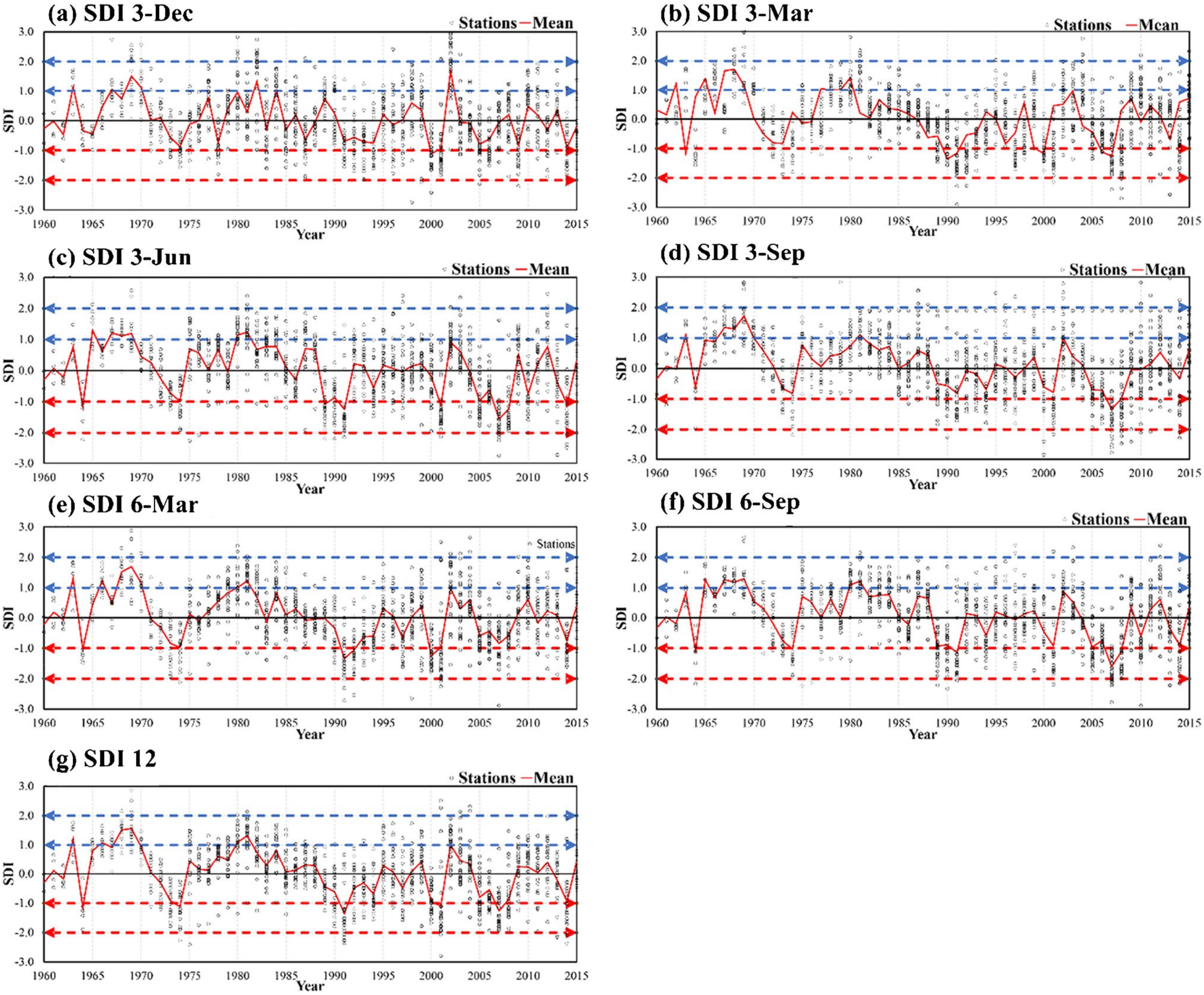


**Fig. 2** Temporal variation of drought for different timescales

or SD periods have occurred (Fig. 2a). In 1998 and 1999, an ED has occurred at station D09A006 consecutively. In the second period, ED and SD periods do not occur according to mean values in the first period. However, especially in 11 years, droughts of MoD and above are determined in different numbers of stations. In the third period, MoD occurred in 2000, and in 13 of the 16 years considered MoD and above drought at different stations, and ED occurred at stations D17A017, E09D019, E17D017, and E09D012 in 2000, 2005, 2009, and 2014, respectively. It is seen that the severity of drought increased in third period covering the years 2000–2015.

In Fig. 2b, the distribution of SDI 3-Mar values is given. There is no ED in the first period, while in the second period, ED occurred at two stations in 1991 and at only one station in 1992. Also, there is an increase in the number of years and stations with ED in the third period. Additionally, a significant increase in the year and number of stations in which SD is determined in the last years. The temporal distributions of SDI 3-Jun values are given in Fig. 2c. Although the number of stations determined in ED does not differ much between the periods, it has increased slightly in the last period. In addition, the year in which the SD cases occurred and the number of stations in which the SD cases occurred are increasing from the first period to the last period. The temporal distribution of SDI 3-Sep values is given in Fig. 2d. The station with ED is determined only in 1974 for the first period, in 1990 for the second period, and in 2000, 2001, 2007, 2008, 2009, 2010, 2011, and 2014 for the third period. In addition, the number of stations that have ED formation in these years has increased in recent years for the periods. A similar situation is valid for the SD occurrence. From the temporal distributions of SDI 6-Mar and SDI 6-Sep values estimated for 6-month periods, it is seen that the years and the number of stations, where ED and SD are calculated, are more in TP compared to other periods (Fig. 2e and f). As stated by SDI 6-Mar and SDI 6-Sep values, it is determined that the number of stations and years where SD and ED occurred in the SDI 6-Sep period are higher than those the SDI 6-Mar period. The temporal distribution of SDI 12 values is given in Fig. 2g. From the figure, ED occurred in the first period in 1974 and 1975 only at two stations (E09D012 and D09A006), in the second period in 1991 at five stations (E09D017, E09D018, E09D019, D09A039, and E17D021), for the third period in 2001 at stations D08A067 and E08D008, in 2013 at stations D17A033 and E17D025, and a stations E17D012, E17D020 and E17D025 in 2014. There has been an increase in the number of stations and years, which have been SD in recent years. When all these data are evaluated, it has been determined that the severity of drought in the Mediterranean region has increased remarkably in recent years, and there has been a significant increase in the number of stations and drought years with ED and SD.

