Arabian Journal of Geosciences (2021) 14: 2731
https://doi.org/10.1007/s12517-021-09095-8

ORIGINAL PAPER

A comparison of the China-Z Index (CZI) and the Standardized Precipitation Index (SPI) for drought assessment in the Hirfanli Dam basin in central Turkey

Utku Zeybekoğlu[1] · **Gaye Aktürk**[2]

Received: 5 August 2021 / Accepted: 22 November 2021 / Published online: 4 December 2021

Abstract
In recent years, drought due to climate change cause significant negative effects on hydrological processes and water budget in many river basins around the world. Drought indices are used to determine the spatial and temporal characteristics of drought events. They are based on single or multiple variables and applied in different countries for the assessment of drought. Drought events occur frequently in Turkey, which has semi-arid climate characteristics. Drought is one of the most damaging natural disaster affecting many regions of Turkey. In this study, the capacity of the China-Z Index (CZI) and the Standardized Precipitation Index (SPI) were compared to identify drought periods at different time scales in the Hirfanli Dam basin in central Turkey. For this purpose, monthly precipitation data from 1960 to 2017 collected from six meteorological stations located within the basin were used. The SPI and CZI values were calculated at 1-, 3-, 6-, 9- and 12-month time scales, and the results were compared. The relationships between the outputs of the drought indices were statistically examined. The results indicated that the SPI and CZI values have high correlation coefficients at long time scales (9 and 12 months). It was observed that as the time scale decreased, the correlation between the two drought indices gradually weakened. It was determined that both indices can be utilizied for drought forecasting studies at relatively longer time scales in the study area. It is thought that the results of the study will contribute to the regulation of the management and planning of water resources in river basins in accordance with climatic changes that has become more important in recent years.

Keywords Drought monitoring · Standardized Precipitation Index · China-Z Index · Hirfanli Dam basin · Turkey

Introduction

Natural disasters have had enormous impacts on human life through the course of history. One of the most important of these natural disasters is drought. From the past to the present, there is no single definition of drought accepted by different disciplines. In general, the occurrence of precipitation below normal or below average in any part of the earth and in a certain period of time has been taken as a basis, and also rainfall deficiency, long duration of drought and adverse effects have become common terms in many definitions of drought. One such definition is that drought is a natural phenomenon that results in adverse effects on land and water resources and the disruption of the hydrological balance when precipitation falls significantly below the normal level (Wilhite and Glantz 1985). Drought caused by lack or scarcity of water adversely affects the life of all living things in many areas, in different time periods and in various intensities. Depending on its affected area, various definitions of drought have been developed in the literature. Among them, meteorological, hydrological, agricultural and socio-economic drought definitions are the most common. While the decrease in precipitation in any month can have an immediate effect on soil moisture in a relatively short time (1–3 months), groundwater and rivers are affected over a

Responsible Editor: Broder J. Merkel

✉ Utku Zeybekoğlu
utkuz@sinop.edu.tr

Gaye Aktürk
gayeoguzturk@kku.edu.tr

[1] Construction Department, Boyabat Vocational School of Higher Education, Sinop University, 57200 Boyabat, Sinop, Turkey

[2] Department of Civil Engineering, Faculty of Engineering and Architecture, Kırıkkale University, 71451 Kırıkkale, Turkey

longer period of time (3–6 months). As a result of the precipitation being below the long-term average, it has caused new meteorological drought events, and after that, it has led to the occurrence of agricultural, hydrological and socio-economic droughts.

Drought has negative effects on both natural and modified environments, including agricultural activities, which are reflected in social and economic costs. The environmental and social problems associated with drought are growing rapidly due to climate change, rapid increase of the global population, the destruction of natural vegetation and desertification and have reached dimensions that threaten large segments of humanity. In order to understand and ultimately to mitigate the effects of drought, it is necessary to define and monitor the process of drought in detail. Many drought indices have been developed to characterize drought and to determine the relationship between drought and climate parameters. They can be used to determine the spatial and temporal characteristics of droughts range from the use of a single meteorological parameter such as precipitation to the use of complex methods involving many variables, such as the Palmer Drought Severity Index (PDSI; Palmer 1945), Rainfall Anomaly Index (Van Rooy 1965), Deciles Index (DI; Gibbs and Maher 1967), Palmer Hydrologic Drought Index (PHDI; Karl 1983; Guttman 1991), Z-Score Index (ZSI; Yao and Ding 1990), Standardized Precipitation Index (SPI; McKee et al. 1993), Percent of Normal Index (PN; Willeke et al. 1994), Effective Drought Index (EDI; Byun and Wilhite 1999), China-Z Index (CZI; Wu et al. 2001), Reconnaissance Drought Index (RDI; Tsakiris et al. 2007), Streamflow Drought Index (SDI; Nalbantis 2008) and Standardized Precipitation Evapotranspiration Index (SPEI; Vicente-Serrano et al. 2010). These drought indices have been applied in many parts of the world to determine the existence of drought and analyze its relationship with weather and climate (Lloyd-Hughes and Saunders 2002; Deo and Sahin 2015; Ionita et al. 2016; Gumus and Algin 2017; Yacoub and Tayfur 2017; Ramkar and Yadav 2018; Shin et al. 2018; Wambua et al. 2018; Bacanli and Aksan 2019; Yenigun and Ibrahim 2019; Altin et al. 2020; Sobhani and Zengir 2020; Kumanlioglu 2020; Abbas and Kousar 2021; Habibi and Meddi 2021; Khan et al. 2021; Mohammed and Yimam 2021; Poonia et al. 2021a, b). In addition, the performances of drought indices have been compared in several studies (Wu et al. 2001; Morid et al. 2006, Pandey et al. 2008; Dogan et al. 2012; Vicente-Serrano et al. 2015; Adnan et al. 2018; Ortega-Gómez et al., 2018; Garcia-Leon et al., 2019; Wable et al. 2019; Katipoglu et al. 2020; Liu et al., 2020; Vergni et al. 2021; Yuce and Esit 2021). A comparative study was conducted for drought monitoring four meteorological stations located in China with three drought indices (SPI-CZI-ZSI) by Wu et al (2001). Morid et al. (2006) applied and compared seven drought indices (CZI-Modified CZI-PN-SPI-EDI-ZSI-DI) for monitoring the drought of Tehran province in Iran. Dogan et al. (2012) applied six drought indices (PN-DI-ZSI-CZI-SPI-EDI) for monitoring drought in Konya Closed basin, Turkey, and compare results of drought indices. Jain et al. (2015) monitored drought in Ken River Basin with six drought indices (SPI-EDI-ZSI-CZI-Rainfall Departure-DI). They also compared the performances of the drought indices with each other. In order to monitoring the drought in another study for China, three drought indices (CZI-PN-Soil Moisture Index) were applied in Henan Province by Wang et al (2017). Zarei et al. (2017) compared four drought indices (CZI-ZSI-SPI-EDI) for analysis of drought in Chaharmahal-Bakhtiari province, Iran. Khan et al. (2018) investigated the variability of droughts by applying four drought indices (SPI-SPEI-RDI-EDI) to five meteorological stations in the Songhua River basin in China. Myronidis et al. (2018) utilized ten drought indices (DI-EDI-PDSI- Palmer Z index- Self-calibrated PDSI-SPI-SPEI-CZI-ZSI-RDI) for drought monitoring in OR, USA. Nedham and Hassan (2019) were assessed using three drought indices (SPI-Percentage of Precipitation Anomaly-ZSI) for drought in Iraq. Three drought indices (SPI-RDI-SPEI) were employed to study the variation of drought characteristics in the Ghataprabha river basin, India by Pathak and Dodamani (2019). Payab and Turker (2019) compared and evaluated the performances of six drought indices (CZI-SPI-RDI-Supply and Demand Drought Index-combined China-Z and Supply and Demand Drought Index-ZSI) for the northern part of Cyprus. Bushra et al. (2019) applied three drought indices (PDSI-PHDI-Normalized Difference Vegetation Index) for monitoring drought in a five-state region of the South Central United States. Sener and Sener (2021) determined the drought condition in the Burdur Lake basin, Turkey, with SPI and CZI and compared performances of the indices with each other. Yuce and Esit (2021) monitored the drought using ten drought indices (SPI, SPEI, scPDSI, CZI, MCZI, RAI, RDI, DI, PNI, and ZSI) in the Ceyhan basin, Turkey. In addition, the authors examined the compatibility of the indices with each other at various time scales.

