Arabian Journal of Geosciences (2022) 15: 850
https://doi.org/10.1007/s12517-022-10119-0

ORIGINAL PAPER

Assessment of meteorological drought analysis in the Kizilirmak River Basin, Turkey

Gaye Akturk[1] · Utku Zeybekoglu[2] · Osman Yildiz[1]

Received: 24 September 2021 / Accepted: 13 April 2022 / Published online: 25 April 2022

Abstract

Drought is a natural disaster that may affect our lives in different ways. In this study, a meteorological drought analysis in the Kizilirmak river basin of Turkey was presented. The basin is located in a region with semi-arid climate characteristics. The monthly precipitation data for the 1960–2017 period from 22 meteorological stations within the basin were utilized for the drought analysis. In the scope of this research, firstly the most appropriate probability distributions for the monthly precipitation data were investigated using the goodness-of-fit tests. The Standardized Precipitation Index (SPI) was employed to examine drought characteristics in the basin. The spatial maps of droughts were constructed to identify the spatial variations of droughts for the selected years. According to the study results, the Pearson Type III probability distribution was determined as the best-fit probability distribution for the monthly precipitation at most of the stations within the basin. With the use of SPI time series, it was found that 31 years of the study period were affected by droughts with varying severities. The evaluation of spatial maps also revealed that the Kizilirmak river basin was under the impact of widespread droughts across the country during the study period.

Keywords Drought analysis · The Kizilirmak River Basin · Precipitation · Probability distributions · Turkey

Introduction

It is estimated that the global climate change impacts on the hydrological cycle over time will adversely affect water resources, agricultural production, public health, terrestrial and aquatic ecosystems, coastal regions and meteorological disasters including, for example, heat waves, floods, and droughts. As one of the most devastating disasters, drought can influence the entire life in the world with major effects, especially on the availability of water resources, agriculture, forestry, hydropower, health, and other socio-economic sectors. In fact, the effects of drought on water resources appear as decreases in soil moistures, river flows, dam reservoirs, and groundwater storages (Nan et al. 2011; Zhang et al. 2019; Poschlod et al. 2020). Drought can occur suddenly, and it spreads quickly. Uncertainty in the beginning and end of a drought, its cumulative increase with impacts on multiple sources at the same time, and its high economic dimension are the most important features that distinguish it from other natural disasters (Wilhite 2000; Tallaksen and Van Lanen 2004).

As a natural climatic phenomenon, drought can be characterized as a shortage of water caused by a temporary imbalance in the amount of moisture in a region. Actually, several drought definitions have been proposed in the literature due to the fact that a drought event can influence the life of people in various forms. However, the following definitions are more widely used in practice: (i) meteorological drought is actually connected with the precipitation deficit significantly below normal levels over an extended period of time, (ii) agricultural drought is explained as the lack of soil water or moisture needed by plants during the growing season and development, (iii) hydrological drought is

Responsible Editor: Broder J. Merkel

✉ Utku Zeybekoglu
utkuz@sinop.edu.tr

Gaye Akturk
gayeoguzturk@kku.edu.tr

Osman Yildiz
osmanyildiz@kku.edu.tr

[1] Faculty of Engineering and Architecture, Kirikkale University, Yahsihan, 71450 Kirikkale, Turkey

[2] Boyabat Vocational School of Higher Education, Sinop University, Boyabat, 57200 Sinop, Turkey

associated with the lack of rainfall into groundwater, surface, and subsurface waters and may persist after the meteorological drought, (iv) socioeconomic drought occurs when the social and economic effects of water shortage are significant, for example, if supply and demand balance in economy is disturbed due to drought (Wilhite and Glantz 1985; Dai 2011; Potop et al. 2012; Mouatadid et al. 2018; Bacanli and Aksan 2019).

Researchers all over the world conduct different drought studies by using different parameters (e.g., precipitation, temperature, evapotranspiration, soil moisture, streamflow). In this regard, different drought indices have been developed in order to provide useful information about drought features including duration, intensity, magnitude, frequency, spatial extent, and temporal evolution. In fact, they can be helpful for detecting and monitoring of droughts in time and space. They can also produce valuable data for early drought warning systems, mitigation of drought effects as well as drought risk analysis and management (Svoboda et al. 2015; Ozger et al. 2020). Although there are many drought indices introduced in the literature, the Standardized Precipitation Index (SPI) developed by McKee et al. (1993, 1995) is among the most commonly employed for drought studies. Mishra and Singh (2010) presented a comparison study on drought indices. The authors evaluated the intensity and return periods of various drought events, and they eventually reported that the best results for the SPI method were obtained using the Gamma probability distribution, which is one of the best-fit distribution for monthly precipitation data. Since the SPI method has a simple and fast algorithm, many different drought studies using this method around the world can be found in the literature.

Located in a semi-arid climate zone in the world, Turkey is actually under the effect of Mediterranean macroclimate. Drought events are experienced across the country very frequently dependent on atmospheric states, climate conditions, and physical geography factors as well. The long-term average of the annual precipitation in the country is about 643 mm, and approximately 67% of it falls in winter and spring seasons. Most of the central and southeastern regions of the country have semi-arid climate characteristics, while some parts of the central Anatolia near Lake Tuz are considered to have arid conditions with 300 mm of annual precipitation (Komuscu 2001; Sonmez et al. 2005). The precipitation levels significantly below the long-term averages in many parts of the country have caused meteorological drought events and subsequent agricultural, hydrological, and socioeconomic droughts. In Turkey, the most widespread droughts with relatively high intensities occurred during the periods of 1932, 1955–1956, 1971–1974, 1977, 1983–1984, 1989–1991, 1996, 1999–2001, 2007–2008, and 2013–2014 (Turkes 1996, 2012, 2014; Komuscu 2001; Molavizadeh et al. 2016; Alqaysi et al. 2017; Aksoy et al. 2021). Especially since the early 1970s, increases in the areal coverage, frequency, and severity of drought events have been observed over the country (Turkes 1996, 1998, 2003; Turkes and Erlat 2003, 2005).

Drought researches in Turkey have started as early as the 1940s. In recent decades, a number of regional drought studies in different parts of the country with several drought indices have been presented in the literature. Sirdas and Sen (2003) conducted a spatiotemporal drought analysis in the Trakya region using the SPI and the run analysis methods. Pamuk et al. (2004) investigated the meteorological drought characteristics in the Aegean region utilizing the SPI time series at various time scales. Keskin and Sorman (2010) used the SPI along with the Standardized Potential Evapotranspiration Index (SPEI) and the Standardized Runoff Index (SRI) to examine hydrological and meteorological dry and wet episodes in the Camlidere dam basin. Durdu (2010) presented a study to estimate seasonal as well as non-seasonal SPI time series in the Buyuk Menderes river basin by linear stochastic models. Dogan et al. (2012) utilized six different drought indices including the SPI to identify meteorological droughts in the Konya closed basin, where arid and semi-arid climate conditions prevail extensively. Yildiz (2014) determined the spatial and temporal features of meteorological droughts in the central Anatolia with the SPI method. Oguzturk and Yildiz (2016) performed a drought analysis in the Hirfanli dam basin using the SPI time series at several time scales and indicated that the SPI can be a useful method for drought prediction in the study area. Karabulut (2015) examined the drought conditions at different time scales over the 1975–2010 period in the Antakya-Kahramanmaras graben using the SPI and cumulative deviation curve methods. Gumus and Algin (2017) presented a hydrometeorological drought analysis in the Seyhan and Ceyhan river basins to define temporal and spatial drought variations employing the SPI and the Streamflow Drought Index (SDI). Dikici (2020) carried out a drought risk analysis in the Asi river basin with the help of different drought indices including the SPI to calculate the magnitude and severity of droughts. Kumanlioglu (2020) investigated meteorological and hydrological drought characteristics in the Demirkopru dam basin with the use the SPI, SPEI, and SRI methods. Topcu et al. (2021) conducted a drought analysis in the Eastern Mediterranean, Seyhan, Ceyhan, and Asi river basins with the Aggregate Drought Index (ADI). Katipoglu et al. (2021) assessed the meteorological and hydrological drought risks in the Euphrates basin with the help of four different drought indices including the SPI.