Figure 3 shows that the percentages of drought take place at stations according to Table 2 for all timescales. According to Fig. 3, the most occurring drought type is MD for all timescales. It is noteworthy that there is no drought in different timescales between 1966 and 1970, but especially after 1990, the severity of drought increased. The drought rates of MoD and above exceeded by 50% in some years. This result

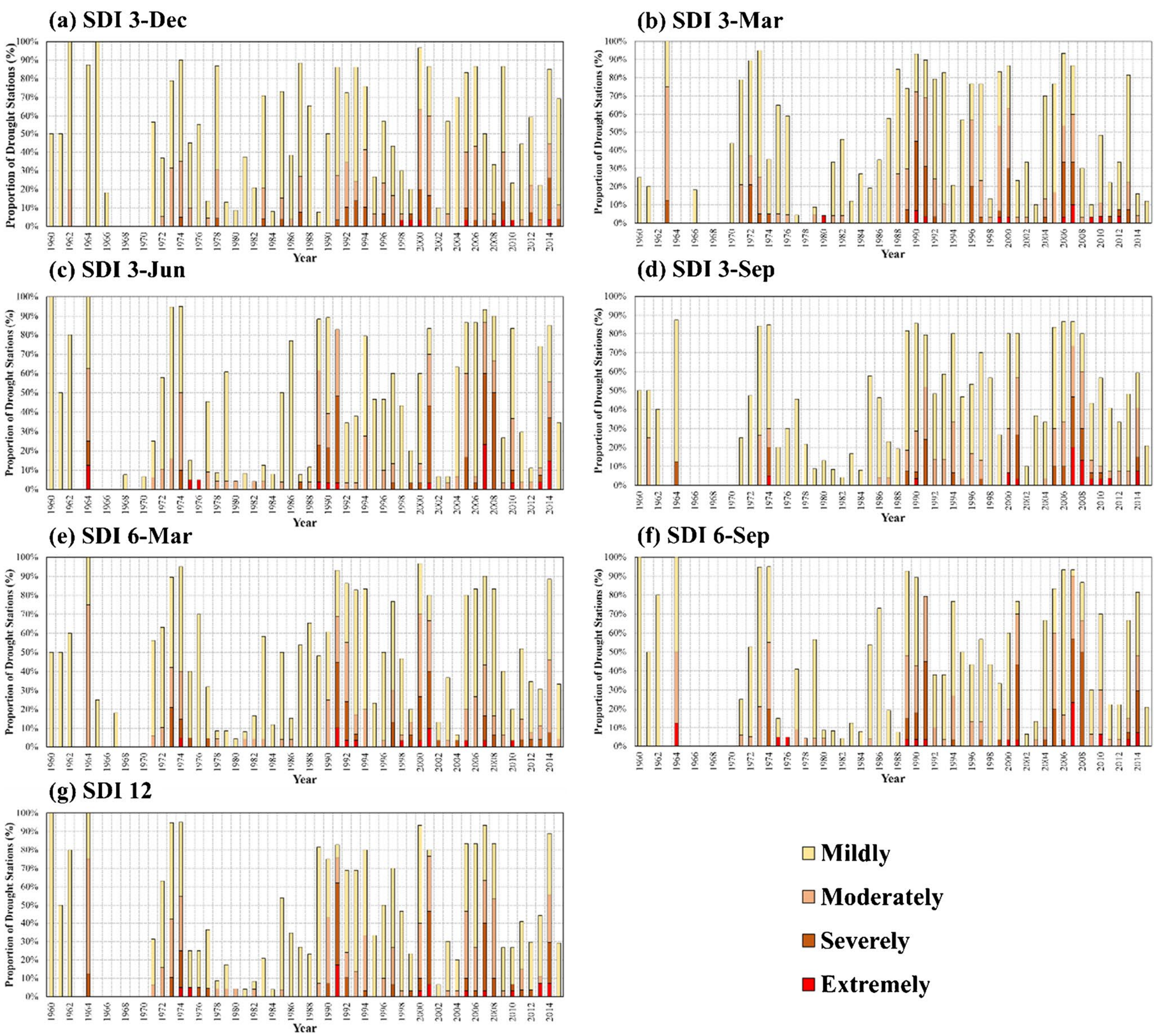


Fig. 3 Proportion of drought stations for all timescales

indicates a relatively good agreement with the results of the study by Türkeş and Tatlı (2009), which used SPI method to analyze drought of severity in Turkey.

## Spatial variation of drought

The spatial distributions of MD, MoD, SD, and ED are given in Fig. 4, Fig. 5, Fig. 6, and Fig. 7, respectively. It is clearly seen from Fig. 4 that MD occurrence levels are between 0 and 95% for different timescales. The highest MD occurrence level is obtained in SDI 3-Dec and appeared in the northwestern part of the basin. It is observed that the occurrence level of MD is about 19–38% in the entire basin.

According to the spatial distribution of the MoD occurrence percentages given in Fig. 5, the MoD occurrence level is between 0 and 24%. The highest rate of MoD occurrence takes place at SDI 6-Sep. The lowest MoD occurrence level is determined in the western part of the basin in SDI 3-Sep, but in all timescales, MoD occurrence level in the eastern part of the basin is relatively higher than the other parts of the basin.

Figure 6 shows the spatial distribution of the SD occurrence levels. From Fig. 6, the occurrence levels of SD are between 0 and 12%, and the driest region is observed in the middle of the northeastern region of the basin for SDI 6-Mar and SDI 12. It has been seen that SDI 3-Dec and SDI 3-Sep