As can be understood from the literature review, the CZI method, which is also preferred in this study, is widely used successfully by researchers in detecting drought all over the world. The main reason why CZI is preferred is that it has the simplicity of calculation compared to SPI and allows incomplete data in determining the severity of the drought (Wu et al. 2001; Morid et al. 2006; Dogan et al. 2012; Jain et al. 2015; Kumar et al. 2021).

Regions with arid and semi-arid climates are more sensitive to climate change. Located in a semi-arid region, Turkey experiences frequent drought events depending upon atmospheric states, physical geography factors and climate conditions. And also the spatial and temporal distribution of precipitation varies according to regions and seasons. This situation affects the water use in the basins and causes water shortage. So the effects of the drought can be minimized if its spatial and temporal alterations are observed closely. In this study, drought was analysed by using drought indices for the Hirfanli Dam basin that has semi-arid climate characteristics in the Kizilirmak River basin in the central of Turkey. This study aimed to compare the performance of two rainfall-based drought indices, SPI and CZI. It also enables both the determination of the conditions of drought indices at different time scale (1-, 3-, 6-, 9- and 12-month scale) and the evaluation of the applicability of CZI. Before the drought analysis, Chi-square test was performed to evaluate whether data members of the same population. As far as the authors know, this is the first time that CZI is applicable to the Hirfanlı Dam basin with this study.

Materials and methods

Study area

The sub-basin containing the Hirfanlı Dam, which is located between longitudes 33.3° E and 38.7°E and latitudes 38.3°N and 40.1° N, is within the Kızılırmak River basin and has a surface area of approximately 26,700 km^2. The Kızılırmak river with 1355 km length is the one of the major water resources of the country, and it has long term annual average flow rate of 185 m^3/s its outlet to the Black sea. The river transports an average of 831 million m^3 of water per year to the Black Sea. Hirfanlı Dam, which was built on the Kızılırmak River in 1959 for flood control and hydropower purposes, has a surface area of 263 km^2 and a reservoir volume of 5980 hm^3 at normal water surface level. The monthly average flow to the dam is approximately 77.42 m^3/s. Hirfanli Dam basin has high topographic characteristics and shows mountainous plateau features. In the basin, the altitude varies between 799 and 3880 m (Fig. 1) and also decreases from the east to the west. Plateau and meadows are more common in the west part of the basin. The mountains of volcanic origin that are found one by one in this region attract attention, and there are wide plains around these mountains. Erciyes Mountain is one of the most important volcanic origin mountains in the basin. The eastern part of the basin has high, rugged and mountainous plateau characteristics, and the low hills are the most important surface elements in the region. Typical dry climate is dominant in the basin.

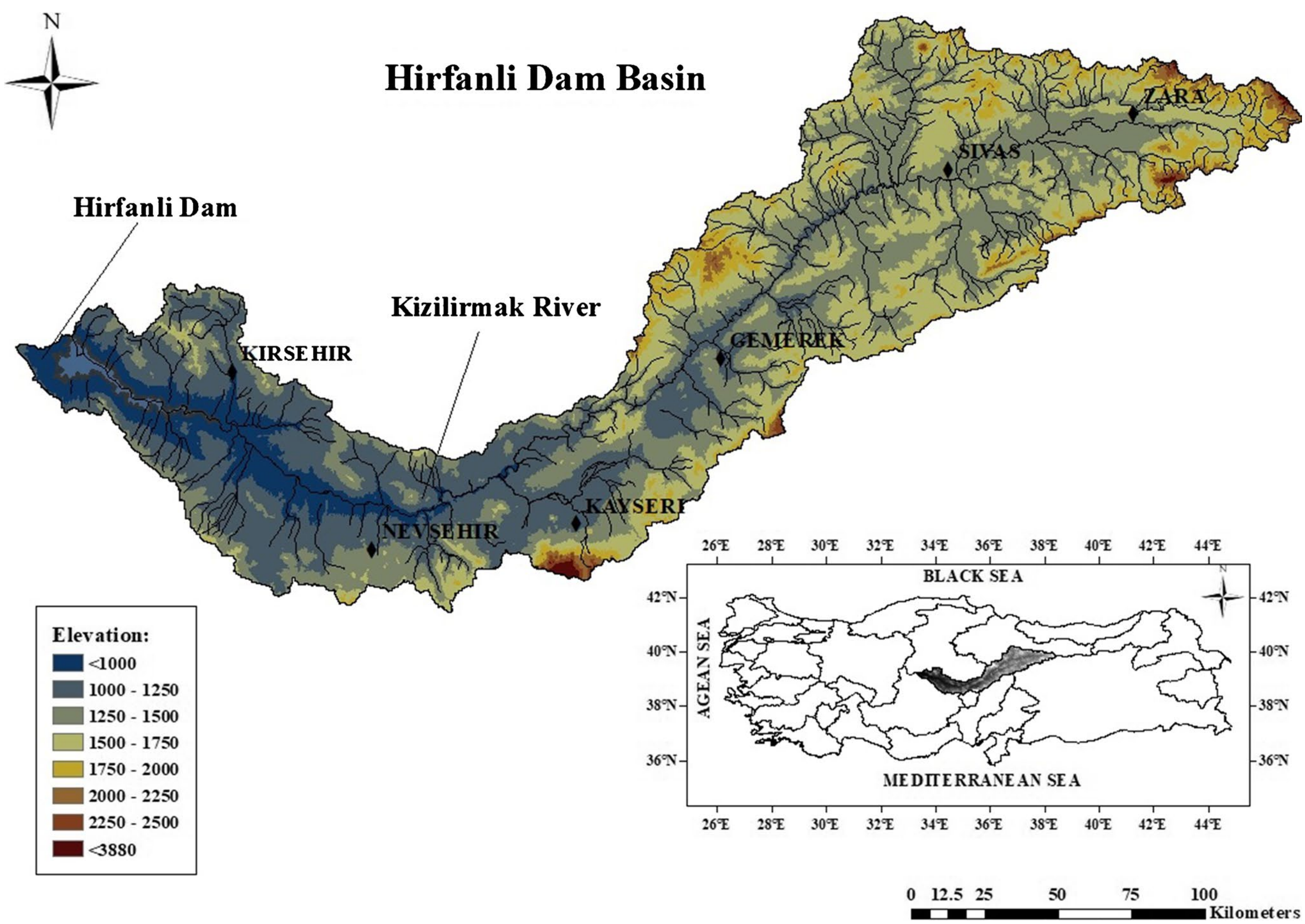

Fig. 1 Location and elevation of the study area and spatial distribution of the meteorological stations used

The mean temperature is around 10 °C and the regional mean annual precipitation of about 417 mm which is about 65% of the country average. Basin is dominated by convective and frontal precipitation in general. The maximum precipitation is seen during the spring months April and May; the least amount of precipitation is seen in the summer months July and August in the basin. The Hirfanli Dam basin covers plateaus and also meadows and pastures for animal grazing and wide plains dominate for agriculture. Because of this, agriculture is a major economic sector in the basin and wheat, barley, potato and sugar beet are important agricultural products (Yıldız 2014).