The main objective of this study is to evaluate meteorological droughts in the Kizilirmak river basin located in a semi-arid region in Turkey. For this purpose, the monthly precipitation data between 1960 and 2017 obtained from 22 meteorological stations across the basin were utilized. In the study, appropriate probability distributions for the precipitation time series at each individual station were first determined using the Kolmogorov–Smirnov and chi-square goodness-of-fit tests. The SPI method was then employed to assess the historical droughts in the basin during the study period. The SPI values were calculated at different time scales to assess drought characteristics including duration, magnitude, and intensity. Later, the drought maps for the selected drought years were obtained in order to indicate the temporal and spatial variations of droughts within the basin.

The study area and data

The basin is geographically located at 32.80°–38.35° E longitudes and 35°–41.75° N latitudes. The basin has a surface area of 82,082 km^2, which corresponds to approximately 10% of Turkey's surface area (Fig. 1). The Kizilirmak river is among the most important water resources in the country with a long-term annual average flow rate of 184 m^3/s at its outlet to the Black Sea. The Kizilirmak river basin is generally characterized by wide-ranging plateaus and meadow highlands with an altitude up to 3880 m above the sea level (Fig. 1). The basin with a relatively large area has quite different topographic, geographical, and climatic features. Therefore, the basin is divided into 3 subregions namely upper, middle, and lower. The upper region bordered by high mountains from north to south at the upstream of the basin is usually characterized by high plateaus and hilly lands. The middle region mostly consists of relatively low plateaus and meadows and has a number of dams built for irrigation and hydropower. The lower region contains relatively low downstream lands of the basin with the outlet to the Black Sea. Since the northern Anatolian mountains in the region form a barrier in front of moist air masses from the sea, the inner parts of the basin are characterized by a relatively drier climate (Oguzturk 2010; Sagdic and Koc 2012; Yildiz 2014).

The monthly precipitation data between 1960 and 2017 were obtained from the General Directorate of Meteorology (MGM) of Turkey. A total number of 22 meteorological stations with available data were selected for the

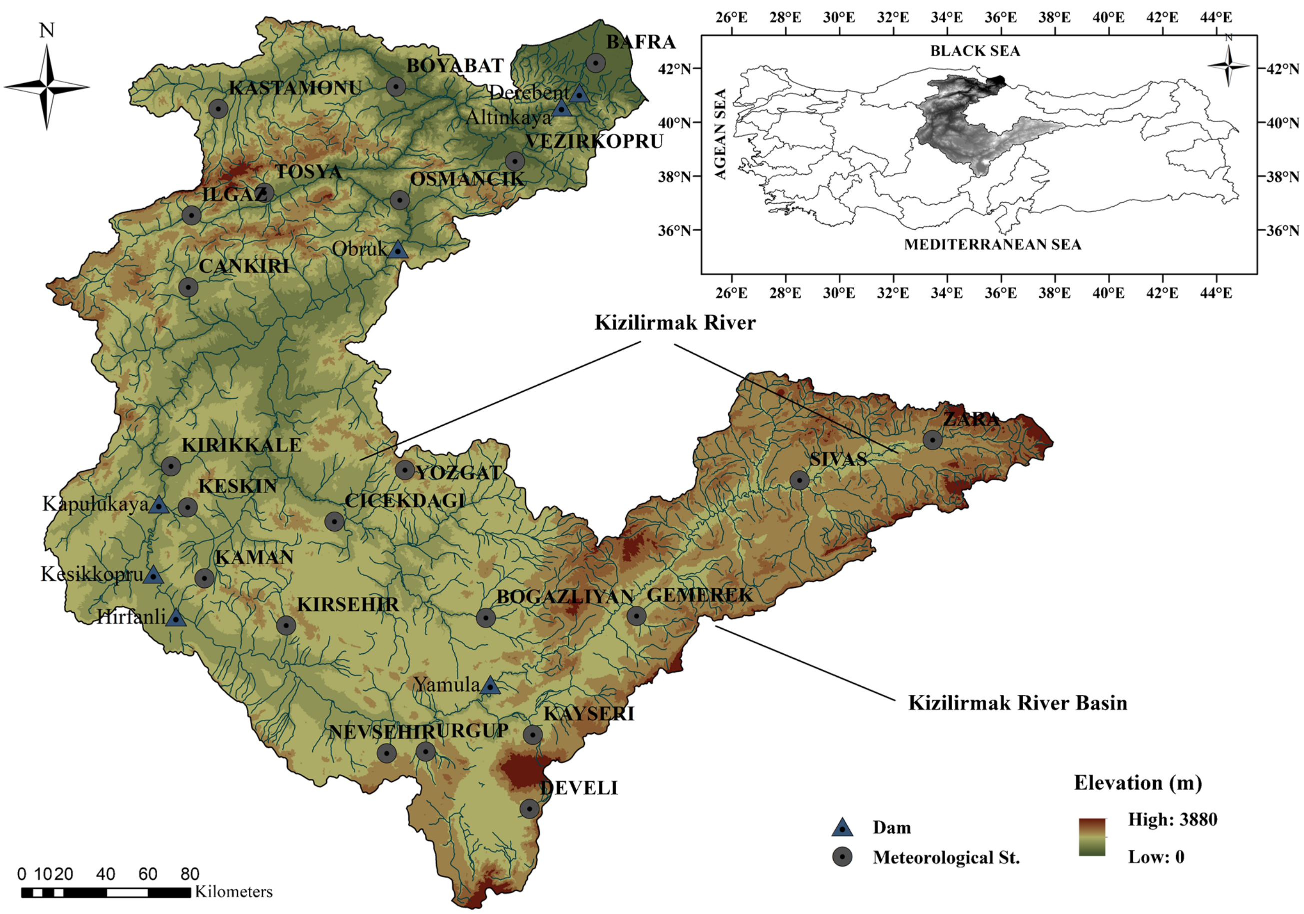


Fig. 1 The study area and the location of meteorological stations utilized in the study

Table 1 Statistics of monthly precipitation data at selected meteorological stations

Station name	Data period	Mean (mm)	Max (mm)	Std. dev. (mm)	Kurtosis	Skewness
Bafra	1960–2017	64.33	343.90	45.48	3.21	1.38
Bogazliyan	1960–2017	30.54	159.90	25.62	1.61	1.11
Boyabat	1960–2017	34.82	241.50	28.52	6.63	1.93
Cankiri	1960–2017	34.36	149.80	27.35	1.37	1.14
Cicekdagi	1972–2017	28.73	171.10	23.89	2.52	1.19
Develi	1960–2017	30.27	159.60	26.36	1.14	1.02
Gemerek	1960–2017	33.29	160.00	27.24	1.51	1.07
Ilgaz	1960–2017	40.26	216.60	31.45	3.09	1.36
Kaman	1960–2017	38.91	246.20	33.67	2.82	1.26
Kastamonu	1960–2017	41.73	278.70	32.08	5.89	1.80
Kayseri	1960–2017	32.46	164.70	25.85	0.98	0.93
Keskin	1960–2017	33.92	145.90	27.66	0.80	1.02
Kirikkale	1960–2017	31.87	150.15	26.81	0.91	1.02
Kirsehir	1960–2017	31.94	161.40	26.82	1.26	1.04
Nevsehir	1960–2017	34.41	148.80	27.54	0.43	0.81
Osmancik	1976–2017	32.90	139.00	24.85	0.92	1.01
Sivas	1960–2017	36.58	154.80	28.29	0.64	0.85
Tosya	1960–2017	39.43	157.20	28.35	1.03	0.99
Urgup	1964–2017	30.47	138.30	25.39	0.95	0.98
Vezirkopru	1960–2017	48.39	172.00	29.76	0.63	0.73
Yozgat	1960–2017	48.92	192.30	38.55	0.44	0.85
Zara	1960–2017	43.83	171.40	33.90	0.61	0.90

drought analysis (Table 1). The evaluation of precipitation records indicates that the long-term mean annual precipitation is about 450 mm, and most of the precipitation falls during the spring in the basin.

