Acta Geophysica (2022) 70:361–371
https://doi.org/10.1007/s11600-021-00719-x

RESEARCH ARTICLE - HYDROLOGY

Spatiotemporal analysis of droughts in Hirfanli Dam basin, Turkey by the Standardised Precipitation Evapotranspiration Index (SPEI)

Utku Zeybekoglu[1]

Received: 21 September 2021 / Accepted: 11 December 2021 / Published online: 25 January 2022

Abstract

Drought is generally defined as a disaster affecting vital activities negatively because of water scarcity as a result of precipitation falling below the recorded normal levels. In the present study, the Standardized Precipitation Evapotranspiration Index was applied for the first time in Hirfanli Dam basin, which has the characteristics of a semiarid climate in Turkey. The annual drought events in the basin between 1968 and 2017 were investigated by using the precipitation and temperature data obtained from Gemerek, Kayseri, Kirsehir, Nevsehir, Sivas, and Zara meteorology observation stations located in Hirfanli Dam basin. The dry and wet years were determined in the basin, and evaluations were made in this respect. The years when the most severe droughts happened in the basin were determined, and drought maps, which showed the spatial distribution of drought, were prepared. In the light of the analyses and maps made, it was found that the most severe drought happened in 2001 in Hirfanlı Dam basin.

Keywords Drought analysis · Hirfanli Dam basin · Standardised Precipitation Evapotranspiration Index (SPEI) · Turkey

Introduction

Drought, which is the most dangerous disaster, has not yet been defined in world literature. However, the effects of it are felt increasingly in the entire world. Generally, human beings become aware of it when water shortage starts (Hejazizadeh and Javizadeh 2011). Drought is defined as water scarcity caused by the temporary imbalance of the amount of moisture lasting from a few weeks to several months with little or no rainfall at all (Tallaksen and Van Lanen 2004). According to another definition, drought appears when rainfall is inadequate for the water requirements of plants, urban water supply, and the amount of water entering the dam lakes (Salinger 1995). According to the definition of drought in the International Convention to Combat Desertification, on the other hand, drought is a natural event occurring when precipitation is quite below normal levels causing serious hydrological imbalance by affecting land resources production systems negatively (UNEP 1994). The uncertain onset and end of the drought, its cumulative increase, its simultaneous effects on more than one resource, and its high economic dimension are the most important characteristics distinguishing it from other disasters (Ozgurel et al. 2003). Among other disasters, drought has the greatest effect on life and the economy with its ability to develop under different meteorological and environmental conditions (Oguzturk and Yildiz 2014).

Drought, whose effects are widely seen in the entire world, is expressed in four different ways according to its occurrence as Meteorological Drought, Agricultural Drought, Hydrological Drought, and Socioeconomic Drought (Wilhite and Glantz 1985; Tate and Gustard 2000; Mishra and Singh 2010). Meteorological drought: In the simplest sense, Meteorological drought can be defined as the insufficient amount of rainfall causing water deficiency when water is required (Lutgens and Tarbuck 2006; Turkes and Tatli 2008; Mishra and Singh 2010). Meteorological drought also triggers other drought types. The decrease in meteorological factors such as rainfall, temperature, and humidity also affects other sources in time, thus resulting in other drought types (Sirdas 2002; Sen 2009). Agricultural

Communicated by Dr. Michael Nones (CO-EDITOR-IN-CHIEF).

✉ Utku Zeybekoglu
utkuz@sinop.edu.tr

[1] Department of Construction, Boyabat Vocational School of Higher Education, Sinop University, Boyabat, Sinop, Turkey

drought: It is a typical condition occurring after meteorological drought and before hydrological drought and is expressed as the condition when there is not adequate moisture for plants to grow and develop in their root zones (Gibbs and Maher 1967; Wilhite and Glantz 1985). Agricultural drought is a typical drought type between meteorological drought and hydrological drought (Wilhite 2000; Sen 2009). Hydrological drought: It is the gap between the flow values of rivers and other surface water sources and groundwater sources (Whipple 1966; Turkes 1990). Hydrological drought, which is related to the effect of groundwater resources, surface waters, or rainfall periods, is defined as the decrease and deficiency in the earth and groundwater as a result of a long-lasting lack of rainfall (Ozgurel et al. 2003; Sonmez et al. 2005; Kadioglu 2008). Hydrological drought usually appears with a combination of meteorological and agricultural droughts (Saylan et al. 1997). Socioeconomic drought: Droughts can cause socioeconomic drought when severe and prolonged droughts start to affect human life, and when drought action plans or works to avoid drought become inadequate (Wilhite and Glantz 1985; Turkes 2017).

In its 4th Report, the Intergovernmental Panel on Climate Change stated that areas that were affected by drought increased globally after the 1970s (IPCC 2007). For this reason, researchers pay more attention to studies on drought because of the increasing effects of global warming (Lloyd-Hughes and Saunders 2002; Qin et al. 2015; Oguzturk et al. 2016).

It is possible to decrease the impacts of drought and to avoid this threat and danger when the findings obtained as a result of scientific studies on drought are evaluated accurately (Karl 1983; McKee et al. 1993; Bonaccorso et al. 2003; Morid et al. 2006; Tabari et al. 2012; Merkoci et al. 2013; Deo and Sahin 2015; Jain et al. 2015; Ionita et al. 2016; Yacoub and Tayfur 2017; Yenigun and Ibrahim 2019). Research works and applications were conducted to determine, analyze, and evaluate the drought in Turkey (Erinc 1949; Sirdas and Sen 2003; Keskin et al. 2009; Turkes and Tatli 2009; Bacanli et al. 2011; Dogan et al. 2012; Gumus and Algin 2017; Bacanli and Aksan 2019; Kumanlioglu 2020; Altin et al. 2020; Danandeh Mehr and Vaheddoost 2020). The most severe and common droughts in Turkey, which is located in semiarid climate zone, occurred in 1932, 1955–1956, 1971–1974, 1977, 1983–1984, 1989–1991, 1996, 1999–2001, 2007–2008 and 2013–2014 (Turkes 1996, 2003, 2012, 2014; Komuscu 2001; Kapluhan 2013; Akturk and Yildiz 2018).

In this study, drought research was performed for Hirfanli Dam basin for the 1968–2017 period by using the Standardized Precipitation Evapotranspiration Index (SPEI). The severity of the annual droughts was determined and analyzed to determine the drought in the basin better. As far as the researcher knows, the present study is the first one conducted in the basin by using the SPEI. Drought maps were also prepared in this respect by using the Geographical Information Systems to express the spatial distribution of the droughts in the basin.

Study Area and Data

The sub-basin that feeds Hirfanli Dam, which is located between the longitudes of 33.3°E and 38.7°E and the latitudes of 38.3°N and 40.1°N, is in Kizilirmak River basin. Its surface area is approximately 26,700 km^2. With its 1355 km length, the Kizilirmak river is one of the major water resources of Turkey. Hirfanli Dam was built on Kizilirmak River in 1959 to control floods and for hydropower use. Hirfanli Dam basin has high topographic features with a mountainous plateau. The altitude varies between 799 and 3880 m (Fig. 1) and decreases from the east to the west in the basin. In the west of the basin, plateaus and meadows are more common. Volcanic mountains are also found in this area with wide plains around them. Erciyes Mountain is among the most important volcanic mountains in the basin. The Eastern basin has high, rugged and mountainous plateaus, and the low hills in the area are the most important surface elements. In the basin, a typical dry climate is dominant, and the Hirfanli Dam basin covers plateaus, meadows, and pastures for animal grazing and wide plains for agricultural activities. For this reason, agriculture is a major economic factor in the basin (Yildiz 2009, 2014; Oguzturk and Yildiz 2016).