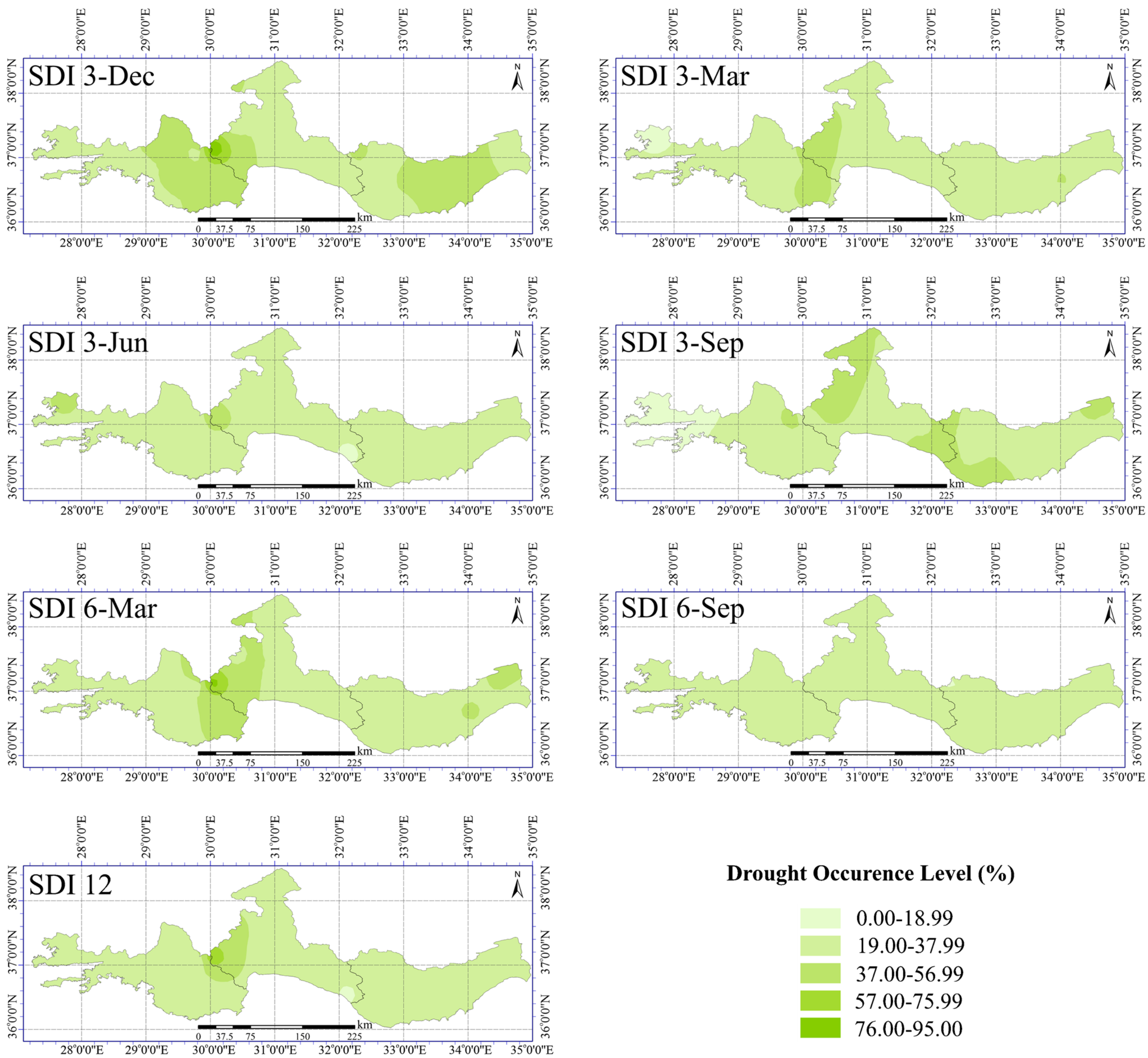


**Fig. 4** Spatial distribution for a proportion of mild drought occurrence events

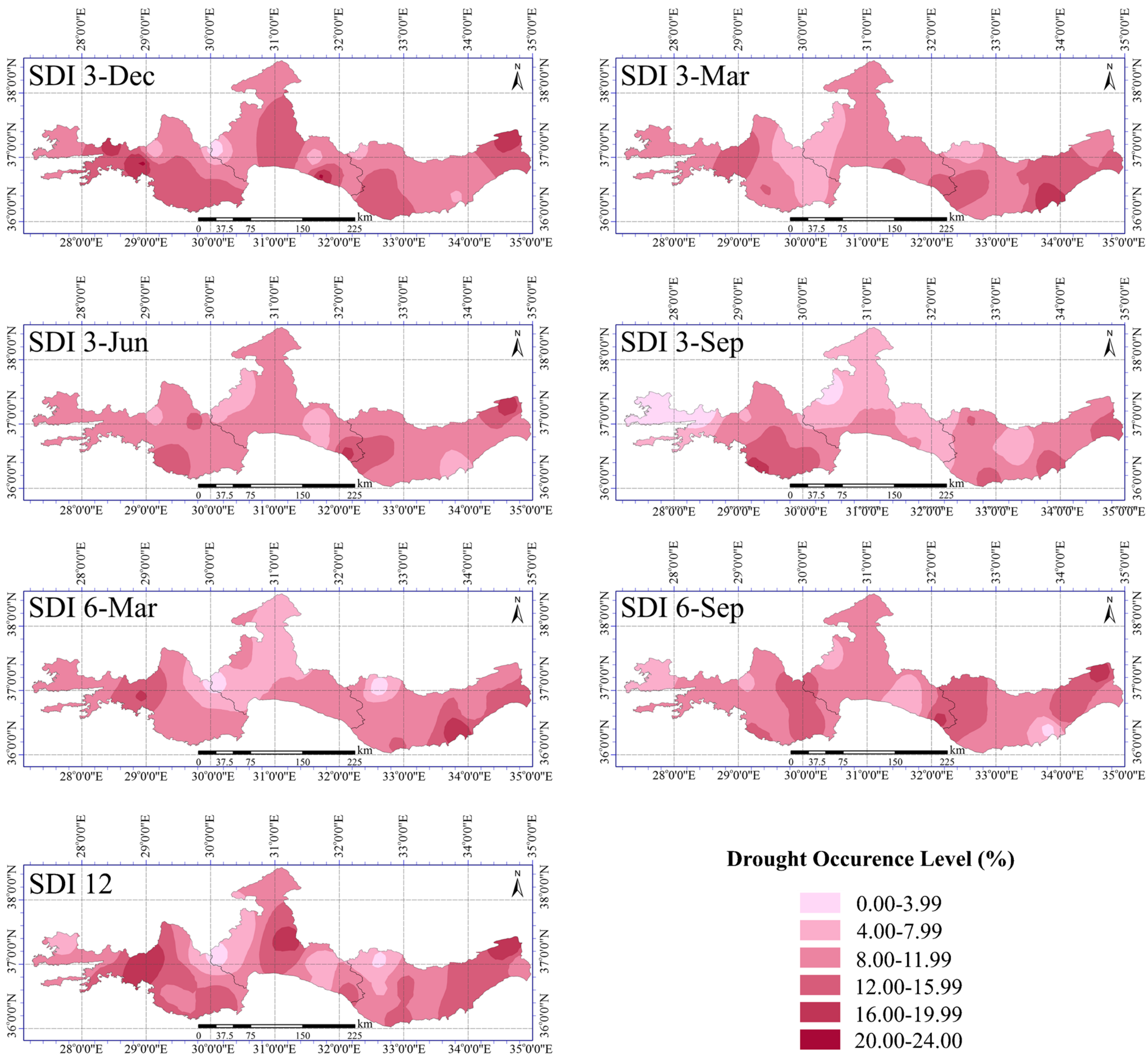


**Fig. 5** Spatial distribution for a proportion of moderate drought occurrence events

have fewer SD occurrence level than other timescales and the most SD occurrence level has existed for SDI 3-Jun.