Methodology

Probability distribution functions

In this study, the normal, lognormal, two-parameter Gamma and Pearson type III probability distributions were selected for the best-fit analysis of the monthly precipitation data.

Normal distribution

The normal distribution is a probability distribution centered on the mean. It is also known as Gaussian distribution and characterized by a bell-shaped curve. The probability density function (PDF), and cumulative distribution function (CDF) for a normal random variable x are given in Eqs. (1)–(2):

$$f(x) = \frac{1}{\sigma_x\sqrt{2\pi}}\exp\left[-\left(x-\mu_x\right)^2/2{\sigma_x}^2\right] \tag{1}$$

$$F(x) = \frac{1}{\sigma_x\sqrt{2\pi}}\int_{-\infty}^{\infty}\left(\exp\left[-\left(x-\mu_x\right)^2/2{\sigma_x}^2\right]\right)dx \tag{2}$$

where μ_x is mean, and σ_x is standard deviation (Forbes et al. 2010).

Lognormal distribution

The lognormal distribution is a continuous probability distribution of logarithmic values from a related normal distribution. That is, when a random variable x is transformed into $y=\ln(x)$, the distribution of x is called lognormal, if the distribution of the transformed variable y is normal. In this case, the PDF and CDF of $x\geq 0$ are given by Eqs. (3)–(4):

$$f(x) = \frac{1}{x\sigma_Y\sqrt{2\pi}}\exp\left[-\left(\ln(x)-\mu_Y\right)^2/2{\sigma_Y}^2\right] \tag{3}$$

$$F(x) = \frac{1}{\sigma_Y\sqrt{2\pi}}\int_{0}^{x}\left(\frac{1}{x}\exp\left[-\left(\ln(x)-\mu_Y\right)^2/2{\sigma_Y}^2\right]\right) \tag{4}$$

where μ_Y and σ_Y are respectively mean and standard deviation for variable y, and they can be estimated by Eqs. (5)–(6).

$$\mu_Y = \ln[\mu_x / \left(\sigma_x{}^2 / \mu_x{}^2 + 1\right)^{1/2}] \tag{5}$$

$$\sigma_Y = \left[\ln(\sigma_x{}^2 / \mu_x{}^2 + 1\right]^{1/2} \tag{6}$$

in which μ_x is mean, and σ_x is standard deviation for variable x (Forbes et al. 2010).

Gamma distribution

The Gamma distribution is a two-parameter family of continuous probability distributions. The PDF and CDF of a random variable $x \geq 0$ are stated by Eqs. (7)–(8)

$$f(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{(-x/\beta)} \tag{7}$$

$$F(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{(-x/\beta)} dx \tag{8}$$

where Γ is the Gamma function and, α and β are respectively shape and scale parameters ($\alpha > 0$ and $\beta > 0$) estimated by Eq. (9):

$$\mu_x = \alpha\beta; \sigma_x{}^2 = \alpha\beta^2; C = 2/\sqrt{\alpha} \tag{9}$$

in which μ_x and σ_x are mean and standard deviation, respectively, and C is coefficient of skewness for variable x (Forbes et al. 2010).

Pearson type III distribution

As one of the most commonly employed probability distributions for hydrologic frequency analysis, the Pearson type III distribution is the generalized Gamma distribution with three parameters. The PDF and CDF of a random variable $x \geq \xi$ are defined by Eqs. (10)–(11)

$$f(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} (x - \xi)^{\alpha-1} e^{-(x-\xi)/\beta} \tag{10}$$

$$F(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x (x - \xi)^{\alpha-1} e^{-(x-\xi)/\beta} dx \tag{11}$$

in which Γ is the Gamma function, and α, β and ξ are respectively shape, scale, and location parameters estimated by Eq. (12):

$$\mu_x = \xi + \alpha\beta; \sigma_x{}^2 = \alpha\beta^2; C = 2/\sqrt{\alpha} \tag{12}$$

where μ_x and σ_x are mean and standard deviation, respectively, and C is coefficient of skewness for variable x (Forbes et al. 2010).

Goodness-of-fit test

As a statistical hypothesis test, the goodness-of-fit test is utilized to see how well the sample data fits a distribution from a population with the normal distribution (Han 1979). In this study, chi-square and Kolmogorov–Smirnov tests were applied to the selected probability distributions in order to find the best-fit distribution for the monthly precipitation data in the basin.

Chi-square test

The chi-square test is employed for goodness-of-fit of empirical data to specified theoretical frequency distributions. The test statistic $\mathcal{X}^2$ is calculated from the relationship in Eq. (13)

$$\mathcal{X}^2 = \sum_{i=1}^{m} \left(Q_i - E_i\right)^2 / E_i \tag{13}$$

in which m is the number of class intervals, Q_i and E_i are the observed and the expected number of observations, respectively, in the ith class interval. As known that the distribution of χ^2 is a chi-squared distribution with m–k-1 degrees of freedom (D.F.) where k is the number of parameters estimated from the data. The hypothesis that the sample data is from the specified distribution is then accepted if

$$\chi^2 < \mathcal{X}^2_{1-p,m-k-1} \tag{14}$$

where p is significance level (Han 1979).

Table 2 The SPI categories (McKee et al. 1993)

SPI interval	Category
$2.00 \leq$ SPI	Extremely wet
$1.50 \leq$ SPI < 2.00	Very wet
$1.00 \leq$ SPI < 1.50	Moderately wet
$-1.00 \leq$ SPI < 1.00	Near normal
$-1.50 <$ SPI ≤ -1.00	Moderately dry
$-2.00 <$ SPI ≤ -1.50	Severely dry
$-2.00 \geq$ SPI	Extremely dry