The mean temperature of the basin is 10.03 °C, and the mean annual precipitation value is 424.82 mm. In addition, geographical and meteorological details of the stations are given in Table 1. The temperatures in the basin decrease from west to east, and the distribution of precipitation increases from west to east contrary to temperatures. The spatial distribution of temperature and precipitation is given for the basin in Figs. 2 and 3, respectively.

Methodology

The SPEI was developed by Vicente-Serrano et al. (2010) to analyze and track droughts. In addition to the monthly precipitation amounts, SPEI also adds temperature and evaporation data to the calculation method enabling us to obtain more significant results in agricultural drought studies (Vicente-Serrano et al. 2015; Ribeiro et al. 2019; Starks et al. 2019; Yesilkoy 2020). Drought categories of the SPEI values are given in Table 2 (Nam et al. 2015; Dikici 2020).

The SPEI is expressed as the difference (D) between monthly or weekly potential evapotranspiration (PET) and precipitation (P). It is also adjusted to log-logistic

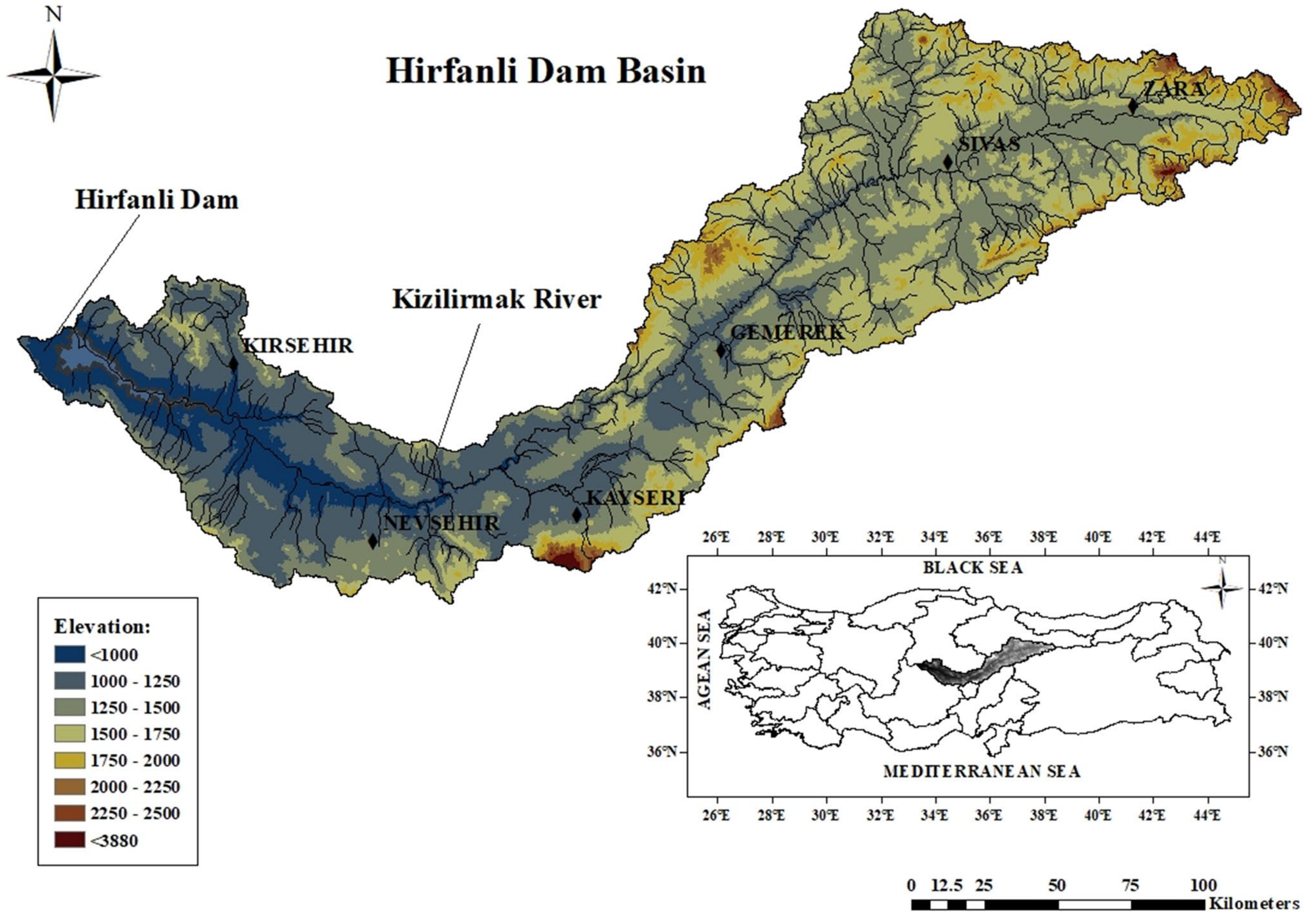

Fig. 1 The geographical and topographical situation of the Hirfanli Dam Basin, Turkey

Table 1 Geographical and meteorological information of the stations in Hirfanli Dam basin

Station	Latitude (N)	Elevation (m)	P_{mean} (mm/year)	T_{mean} (°C/year)
Gemerek	39° 11'	1173	403.31	9.64
Kayseri	38° 41'	1092	390.13	10.54
Kirsehir	39° 09'	1007	383.49	11.47
Nevsehir	38° 37'	1259.5	413.20	10.70
Sivas	39° 44'	1285	443.70	9.19
Zara	39° 52'	1348	515.11	8.66

distribution (Vicente-Serrano et al. 2010). This difference (D) is the excessive or scarce water for a selected period (i) and is calculated by using Eq. 1:

$$D_i = P_i - \mathrm{PET}_i. \tag{1}$$

The Thornthwaite Equation (Thornthwaite 1948), which requires monthly average temperature and latitude data of the selected station, was used in PET calculation.

The SPEI can be calculated by using the same steps as in the SPI and is determined by transforming the log-logistic distribution into standard normal distribution (Kumanlioglu 2020). The probability of the D value was calculated with the cumulative distribution function $F(x)$ of the probability distribution by using the parameters of the log-logistic distribution. The SPEI values are obtained for the selected periods by using $F(x)$ standard values of the cumulative distribution functions and eqs. 2 to 4 (Abramowitz and Stegun 1965; Vicente-Serrano et al. 2010; Stagge et al. 2015; Kumanlioglu 2020):

$$F(x) = \left[1 + \left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{2}$$

$$\mathrm{SPEI} = W - \frac{c_0 + c_1 w + c_2 w^2}{1 + d_1 w + d_2 w^2 + d_3 w^3} \tag{3}$$

