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Comparison of four precipitation based meteorological drought indices in the Yesilirmak Basin, Turkey

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Abstract— Drought, which is often defined as not enough precipitation, does not a mean simple lack of precipitation. This condition, which occurs when humidity is less than the average value for many years, is caused by a disrupted balance between precipitation and evaporation in a region. It is very difficult to predict the start and the end time of drought. In the present study, the drought conditions of the stations selected from Yesilirmak Basin between 1970 and 2014 were determined by using Z-Score Index (ZSI), China-Z Index (CZI), Modified China-Z Index (MCZI), and Standard Precipitation Index (SPI), and the compliance of these indices to the SPI was investigated. It was determined that these indices gave parallel results to each other, and SPI detected drought earlier than other indices.

Key-words: drought indices, drought monitoring; standard precipitation index, Z-score index, modified China-Z index

1. Introduction

Drought, which is the most dangerous among natural disasters, has not yet been defined in full in the world literature. The effects of drought are felt increasingly all over the world. In general, human beings become aware of drought when there is water shortage (*Hejazizadeh* and *Javizadeh,* 2011). It is very difficult to predict the start and end time of droughts because it is a disaster occurring insidiously showing effects gradually, and continuing for a long time. Although earthly and regional climate characteristics play very important roles in the emergence of drought, the change of climate is not the only reason. The reasons for the emergence of droughts are not always the same factor in every basin. Also, the same lack of precipitation causes different perceptions at different times of the year in different areas. The causes of droughts are not yet clearly defined. Drought, which is often defined as not enough precipitation, is not a mere lack of precipitation. Drought occurs if humidity is less than the average value for many years due to a disrupted balance between precipitation and evaporation in an area (*Downer et al.,* 1967).

It has been observed in recent years that researchers have used various drought indices with greater emphasis on drought studies with global warming (*Lloyd-Hughes* and *Saunders,* 2002; *Sirdas* and *Sen,* 2003; *Yildiz*, 2009; *Oguzturk* and *Yildiz,* 2014, 2015, 2016; *Deo* and *Sahin,* 2015; *Yue et al.,* 2015; *Osuch et al.,* 2016; *Ionita et al.,* 2016; *Wang et al.,* 2017; *Gumus* and *Algin,* 2017; *Yacoub* and *Tayfur,* 2017; *Ramkar* and *Yadav,* 2018; *Myronidis et al.,* 2018; *Bushra et al.,* 2019; *Garcia-Leon et al.,* 2019; *Payab* and *Turker,* 2019; *Pathak* and *Dodamani,* 2019; *Yenigun* and *Ibrahim*, 2019; *Kumanlioglu,* 2020; *Vergni et al.,* 2021). *Wu et al.* (2001) compared results of three drought indices (standard precipitation index (SPI), China-Z index (CZI), and Z-score index (ZSI)) for China. *Morid et al.* (2006) compared seven different drought indices (SPI, percent of normal (PN), deciles iIndex (DI), ZSI, CZI, modified China-Z index (MCZI), and effective drought index (EDI)). As a result of the study, it was concluded that DI reacted rapidly to precipitation events in certain years, but exhibited temporal and field inconsistencies, while SPI and EDI were good at detecting the start of drought showing temporal and field consistency, but EDI produced more sensitive results than SPI. *Dogan et al.* (2012) compared six different drought indices in the Konya Closed Basin. They used the drought indices of PN, rainfall decile-based drought index (RDDI), ZSI, CZI, SPI and EDI. *Soleimani et al.* (2013) conducted a study to determine drought in Talegani city, which is a semi-arid area in Iran and analyzed SPI, RDDI, and CZI relatively to each other. They found that SPI yielded the best results. *Jain et al.* (2015) observed drought events in the Ken River Basin with SPI, EDI, ZSI, CZI, Rainfall Departure and DI. *Zarei et al.* (2017) compared performance of CZI, ZSI, SPI, and EDI for drought assessment in Chaharmahal-Bakhtiari province, Iran. *Nedham* and *Hassan* (2019) compared SPI, ZSI, and PPA in Iraq. The authors revealed, that all drought indices had a strong positive relationship between each other. *Katipoglu et al.* (2020) investigated droughts of the Euphrates Basin with SPI, ZSI, RAI, SPEI, and RDI. *Sridhara et al.* (2021) applied and compared five precipitation-based indices (DI, PN, CZI, ZSI, and SPI). Authors stated that SPI, CZI, and ZSI performances were similar in identifying drought. *Dikici* and *Aksel* (2021) monitored meteorological and hydrological drought by 13 drought indices for Ceyhan Basin, Turkey.

The purposes of this study were (i) to identify drought events and (ii) to evaluate the performance of four meteorological drought indices (ZSI, CZI, MCZI, SPI) in the Yesilirmak Basin. The monthly precipitation records of four meteorological observation stations (Amasya, Corum, Samsun, and Tokat) located in Yesilirmak Basin were used. When longer records are used to calculate drought indices, more reliable results can be obtained (*Wu et al.,* 2001). For this reason, applications were made for a 45-year-long period between 1970 and 2014, which was the longest data range available at the meteorology stations in the basin.