Monthly rainfall data from the Gemerek, Kayseri, Kirsehir, Nevsehir, Sivas and Zara meteorological stations were obtained from the Turkish State Meteorological Service (TSMS) (Fig. 1). Statistical characteristics of the rainfall data (minimum, maximum, mean, standard deviation (SD), skewness and kurtosis) and the station locations are shown in Table 1 and 2.

Chi-square test

The Chi-square test was used to determine the most appropriate statistical distributions for the precipitation data (Cochran 1952; Haan 1977; Yuan et al. 2018).

The Chi-square test statistic $\chi 2$ is generated with Eq. 1 (Sharma and Singh 2010; Khudri and Sadia 2013; Sukrutha et al. 2018).

$$X^2 = \sum_{i=1}^{n} \frac{\left(Q_i - E_i\right)^2}{E_i}, d = n - p - 1 \quad (1)$$

where Q_i and E_i are the observed and expected frequencies, respectively, in the ith cell; *n* is a number of intervals; *d* denotes the number of degrees of freedom; and *p* is the number of parameters used in fitting the proposed distribution. The null hypotheses (H_0) of the Chi-square test is that there is no difference between estimated and observed values and that the tested distribution describes the observed data, while the alternative hypothesis (H_1) is that the tested distribution does not describe the observed data. The null hypothesis is rejected if $\chi 2$ is greater than the critical value which is determined from the $\chi 2$ distribution with a significance level of 'd' degrees of freedom (Alghazali and Alawadi 2014).

China-Z Index

Variations of the CZI have been used by the Chinese National Climate Center to monitor the drought situation across the country since 1995 (Wu et al. 2001; Dogan et al. 2012; Jain et al. 2015). The CZI is based on the Wilson–Hilferty cube-root transformation distribution (Wilson and Hilferty 1931; Kendall and Stuart 1977; Wu et al. 2001; Morid et al. 2006; Zarei et al. 2017) and assumes that precipitation data obey the Pearson Type III distribution (Wu et al. 2001; Garcia-Leon et al. 2019; Payab and Turker 2019). The classes of CZI values are presented in Table 3.

The CZI is computed as

Table 1 Statistical parameters for rainfall data recorded at the six weather stations in the Hirfanli Dam basin in central Turkey

Meteorological Stations	Monthly rainfall records of 1960–2017 (mm)					
	Mean	Min	Max	SD	Skewness	Kurtosis
Gemerek	33.29	0	160.00	27.24	1.07	1.51
Kayseri	32.46	0	164.70	25.85	0.93	0.98
Kirsehir	31.96	0	161.40	26.82	1.04	1.26
Nevsehir	34.41	0	148.80	27.54	0.81	0.43
Sivas	36.58	0	154.80	28.29	0.85	0.64
Zara	43.83	0	171.40	33.90	0.90	0.61

Table 2 The meteorology stations utilized in the study

Meteorological stations	Altitude (m)	Latitude (°N)	Longitude (°E)	Monthly rainfall data (month)
Gemerek	1182	39.18	36.08	1960–2017 (696 months)
Kayseri	1094	38.68	35.50	1960–2017 (696 months)
Kirsehir	1007	39.16	34.15	1960–2017 (696 months)
Nevsehir	1260	38.61	34.70	1960–2017 (696 months)
Sivas	1294	39.74	37.01	1960–2017 (696 months)
Zara	1338	39.89	37.74	1960–2017 (696 months)

$$CZI_j = \frac{6}{C_s}\left(\frac{C_s}{2}\varnothing_j + 1\right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6}, C_s = \frac{\sum_{j=1}^{n}\left(x_j - \bar{x}\right)^3}{n * \sigma^3}, \varnothing_j = \frac{x_j - \bar{x}}{\sigma} \tag{2}$$

where C_s is the coefficient of skewness, n is the total number of months in the record, $\varnothing_j$ is a standardized variate (also called the Z-Score) and x_j is the precipitation in period j.

Standardized Precipitation Index

The SPI is a widely used index to evaluate meteorological drought at different time scales (Bonaccorso et al. 2003; Khan et al. 2018). The SPI was developed by McKee et al. (1993). The classes of SPI values are presented in Table 3. Computation of the SPI involves fitting a gamma probability density function to a given time series of precipitation data (McKee et al. 1993), whose probability density function, g(x), is defined in Eq. (3) (Sonmez et al. 2005; Yacoub and Tayfur 2017, 2020).

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \tag{3}$$

where $\alpha > 0$ is the shape parameter, $\beta > 0$ is the scale parameter and $x > 0$ is the amount of precipitation (Lloyd-Hugnes and Saunders 2002; Wu et al. 2005; Bacanli 2017). $\Gamma(\alpha)$ is the gamma function which is defined in Eq. (4) (Tsakiris and Vangelis 2005; Alami et al. 2018).

$$\Gamma(\alpha) = \int_0^{\infty} \gamma^{\alpha-1} e^{-y} dy \tag{4}$$

α and β are the shape and scale parameters, respectively, which can be estimated as follows (Thom 1958; Yacoub and Tayfur 2020):

$$\alpha = \frac{1}{4A}(1 + \sqrt{1 + \frac{4A}{3}}, \beta = \frac{\bar{x}}{\alpha}, A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \tag{5}$$

Table 3 Categories for the China-Z Index and Standardized Precipitation Index, ranging from extreme drought to extremely wet periods (from McKee et al. 1995; Kutiel et al. 1996; Morid et al. 2006; Jain et al. 2015)

Category	CZI	SPI
Extremely wet	≥ 2	≥ 2
Very wet	1.5 to 1.99	1.5 to 1.99
Moderately normal	1 to 1.49	1 to 1.49
Near normal	− 0.99 to 0.99	− 0.99 to 0.99
Moderate drought	− 1 to 1.49	− 1 to 1.49
Severe drought	− 1.5 to − 1.99	− 1.5 to − 1.99
Extreme drought	≤ − 2	≤ − 2

In Eq. (5), n is the number of observations. After estimating α and β, the probability density function is integrated with respect to x, which yields the expression G(x), for the cumulative probability, as follows (Yacoub and Tayfur 2020):

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \tag{6}$$

By substituting t for x/β in Eq. (4), the equation is reduced to (Alami et al. 2018)

$$G(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-t} dt \tag{7}$$

As the gamma function is not defined for $x = 0$, for the possibility of zero values the cumulative probability function becomes (Alami et al. 2018)

$$H(x) = q + (1 - q)G(x) \tag{8}$$

where q is the probability of zero precipitation. The cumulative probability distribution is then transformed into the standard normal distribution to yield the SPI (Abramowitz and Stegun 1965; Yacoub and Tayfur 2017, 2020). The approximate conversion is given as.

for $0 < H(x) < 0.5$

$$SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \tag{9}$$

for $0.5 < H(x) < 1.0$

$$SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \tag{10}$$

where $c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$ and $d_3 = 0.001308$ (McKee et al. 1995).