$$W = \sqrt{2ln(P)};\; P \le 0.5. \tag{4}$$

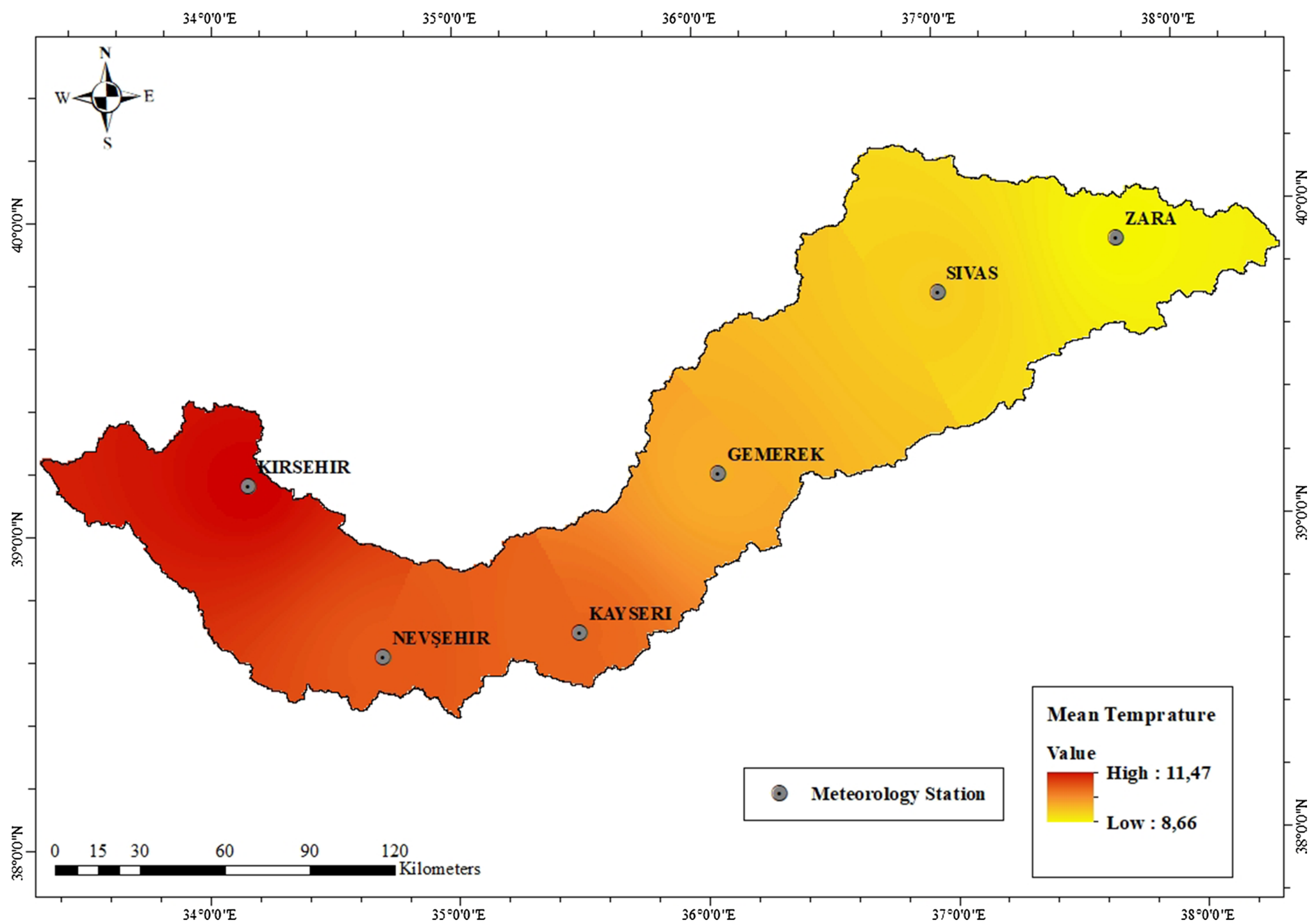

Fig. 2 Spatial distribution of mean temperatures in the Hirfanli dam basin 1968–2017

The α, β, γ values are the scale, shape, and origin parameters within the $\gamma > D < \infty$ range of the D values. Let P be the exceeding probability value; *1-p* is written instead of P value in case $P > 0.5$. The sign of the calculated SPEI value is reversed. $c_0 = 2.515547$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$.

As a result of the given calculation method, the SPEI values that have an average value of zero and a Standard Deviation of 1 are obtained. The details for the calculation of SPEI values are given in references (Stagge et al. 2015; Trivarombo et al. 2018; Kumanlioglu 2020; Bakanogullari 2020a; Pei et al. 2020).

Results

The annual drought analyses were made for Hirfanli Dam basin in the present study by using 50-year (1968–2017) climatic data and the SPEI. The temporal distribution of the SPEI series obtained for each station in the basin and for the entire basin is given in Figs. 4 and 5.

According to the SPEI results, the driest year was 1999 for Gemerek with − 1.95, as seen in Fig. 4. The year 2016 was the driest year for Kayseri with − 2.09; and the year 2008 was the driest year for Kirsehir (− 1.72). The year of 2012 was found to be the driest year for Zara (− 2.12). For Nevsehir and Sivas, the driest year was 2001; and for these two stations, the SPEI values in the driest years were found to be − 1.85 and − 1.78, respectively.

The longest dry and wet periods for the stations were determined based on Fig. 4, where the changes in SPEI values of the stations in the basin according to time are given. The resulting wet and dry periods are given in Table 3.

As can be seen in Table 3 and Fig. 4, the longest drought occurred in Nevsehir for a 6-year period as of 2001. The longest dry periods were 3 years for Gemerek, Kayseri and Sivas. In Gemerek, the longest dry period began in 1999 and 2012, and in 2003 for Kayseri, and in 2013 for Sivas. 4-year dry periods were specified Kirsehir and Zara. The beginning of the longest drought was in 2001 in Kirsehir and 2012 for Zara. The longest wet period was detected in Zara with a 4-year period after 1995. It was found that the longest wet lasted 3 years in the other five stations in the basin. The