Table 3 Goodness-of-fit test results

Station (sample Size)	Prob. dist	D	Prob. dist	χ^2	# of D.F
Bafra (696)	Normal	0.08639	Normal	91.47130	
	Lognormal	0.06790	Lognormal	55.86780	
	Gamma 2	0.02726	*Gamma 2*	*3.97126* [a]	*7*
	Pearson III	*0.0223* [a]	Pearson III	4.22989	
Bogazliyan (696)	Normal	0.11515	Normal	197.402	
	Lognormal	0.16720	Lognormal	225.977	
	Gamma 2	0.11192	Gamma 2	108.707	
	Pearson III	*0.07103*	*Pearson III*	*16.060* [c]	*7*
Boyabat (696)	Normal	0.11729	Normal	180.092	
	Lognormal	0.08776	Lognormal	48.8276	
	Gamma 2	*0.0389* [a]	*Gamma 2*	*17.592* [c]	*7*
	Pearson III	0.09078	Pearson III	32.7644	
Cankiri (696)	Normal	0.10304	Normal	213.684	
	Lognormal	0.12928	Lognormal	172.506	
	Gamma 2	0.05766	Gamma 2	38.0517	
	Pearson III	*0.0509* [b]	*Pearson III*	*11.414* [b]	*6*
Cicekdagi (552)	Normal	0.11271	Normal	187.746	
	Lognormal	0.17233	Lognormal	192.348	
	Gamma 2	0.08917	Gamma 2	73.7246	
	Pearson III	*0.0605* [c]	*Pearson III*	*15.971* [c]	*6*
Develi (696)	Normal	0.12396	Normal	304.319	
	Lognormal	0.19479	Lognormal	299.509	
	Gamma 2	0.11044	Gamma 2	119.328	
	Pearson III	*0.09073*	*Pearson III*	*26.2759*	*5*
Gemerek (696)	Normal	0.10944	Normal	211.299	
	Lognormal	0.16100	Lognormal	203.856	
	Gamma 2	0.09824	Gamma 2	94.4598	
	Pearson III	*0.06596*	*Pearson III*	*11.931* [b]	*6*
Ilgaz (696)	Normal	0.09880	Normal	196.155	
	Lognormal	0.11883	Lognormal	134.948	
	Gamma 2	0.06230	Gamma 2	44.6034	
	Pearson III	*0.0356* [a]	*Pearson III*	*23.4828*	*6*
Kaman (696)	Normal	0.12252	Normal	205.652	
	Lognormal	0.17007	Lognormal	267.480	
	Gamma 2	0.10648	Gamma 2	102.670	
	Pearson III	*0.06901*	*Pearson III*	*19.0632*	*7*
Kastamonu (696)	Normal	0.11286	Normal	157.161	
	Lognormal	0.06690	Lognormal	41.0402	
	Gamma 2	*0.03031* [a]	*Gamma 2*	*11.902* [a]	*7*
	Pearson III	0.06152	Pearson III	21.7874	
Kayseri (696)	Normal	0.10354	Normal	231.960	
	Lognormal	0.16456	Lognormal	218.167	
	Gamma 2	0.10463	Gamma 2	102.851	
	Pearson III	*0.06842*	*Pearson III*	*14.459* [c]	*6*
Keskin (696)	Normal	0.10861	Normal	233.023	
	Lognormal	0.14686	Lognormal	181.213	
	Gamma 2	0.08424	Gamma 2	54.8333	
	Pearson III	*0.06857*	*Pearson III*	*12.879* [c]	*6*

Table 3 (continued)

Station (sample Size)	Prob. dist	D	Prob. dist	χ^2	# of D.F
Kirikkale (696)	Normal	0.11583	Normal	226.213	
	Lognormal	0.15988	Lognormal	216.644	
	Gamma 2	0.08641	Gamma 2	65.2069	
	Pearson III	*0.07876*	*Pearson III*	*10.786* [b]	*6*
Kirsehir (696)	Normal	0.11544	Normal	231.902	
	Lognormal	0.1758	Lognormal	242.534	
	Gamma 2	0.10539	Gamma 2	93.6552	
	Pearson III	*0.07685*	*Pearson III*	*18.167* [c]	*6*
Nevsehir (696)	Normal	0.1043	Normal	235.983	
	Lognormal	0.16738	Lognormal	242.851	
	Gamma 2	0.11269	Gamma 2	113.368	
	Pearson III	*0.07664*	*Pearson III*	*12.707* [c]	*6*
Osmancik (504)	Normal	0.09074	Normal	86.3175	
	Lognormal	0.10953	Lognormal	96.5159	
	Gamma 2	0.0599	Gamma 2	18.2222	
	Pearson III	*0.0454* [a]	*Pearson III*	*5.7222* [a]	*6*
Sivas (696)	Normal	0.09658	*Normal*	*11.282* [c]	*5*
	Lognormal	0.16103	Lognormal	251.356	
	Gamma 2	0.10329	Gamma 2	97.9655	
	Pearson III	*0.06461*	Pearson III	25.6954	
Tosya (696)	Normal	0.08074	Normal	81.9885	
	Lognormal	0.10188	Lognormal	110.753	
	Gamma 2	0.04858	Gamma 2	23.9425	
	Pearson III	*0.0348* [a]	*Pearson III*	*10.897* [b]	*6*
Urgup (648)	Normal	0.11349	Normal	212.410	
	Lognormal	0.17807	Lognormal	246.769	
	Gamma 2	0.11655	Gamma 2	128.485	
	Pearson III	*0.07888*	*Pearson III*	*14.546* [c]	*7*
Vezirkopru (696)	Normal	0.05053	Normal	18.6839	
	Lognormal	0.09766	Lognormal	92.4483	
	Gamma 2	0.0518	Gamma 2	36.0977	
	Pearson III	*0.0238* [a]	*Pearson III*	*3.4540* [a]	*6*
Yozgat (696)	Normal	0.1008	Normal	221.098	
	Lognormal	0.15858	Lognormal	215.494	
	Gamma 2	0.09923	Gamma 2	82.5345	
	Pearson III	*0.06970*	*Pearson III*	*13.081* [c]	*6*
Zara (696)	Normal	0.09657	Normal	94.4310	
	Lognormal	0.16464	Lognormal	203.253	
	Gamma 2	0.09336	Gamma 2	96.0115	
	Pearson III	*0.0613* [c]	*Pearson III*	*14.000* [c]	*6*

Superscripts a, b, and c indicate that the probability distribution is the best-fit at 0.1, 0.05, and 0.01 significance levels, respectively

Kolmogorov–Smirnov test

As a non-parametric test, the Kolmogorov–Smirnov (K-S) test focuses on the deviations between the hypothesized CDF $F_X(x)$ and the observed cumulative histogram (also called the empirical CDF):

$$F^*\left(X^{(i)}\right) = \frac{i}{n} \tag{15}$$

where $X^{(i)}$ is the ith largest observed value in the random sample of size n. The K-S test statistic D is then determined with Eq. (16):

$$D = \max_{i=1}^{n} \left[\left| F^{*}\left(X^{(i)}\right) - F_X\left(X^{(i)}\right) \right| \right] = \max_{i=1}^{n} \left[\left| \frac{i}{n} - F_X\left(X^{(i)}\right) \right| \right] \tag{16}$$

Here, D is the largest of the absolute values of the n differences between the hypothesized and empirical CDFs determined at the observed values in the sample. Since the distribution of statistic D is known, one can determine the critical value D_c at a given significance level for checking the hypothesis. Accordingly, the hypothesis that X has a specified distribution is accepted if $D \leq D_c$ (Benjamin and Cornell 1970; Naaman 2021).

SPI

The Standardized Precipitation Index (SPI) method was developed by McKee et al. (1993, 1995) for providing an indicator of drought severity. In essence, based on the probability of precipitation data for a specified period of time, the SPI methodology is simple, as the precipitation is the only variable to be considered. Additionally, the method provides the utility of different time scales for meteorological drought evaluations at the basin scale. A standardized precipitation series is determined using the arithmetic average (μ_x) and standard deviation (σ_x) of the precipitation data. For a given X_1, X_2, …, X_n precipitation data, SPI series, x_i, is obtained from Eq. (17):

$$x_i = \left(X_i - \mu_x\right)/\sigma_x \tag{17}$$

Here, the negative and positive values of x_i represent precipitation deficits (dryness) and precipitation excesses (wetness), respectively. The SPI categories or classifications for the specified SPI intervals are given in Table 2.

IDW interpolation method

The inverse distance weighting (IDW) interpolation method is frequently used in the estimation of spatial distribution for precipitation data. In this method, the relationship and similarity between two points are assumed to be proportional to the distance between them, and therefore as the distance increases, the impact and importance on the point to be estimated decreases. In other words, the influence of the near points to the unknown value at a certain place is greater than that of the far points. The underlying conjecture of the IDW interpolation is the positive spatial autocorrelation conjecture. The spatial distribution of precipitation is predicted by weighting it inversely as the square of the distance from the observation points to the predicted point (Watson and Philip 1985; Armstrong and Marciano 1994). The equation of the IDW interpolation is given by Eq. (18):

$$P = \left(\sum_{i=1}^{n} \frac{1}{d_i^2} P_i / \sum_{i=1}^{n} \frac{1}{d_i^2} \right) \tag{18}$$

where P is the predicted value at an unobserved point; P_i is the observed value at the point i; n is the number of sample points; and d is the distance between the point i and certain observed point.