Results and discussion

The four probability distributions (Normal, Lognormal, Pearson Type III and Gamma distribution) were subjected to the Chi-square test to determine the best-fitting probability distribution model, as per Amin et al. (2016). The test statistics are presented in Table 4. In the table, a, b and c denote the probability distributions accepted at confidence intervals of 99%, 95% and 90%, respectively.

The Pearson Type III distribution provided the best fit for all the stations in the Hirfanli dam basin. For all the stations, except for Kirsehir and Nevsehir, the H_0 hypothesis was accepted at all confidence intervals. For

Table 4 Results for the $\chi 2$ test for 6 weather stations in the Hirfanli Dam basin in central Turkey

Meteorological stations	Distributions				D. of F
	Normal	Lognormal	Gamma	Pearson Type III	
Gemerek	211.299	203.856	94.4598	11.931[a,b,c]	9
Kayseri	231.96	218.167	102.851	14.4598[a,b,c]	9
Kirsehir	231.902	242.534	93.6552	18.1667[a]	9
Nevsehir	235.983	242.851	113.368	12.7069[a,b,c]	9
Sivas	80.2931	251.356	97.9655	25.6954	9
Zara	94.431	203.253	96.0115	14.00[a,b,c]	9

the Kirsehir station, the H_0 hypothesis was accepted only at the 99% confidence interval. In addition, for the Sivas station, the H_0 hypothesis was rejected at all confidence intervals.

The SPI and CZI values were calculated at 1-, 3-, 6-, 9- and 12-month scales for all stations in the Hirfanli Dam basin (Figs. 2, 3). The correlation coefficient (R) values between the SPI and CZI values for all stations were also calculated and are shown in Table 5. Also, Table 5 shows the mean R values for SPI with CZI values for each station. In the mean of R values (the mean R values) for all of the stations across the 5 tested scales, the lowest was

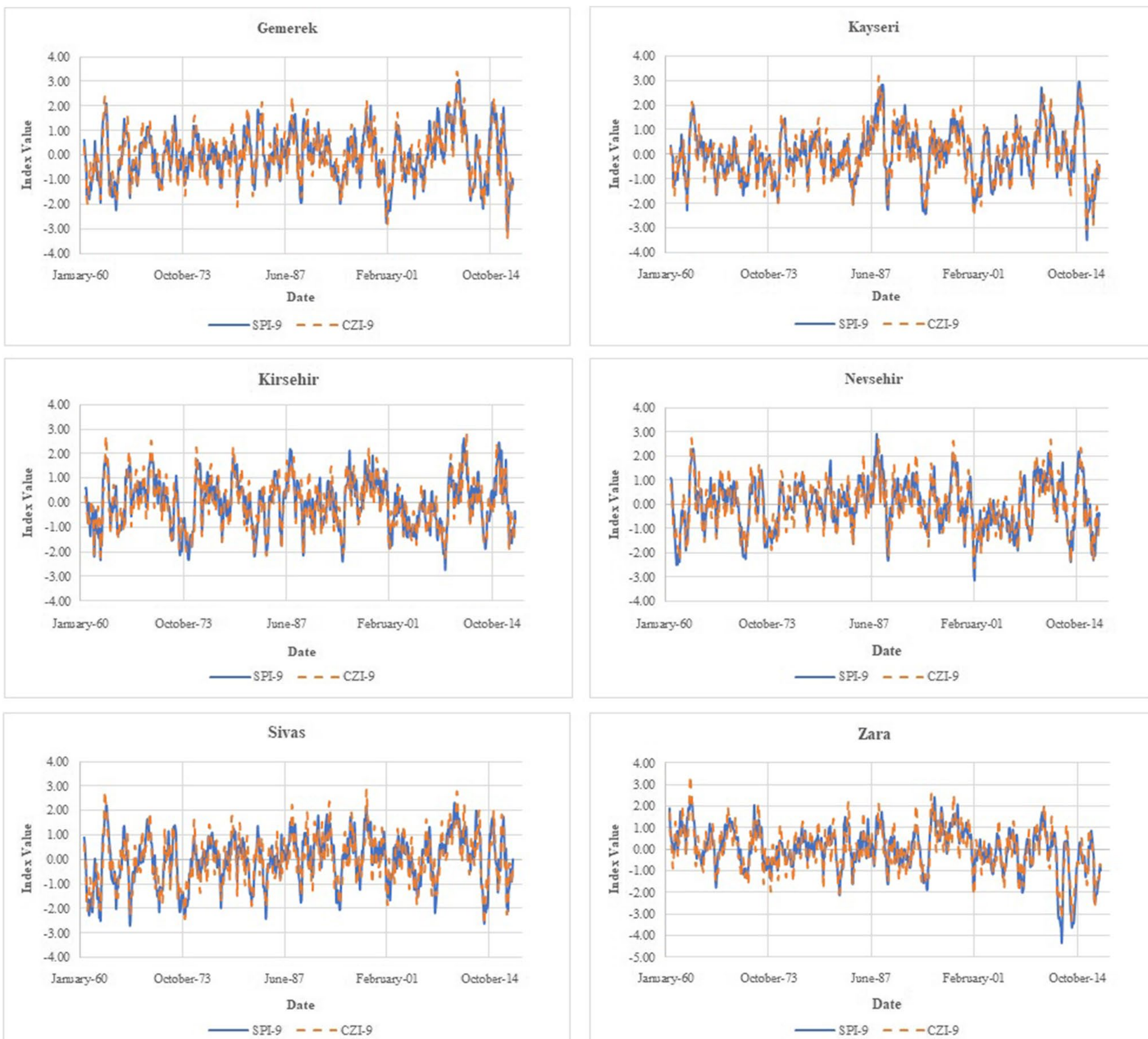

Fig. 2 Comparisons of the SPI values and CZI values for 9-month scale

for Nevsehir at 0.7759, and the highest was for Kayseri at 0.8233.

Across the different time scales assessed, the 12-month values for CZI and SPI had the highest mean *R* value of 0.9958, whereas the lowest mean value of 0.6728 was for 3-month time scale. The ranges of the *R* values, which generally increased as the time scale increased, ranged from 0.6868 to 0.7364 for the 1-month time scale, 0.6349 to 0.7017 for 3-month scale, 0.7063 to 0.7861 for 6 month, 0.8520 to 0.8955 for 9-month time scale and from 0.9918 to 0.9979 for 12-month time scale. The maximum *R* value of 0.9979 was obtained for the SPI-12 and CZI-12 values for Kirsehir. There were also very high *R* values for the 12-month time scale for the other five meteorology stations.

Additionally, Kayseri had the highest *R* value of 0.8955 for 9-month time scale, followed by Gemerek (0.8791), Kirsehir (0.8779), Zara (0.8620), Nevsehir (0.8543) and Sivas (0.8520). In contrast, the lowest *R* value for SPI and CZI values was 0.6349 in Nevsehir for the 3-month time scale. Also, *R* values of 0.6565, 0.6615, 0.6864, 0.6957 and 0.7017 were determined for Zara, Sivas, Gemerek, Kirsehir and Kayseri, respectively. Overall, the results of this study showed that values for the SPI were highly correlated with those for the CZI at the 9-month and 12-month time scales.