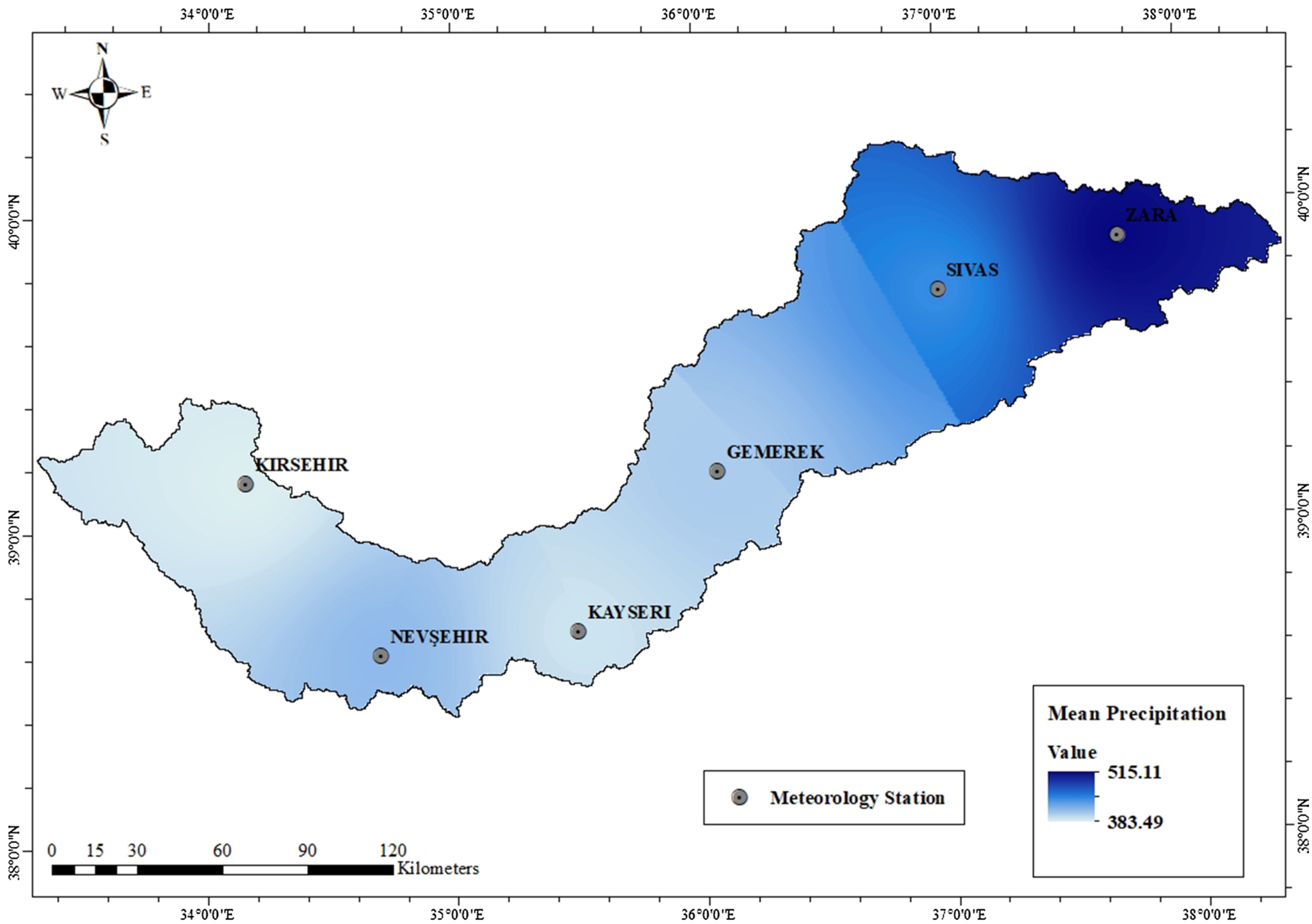

Fig. 3 Spatial distribution of mean annual precipitation in the Hirfanli dam basin 1968–2017

Table 2 SPEI drought categories

SPEI values	Drought class
Greater than 2.00	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0.50 to 0.99	Slightly wet
−0.49 to 0.49	Near normal
−0.99 to −0.50	Mild dry
−1.49 to −1.00	Moderately dry
−1.99 to −1.50	Severely dry
Less than −2.00	Extremely dry

longest wet periods were experienced in two times in Kayseri, and the beginning of the periods was 1986 and 1990. The starting times of the longest wet periods for Kirsehir, Nevsehir, Sivas and Gemerek were 1968, 1990, 1991 and 2009, respectively.

The distribution of the SPEI values of the stations and the index values of the basin according to the drought classifications are given in Table 4.

According to Table 4, normal, mild arid, and slightly moist-drought events occurred more than other drought classes in the stations in the basin. Despite this, extremely dry years were detected in Kayseri and Zara, which were 2001 and 2016 in Kayseri, and 2012 in Zara. According to Table 4, in which the numbers of dry and wet years of the stations are given, 17 years were determined as dry and wet in Nevsehir and Sivas. The number of wet years was higher in Gemerek, Kayseri and Kirsehir than the dry year count. In Gemerek, 15 years were wet, 13 years dry; 16 years wet 15 years dry in Kayseri; and 17 years wet, 16 years dry in Kirsehir. The number of dry years in Zara, which is located in the far eastern part of the basin, was higher than wet years. A total of 19 years were determined to be dry, and 16 years were determined as wet.

The distribution of the dry and wet years for the entire basin was determined by taking the averages of the SPEI values of the basin (Fig. 5). It can be argued that 15 years were wet, and 17 years were dry in the basin. 1970, 1973–1974, 1984, 1989, 1994, 1999, 2001, 2003–2006, 2008, 2013–2014, 2016–2017 were determined as dry years in the basin. On the other hand, wet years were detected

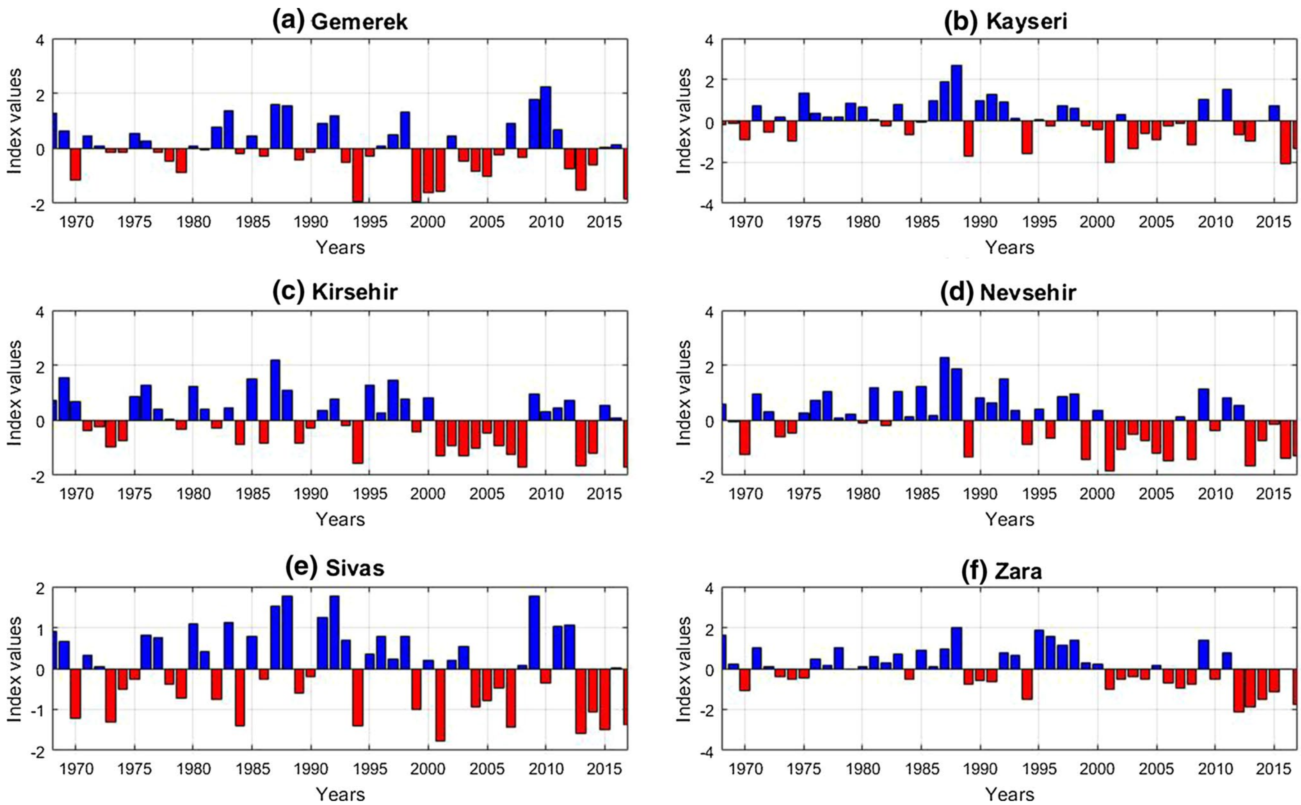

Fig. 4 The temporal distribution of SPEI values for dry and wet situations in stations of Hirfanli Dam Basin