Results and discussion

Goodness-of-fit test results for the selected probability distributions

In this study, four probability distributions including the normal, lognormal, two-parameter Gamma and Pearson type III were chosen for the best-fit analysis of the monthly precipitation data. The selected probability distributions were subjected to goodness-of-fit tests with the Kolmogorov–Smirnov (K-S) and chi-square tests. The best-fit probability distribution for the selected meteorological stations in the Kizilirmak river basin was determined according to D (K-S) and χ^2 (chi-square) statistics at 0.1, 0.05, and 0.01 significance levels. The goodness-of-fit test results for each station are tabulated in Table 3, where Pearson type III probability distribution appears to be the best-fit for the monthly precipitation data at 19 out of 22 meteorological stations. On the other hand, the Gamma and normal probability distributions were found to be the best-fit at the remaining stations. As shown in the Table, Pearson type III is accepted as the most appropriate probability distribution with the lowest

Table 4 The critical values of Kolmogorov–Smirnov (D_c) and chi-square (χ^2) statistics for $p=0.1$, 0.05, and 0.01 significance levels

Sample size	Kolmogorov–Smirnov (D_c)		
	$p=0.1$	$p=0.05$	$p=0.01$
696	0.04636	0.05147	0.06175
552	0.05205	0.05780	0.06933
504	0.05448	0.06049	0.07256
648	0.04804	0.05335	0.06399
	Chi-square (χ^2)		
# of D.F	$p=0.1$	$p=0.05$	$p=0.01$
4	7.779	9.488	13.28
5	9.236	11.07	15.09
6	10.64	12.59	16.81
7	12.02	14.07	18.48

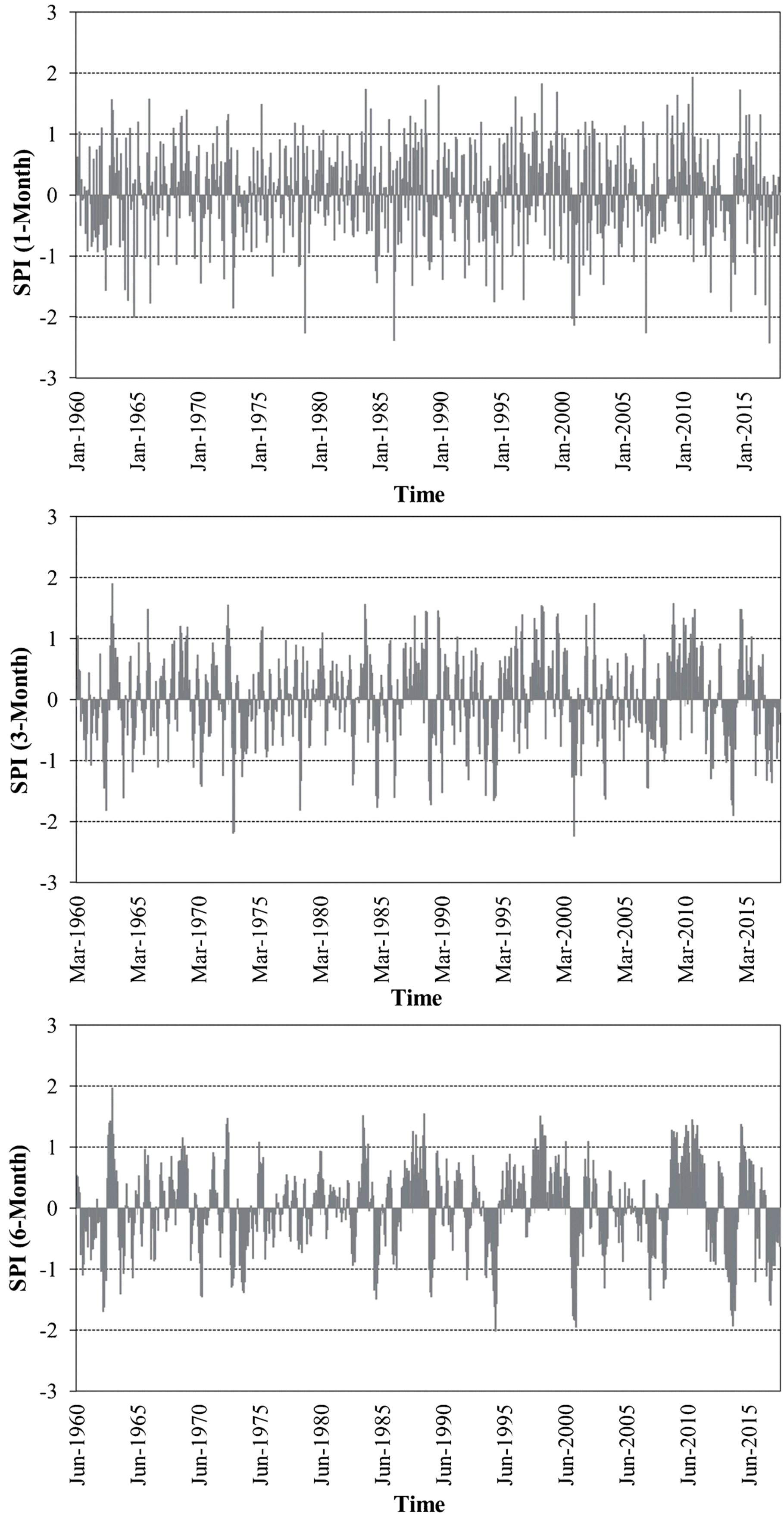
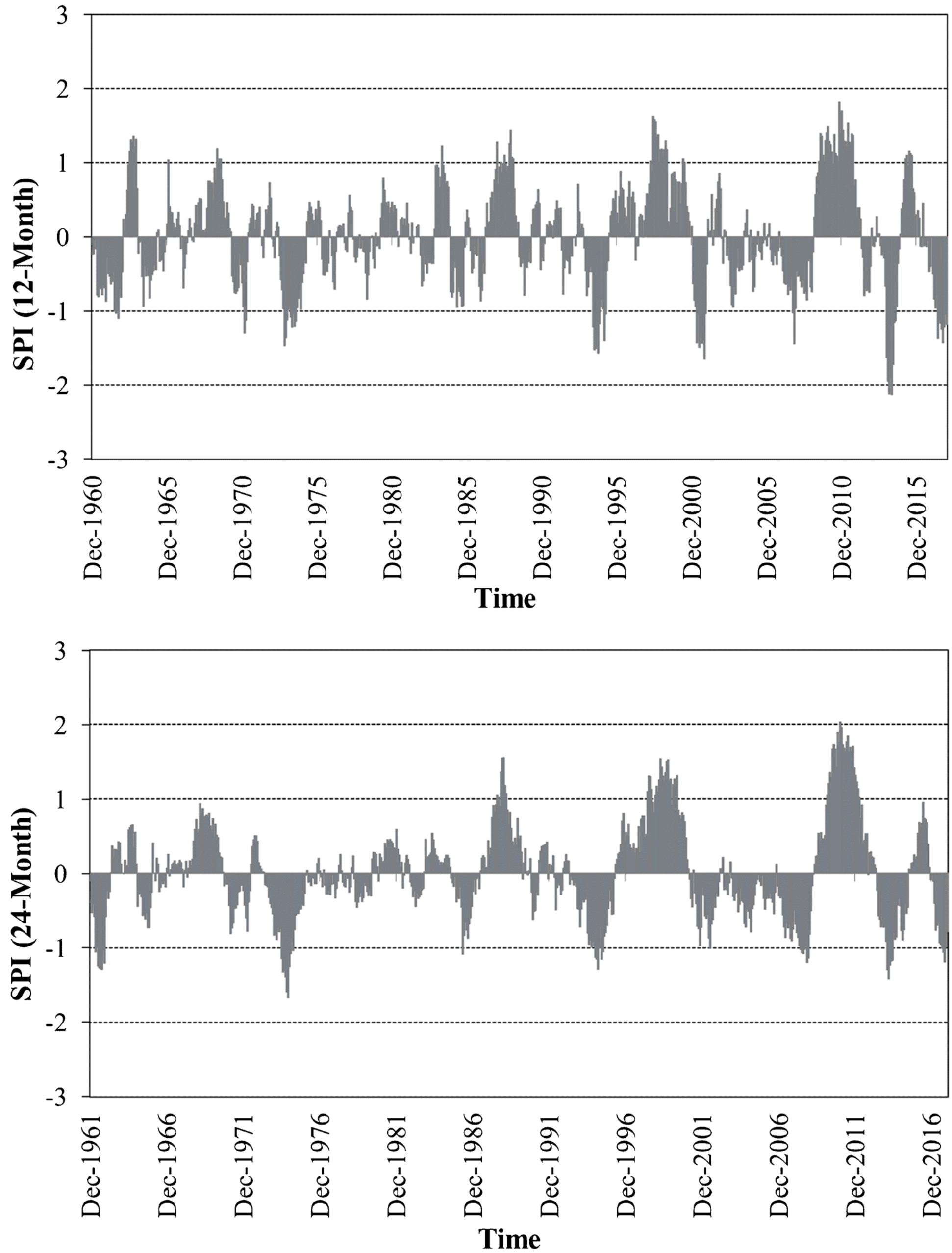