Dogan et al. (2012) stated that there were low and high correlations between short- and long-term index values, respectively, for six drought severity indices (PN, DI, ZSI, CZI, SPI and EDI) applied to the rainfall records for the semi-arid Konya basin. As can be seen in Table 4 and earlier explanations, this situation was mirrored in the present study in that as the time interval increased, the correlations between the values for the indices also increased.

From Figs. 2 and 3, the lowest CZI values for Kirsehir (9–12 months), Kayseri (12 months), Gemerek (9 months), and Zara (12 months) corresponded to the minimum SPI values at the same time scale. On the other hand, only the highest CZI (3.70) and SPI (2.40) values for Sivas were determined in the same month (October 2010) at the 12-month scale. For example, when the minimum SPI-9 for Kirsehir was − 2.74 in August 2008, the corresponding CZI was negative (− 2.23) in the same month. The maximum negative value for the 12-month CZI was − 1.90 for May 2014, while the SPI value for the same month in Zara was − 3.72. In June 1963, the peak value of the CZI-9 was + 3.44 when the corresponding SPI 2.22 for Zara.

Separately, scatter diagrams for SPI and CZI values from 1960 to 2017 indicate that SPI and CZI values generally corresponded well for the 9- and 12-month scales for all stations (Fig. 4 and 5).

Conclusions

Hirfanlı Dam basin located in a semi-arid region, in Turkey. Frequent, severe and long-term droughts have been experienced throughout the basin that affect the regional water resources and agricultural and cause economic losses. For this study, drought assessment was performed at different time scales by using various indices, and the relationships between drought indices are statistically examined. In this study, the historical droughts over a 57-year period in the Hirfanlı Dam basin in Turkey were examined by using the CZI and the SPI. The precipitation data covered the period 1960 to 2017 and was supplied by the TSMS.

The following conclusions can be drawn from this study:

The precipitation registered at the four meteorological stations in the Hirfanlı Dam basin fitted the Pearson Type III distribution, based on the results of the Chi-square test. Therefore, the use of the CZI was based on the assumption that precipitation data fitted the Pearson Type III distribution.

The SPI was selected as the reference drought index, whereas CZI was applied for the first time to rainfall data from this basin. So comparison of two indices can help to display which one is the most appropriate index for monitoring the evolution and characteristics of drought in the semi-arid region of central Turkey. Specifically, the SPI and CZI were calculated and compared at five-time scales, namely 1, 3, 6, 9 and 12 months. The results of a correlation analysis between the SPI and CZI demonstrated that the two indices were highly correlated for the same time scales and that the degree of correlation increased as the scales got longer, that is, there were higher correlations for the 9- and 12-month time scales in comparison to shorter scales. Overall, the SPI and CZI were good tools to define, detect and monitor drought.

In the Hirfanlı Dam basin, a drought action plan should be developed for the purpose of minimizing the effects of drought. This task is especially urgent given that climate change is already causing more volatility in rainfalls patterns in parallel with increasing demands on available water resources for domestic and agricultural purposes. Drought patterns in the sub-basin containing the Hirfanlı Dam basin in Turkey should be examined further with different drought indices from those employed in this study. And also on the basis of their collective findings and other relevant information, the most appropriate measures for the management of the limited water resources in the basin should be implemented. As an example, training on ‘best practice’ water use should be provided to the

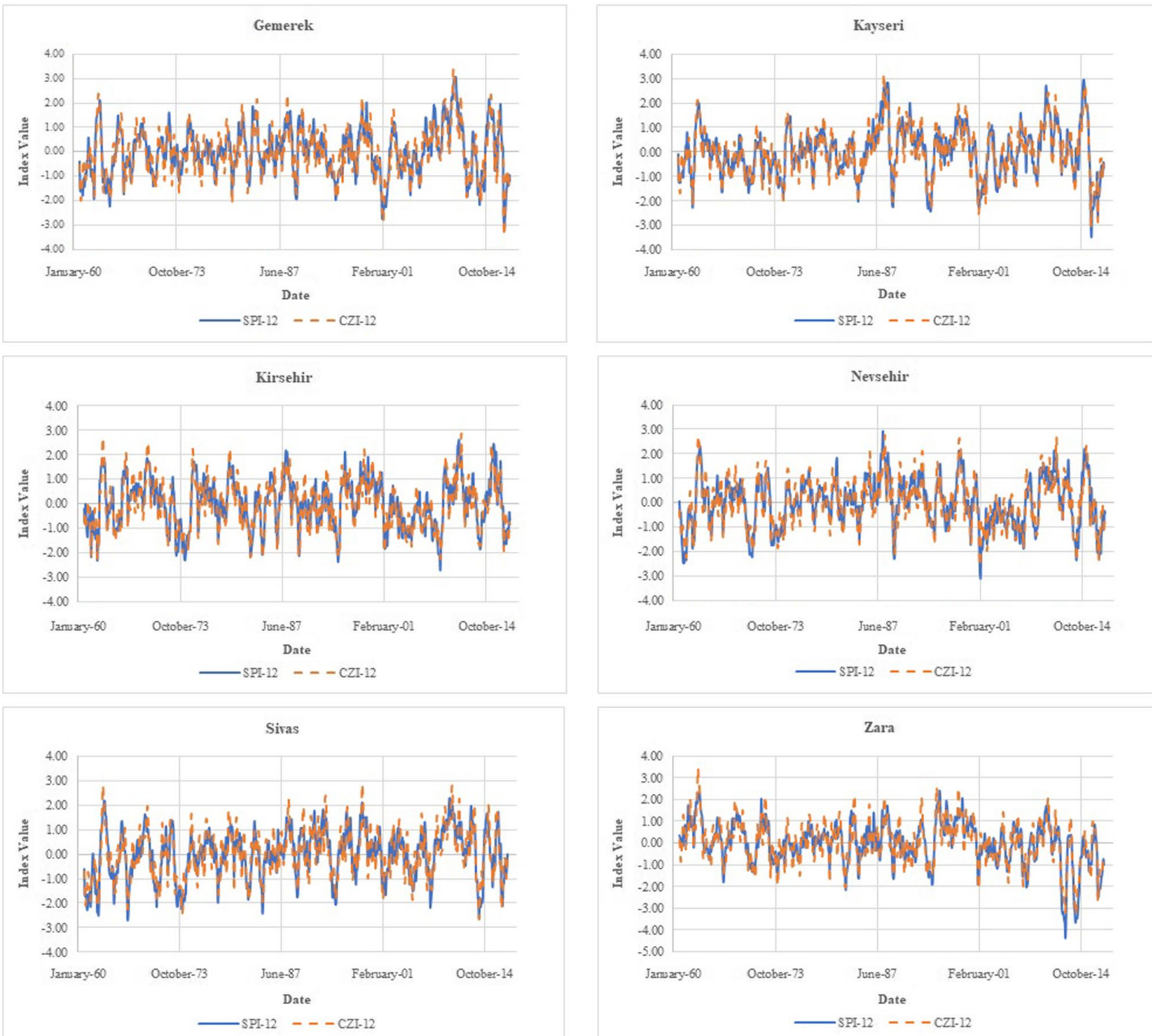

Fig. 3 Comparisons of the SPI values and CZI values for 12-month scale

Table 5 Correlation coefficients (R) between China-Z Index and Standardized Precipitation Index values for 6 weather stations in the Hirfanli Dam basin in central Turkey