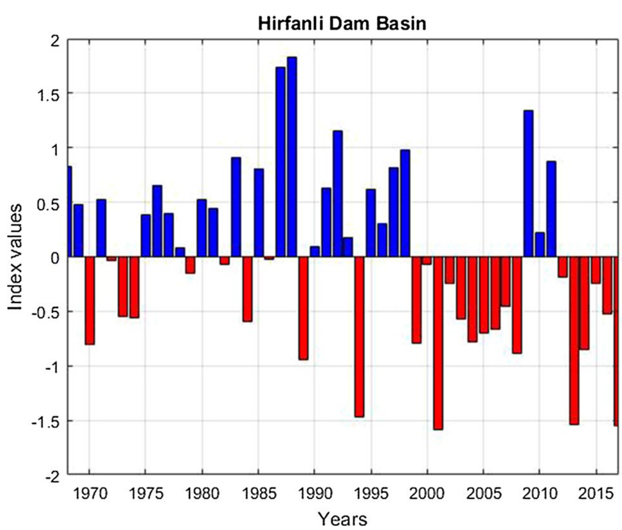

Fig. 5 The temporal distribution of SPEI values for dry and wet situations in Hirfanli Dam Basin

as 1968, 1971, 1976, 1980, 1983, 1985, 1987–1988, 1991–1992, 1995, 1997–1998, 2009, 2011. The number of normal, slightly arid, and slightly humid years was 18 years, 13 years, and 11 years, respectively, in the basin, which shows that the basin is under the effect of drought.

Table 3 Maximum dry and wet durations for the SPEI

Station	Wet		Dry	
	Starting	Duration (Year)	Starting	Duration (Year)
Gemerek	2009	3	1999, 2012	3
Kayseri	1986, 1990	3	2003	3
Kirsehir	1968	3	2001	4
Nevsehir	1990	3	2001	6
Sivas	1991	3	2013	3
Zara	1995	4	2012	4

According to Fig. 5, in which the SPEI values for the 1968–2017 period are shown as time series of average values across the basin, the longest dry period was determined as 4 years between 2003 and 2006 in the basin. In addition, 2-year dry periods were specified in 1973–1974, 2013–2014 and 2016–2017. The longest wet periods were 1987–1988, 1991–1992, and 1997–1998 with 2-year periods. The years 2001, 2013 and 2017 are classified as severe dry years, and the SPEI values are – 1.59, – 1.54 and – 1.55, respectively. The driest year was determined as 2001 in the basin with an SPEI value of – 1.59. In 2001, severe droughts were

Table 4 Distribution of SPEI drought classes by years

Drought class	Gemerek	Kayseri	Kirsehir	Nevsehir	Sivas	Zara	Basin
Extremely wet	1	1	1	1	–	1	–
Severely wet	3	2	2	2	4	3	2
Moderately wet	4	3	5	5	5	5	2
Slightly wet	7	10	9	9	8	7	11
Near normal	22	19	17	16	16	15	18
Mild dry	5	8	7	6	7	12	13
Moderately dry	2	3	5	9	8	4	1
Severely dry	6	2	4	2	2	2	3
Extremely dry	–	2	–	–	–	1	–
Wet/dry	15/13	16/15	17/16	17/17	17/17	16/19	15/17

determined in Gemerek, Nevsehir and Sivas with SPEI values of − 1.56, − 1.85 and − 1.78, respectively. While there was moderate drought with an index value of − 1.30 in Kirsehir, mild drought was detected in Zara with an index value of − 0.99. Extreme drought was determined only in Kayseri with − 2.04 index value. This can be seen in the drought map that was prepared by using the 2001 SPEI values of the stations. In this case, it can easily be argued that 2001 was the driest year for Hirfanli Dam basin, which was also one of the years with severe droughts throughout Turkey.

Drought maps of the basin were prepared by using the SPEI values for 1999, 2001, 2008, 2012, and 2016, which were determined as the driest years of the stations. These maps are given in Fig. 6.

Discussion

There have been many studies on drought since Turkey is located in a semiarid climate zone. When previous studies on drought using different indices at different time scales were analyzed, it was found out that drought occurred in similar periods for the geography of Turkey.

In the case of the Seyhan-Ceyhan River basins located in the south of the country, it was observed in the studies using the SPI method that the longest-term meteorological drought occurred in the years 1971–1973, 1988–1990 and 2003–2005, and according to the results of the studies using the SDI method, it was reported that the longest-term hydrological droughts occurred in the years 1971–1973 and 1989–1992 (Gumus and Algin 2017). In the studies conducted using DI, SPI, SPEI and SRI for the Asi basin located in the south of the country, it was stated that the effects of drought were seen in the years 1973–1974, 1989–1991, 1993–1994, 2000–2001, 2004–2005, 2014 and 2016 (Dikici 2020). According to the results of the studies on drought conducted using SPEI for the Mediterranean region, it was reported that the region was under the influence of drought in the early 1970s and early 1990s (Bacanli and Aksan 2019). The meteorological and hydrological drought research of the Upper Gediz basin in western Turkey was carried out by Kumanlioglu (2020) using SPI, SPEI and SRI. It was reported that the widespread droughts occurred in the years 1973–1974, 1985–1995, 2000–2002, and 2006–2009 (Kumanlioglu 2020). In another study using SPI for the Upper Gediz basin, it was stated the years between 1984 and 1996 as the longest drought period; 1961, 1987, 2006, 2008, 2011 and 2014 as severe drought years (Kumanlioglu and Fistikoglu 2019). In a study carried out for the Kemer Dam basin located in the southwest of the country, according to SPI results, long-term droughts were observed in the years 1955–1959, 1963–1964, 1972–1974, 1985–1987, 1989–1993 and 1990–2000 (Oguzturk and Yildiz 2015). In the analyses for the Damlica basin located in the Marmara region in the northwest of Turkey, the years 1982–1983, 1989, 1992–1993, 2004, 2006 according to the SPI results and the years 1982–1983, 1989, 1992–1994, 1999–2000, 2009–2004 and 2006 according to the SPEI results were determined to be drought years (Bakanogullari 2020a). In the Kumdere basin located in the same region, the years 1985–1986, 1991–1993, 2000–2002, 2004 and 2008 (according to SPI results), and the years 1985–1986, 1991, 1993, 2000–2002, 2004, 2007–2008 (according to SPEI results) were pointed out as dry years (Bakanogullari 2020b). According to the results of SPI, ZSI, RAI, SPEI and RDI, it was reported that the most severe meteorological droughts occurred in the years 1989 and 2012–2017 in the Euphrates basin, which has a wide area in the east and southeast of Turkey (Katipoglu et al. 2021). In addition, it was recorded that 1996–2002 were the longest and most severe drought years in the Lake Van basin located in the east of the country (Yetmen 2013). While it was reported that drought intensified in the years 1970–1979 in a study conducted using EDI for the southeastern region of Anatolia (Tugrul et al. 2019), 1976–1977, 1982–1983, 1985–1986, 1994, 2001, 2003, 2007–2008 were significant dry years for the central Black Sea in the north of the country according