Fig. 2 The SPI time series at 1, 3, 6, 12, and 24-month scales for the Kizilirmak river basin (1960–2017)

Fig. 2 (continued)



values of D and χ^2 statistics for the Develi and Kaman stations where no significance level could be obtained. Table 4 contains the critical values of D and χ^2 statistics for $p = 0.1$, 0.05, and 0.01 significance levels with the given sample size and number of degrees of freedom (# of D.F.).

SPI results

The temporal characteristics of the historical droughts including intensity and magnitude in the Kizilirmak river basin were determined by means of the SPI method. The SPI values at different time scales were therefore calculated by using the regional average of monthly precipitation data. The temporal evolution of SPI at 1, 3, 6, 12, and 24-month scales is presented in Fig. 2 which displays droughts of varying durations and intensities during the study period. As shown in the figure, the frequency of dry periods (SPI < 0) is relatively high at short timescales, and it decreases as the timescale increases. Also, the average duration of droughts changes significantly depending on the time scale.

It is essentially important to analyze SPI time scales longer than 6 months to identify the main droughts because at shorter time scales, the SPI values of high frequency can hide the most significant dry periods (Vicente-Serrano and Lopez-Moreno 2005). For example, as shown in Fig. 2, the prolonged dry episodes within the study basin from 1960 to 2017 become more visible at the SPI time scales longer than 6 months.

The annual SPI time series for the basin during the 1960–2017 period is shown in Fig. 3, where the long-term average drought intensity is nearly − 0.25 with a maximum value of about − 1.70 in 2013. Here, it should be noted that 31 out of 58 years were affected by droughts with 1 severe, 2 moderate, and 28 mild categories. The major drought events in 1962, 1964, 1970, 1973–1974, 1982, 1984, 1986, 1993–1994, 2001, 2007–2008, 2013, and 2017 can be detected from the figure. The spatial maps for the selected historical droughts are displayed in Fig. 4. Here, the spatial distribution of annual drought intensities was estimated by the IDW interpolation technique. The evaluation of the drought maps actually indicates that the Kizilirmak river basin was influenced by the widespread drought events in the entire country during the study period. As the figure indicates, a significant part of the basin was under extreme drought impacts during 1973 and 2013.

Conclusion

The aim of this research was to find the most appropriate probability distributions for the monthly precipitation time series in the Kizilirmak river basin, Turkey, for the evaluation of temporal and spatial characteristics of the meteorological droughts during the 1960–2017 period. Kolmogorov–Smirnov (K-S) and chi-square goodness-of-fit tests were applied to evaluate the best-fit probability distribution for the monthly precipitation at the selected meteorological stations across the basin. The Standardized Precipitation Index (SPI) method was then utilized in order to investigate the temporal and spatial features of the selected historical droughts in the study area.

In the study, the normal, lognormal, two-parameter Gamma and Pearson type III probability distributions were chosen for the best-fit analysis, and they were subjected to goodness-of-fit tests. As the study results revealed, the Pearson type III probability distribution was found to be the best-fit for the monthly precipitation at the majority of stations (19 out of 22). Also, the two-parameter Gamma and normal probability distributions were determined as the best-fit for the remaining stations in the basin. For the goodness-of-fit test, K-S, and chi-square test statistics (D and χ^2, respectively) were evaluated at $p = 0.1$, 0.05 and 0.01 significance levels.

The SPI time series at 1, 3, 6, 12, and 24-month scales obtained from the basin's averaged monthly precipitation data were utilized for assessing the temporal characteristics of historical droughts, such as duration, magnitude, and intensity. The analysis of the SPI results indicated that during the study period, the frequency of dry periods decreases rapidly with the increase of time scale, and the average duration of droughts changes significantly depending on the time scale.

According to the annual SPI time series, the long-term average drought intensity is nearly − 0.25 with a maximum value of − 1.70 in 2013 within the basin. It was also determined that 31 years in the study period were under drought effects with 1 severe, 2 moderate, and 28 mild categories. The drought maps were constructed using the IDW interpolation technique for the spatial evaluation of the selected historical droughts. Thus, it was observed that the Kizilirmak river basin was under the impact of widespread droughts across the country during the study period.

In recent years, assessing the impacts of climate change, which has actually become more pronounced all over the world, has emerged as an important hydrological problem in

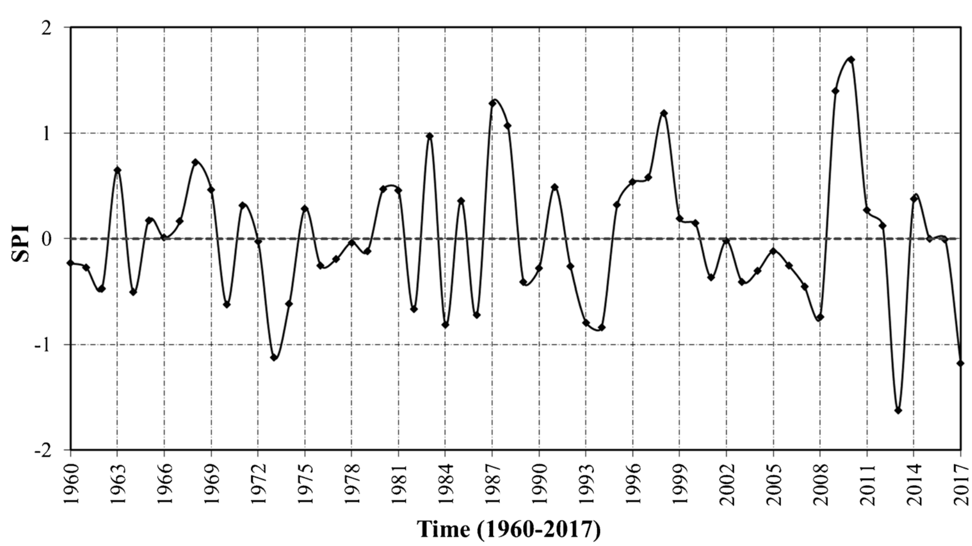


Fig. 3 The regional mean of annual SPI time series for the Kizilirmak river basin