Meteorological stations	1 month	3 months	6 months	9 months	12 months	Mean
Gemerek	0.7174	0.6864	0.7724	0.8791	0.9942	0.8099
Kayseri	0.7363	0.7017	0.7861	0.8955	0.9971	**0.8233**
Kirsehir	0.7364	0.6957	0.7620	0.8779	0.9979	0.8140
Nevsehir	0.6868	0.6349	0.7063	0.8543	0.9973	**0.7759**
Sivas	0.7056	0.6615	0.7330	0.8520	0.9967	0.7898
Zara	0.6947	0.6565	0.7583	0.8620	0.9918	0.7927
Mean	0.7129	**0.6728**	0.7530	0.8701	**0.9958**	0.8009

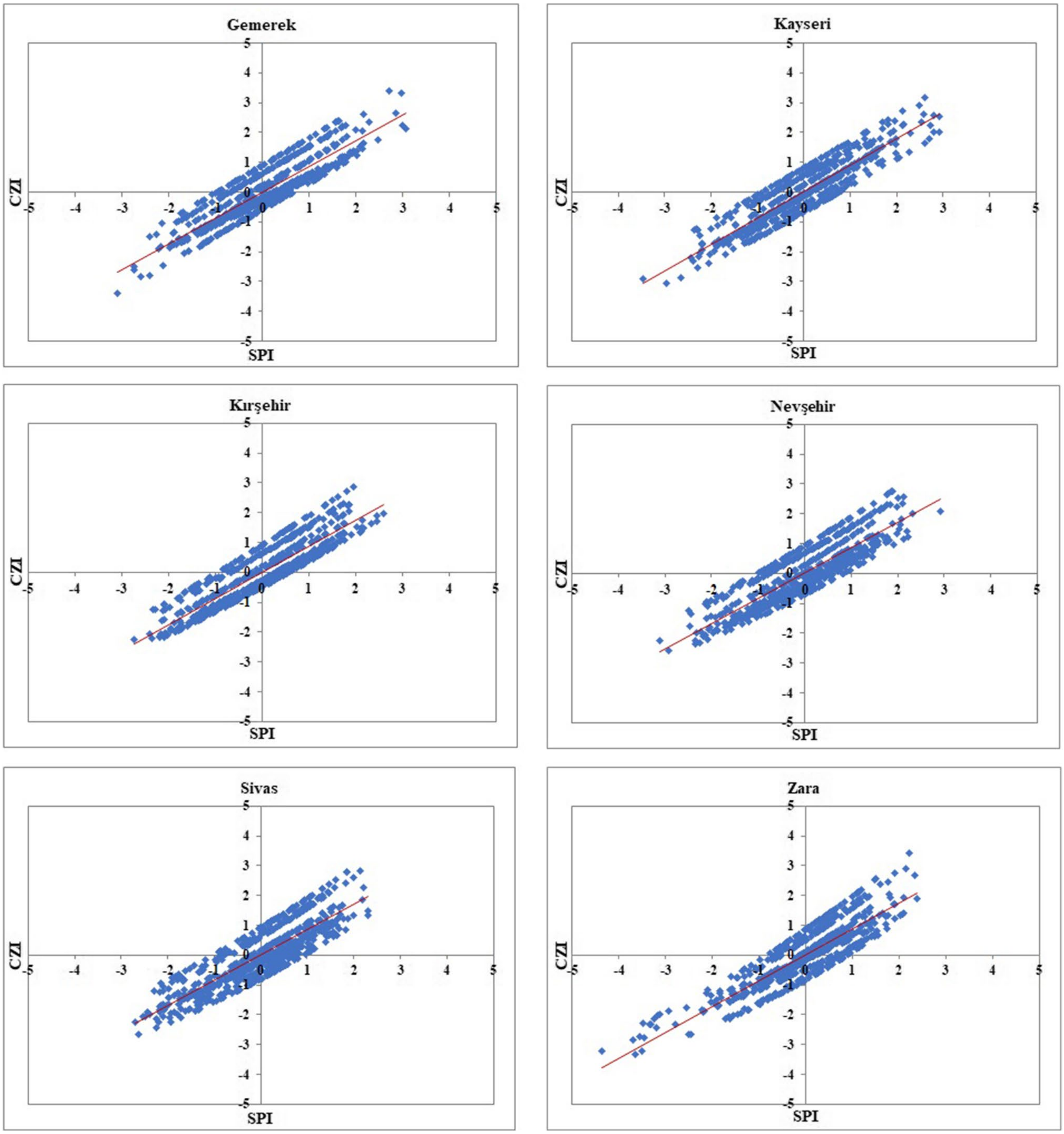

Fig. 4 Scatter diagrams of SPI values versus CZI values for 9-month scale

farmers in the region. This suggests that it is necessary to study with the different drought indices at different time scales to investigate their usefulness for monitoring droughts under different environmental conditions, climatic characteristics and water demand situations. In further studies, it will be useful to investigate drought studies in the Hirfanli Dam basin in long time scales of different drought indices. Especially, regulation of the management and planning of water resources in river basins in accordance with climatic changes has become more important in recent years. As a result; it is thought that the findings obtained in this study will contribute to the studies on the planning and management of water resources in the basin, which is the