2. Study area

The Yesilirmak Basin covers the area in the northern part of Anatolia, which discharges its waters into the Black Sea with Yesilirmak. The Basin Area is surrounded by the Canik, Giresun, Gumushane, Pulur, Cimen, Kizildag, Kose, Tekeli, Yildiz, Çamlıbel, Akdaglar, Karababa, İnegöl, and Kunduz mountain peaks with water separation line, and the Black Sea; and constitutes approximately 38732.8 km^2. The precipitation area of the Yesilirmak Basin is 36129 km^2, with an annual precipitation of 646 mm (*TUBITAK,* 2010). The localization of Amasya, Corum, Samsun, and Tokat meteorological stations used in the study in the basin are given in *Fig 1* and positional characteristics are given in *Table 1*.

Table 1. Positional characteristics of selected meteorological stations

Station Name	Station Code	Elevation (m)	Latitude (N)	Longitude (E)
Amasya	17085	409	40.6668	35.8353
Corum	17084	776	40.5461	34.9362
Samsun	17030	4	41.3435	36.2553
Tokat	17086	611	40.3312	36.5577

Fig. 1. Distribution of meteorological stations in the Yesilirmak Basin (*TUBITAK*, 2010)

3. Drought indices

3.1. Standard precipitation index

McKee et al. (1993) developed SPI to identify and monitor regional droughts. In fact, SPI ensures the standardized conversion of the observed precipitation probability; and can be calculated for desired time periods (1, 3, 6, 9, 12, 24, and 48 months). Short-term time periods (weekly and monthly) are important for agricultural water requirements and water potentials, and long-term time periods such as years (12, 24, 36 months) are important for water supply, water resources management, and groundwater studies (*Mishra* and *Singh,* 2011). SPI can be used according to normal, log-normal, and gamma distributions of precipitation (*Yacoub* and *Tayfur,* 2017). However, it was reported that climatic precipitation series match gamma distribution better (*Thom*, 1958; *Mishra* and *Singh,* 2010; *Yacoub* and *Tayfur,* 2017). The probability density function of the gamma distribution, *g(x)* is given as

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}}; x, \alpha, \beta > 0 \,, \tag{1}$$

and the gamma function is given as

$$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1} e^{-y} dx \,, \tag{2}$$

where x refers to the amount of precipitation, $\Gamma(\alpha)$ is the gamma function, α and β *are the shape and scale parameters, respectively*. SPI requires that a Gamma probability density function is adapted to frequency distribution given with precipitation totals for a station. The shape (α) and scale (β) parameters of the gamma probability density function are predicted for each station and time period in question. The maximum probability solutions given by *Thom* (1958) are used in predicting the α and β (*Bacanli et al.,* 2009; *Bacanli* and *Kargi,* 2019). α and β are obtained as

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

where n refers to the number of observations. The resulting parameters are used in forming the probability function *G(x)* given by the following formula (*Bacanli,* 2017)

$$G(x) = \int_0^{x} g(x) dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^{x} x^{\alpha-1} e^{\frac{-x}{\beta}} dx \tag{4}$$

When $t=x/\beta$, the gamma function is by the following formula (*Yacoub* and *Tayfur,* 2020)

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-t} \, dt \, . \tag{5}$$

The gamma distribution is non-defined for zero values of x; however, since the precipitation series may contain zero values, the cumulative probability distribution *H(x)* for zero precipitation and precipitations other than zero is identified as (*Lloyd-Hughes* and *Saunders,* 2002):

$$H(x) = q + (1 - q)G(x) \tag{6}$$

where q is the probability of zero. If m is the number of zeros in the precipitation time series, it can be predicted as $q=m/n$. The probability function *H(x)* is converted into SPI that has an average of zero and a variance of 1 with a standard normal random value. The SPI value according to the *H(x)* value obtained in this way is calculated by the following formulas (*Abramowitz* and *Stegun,* 1965):

$$0 < H(x) < 0.5, SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{ln\left(\frac{1}{(H(x))^2}\right)}, \tag{7}$$

and

$$0.5 < H(x) < 1.0, SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{ln\left(\frac{1}{(1.0 - H(x))^2}\right)}, \tag{8}$$

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

Dry and humid periods are represented in the same way in the selected time period as a result of the normalization of SPI values. The month in which the index value falls below -1 is defined as the start of the drought, and the time period in which the index continues below -1 is defined as the dry period in drought evaluations (*McKee et al.*, 1995; *Mishra* and *Singh,* 2011). According to the index results, drought categories are given in *Table 2*.

3.2. Z-score index

Raw precipitation data are used in the ZSI method, which is a unidimensional drought index. As seen in Eq.(9), it is obtained by dividing the difference of the average into the standard deviation without converting the precipitation to normal distribution within the specified time period (*Wu et al.,* 2001). ZSI has standard deviation and standard average, in other words, the standard average is 0, and the standard deviations of ZSI values are equal to 1, the values above the average are positive, and those below are negative.

$$ZSI = \frac{x_i - \bar{x}}{\sigma}, \quad (9)$$

where x_i refers to the precipitation values in the time period, $\bar{x}$ refers to the average precipitation data, and σ refers to the standard deviation. The drought classification according to ZSI is given in *Table 2*.