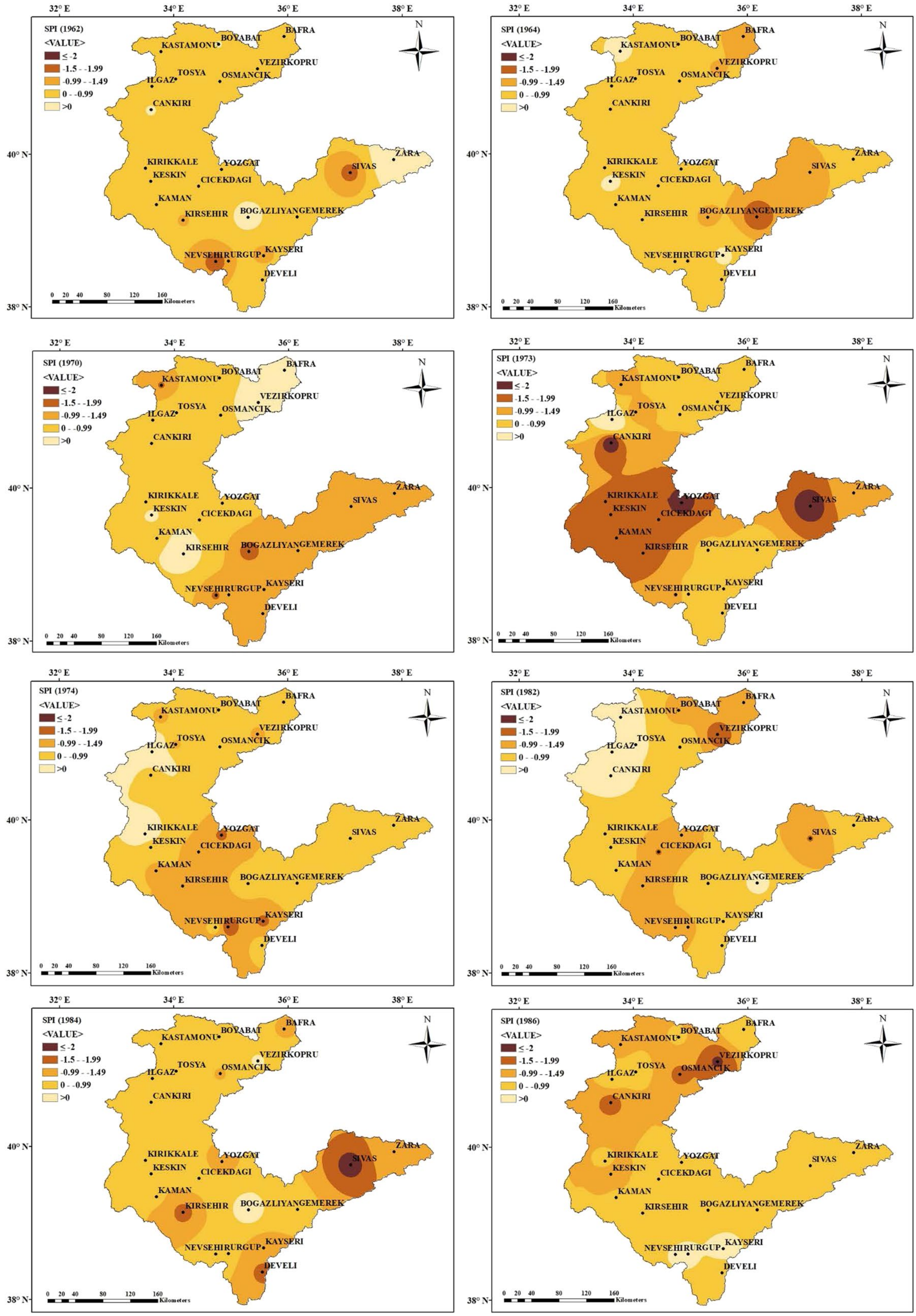


Fig. 4 The drought maps for historical droughts in the Kizilirmak river basin

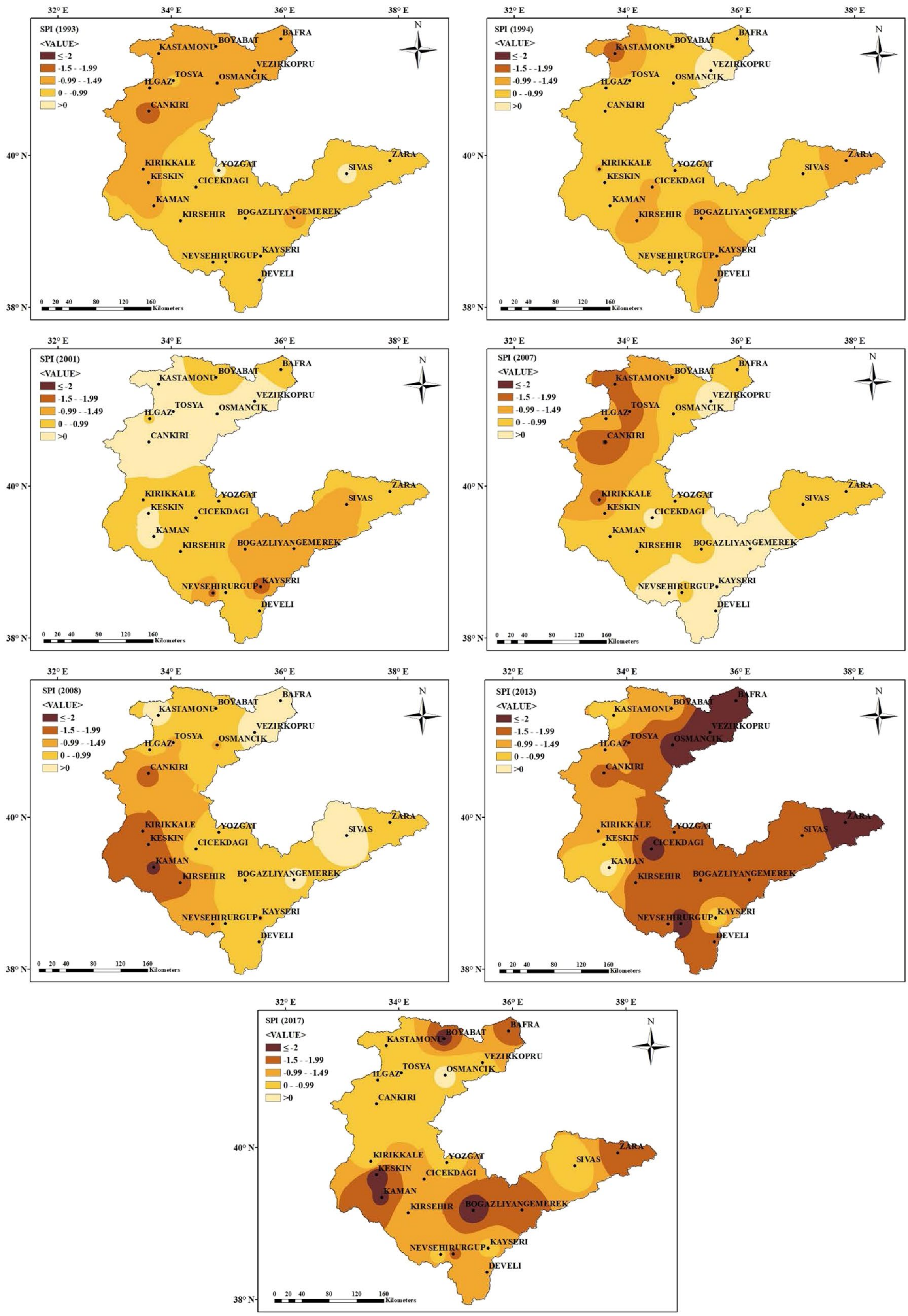


Fig. 4 (continued)

terms of water budget in river basins. In this respect, drought analysis studies can produce helpful information for forecasting and mitigating drought impacts at the basin scale (Kim et al. 2002; Yildiz 2014; Alivi et al. 2021). In this study, the most appropriate probability distributions for the monthly precipitation data in the Kizilirmak river basin were determined and then, the temporal and spatial characteristics of meteorological droughts were analyzed with the SPI method. In summary, the study results revealed very useful drought information which can be employed for drought prediction and management purposes in the basin. In further studies, besides the SPI method, other drought indices suitable for the study basin can be utilized for comparison and additional drought analysis works.