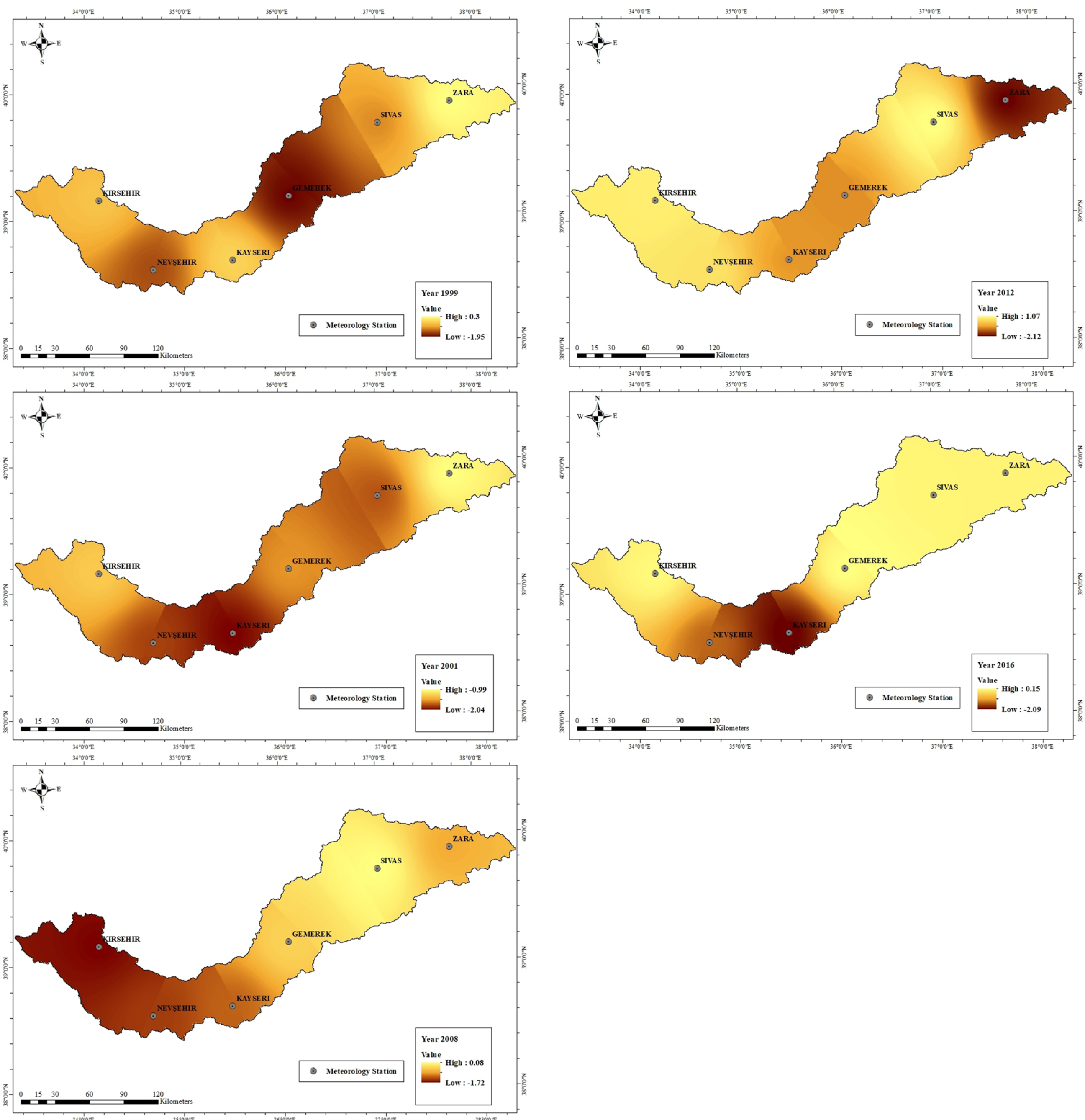

Fig. 6 Drought maps of 1999, 2001, 2008, 2012, 2016 in Hirfanli Dam basin

to the SPI results (Yetmen 2014). According to the SPI method, the years 1956, 1961, 1964, 1973, 1977, 1984, 1989, 1993–1994, 1999–2001 and 2004 were reported as important dry years in the Central Anatolia region, where the study area is also located (Yildiz 2014). In the study handled by Yildiz (2009) in the Hirfanlı Dam basin, which is the same study area, significant droughts were reported in the years 1955–1956, 1964, 1973, 1984, 1989, 1999 and 2001 according to the SPI results. In another study conducted by Oguzturk and Yildiz (2016) using SPI for the same study area, long-term droughts were determined as the years 1952–1957, 1961–1962, 1973–1974, 1989–1990, 1993–1994, 2003–2005.

While SPI method was preferred in the studies on drought carried out in the basin, no study using SPEI was found. This study conducted using SPEI parallels with the results of the studies conducted by Yildiz (2009, 2014) and Oguzturk and Yildiz (2016) using SPI and supports each other.

Conclusion

In the present study, the annual drought of Hirfanli Dam basin was analyzed by using the SPEI. The precipitation and temperature data for the 1968–2017 period of the meteorology stations of Gemerek, Kayseri, Kirsehir, Nevsehir, Sivas, and Zara located in the basin and operated by the Turkish State Meteorology Service were used for the analyses. Turkey, which is located in a semiarid climate zone, is exposed to frequent and severe drought effects. The results of the present study, in which the SPEI was applied for the first time in Hirfanli Dam basin and the dry years were determined, were found to be parallel to the results of previous studies conducted throughout Turkey. This shows clearly that Hirfanli Dam basin is also affected by the significant drought conditions that affect Turkey. Decreases in precipitation have significant effects on water resources; and vital activities are also affected as a result of these effects. Many areas affecting human life, such as the climate and vegetation in an area, yield of agricultural products, industrial production activities, and energy production are directly or indirectly affected negatively in this respect. It is necessary to conduct regular and detailed follow-up studies with drought analyses to be protected from the effects of drought. As a result of future drought analyses and follow-up studies that will be conducted, it will be beneficial to make plans for the climate, vegetation, development, for saving water resources and to resolve agricultural issues to prepare drought action plans in the light of holistic approaches.

Acknowledgements The authors thank the reviewers for their constructive criticisms which have considerably improved this manuscript.

Declarations

Conflict of interest The author declares no conflict of interest.