3.3. China-Z index

It is a drought index assuming that the CZI precipitation data fits to the Pearson-type III distribution. It has been used by the China National Climate Center since 1995 to monitor drought conditions throughout the country; and is calculated as (*Morid et al.,* 2006; *Dogan et al.,* 2012; *Jain et al.,* 2015; *Payab* and *Turker,* 2019):

$$CZI = \frac{6}{C_s}\left(\frac{C_s}{2} ZSI + 1\right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6};\ C_s = \frac{\sum_{j=1}^{n}\left(x_j - \bar{x}\right)^3}{n * \sigma^3}, \quad (10)$$

where x_j refers to the amount of precipitation converted into normal distribution in the time period, n refers to the total number of time periods, ZSI refers to the results of the Z-score index, and C_s refers to the skewness coefficient of precipitation data. The drought classification according to CZI value is given in *Table 2*.

3.4. Modified China-Z index

The calculation of MCZI is similar to the calculation of CZI, only the median value (*Me*) is used instead of the average in Eq.(10) (*Wu et al.,* 2001; *Morid et al.,* 2006). The acquisition of the index is given as (*Morid et al.,* 2006):

$$MCZI = \frac{6}{C_s}\left(\frac{C_s}{2}\varphi_j + 1\right)^{1/3} - \frac{6}{C_s} + \frac{C_s}{6};\ C_s = \frac{\sum_{j=1}^{n}\left(x_j - Me\right)^3}{n * \sigma^3};\ \varphi_j = \frac{x_j - Me}{\sigma}, \quad (11)$$

where φ_j is the standard variable, and *Me* refers to the median value of precipitation. The drought classification according to MCZI value is given in *Table 2*.

Table 2. Classification of drought conditions according to the SPI, ZSI and CZI/MCZI (*Morid et al.,* 2006; *McKee et al.,* 1995; *Kutiel et al.,* 1996; *Jain et al.,* 2015)

Category	SPI	ZSI	CZI/MCZI
Normal	−0.99 to 0.99	−0.99 to 0.99	−0.99 to 0.99
Moderately dry	−1.0 to −1.49	−1.0 to −1.49	−1.0 to −1.49
Severe dry	−1.5 to −1.99	−1.5 to −1.99	−1.5 to −1.99
Extreme dry	≤−2	≤−2	≤−2

4. Results and discussion

In the scope of the study, SPI, ZSI, CZI, and MCZI were applied in three different time scales (3 months,12 months, 24 months) for 4 meteorological stations selected in the Yesilirmak Basin, and the progression of the indices on the time axis are given in *Figs. 2–5*. In the evaluations, SPI was identified as the reference index since it showed the beginning of droughts earlier, moreover, it was reliable, required only precipitation data, and yielded better results (*Morid et al.,* 2006; *Dogan et al.*, 2012; *Mishra* and *Singh,* 2011; *Yacoub* and *Tayfur,* 2017).

Figs. 2–5 in which the temporal change of the 4 drought indices were given were evaluated, and *Tables 3–6* were prepared. The most severe and the longest durations of the droughts determined by the indices for each station are determined in these Tables, and the start and end dates of the droughts in question are given.