Figure 7 shows that ED occurrence levels are between 0 and 7%. Accordingly, the highest ED has occurred in the central part of the northwest region of the basin for SDI 6-Mar. It is determined that ED occurrence levels appeared in the middle part of the basin for all timescales. Also, ED occurrence levels in this part are generally higher than the other parts of the basin.

According to the different timescales of the drought, calculated from temporal and spatial analysis, it is seen that the severity of the drought and the number of ED increase from past to present years. Although there is no study conducted using SDI in the study region, it is similar to the results of Gumus and Algin (2017) in Seyhan-Ceyhan river basins, near the region to the east of this study area. This result of the present study agrees well with the results reported by Cook et al. (2016).

It has been stated by different researchers that there is a significant relationship between meteorological drought calculated with the SPI method and hydrological drought determined with the SDI method (Gumus and Algin 2017; Kumanlioglu 2020). Although there is no study to determine hydrological drought using streamflow data in the Mediterranean region, Gumus and Algin (2017) determined SPI values are significantly correlated with the SDI values of the

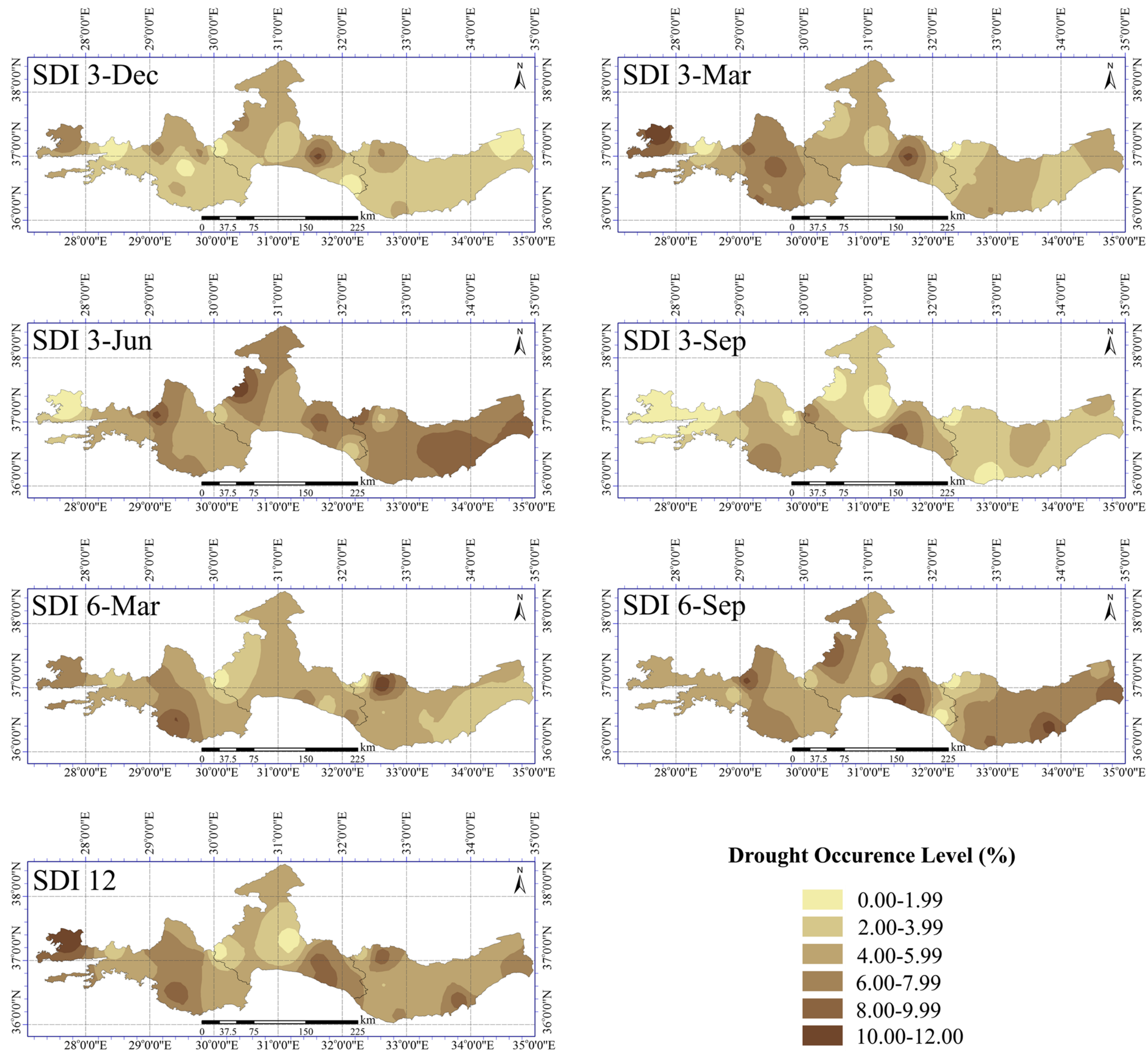


**Fig. 6** Spatial distribution for a proportion of severe drought occurrence events

following year in the Seyhan and Ceyhan basins, located in the east of the Mediterranean basin. In addition, there are significant relationships between SPI and SDI in drought studies conducted in different parts of the world (Kazemzadeh and Malekian 2016; Chitsaz and Hosseini-Moghari 2018). The SPI method is used to determine the meteorological drought with precipitation data. Although precipitation is the main parameter of the streamflow, not all of it turns into streamflow due to infiltration, evapotranspiration, etc. For this reason, meteorological drought index values, determined using precipitation data, do not represent hydrological drought completely. Streamflow values are the main parameter in the planning and operation of dams, which are generally built for electricity generation, agricultural irrigation, and flood control. Hydrological drought indices obtained with streamflow values (SDI values in this study) can be safer than meteorological drought indices determined with precipitation data for planning and operation of dams.