References

Abramowitz M, Stegun IA (1965) Handbook of mathematical functions with formulas, graphs, and mathematical tables. Dover Publications Inc., New York

Akturk G, Yildiz O (2018) The effect of precipitation deficits on hydrological systems in the Catalan Dam basin, Turkey. Int J Eng Res Dev 10(2):10–28. https://doi.org/10.29137/umagd.441389

Altin TB, Saris F, Altin BN (2020) Determination of drought intensity in Seyhan and Ceyhan River Basins, Turkey, by hydrological drought analysis. Theor Appl Climatol 139(1–2):95–107. https://doi.org/10.1007/s00704-019-02957-y

Bacanli UG, Aksan G (2019) Drought analysis in Mediterranean Region. Pamukkale Univ J Eng Sci 25(6):665–671. https://doi.org/10.5505/pajes.2019.64507

Bacanli UG, Dikbas F, Baran T (2011) Meteorological drought analysis case study Central Anatolia. Desalin Water Treat 26(1–3):14–23. https://doi.org/10.5004/dwt.2011.2105

Bakanogullari F (2020a) Analysis of drought intensity using SPEI and SPI in Damlıca Watershed-İstanbul, Turkey. Soil Water J 9(1):1–10. https://doi.org/10.21657/topraksu.566693

Bakanogullari F (2020b) Defining of drought using two methods (Spei and Spi) in rural watersheds: a case ctudy Kumdere Watershed. Turk J Agric Nat Sci 7(1):146–156. https://doi.org/10.30910/turkjans.680037

Bonaccorso B, Bordi I, Cancelliere A, Rossi G, Sutera A (2003) Spatial variability of drought: an analysis of the SPI in Sicily. Water Resour Manag 17(4):273–296. https://doi.org/10.1023/A:1024716530289

Danandeh Mehr A, Vaheddoost B (2020) Identification of the trends associated with the SPI and SPEI indices across Ankara, Turkey. Theor Appl Climatol 139(3–4):1531–1542. https://doi.org/10.1007/s00704-019-03071-9

Deo RC, Sahin M (2015) Application of the extreme learning machine algorithm for the prediction of monthly Effective Drought Index in eastern Australia. Atmos Res 153:512–525. https://doi.org/10.1016/j.atmosres.2014.10.016

Dikici M (2020) Drought analysis with different indices for the Asi Basin (Turkey). Sci Rep 10:1–12. https://doi.org/10.1038/s41598-020-77827-z

Dogan S, Berktay A, Singh VP (2012) Comparison of multi-monthly rainfall-based drought severity indices, with application to semi-arid Konya closed basin, Turkey. J Hydrol 470–471:255–268. https://doi.org/10.1016/j.jhydrol.2012.09.003

Erinc S (1949) The climates of Turkey according to Thornthwaite's classifications. Ann Assoc Am Geogr 39:26–46. https://doi.org/10.1080/00045604909351994

Gibbs WJ, Maher JV (1967) Rainfall deciles as drought indicators. Bureau of Meteorology Bulletin No: 48

Gumus V, Algin HM (2017) Meteorological and hydrological drought analysis of the Seyhan-Ceyhan River basins, Turkey. Meteorol Appl 24(1):62–73. https://doi.org/10.1002/met.1605

Hejazizadeh Z, Javizadeh S (2011) Introduction to drought and its indices. Samt Publications, Iran

Ionita M, Scholz P, Chelcea S (2016) Assessment of droughts in Romania using the Standardized Precipitation Index. Nat Hazards 81(3):1483–1498. https://doi.org/10.1007/s11069-015-2141-8

IPCC (2007) Climate Change 2007: the physical science basis. Contribution of working group I, II and III to the fourth assessment report of the intergovernmental panel on climate change (Core Writing Team, Pachauri, R. K. & Reisinger, A. (eds)). IPCC, Geneva, Switzerland

Jain VK, Pandey RP, Jain MK, Byun HR (2015) Comparison of drought indices for appraisal of drought characteristics in the Ken River Basin. Weather Clim Extremes 8:1–11. https://doi.org/10.1016/j.wace.2015.05.002

Kadioglu M (2008) Risk management for drought. In: Kadioglu M, Ozdamar E (eds) Afet zararlarını azaltmanın temel ilkeleri. JICA Türkiye Ofisi Yayınları No: 2, Ankara, pp 277–300

Kapluhan E (2013) Drought and drought in Turkey effect on agriculture. Marmara Coğrafya Dergisi 27:487–510

Karl TR (1983) Some spatial characteristics of drought duration in the United States. J Appl Meteorol Climatol 22(8):1356–1366. https://doi.org/10.1175/1520-0450(1983)022%3c1356:SSCODD%3e2.0.CO;2

Katipoglu OM, Acar R, Senocak S (2021) Spatio-temporal analysis of meteorological and hydrological droughts in the Euphrates Basin. Turkey Water Supply 21(4):1657–1673. https://doi.org/10.2166/ws.2021.019

Keskin ME, Terzi O, Taylan ED, Kucukyaman D (2009) Meteorological drought analysis using data-driven models for the Lakes

District, Turkey. Hydrol Sci J 54(6):1114–1124. https://doi.org/10.1623/hysj.54.6.1114

Komuscu AU (2001) An analysis of recent drought conditions in Turkey in relation to circulation patterns. Drought Netw News 13(2–3):5–6

Kumanlioglu AA (2020) Characterizing meteorological and hydrological droughts: a case study of the Gediz River Basin, Turkey. Meteorol Appl 27(1):1–17. https://doi.org/10.1002/met.1857

Kumanlioglu A, Fistikoglu O (2019) Meteorological drought analysis of Upper Gediz basin precipitations. DEUFMD 21(62):509–523. https://doi.org/10.21205/deufmd.2019216216

Lloyd-Hughes B, Saunders MA (2002) A drought climatology for Europe. Int J Climatol 22(13):1571–1592. https://doi.org/10.1002/joc.846

Lutgens FK, Tarbuck E (2006) The atmosphere: an introduction to meteorology, 10th edn. Prentica Hall, Upper Saddle River

Mckee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration of time scales. In: 8th Conference on Applied Climatology, American Meteorological Society, Anaheim CA, USA, January, pp 179–186

Merkoci AL, Mustaqi V, Mucaj L, Dvorani M (2013) Drought and implementation of Standardised Precipitation Index (SPI) on The Albanian Territory. J Faculty Eng Arch Gazi Univ 28(1):161–166

Mishra AK, Singh VP (2010) A review of drought concepts. J Hydrol 391(1–2):202–216. https://doi.org/10.1016/j.jhydrol.2010.07.012

Morid S, Smakhtin V, Moghaddasi M (2006) Comparison of seven meteorological indices for drought monitoring in Iran. Int J Climatol 26(7):971–985. https://doi.org/10.1002/joc.1264

Nam WH, Hayes MJ, Svoboda MD, Tadesse T, Wilhite DA (2015) Drought hazard assessment in the context of climate change for South Korea. Agric Water Manag 160:106–117. https://doi.org/10.1016/j.agwat.2015.06.029

Oguzturk G, Yildiz O (2014) Drought analysis for different time periods in the city of Kirikkale. Int J Eng Res Dev 6(2):19–25. https://doi.org/10.29137/umagd.346084

Oguzturk G, Yildiz O (2015) Hydrologic drought investigation in the Kemer Dam basin using the SPI method. Int J Adv Mech Civ Eng 2(5):35–40

Oguzturk G, Yildiz O (2016) Assessing hydrological responses to droughts in the Hirfanli Dam basin, Turkey. Int J Adv Mech Civ Eng 3(5):116–123

Oguzturk G, Yildiz O, Duvan A (2016) A drought analysis of Sivas using the Standardized Precipitation Index (SPI) method and drought estimation with the artificial neural networks. Int J Adv Mech Civ Eng 2(5):24–30

Ozgurel M, Pamuk G, Topcuoglu K (2003) Comparing two different drought indexes at Aegean Region conditions. J Agric Faculty Ege Univ 40(1):95–102

Pei Z, Fang S, Wang L, Yang W (2020) Comparative analysis of drought indicated by the SPI and SPEI at various timescales in Inner Mongolia. China Water 12(7):1925. https://doi.org/10.3390/w12071925