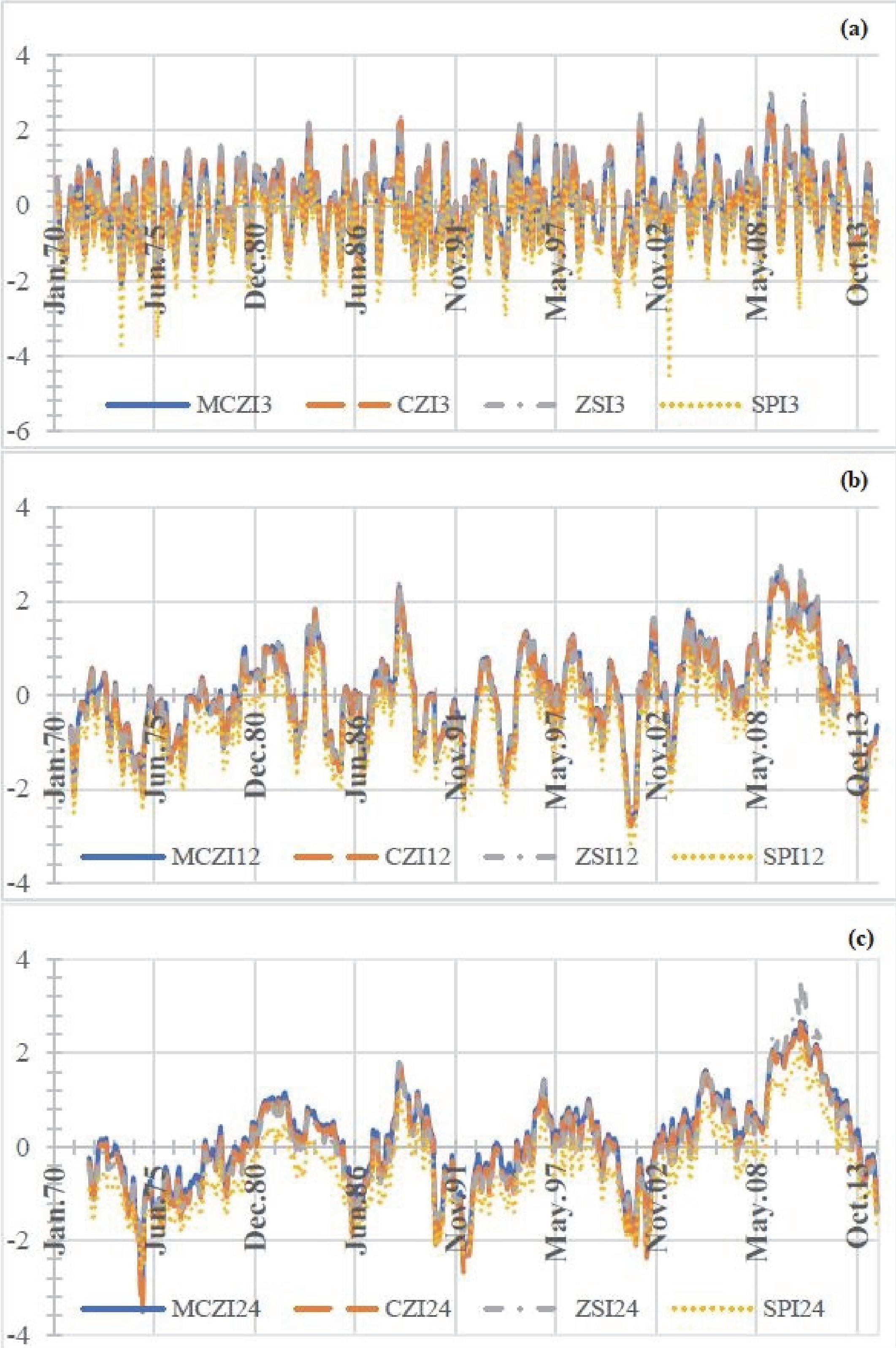

Fig. 2. Drought indices values of Amasya stationfor 3-, 12-, and 24-month periods.