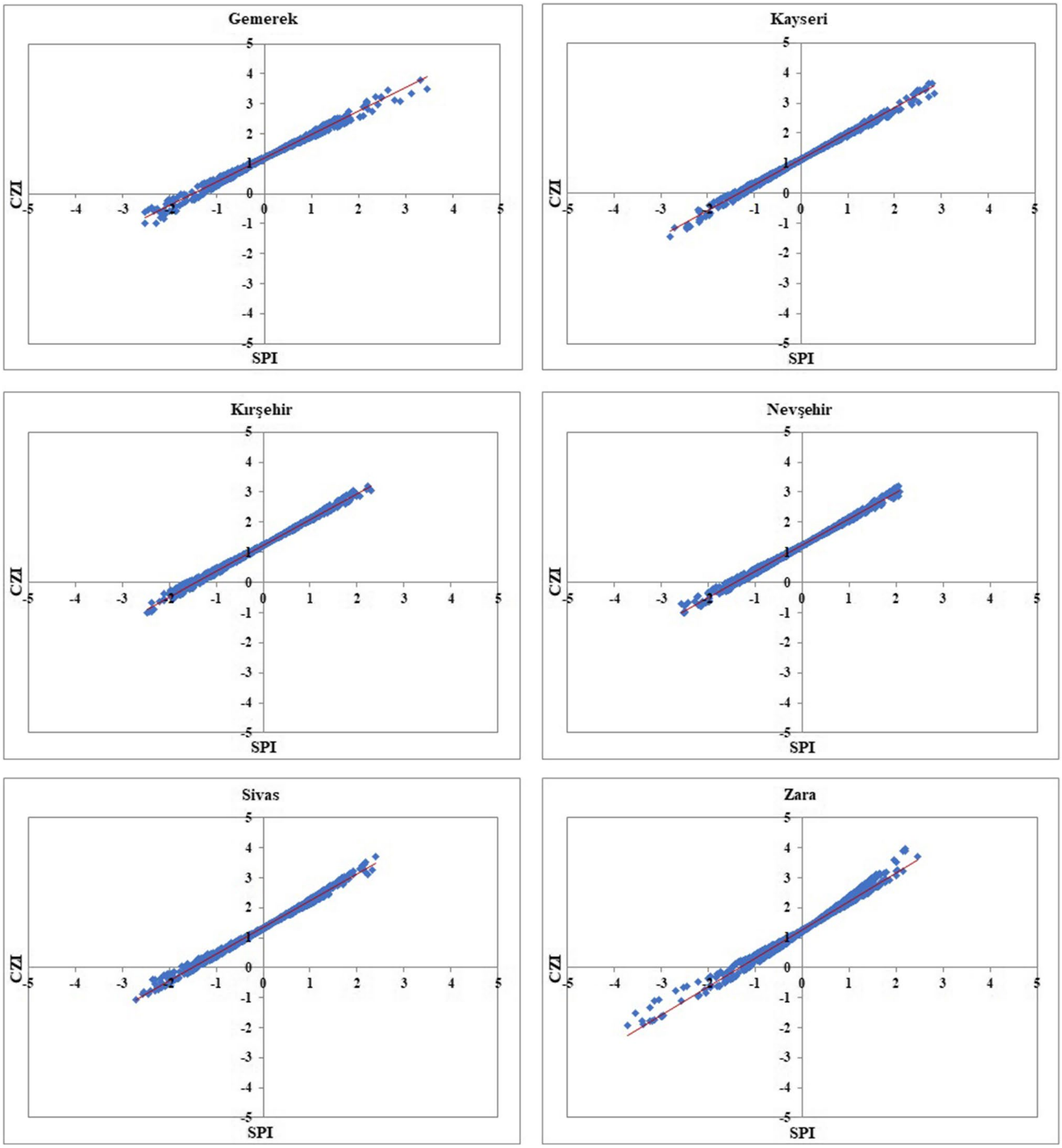

Fig. 5 Scatter diagrams of SPI values versus CZI for 12-month scale

important river basin of the country, and will also be useful in the studies to be carried out against possible climate change in the basin.

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

Declarations

Conflict of interest The authors declare no competing interests.

References

Abbas S, Kousar S (2021) Spatial analysis of drought severity and magnitude using the standardized precipitation index and streamflow drought index over the Upper Indus Basin. Pakistan Environ Dev Sustain 23(10):15314–15340. https://doi.org/10.1007/s10668-021-01299-y

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

Adnan S, Ullah K, Shuanglin L, Gao S, Khan AH, Mahmood R (2018) Comparison of various drought indices to monitor drought status in Pakistan. Clim Dyn 51(5–6):1885–1899. https://doi.org/10.1007/s00382-017-3987-0

Alami MH, Din SW, Tayfur G (2018) Meteorological drought analysis by different methods in Helmand river basin, Afghanistan. Int J Sci Eng Res 8(2):738–744

Alghazali NO, Alawadi DAH (2014) Fitting statistical distributions of monthly rainfall for some Iraqi stations. Civil and Environmental Research 6(6):40–46

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(3–4):95–107. https://doi.org/10.1007/s00704-019-02957-y

Amin MT, Rizvan M, Alazba AA (2016) A best-fit probability distribution for the estimation of rainfall in northern regions of Pakistan. Open Life Sci 11(1):432–440. https://doi.org/10.1515/biol-2016-0057

Bacanli UG (2017) Trend analysis of precipitation and drought in the Aegean region. Turkey Meteorological Applications 24(2):239–249. https://doi.org/10.1002/met.1622

Bacanli UG, Aksan G (2019) Drought analysis in Mediterranean region. Pamukkale University Journal of Engineering Sciences 25(6):665–671. https://doi.org/10.5505/pajes.2019.64507

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

Bushra N, Rohli RV, Lam NSN, Zou LL, Mostafiz RB, Mihunov V (2019) The relationship between the normalized difference vegetation index and drought indices in the South Central United States. Nat Hazards 96(2):791–808. https://doi.org/10.1007/s11069-019-03569-5

Byun HR, Wilhite DA (1999) Objective quantification of drought severity and duration. J Clim 12(9):2747–2756. https://doi.org/10.1175/1520-0442(1999)012%3c2747:OQODSA%3e2.0.CO;2

Cochran WG (1952) The χ^2 test of goodness of fit. Ann Math Stat 23:315–345. https://doi.org/10.1214/aoms/1177729380

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

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

Garcia-Leon D, Contreras S, Hunink J (2019) Comparison of meteorological and satellite-based drought indices as yield predictors of Spanish cereals. Agric Water Manag 213:388–396. https://doi.org/10.1016/j.agwat.2018.10.030

Gibbs WJ, Maher JV (1967) Rainfall deciles as drought indicators. Bureau of Meteorology, 48, Melbourne

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

Guttman NB (1991) Sensitivity of the palmer hydrologic drought index. Water Resour Bull 27:797–807. https://doi.org/10.1111/j.1752-1688.1991.tb01478.x

Haan CT (1977) Statistical method in hydrology. Iowa State University Press, Iowa

Habibi B, Meddi M (2021) Meteorological drought hazard analysis of wheat production in the semi-arid basin of Cheliff-Zahrez Nord, Algeria. Arab J Geosci 14:1–19. https://doi.org/10.1007/s12517-021-07401-y

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

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

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

Katipoglu OM, Acar R, Sengul S (2020) Comparison of meteorological indices for drought monitoring and evaluating: a case study from Euphrates basin, Turkey. Journal of Water and Climate Change 11(S1):29–43. https://doi.org/10.2166/wcc.2020.171

Kendall MG, Stuart A (1977) The advanced theory of statistics. Charles Griffin & Company, London

Khan MI, Liu D, Fu Q, Faiz MA (2018) Detecting the persistence of drying trends under changing climate conditions using four meteorological drought indices. Meteorol Appl 25(2):184–194. https://doi.org/10.1002/met.1680

Khan AA, Zhao Y, Khan J, Rahman G, Rafi M, Moazzam MFUI (2021) Spatial and temporal analysis of rainfall and drought condition in southwest Xinjiang in Northwest China, using various climate indices. Earth Syst Environ 5(2):201–216. https://doi.org/10.1007/s41748-021-00226-5

Khudri MM, Sadia F (2013) Determination of the best fit probability distribution for annual extreme precipitation in Bangladesh. Eur J Sci Res 103(3):391–404

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

Kumar U, Singh S, Bisht JK, Kant L (2021) Use of meteorological data for identification of agricultural drought in Kumaon region of Uttarakhand. J Earth Syst Sci 130(3):1–13. https://doi.org/10.1007/s12040-021-01622-1

Kutiel H, Maheras P, Guika S (1996) Circulation and extreme rainfall condition in the Eastern Mediterranean during the last century. Int J Climatol 16(1):73–92. https://doi.org/10.1002/(SICI)1097-0088(199601)16:1%3c73::AID-JOC997%3e3.0.CO;2-G