Acknowledgements The authors sincerely acknowledge the General Directorate of Meteorology (MGM) of Turkey for providing the precipitation data utilized in this study.

Declarations

Conflict of interest The authors declare no competing interests.

References

Aksoy H, Cetin M, Eris E, Burgan HI, Cavus Y, Yildirim I, Sivapalan M (2021) Critical drought intensity-duration-frequency curves based on total probability theorem-coupled frequency analysis. Hydrol Sci J 66(8):1337–1358. https://doi.org/10.1080/02626667.2021.1934473

Alivi A, Yıldız O, Aktürk G (2021) Investigating the climate change effects on annual average streamflows in the Euphrates Tigris basin using the climate elasticity method. J Fac Eng Archit Gazi Univ 36(3):1449–1466

Alqaysi NHH, Dursun S, Almuslehi MAA (2017) Estimating drought index using standardized precipitation index from 1901 to 2015, Turkey. J Int Environ Appl Sci 12(2):154–160

Armstrong MP, Marciano RJ (1994) Inverse-distance-weighted spatial interpolation using parallel supercomputers. Photogramm Eng Remote Sens 60(10):1097–1103

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

Benjamin JR, Cornell CA (1970) Probability, statistics, and decision for civil engineers. McGraw-Hill, Inc.

Dai A (2011) Drought under global warming: a review. Wiley Interdiscip Rev: Clim Chang 2(1):45–65. https://doi.org/10.1002/wcc.81

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

Durdu OF (2010) Application of linear stochastic models for drought forecasting in the Büyük Menderes river basin, western Turkey. Stoch Env Res Risk Assess 24:1145–1162. https://doi.org/10.1007/s00477-010-0366-3

Forbes C, Evans M, Hastings N, Peacock B (2010) Statistical distributions, 4th edn. John Wiley and Sons, New Jersey

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

Han CT (1979) Statistical methods in hydrology. The Iowa State University Press, Ames

Karabulut M (2015) Drought analysis in Antakya-Kahramanmaraş Graben, Turkey. J Arid Land 7(6):741–754. https://doi.org/10.1007/s40333-015-0011-6

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 F, Sorman AU (2010) Assessment of the dry and wet period severity with hydrometeorological index. Int J Water Resour Environ Eng 2147483647(2):F3374031586. https://doi.org/10.5897/IJWREE.9000006

Kim T-W, Valdés JB, Aparicio J (2002) Frequency and spatial characteristics of droughts in the Conchos River basin, Mexico. Water Int 27(3):420–430. https://doi.org/10.1080/02508060208687021

Komuscu AU (2001) An analysis of recent drought conditions in Turkey in relation to circulation patterns. Drought Network 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

McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales, 8th Conference on Applied Climatology, 17–22 January 1993, Anaheim, California, 179–184

McKee TB, Doesken NJ, Kleist J (1995) Drought monitoring with multiple time scales, 9th Conference on Applied Climatology, 15–20 January 1995, Dallas, Texas, 233–236

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

Molavizadeh N, Sertel E, Demirel H (2016) Drought conditions in Turkey between 2004 and 2013 via drought indices derived from remotely sensed data. In: Grammelis P (eds) Energy, transportation and global warming. Green Energy and Technology. Springer, Cham. https://doi.org/10.1007/978-3-319-30127-3_10

Mouatadid S, Raj N, Deo RC, Adamowski JF (2018) Input selection and data-driven model performance optimization to predict the standardized precipitation and evaporation index in a drought-prone region. Atmos Res 212:130–149. https://doi.org/10.1016/j.atmosres.2018.05.012

Naaman M (2021) On the tight constant in the multivariate Dvoretzky-Kiefer-Wolfowitz inequality. Statist Probab Lett 173:109088. https://doi.org/10.1016/j.spl.2021.109088

Nan Y, Bao-hui M, Chun-kun L (2011) Impact analysis of climate change on water resources. Procedia Eng 24:643–648. https://doi.org/10.1016/j.proeng.2011.11.2710

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 (2010) Drought analysis in the Kızılırmak river basin and drought prediction analysis with neural networks (in Turkish). Master of Science Thesis, Graduate School, Kırıkkale University

Ozger M, Basakin EE, Ekmekcioğlu O, Hacisuleyman V (2020) Comparison of wavelet and empirical mode decomposition hybrid models in drought prediction. Comput Electron Agric 179:105851. https://doi.org/10.1016/j.compag.2020.105851

Pamuk G, Ozgurel M, Topcuoglu K (2004) Drought analysis in the Aegean region with SPI (in Turkish). J Ege Univ Agric Fac 41(1):99–106

Poschlod B, Willkofer F, Ludwig R (2020) Impact of climate change on the hydrological regimes in Bavaria. Water 12(6):1599. https://doi.org/10.3390/w12061599

Potop V, Možný M, Soukup J (2012) Drought evolution at various time scales in the lowland regions and their impact on vegetable crops in the Czech Republic. Agric for Meteorol 156:121–133. https://doi.org/10.1016/j.agrformet.2012.01.002

Sagdic M, Koc H (2012) The climate of the upper Kizilirmak basin. Turk Geogr Rev 58:1–20 (in Turkish)

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

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

Svoboda MD, Fuchs BA, Poulsen CC, Nothwehr JR (2015) The drought risk atlas: enhancing decision support for drought risk management in the United States. J Hydrol 526:274–286. https://doi.org/10.1016/j.jhydrol.2015.01.006

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

Topcu E, Seckin N, Haktanir NA (2021) Drought analyses of Eastern Mediterranean, Seyhan, Ceyhan, and Asi Basins by using aggregate drought index (ADI). Theoret Appl Climatol. https://doi.org/10.1007/s00704-021-03873-w

Türkeş 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<1057::AID-JOC75>3.0.CO;2-D

Turkes M (1998) Influence of geopotential heights, cyclone frequency and southern oscillation on rainfall variations in Turkey. Int J Climatol 18(6):649–680. https://doi.org/10.1002/(SICI)1097-0088(199805)18:6<649::AID-JOC269>3.0.CO;2-3

Turkes M (2003) Spatial and temporal variations in precipitation and aridity index series of Turkey. In: Bolle H-J (ed) Mediterranean climate-variability and trends. Regional Climate Studies. Springer Verlag, Heidelberg, pp 181–213

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

Turkes M (2014) Analysis of 2013–2014 drought in Turkey and its climatological and meteorological reasons. Konya Soil Water J 2:20–34

Turkes M, Erlat E (2003) Precipitation changes and variability in Turkey linked to the North Atlantic Oscillation during the period 1930–2000. Int J Climatol 23(14):1771–1796. https://doi.org/10.1002/joc.962

Turkes M, Erlat E (2005) Climatological responses of winter precipitation in Turkey to variability of the North Atlantic Oscillation during the period 1930–2001. Theoret Appl Climatol 81(1–2):45–69. https://doi.org/10.1007/s00704-004-0084-1

Vicente-Serrano SM, Lopez-Moreno JI (2005) Hydrological response to different time scales of climatological drought: an evaluation of the standardized precipitation index in a Mountainous Mediterranean Basin. Hydrol Earth Syst Sci 9(5):523–533. https://doi.org/10.5194/hess-9-523-2005

Watson DF, Philip GM (1985) A refinement of inverse distance weighted interpolation. Geo-Processing 2(4):315–327

Wilhite DA (2000) Drought: a global assessment, 1st edn. Routledge Press, London and New York

Wilhite DA, Glantz MH (1985) Understanding the drought phenomenon: the role of definitions. Water Int 10(3):110–120. https://doi.org/10.1080/02508068508686328

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

Zhang Y, Li H, Reggiani P (2019) Climate variability and climate change impacts on land surface, hydrological processes and water management. Water 11(7):1492. https://doi.org/10.3390/w11071492