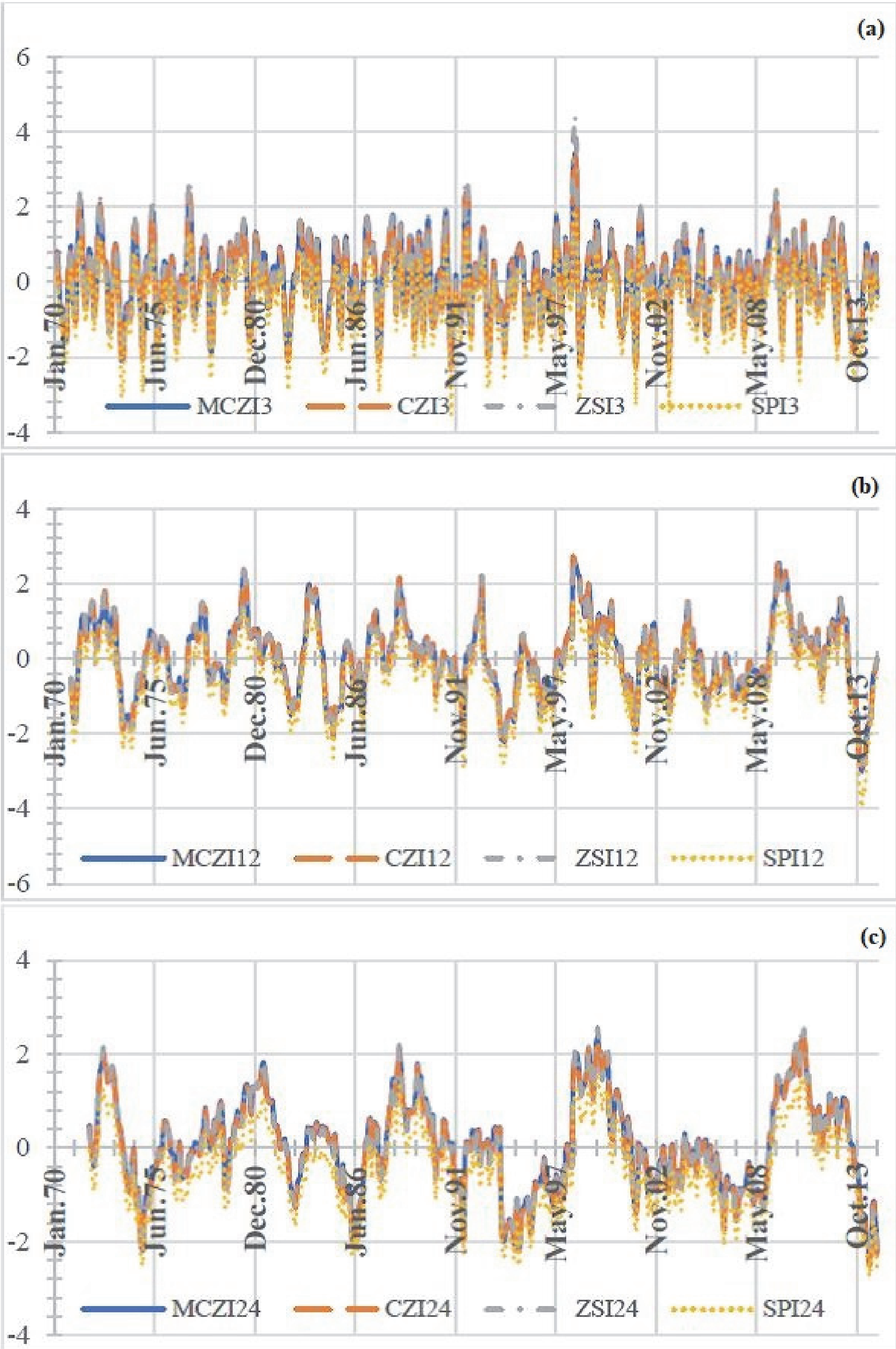

Fig. 3. Drought indices values of Corum station for 3-, 12-, and 24-month periods.

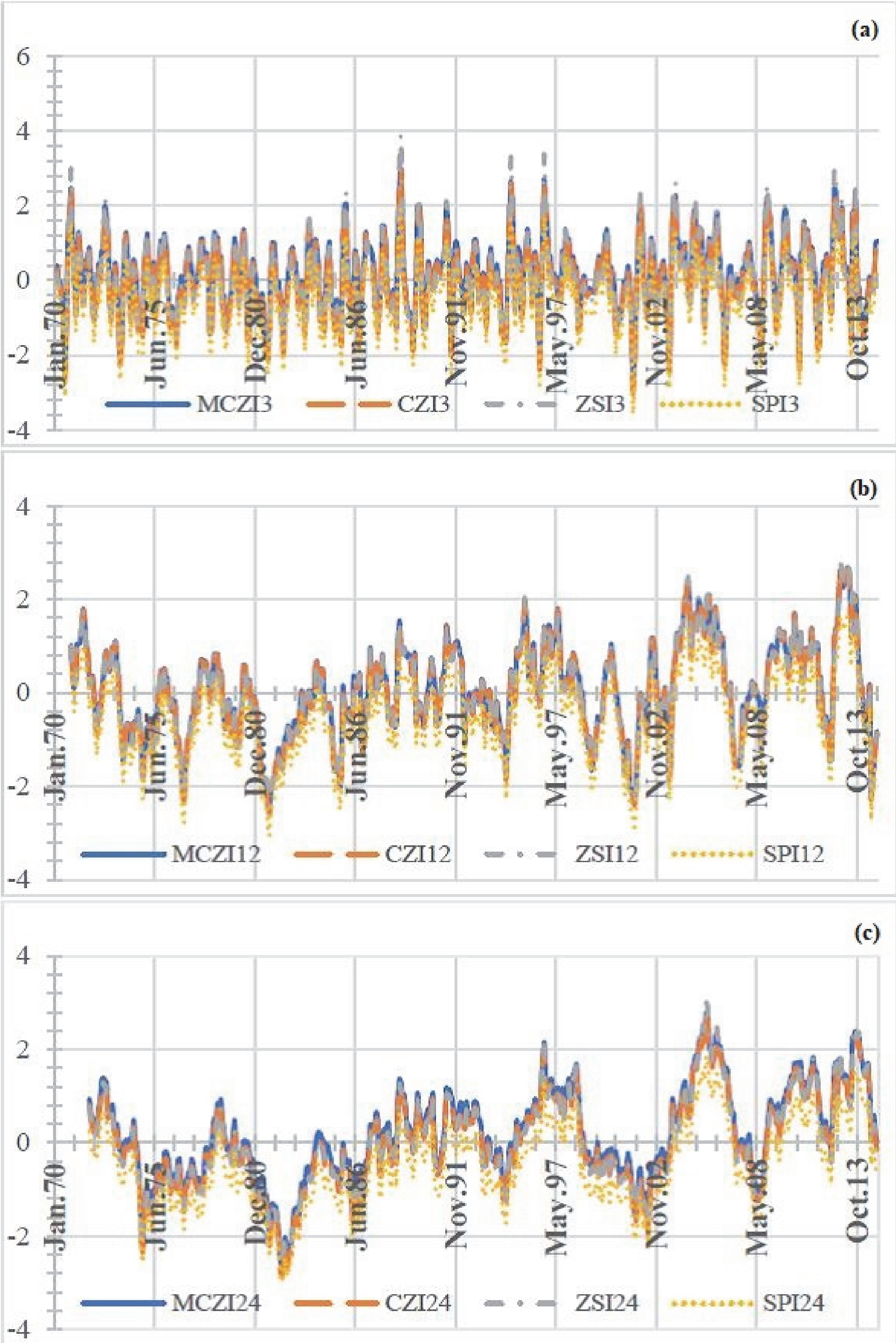

Fig. 4. Drought indices values of Samsun station for 3-, 12-, and 24-months periods.