As the drought analysis studies in Iraq and Syria, which are neighbors to Turkey and the Mediterranean basin, are examined, Al-Faraj and Tigkas (2016) stated that there is a severe drought in the Derbandikhan hydrometric station in Iraq for 1998–2001 and 2007–2008 years according to the SDI values, obtained using the annual streamflow. Abou Zakhem and Kattaa (2016) analyzed the meteorological drought of Damascus station in Syria and Cyprus with the

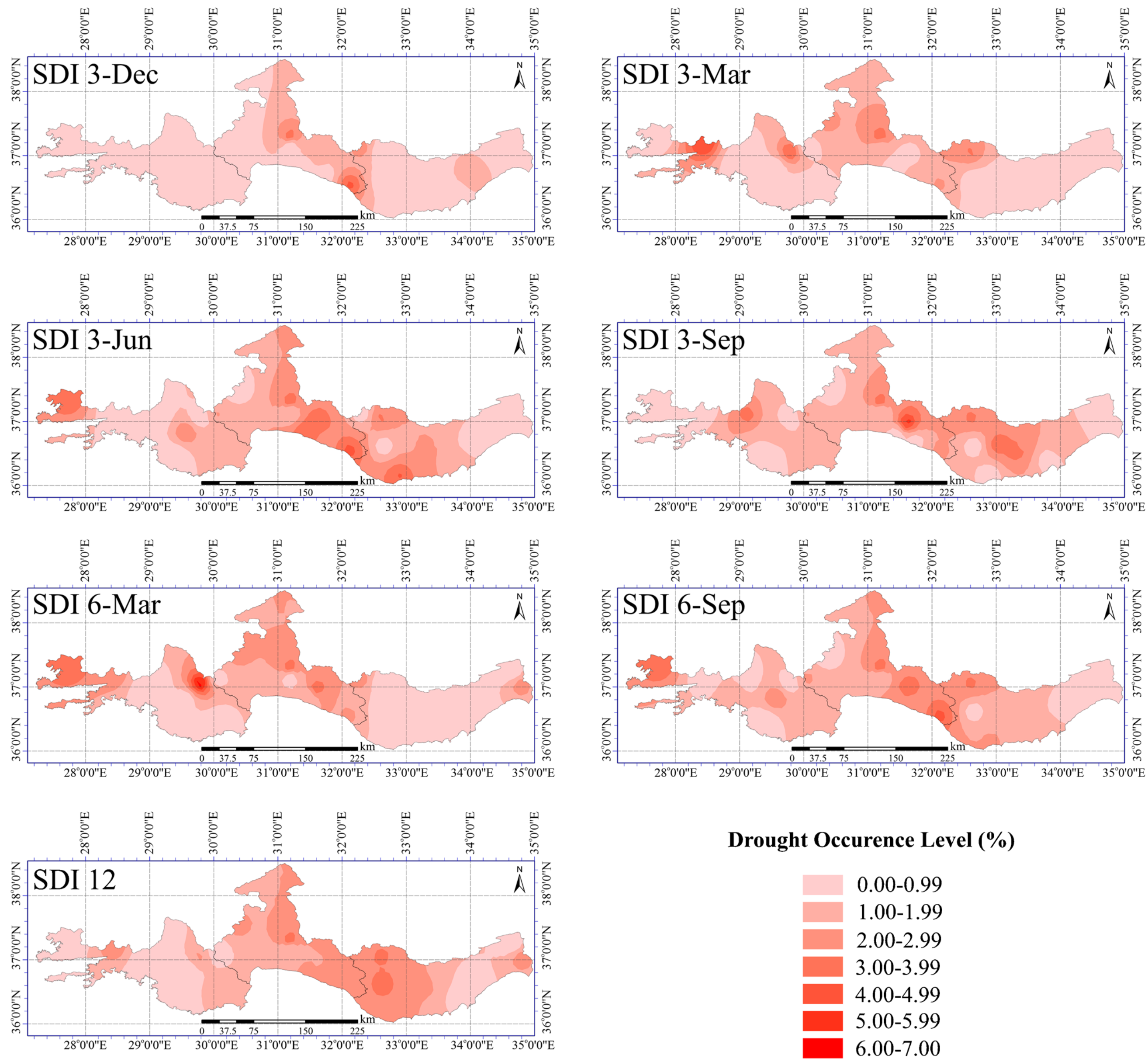


**Fig. 7** Spatial distribution for a proportion of extreme drought occurrence events

SPI method and found severe drought between 1983 and 1991 and extreme drought between 1993 and 2002. Mathbout et al. (2018) analyzed the drought in Syria using SPI and SPEI methods. It is demonstrated that the longest and most intense dry period is 2008–2012 and the 1972–1974, 1983–1985, and 1999–2001 periods are also dry, and there is a statistically significant increase in the severity and intensity of drought in 1999–2012. Yenigun and Ibrahim (2019) analyzed the meteorological drought of the northern Iraq region using the SPI method. In the study, extreme drought values are determined in 1995, 1998, and 2007 for SDI 3-Dec; in 1989, 2008, and 2009 for SPI 3-Mar; in 1999, 2001, and 2008 for SPI 3-Jun; in 2007, 2008, and 2011 for SPI 6-Mar; in 1999, 2001, and 2008 for SPI 6-Sep; and in 1999, 2008, and 2011 for SPI 12 at some stations. Al-Khafaji and Al-Ameri (2021) carried out the drought analysis of the Mosul dam basin in Iraq using SPI, RDI, and SDI methods, and the dry period is found out between the end of 1990 and 2013. Also, it is determined that the years with extreme drought for different timescales have been quite high since 1990. As a result, it is seen that the extreme and severe drought years determined with the SDI and SPI in the region are parallel to each other and the results of this study are similar.

## Trend analysis

Serial correlation effect is checked before applying trend analysis. Lag-1 correlation coefficients of SDI values for three different timescales and serial correlation intervals (red dots) calculated according to the method proposed by Salas et al. (1980) are given in Fig. 8. If there is no serial correlation effect, Lag-1 correlation coefficient calculated for SDI time series should be within the range of red dot lines. Accordingly, positive serial correlation effect is observed in almost all timescales for all stations except D17A017 and E17D025. In stations where serial correlation effect is determined, Mann–Kendall test is applied to pre-whitened series.