Liu Q, Zhang S, Zhang H, Bai Y, Zhang J (2020) Monitoring drought using composite drought indices based on remote sensing. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2019.134585
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
Mckee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration of time scales. Paper presented at 8th Conference on Applied Climatology, American Meteorological Society, Anaheim CA, 179–186
McKee TB, Doesken NJ, Kleist J (1995) Drought monitoring with multiple time scales. Proceedings of the 9th Conference on Applied Climatology, Dallas. Texas
Mohammed Y, Yimam A (2021) Analysis of meteorological droughts in the Lake's region of Ethiopian Rift Valley using reconnaissance drought index (RDI). Geoenviron Disasters 8:1–16. https://doi.org/10.1186/s40677-021-00183-1
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
Myronidis D, Fotakis D, Ioannou K, Sgouropoulou K (2018) Comparison of ten notable meteorological drought indices on tracking the effect of drought on streamflow. Hydrol Sci J 63(15–16):2005–2019. https://doi.org/10.1080/02626667.2018.1554285
Nalbantis I (2008) Evaluation of hydrological drought index. European Water 23(24):67–77
Nedham US, Hassan AS (2019) Comparison of some drought indices in Iraq. Al-Mustansiriyah Journal of Science 30(4):1–9
Ortega-Gómez T, Pérez-Martín MA, Estrela T (2018) Improvement of the drought indicators system in the Júcar River basin, Spain. Sci Total Environ 610–611:276–290. https://doi.org/10.1016/j.scitotenv.2017.07.250
Palmer WC (1945) U.S. Meteorological drought. Research Paper No. 45. US Weather Bureau, Washington DC
Pandey RP, Dash BB, Mishra SK, Singh R (2008) Study of indices for drought characterization in KBK districts in Orissa (India). Hydrol Process 22(21):1895–1907. https://doi.org/10.1002/hyp.6774
Pathak A, Dodamani BM (2019) Comparison of meteorological drought indices for different climatic regions of an Indian river basin. Asia-Pacific J Atmos Sci 56(4):563–576. https://doi.org/10.1007/s13143-019-00162-5
Payab H, Turker U (2019) Comparison of standardized meteorological indices for drought monitoring at northern part of Cyprus. Environ Earth Sci 78(10):309–327. https://doi.org/10.1007/s12665-019-8309-x
Poonia V, Jha S, Goyal MK (2021a) Copula based analysis of meteorological, hydrological and agricultural drought characteristics across Indian river basins. Int J Climatol 41(9):4637–4652. https://doi.org/10.1002/joc.7091
Poonia V, Goyal MK, Gupta BB, Gupta AK, Jha S, Das J (2021b) Drought occurrence in different river basins of India and blockchain technology based framework for disaster management. J Clean Prod 312:127737. https://doi.org/10.1016/j.jclepro.2021.127737
Ramkar P, Yadav SM (2018) Spatiotemporal drought assessment of a semi-arid part of middle Tapi River Basin, India. International Journal of Disaster Risk Reduction 28:414–426. https://doi.org/10.1016/j.ijdrr.2018.03.025
Sener E, Sener S (2021) GIS based spatiotemporal comparation between SPI and CZI drought index: a case study of Burdur lake basin. Journal of Natural Hazards and Environment 7(1):41–58. https://doi.org/10.21324/dacd.800036
Sharma MA, Singh JB (2010) Use of probability distribution in rainfall analysis. New York Science Journal 3(9):40–49
Shin JY, Chen S, Lee JH, Kim TW (2018) Investigation of drought propagation in South Korea using drought index and conditional probability. Terrestrial, Atmospheric and Oceanic Sciences 29(2):231–241. https://doi.org/10.3319/TAO.2017.08.23.01
Sobhani B, Zengir VS (2020) Modeling, monitoring and forecasting of drought in south and southwestern Iran. Iran Model Earth Syst Environ 6(1):63–71. https://doi.org/10.1007/s40808-019-00655-2
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
Sukrutha A, Dyuthi SR, Desai S (2018) Multimodel response assessment for monthly rainfall distribution in some selected Indian cities using best-fit probability as a tool. Appl Water Sci 8(5):145–154. https://doi.org/10.1007/s13201-018-0789-4
Thom HCS (1958) A note on the gamma distribution. Mon Weather Rev 86(4):117–122. https://doi.org/10.1175/1520-0493(1958)086%3c0117:ANOTGD%3e2.0.CO;2
Tsakiris G, Vangelis H (2005) Establishing a drought index incorporating evapo-transpiration. European Water Journal 9:3–11
Tsakiris G, Pangalou D, Vangelis H (2007) Regional drought assessment based on the Reconnaissance drought index (RDI). Water Resour Manage 21(5):821–833. https://doi.org/10.1007/s11269-006-9105-4
Van Rooy MP (1965) A rainfall anomaly index (RAI), Independent of the Time and Space. Notos 14:43–48
Vergni L, Todisco F, Di Lena B (2021) Evaluation of the similarity between drought indices by correlation analysis and Cohen's Kappa test in a Mediterranean area. Nat Hazards 108(2):2187–2209. https://doi.org/10.1007/s11069-021-04775-w
Vicente-Serrano SM, Beguería S, López-Moreno JI (2010) A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. J Clim 23(7):1696–1718. https://doi.org/10.1175/2009JCLI2909.1
Vicente-Serrano SM, Van der Schrier 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
Wable PS, Jha MK, Shekhar A (2019) Comparison of drought indices in a semi-arid river basin of India. Water Resour Manage 33(1):75–102. https://doi.org/10.1007/s11269-018-2089-z
Wambua RM, Mutua BM, Raude JM (2018) Detection of spatial, temporal and trend of meteorological drought using standardized precipitation index (SPI) and effective drought index (EDI) in the Upper Tana river basin Kenya. Open Journal of Modern Hydrology 8(3):83–100. https://doi.org/10.4236/ojmh.2018.83007
Wang FQ, Zheng Z, Kang PP, Wang L (2017) Applicability evaluation on the indexes of typical drought in Henan province, China. Applıed ecology and envıronmental research 15(3):253–262. https://doi.org/10.15666/aeer/1503_253262
Wilhite DA, Glantz MH (1985) Understanding: the drought phenomenon: the role of definitions. Water International 10(33):111–120. https://doi.org/10.1080/02508068508686328
Willeke G, Hosking JRM, Wallis JR, Guttman NB (1994) The national drought atlas. Institute for Water Resources Report 94-NDS-4, U.S. Army Corps of Engineers.
Wilson EB, Hilferty MM (1931) The distribution of Chi-square. Proc Natl Acad Sci USA 17(12):684–688. https://doi.org/10.1073/pnas.17.12.684
Wu H, Hayes MJ, Weiss A, Hu Q (2001) An evaluation of the standardized precipitation index, the China-Z index and the statistical Z-score. Int J Climatol 21(6):745–758. https://doi.org/10.1002/joc.658

Wu H, Hayes MJ, Wilhite DA, Svoboda MD (2005) The effect of the length of record on the standardized precipitation index calculation. Int J Climatol 25(4):505–520. https://doi.org/10.1002/joc.1142

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

Yacoub E, Tayfur G (2020) Spatial and temporal of variation of meteorological drought and precipitation trend analysis over whole Mauritania. J Afr Earth Sc 163:1–12. https://doi.org/10.1016/j.jafrearsci.2020.103761

Yao Z, Ding Y (1990) Climate statistics. Meteorological Press, Beijing, China

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

Yıldız O (2014) Spatiotemporal analysis of historical droughts in the central anatolia. Turkey Gazi University Journal of Science 27(4):1177–1184

Yuan J, Emura K, Farnham C, Alam MA (2018) Frequency analysis of annual maximum hourly precipitation and determination of best fit probability distribution for regions in Japan. Urban Climate 24:276–286. https://doi.org/10.1016/j.uclim.2017.07.008

Yuce MI, Esit M (2021) Drought monitoring in Ceyhan basin, Turkey. Journal of Applied Water Engineering and Research. https://doi.org/10.1080/23249676.2021.1932616

Zarei A, Asadi E, Ebrahimi A, Jafary MM, Malekian A, Tahmoures M, Alizadeh EE (2017) Comparison of meteorological indices for spatio-tem-poral analysis of drought in Chahrmahal-Bakhtiyari province in Iran. Hrvatski Meteorološki Časopis 52(52):13–26