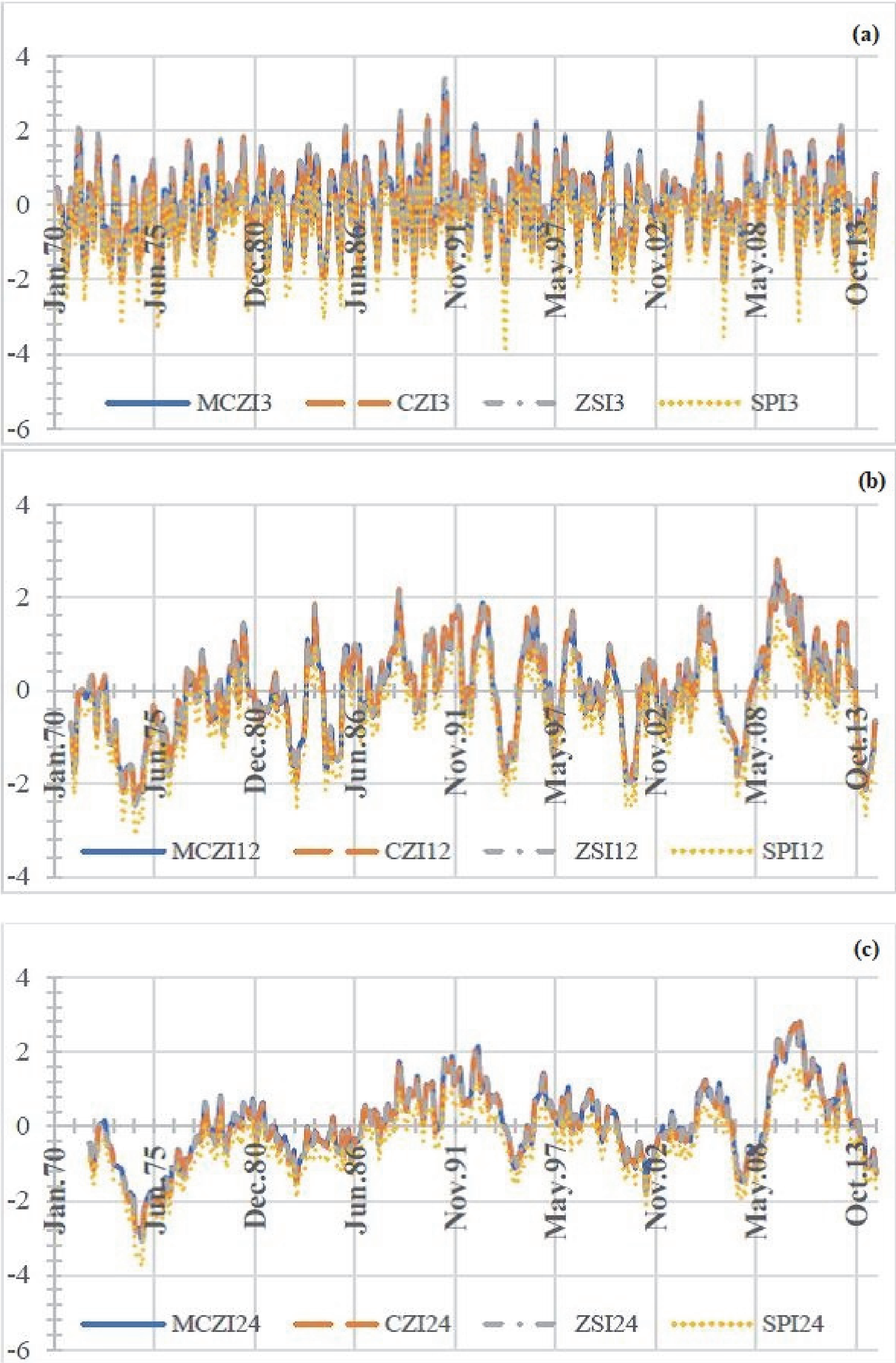

Fig. 5. Drought indices values of Tokat for 3-, 12-, and 24-month periods.

Table 3. The longest dry periods and the date of the most extreme dry period for Amasya station

Indices	The longest dry period	Duration (Month)	Value of the most extreme drought	Date
SPI-3	Jun 2013 - Feb2014	8	-4.54	Aug 2003
ZSI-3	Aug 2000-Jan 2001	6	-2.00	Aug 2003
CZI-3	Aug 2000-Jan 2001	6	-2.18	Aug 2003
MCZI-3	Aug 2000-Jan 2001	6	-2.18	Aug 2003
SPI-12	Jul 1973-Feb 1975	20	-3.17	Jun2001
ZSI-12	Dec 2013-Okt 2014	11	-2.45	Jun2001
CZI-12	Dec 2013-Okt 2014	11	-2.79	Jun2001
MCZI-12	Feb 2001-Nov 2001	10	-2.74	Jun2001
SPI-24	Sep 1973-Feb 1978	54	-2.62	Nov 1974
ZSI-24	Nov 1991-Nov 1992	13	-2.06	Nov 1974
CZI-24	Nov 1991-Nov 1992	13	-3.54	Nov 1974
MCZI-24	May 1975-Dec 1975	8	-3.10	Nov 1974

Table 4. The longest dry periods and the date of the most extreme dry period for Corum station