The results of trend analysis obtained from the Mann–Kendall test and Sen's slope method are given in Table 3. In the table, stations with significant trends at 95% significant level are in bold, italic, and marked with double stars (**), and stations with trends at 90% significant level are also denoted in bold and marked with a single star (*). The numbers of stations with significant trends for SDI 3-Dec, SDI 3-Mar, SDI 3-Jun, SDI 3-Sep, SDI 6-Mar, SDI 6-Sep, and SDI 12 at 95% confidence intervals are 5, 5, 9, 10, 5, 9, and 4, respectively. At 90% confidence level, for SDI 3-Dec, SDI 3-Mar, SDI 3-Jun, SDI 3-Sep, SDI 6-Mar, SDI 6-Sep, and SDI 12, significant trends are determined at 2, 2, 1, 3, 2, 3 and 6 stations, respectively.

The trend direction is determined to be negative in all stations except D08A101, where a significant trend is determined. Mean SDI values for the entire basin are given in the last row of the table, and there is a significant decreasing trend for only SDI 3-Jun and SDI 3-Sep. In the station-based evaluations, a significant decreasing trend is observed in all timescales at stations E17D012, E17D014, E17D017, and E17D019. A significant decreasing trend is detected in all timescales, except SDI 3-Dec at station D17A007 and SDI 3-Mar at station E17D020. It is seen that linear slope directions have a mostly decreasing trend for all timescales. For example, 73% of stations for SDI 3-Dec, SDI 3-Mar, and SDI 6-Mar; 80% of stations for SDI 3-Sep; 83% of stations for SDI 12, SDI 3-Jun, and SDI 6-Sep; and 93% of the stations showed negative trend.

Figure 9 shows spatial distributions of the stations based on the Mann–Kendall test and the interpolation of Sen's slope magnitude (mm/decade) for all timescales. According to Fig. 9, for SDI 3-Dec, an increasing trend is determined in six stations, one in the east in the basin, three in the middle south, one in the northwest, and one in the west. These trends are not significant, and the 10-year index value increased the range from 0.01 to 0.19. A decreasing trend is observed for the rest of the basin for SDI 3-Dec. The amount of decreasing occurred in the range of − 0.20 to − 0.59 for 10 years. Similar to SDI 3-Dec for SDI 3-Mar (mid-south, west region), trend presence is observed in an upward direction. Also, for SDI 3-Mar, a significant increasing trend is observed in only one station in the mid-south region of the study area. While the amount of increase in this timescale is more than SDI 3-Dec, the decreasing slope is less. In the station where there is a significant increasing trend in SDI 3-Mar, an increasing trend is determined in SDI 3-Jun, and a decline slope of − 0.01 to − 0.59 is observed in the SDI values for 10 years in all the other parts. For SDI 3-Sep, it tended to decrease except for a few stations, and the slope value is similar to SDI 3-Jun. For SDI 6-Mar, the slope values are similar to SDI 3-Mar; only the amount of decrease is greater than that of SDI 3-Mar, while