Qin Y, Yang D, Lei H, Xu K, Xu X (2015) Comparative analysis of drought based on precipitation and soil moisture indices in Haihe basin of North China during the period of 1960–2010. J Hydrol 526:55–67. https://doi.org/10.1016/j.jhydrol.2014.09.068

Ribeiro AFS, Russo A, Gouveia CM, Páscoa P (2019) Copula-based agricultural drought risk of rainfed cropping systems. Agric Water Manag 223:1–11. https://doi.org/10.1016/j.agwat.2019.105689

Salinger J (1995) Conditions leading to drought in New Zealand. Water Atmos 3(1):11–12

Saylan L, Durak M, Sen O (1997) Kuraklık ve etkileri, In: Meteorolojik Karakterli Doğal Afetler Sempozyumu Bildiriler Kitabı, Ankara, pp 433–444

Sen Z (2009) Kuraklık afet ve modern hesaplama yöntemleri. Su Vakfı Yayınları, Istanbul

Sirdas S, Sen Z (2003) Spatio-temporal drought analysis in the Trakya region, Turkey. Hydrol Sci J 48(5):809–820. https://doi.org/10.1623/hysj.48.5.809.51458

Sirdas S (2002) Meteorological drought modelling and application to Turkey. Ph.D. thesis, Istanbul Technical University, Istanbul, Turkey

Sonmez FK, Komuscu AU, Erkan A, Turgu E (2005) An analysis of spatial and temporal dimension of drought vulnerability in Turkey using the standardized precipitation index. Nat Hazards 35(2):243–264. https://doi.org/10.1007/s11069-004-5704-7

Stagge JH, Tallaksen LM, Gudmundsson L, Van Loon AF, Stahl K (2015) Candidate distributions for climatological drought indices (SPI and SPEI). Int J Climatol 35(13):4027–4040. https://doi.org/10.1002/joc.4267

Starks PJ, Steiner JL, Neel JP, Turner KE, Northup BK, Gowda PH, Brown MA (2019) Assessment of the standardized precipitation and evaporation index (SPEI) as a potential management tool for grasslands. Agronomy 9(5):235. https://doi.org/10.3390/agronomy9050235

Tabari H, Abghari H, Talaee PH (2012) Temporal trends and spatial characteristics of drought and rainfall in arid and semiarid regions of Iran. Hydrol Process 26(22):3351–3361. https://doi.org/10.1002/hyp.8460

Tallaksen LM, Van Lanen HAJ (2004) Hydrological drought: processes and estimation methods for streamflow and groundwater. Developments in Water Science 48. Elsevier, Amsterdam

Tate EL, Gustard A (2000) Drought definition: a hydrological perspective. In: Vogt JV, Somma F (eds) Drought and drought mitigation in Europe. Advances in natural and technological hazards research, vol 14. Springer, Dordrecht. https://doi.org/10.1007/978-94-015-9472-1_3

Thornthwaite CW (1948) An approach toward a rational classification. Geogr Rev 38(1):55–94. https://doi.org/10.2307/210739

Tirivarombo S, Osupile D, Eliasson P (2018) Drought monitoring and analysis: Standardised Precipitation Evapotranspiration Index (SPEI) and Standardised Precipitation Index (SPI). Phys Chem Earth Parts a/b/c 106:1–10. https://doi.org/10.1016/j.pce.2018.07.001

Tugrul T, Dogan S, Dursun S (2019) Drought analysis of provinces in Southeastern Anatolia Region, Konya. J Eng Sci 7(4):705–712. https://doi.org/10.36306/konjes.654866

Turkes M (1990) Türkiye'de kurak bölgeler ve önemli kurak yıllar. Ph.D. thesis, Istanbul University, Istanbul, Turkey

Turkes M (1996) Spatial and temporal analysis of annual rainfall variations in Turkey. Int J Climatol 16(9):1057–1076. https://doi.org/10.1002/(SICI)1097-0088(199609)16:9%3c1057::AID-JOC75%3e3.0.CO;2-D

Turkes M (2003) Spatial and temporal variations in precipitation and aridity index series of Turkey. In: Bolle HJ (eds) Mediterranean Climate. Regional Climate Studies. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-55657-9_11

Turkes M (2012) Observed and projected climate change, drought and desertification in Turkey. Ankara Univ J Environ Sci 4(2):1–32. https://doi.org/10.1501/Csaum_0000000063

Turkes M (2014) Analysis of reasons of 2013–2014 drought and climatological/meteorological in Turkey. Konya Toprak Su Dergisi 2:20–34

Turkes M (2017) Drought vulnerability and risk analysis of Turkey with respect to climatic variability and socio-ecological indicators. Aegean Geogr J 26(2):47–70

Turkes M, Tatli H (2008) A new standardized Precipitation Index (New-SPI) for determining extreme droughts and wet conditions: application in Turkey, IV. In: International symposium on atmospheric sciences, Istanbul, pp 528–538

Turkes M, Tatli H (2009) Use of the Standardized Precipitation Index (SPI) and a modified SPI for shaping the drought probabilities over Turkey. Int J Climatol 29(15):2270–2282. https://doi.org/10.1002/joc.1862

United Nations Environment Programme-UNEP (1994) United Nations Convention to Combat Desertification in Countries Experiencing Serious Drought, Particularly in Africa. Geneva, Switzerland

Vicente-Serrano SM, Begueria S, Lopez-Moreno JI (2010) A multiscalar drought index sensitive to global warming: the standardised precipitation evapotranspiration Index. J Clim 23(7):1696–1718. https://doi.org/10.1175/2009JCLI2909.1

Vicente-Serrano SM, Van der Schrierb G, Beguería S, Azorin-Molina C, Lopez-Moreno JI (2015) Contribution of precipitation and reference evapotranspiration to drought indices under different climates. J Hydrol 526:42–54. https://doi.org/10.1016/j.jhydrol.2014.11.025

Whipple W Jr (1966) Regional drought frequency analysis. J Irrig Drain Div 92(2):11–32

Wilhite DA (2000) Drought: A global assessment. Routledge Publishers, London

Wilhite DA, Glantz MH (1985) Understanding: the drought phenomenon: the role of definitions. Water Int 10(3):111–120. https://doi.org/10.1080/02508068508686328

Yacoub E, Tayfur G (2017) Evaluation and assessment of meteorological drought by different methods in Trarza Region, Mauritania. Water Resour Manag 31(3):825–845. https://doi.org/10.1007/s11269-016-1510-8

Yenigun K, Ibrahim WA (2019) Investigation of drought in the northern Iraq region. Meteorol Appl 26(3):490–499. https://doi.org/10.1002/met.1778

Yesilkoy S (2020) Determination and modelling water footprint in agricultural ecosystem in Thrace region. Ph.D. thesis, Istanbul Technical University, Istanbul, Turkey

Yetmen H (2013) Van Lake basin drought analysis. Educ Soc 21st Cent 2(5):184–198

Yetmen H (2014) Characteristics of drought events in the Middle Black Sea region. TÜCAUM VIII. Coğrafya Sempozyumu, Ankara, Turkey, pp 87–96

Yildiz O (2009) Assessing temporal and spatial characteristics of droughts in the Hirfanli Dam basin, Turkey. Sci Res Essay 4(4):249–255. https://doi.org/10.5897/SRE.9000212

Yildiz O (2014) Spatiotemporal analysis of historical droughts in the Central Anatolia, Turkey. Gazi Univ J Sci 27(4):1177–1184