Indices	The longest dry period	Duration (Month)	Value of the most extreme drought	Date
SPI-3	Jun 2013-Feb 2014	9	-3.54	Sep 1991
ZSI-3	Jul 2013-Feb 2014	8	-1.92	Sep 1991
CZI-3	Jul 2013-Feb 2014	8	-2.37	Sep 1991
MCZI-3	Jul 2013-Feb 2014	8	-2.27	Sep 1991
SPI-12	Jul 2013-Sep 2014	15	-3.97	Feb 2014
ZSI-12	Sep 1973-Jul 1974	11	-3.04	Feb 2014
CZI-12	Nov 1984-Sep 1985 May 1994-Mar 1995	11	-3.00	Feb 2014
MCZI-12	Oct 2013-Aug 2014	11	-3.01	Feb 2014
SPI-24	Jun 1994-Jun 1996	28	-2.75	Jul 2014
ZSI-24	Jun 1994-Mar 1996	22	-2.28	Jul 2014
CZI-24	Jun 1994-Mar 1996	22	-2.52	Jul 2014
MCZI-24	Jun 1994-Mar 1996	22	-2.47	Jul 2014

Table 5. The longest dry periods and the date of the most extreme dry period for Samsun station

Indices	The longest dry period	Duration (Month)	Value of the most extreme drought	Date
SPI-3	Apr 1976-Oct 1976 Mar 1985-Sep 1985	7	-3.58	Aug 2001
ZSI-3	Aug 1974-Nov 1974 Jul 1981-Oct 1981 Jun 1994-Sep 1994 Jan 2014-Apr 2014	4	-2.08	
CZI-3	Aug 1974-Nov 1974 Jul 1981-Oct 1981 Jun 1989-Sep 1989 Jun 1994-Sep 1994 Jul 2001-Oct 2001 Jan 2014-Apr 2014		-3.05	
MCZI-3	Aug 1974-Nov 1974 Jul 1981-Oct 1981 Jun 1994-Sep1994		-2.76	
SPI-12	Mar 1981-May 1983	27	-3.07	Oct 1981
ZSI-12	Apr 1981-Jul 1982	16	-2.44	
CZI-12			-2.59	
MCZI-12			-2.56	
SPI-24	Dec 1980-Mar 1984	40	-2.99	Jun 1982
ZSI-24	Jul 1981-Sep 1983	27	-2.45	
CZI-24			-2.87	
MCZI-24	Jul 1981-Jun 1983	24	-2.65	

Table 6: The longest dry periods and the date of the most extreme dry period for Tokat station

Indices	The longest dry period	Duration (Month)	Value of the most extreme drought	Date
SPI-3	Jul 1974-Nov 1974 Aug 1975-Dec 1975 Aug 1982-Dec 1982 Aug 1984-Dec 1984	5	-3.97	Sep 1994
ZSI-3	Aug 1984-Dec 1984		-1.96	
CZI-3			-2.13	
MCZI-3			-2.11	
SPI-12	Jun 1973-May 1975	24	-3.13	Jun 1974
ZSI-12	Jun 1973-Mar 1975	22	-2.49	
CZI-12			-2.40	
MCZI-12			-2.44	
SPI-24	Feb 1973-Aug 1977	55	-3.76	Oct 1974
ZSI-24	Apr 1973-Sep 1976	42	-3.11	
CZI-24			-3.04	
MCZI-24			-3.01	

As seen in *Figs. 2–5* and *Tables 3–6*, according to the results of 3-month indices for Amasya, the driest month was August 2003, while June 2001was the driest month for the 12-month indices, and November 1974 for the 24-month indices (*Table 3*). For Corum, September 1991, February 2014, and July 2014 were the driest months for the 3-, 12-, and 24-month indices, respectively (*Table 4*). For Samsun, August 2001, October 1981, and June 1982 were found to be the driest months according to the results of the 3-, 12-, and 24-month indices, respectively (*Table 5*). For Tokat, the driest month was September 1994 according to the 3-month indices, June 1974 for the 12-month indices, and October 1974 for 24-months indices (*Table 6*). The driest dates indicated by different drought indices in selected time periods for each station were parallel.

As seen in *Tables 3–6*, as the time periods examined in the indices increased, the duration of droughts increased. Also, among all indices, SPI results yielded the longest droughts in all time periods. The longest dry periods were 8 months, 9 months, 7 months, and 5 months, respectively, according to the SPI-3 results for Amasya, Corum, Samsun, and Tokat; 20 months, 15 months, 27 months, and 24 months for SPI-12; and 24 months, 28 months, 40 months, and 55 months for SPI-24.

It was seen that SPI determined drought earlier than other indices used. This was evident in Samsun and Tokat for the 12-month index values and at all stations for the 24-month index values. It was seen that the fact that the SPI determined the drought earlier was a remarkable feature of the index.

The correlation matrix and scatter diagrams of the stations were also prepared to examine the agreement between the better indices. The correlation (R) matrix is given in *Tables 7–9*, and the scatter diagrams are given in *Figs. 6–9*.