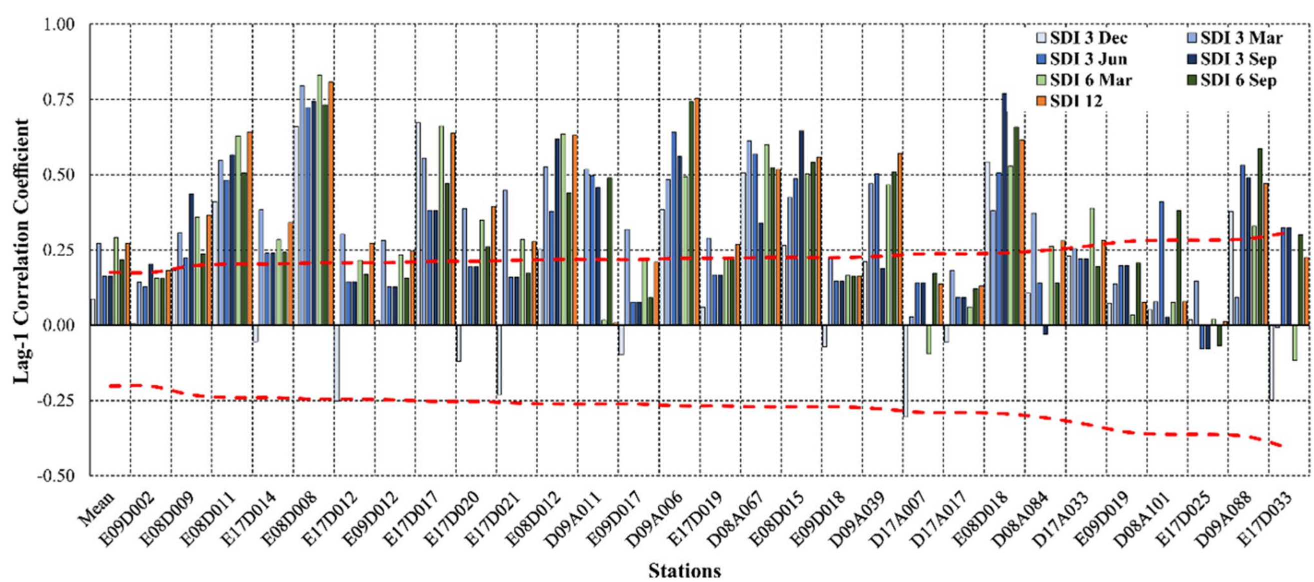


**Fig. 8** Lag-1 serial correlation coefficient for the stations

**Table 3** Trend analysis results for SDI 3, SDI 6, and SDI 12 (the unit of $Q_{med}$ is SDI/decade)

| No | SDI 3-Dec | | SDI 3-Mar | | SDI 3-Jun | | SDI 3-Sep | | SDI 6-Mar | | SDI 6-Sep | | SDI 12 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Z | $Q_{med}$ | Z | $Q_{med}$ | Z | $Q_{med}$ | Z | $Q_{med}$ | Z | $Q_{med}$ | Z | $Q_{med}$ | Z | $Q_{med}$ |
| D08A067 | 0.00 | 0.08 | −0.48 | −0.14 | −0.80 | −0.12 | 0.43 | 0.11 | −0.46 | −0.10 | −0.50 | −0.08 | −0.54 | −0.08 |
| D08A084 | −0.38 | −0.08 | 0.92 | 0.05 | −0.23 | −0.03 | 0.35 | 0.01 | 0.92 | 0.03 | −0.23 | −0.03 | 0.92 | 0.01 |
| D08A101 | 0.26 | 0.11 | 0.75 | 0.28 | −1.05 | −0.46 | 2.78** | 0.01 | 0.79 | 0.24 | −0.77 | −0.32 | 0.40 | 0.15 |
| E08D008 | −2.22** | −0.39 | −1.00 | −0.29 | −1.37 | −0.33 | −1.59 | −0.43 | −1.22 | −0.33 | −1.30 | −0.39 | −1.25 | −0.36 |
| E08D009 | −0.97 | −0.07 | −0.74 | −0.06 | −1.07 | −0.10 | −2.20** | −0.28 | −0.68 | −0.07 | −1.29 | −0.11 | −1.14 | −0.07 |
| E08D011 | −1.04 | −0.22 | −1.40 | −0.26 | −1.42 | −0.26 | −1.43 | −0.21 | −1.45 | −0.27 | −1.43 | −0.26 | −1.48 | −0.27 |
| E08D012 | −1.55 | −0.24 | −1.59 | −0.27 | −2.06** | −0.32 | −2.39** | −0.38 | −1.34 | −0.28 | −2.27** | −0.36 | −1.61 | −0.32 |
| E08D015 | −1.21 | −0.21 | −0.69 | −0.11 | −0.75 | −0.15 | −0.25 | −0.09 | −0.65 | −0.14 | −0.86 | −0.16 | −0.86 | −0.13 |
| E08D018 | −1.35 | −0.13 | −0.07 | −0.11 | −0.59 | −0.20 | −0.59 | −0.24 | −0.64 | −0.11 | −0.54 | −0.22 | −0.43 | −0.12 |
| D09A006 | 0.94 | 0.19 | 2.58** | 0.41 | 2.03** | 0.55 | 1.08 | 0.20 | 1.97** | 0.34 | 1.69* | 0.53 | 1.73* | 0.52 |
| D09A011 | −1.91* | −0.03 | −0.47 | −0.17 | −0.44 | −0.18 | −1.69* | −0.32 | −1.60 | −0.04 | −1.00 | −0.26 | −1.85* | −0.07 |
| D09A039 | −0.75 | −0.10 | −0.73 | −0.07 | −0.53 | −0.10 | 1.38 | 0.14 | −1.02 | −0.11 | −0.48 | −0.09 | −0.57 | −0.07 |
| D09A088 | −1.41 | −0.58 | −1.05 | −0.39 | −1.36 | −0.77 | −0.32 | −0.49 | −0.97 | −0.42 | −1.02 | −0.78 | −1.56 | −0.70 |
| E09D002 | 0.16 | 0.01 | −2.10** | −0.10 | −2.44** | −0.11 | −0.11 | −0.05 | −1.34 | −0.07 | −2.26** | −0.10 | −1.13 | −0.09 |
| E09D012 | −0.76 | −0.08 | −0.94 | −0.09 | −1.62 | −0.14 | −1.62 | −0.14 | −0.83 | −0.08 | −1.71* | −0.17 | −1.67* | −0.15 |
| E09D017 | −0.22 | −0.03 | −0.28 | −0.12 | −0.99 | −0.12 | −0.99 | −0.12 | −0.81 | −0.10 | −1.12 | −0.14 | −0.84 | −0.09 |
| E09D018 | 0.00 | 0.00 | 0.06 | 0.01 | −1.79 | −0.21 | −1.79* | −0.21 | 0.01 | 0.01 | −1.57 | −0.20 | −0.66 | −0.09 |
| E09D019 | 0.38 | 0.13 | 0.67 | 0.27 | −1.33 | −0.35 | −1.33 | −0.35 | 0.88 | 0.23 | −1.13 | −0.34 | 0.38 | 0.10 |
| D17A007 | −1.11 | −0.20 | −1.74* | −0.30 | −1.67* | −0.24 | −1.67* | −0.24 | −1.69* | −0.29 | −1.79* | −0.26 | −1.79* | −0.24 |
| D17A017 | 0.51 | 0.09 | −0.15 | −0.04 | −2.61** | −0.36 | −2.61** | −0.36 | 0.19 | 0.03 | −2.71** | −0.28 | −1.74* | −0.20 |
| D17A033 | −0.44 | −0.09 | −0.68 | −0.16 | −1.53 | −0.33 | −1.53 | −0.33 | −0.07 | −0.10 | −1.36 | −0.29 | −0.71 | −0.19 |
| E17D012 | −1.92* | −0.11 | −2.85** | −0.34 | −2.73** | −0.26 | −2.73** | −0.26 | −2.54** | −0.31 | −2.95** | −0.28 | −3.05** | −0.36 |
| E17D014 | −2.80** | −0.21 | −2.86** | −0.35 | −2.88** | −0.30 | −2.88** | −0.30 | −3.06** | −0.31 | −2.63** | −0.29 | −3.03** | −0.39 |
| E17D017 | −1.96** | −0.45 | −1.66* | −0.32 | −2.13** | −0.39 | −2.13** | −0.39 | −1.68* | −0.39 | −2.11** | −0.42 | −1.73* | −0.45 |
| E17D019 | −2.47** | −0.30 | −2.52** | −0.42 | −3.59** | −0.42 | −3.59** | −0.42 | −2.66** | −0.38 | −3.84** | −0.46 | −3.55** | −0.49 |
| E17D020 | −2.58** | −0.25 | −1.61 | −0.33 | −3.35** | −0.35 | −3.35** | −0.35 | −2.22** | −0.36 | −2.90** | −0.39 | −2.72** | −0.42 |
| E17D021 | −0.19 | −0.03 | −0.61 | −0.16 | −2.23** | −0.24 | −2.23** | −0.24 | −0.29 | −0.12 | −2.25** | −0.25 | −1.14 | −0.25 |
| E17D025 | −0.22 | −0.13 | 1.28 | 0.29 | −0.84 | −0.27 | −0.84 | −0.27 | 0.62 | 0.15 | −0.88 | −0.24 | −0.62 | −0.16 |
| E17D033 | −0.82 | −0.28 | 0.21 | 0.15 | −0.49 | −0.55 | −0.49 | −0.55 | −0.06 | −0.08 | −1.42 | −0.50 | −0.75 | −0.36 |
| Mean | −0.93 | −0.04 | −1.02 | −0.09 | −2.39** | −0.11 | −2.39** | −0.11 | −0.95 | −0.08 | −1.48 | −0.11 | −1.09 | −0.10 |

Stations with significant trends at 95% significant level are in bold, italic, and marked with double stars (**), and stations with trends at 90% significant level are also denoted in bold and marked with a single star (*)

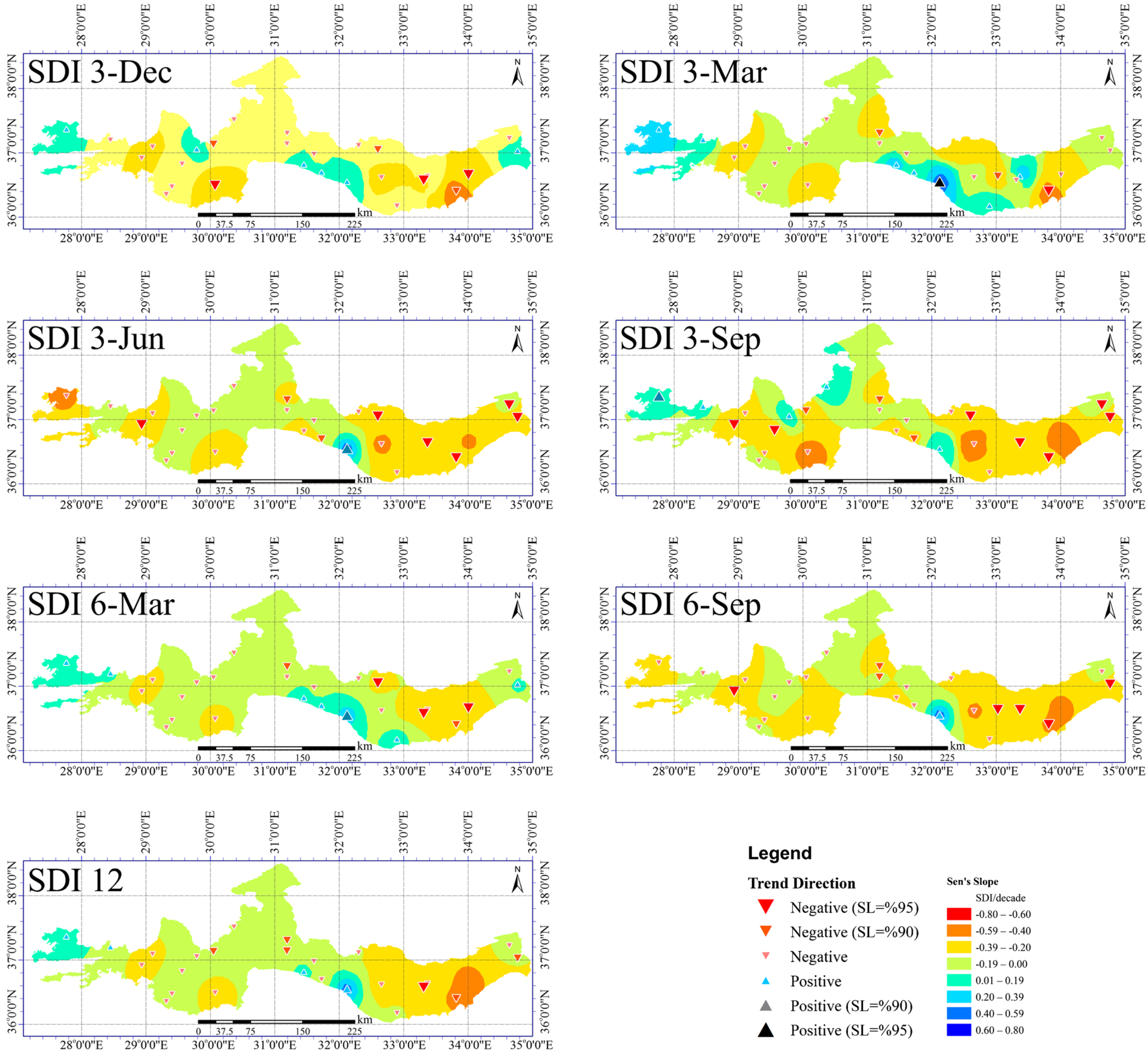


**Fig. 9** Spatial distributions of the stations based on the Mann–Kendall test and the interpolation of Sen's slope magnitude (mm/decade) for all timescales

a decreasing trend is observed in almost the entire basin in SDI 6-Sep. In SDI 12, an increase is observed in the western part of the basin and the middle-south region, as expected, as a mixture of almost all timescales, while it tends to decrease in the remaining regions. When all timescales are considered, a statistically significant decreasing trend is observed in the western part of the basin. The result concluded in this study is considered to be related to the significant decrease in precipitation and the significant increase in temperatures concluded by Gumus (2019) in the Seyhan and Ceyhan basins located in the east of the Mediterranean Basin. Kahya and Kalaycı (2004) have made an analysis of streamflow trends in value between 1964 and 1994 across 83 stations in Turkey. Eight of these 83 stations are within the basin subject considered in this study. A decreasing trend is determined at these stations, which are within the scope of this study. The findings obtained as a result of this study are in the same line with the ones reported by Kahya and Kalaycı (2004).

## Conclusion

Spatial and temporal hydrological drought analysis of 3-, 6-, and 12-month periods was performed by using streamflow data of 29 stream gauging stations in the Mediterranean Basin which is located at the south of Turkey. The monotonic trends and linear slopes of the indices obtained from the SDI method were determined.

As a result of the study, the following conclusions were made.

- In all timescales, it has been determined that there has been a significant increase in drought severity in recent years.
- According to the drought occurrence percentages, it has been observed that the most repetitive type of drought is MD for all timescales, and especially the drought severity that occurred after 1990 has increased.
- For all timescales, it has been determined that the central part of the basin generally has higher ED occurrence percentages than the other parts of the basin.
- The rate of stations with significant trends at 95% confidence interval according to the Mann–Kendall test was between 13 and 35% for different timescales. It was observed that the determined trend in most of the stations with a significant trend was in the decreasing direction.
- According to Sen's trend slope method, 73% of stations for SDI 3-Dec, SDI 3-Mar, and SDI 6-Mar, 80% of stations for SDI 3-Sep, 83% for SDI 12, and 93% for SDI 3-Jun and SDI 6-Sep of the stations showed a diminishing trend.
- According to the spatial distribution of trend slopes, there was an increasing tendency in the western part of the basin and in the middle-south region, while the decreasing trend was intense in the remaining regions. Also, a statistically significant decreasing trend was determined in the western region of the basin for all timescales.

As a result, the slope of the drought indices is in the range of − 0.2/decade to − 0.59/decade in the study area where agricultural activities are intensely carried out. Since such a decrease will indicate that there will be a serious increase in drought, it is necessary to plan for drought in the relevant region and to use water resources effectively and efficiently.

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## Declarations

**Conflict of interest** The author declares that he has no competing interests.

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