Table 7. Correlation matrix of drought indices (3 months scale)

Station	Indices	ZSI-3	CZI-3	MCZI-3
Amasya	SPI-3	0.9652	0.9766	0.9766
Corum		0.9635	0.9892	0.9889
Samsun		0.9764	0.9989	0.9985
Tokat		0.9585	0.9721	0.9721

Table 8. Correlation matrix of drought indices (12 months scale)

Station	Indices	ZSI-12	CZI-12	MCZI-12
Amasya		0.9935	0.9990	0.9990
Corum	SPI-12	0.9937	0.9931	0.9931
Samsun		0.9957	0.9983	0.9983
Tokat		0.9957	0.9935	0.9935

Table 9. Correlation matrix of drought indices (24 months scale)

Station	Indices	ZSI-24	CZI-24	MCZI-24
Amasya		0.9951	0.9914	0.9933
Corum	SPI-24	0.9977	0.9997	0.9997
Samsun		0.9972	0.9997	0.9997
Tokat		0.9961	0.9950	0.9950

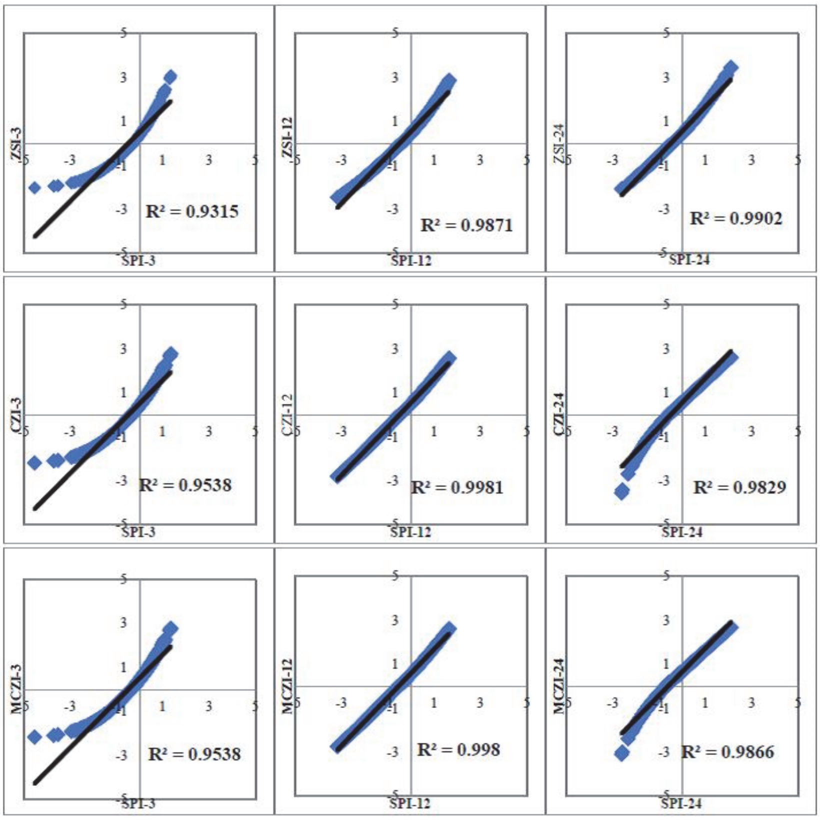

Fig. 6. Scatter diagram of Amasya station.

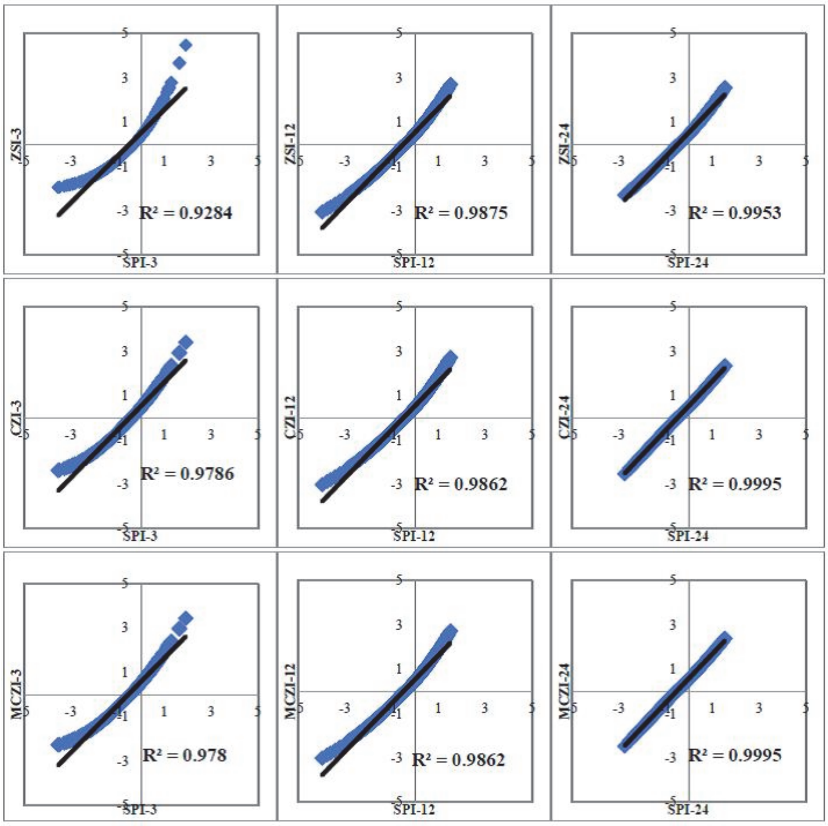

Fig. 7. Scatter diagram of Corum station.

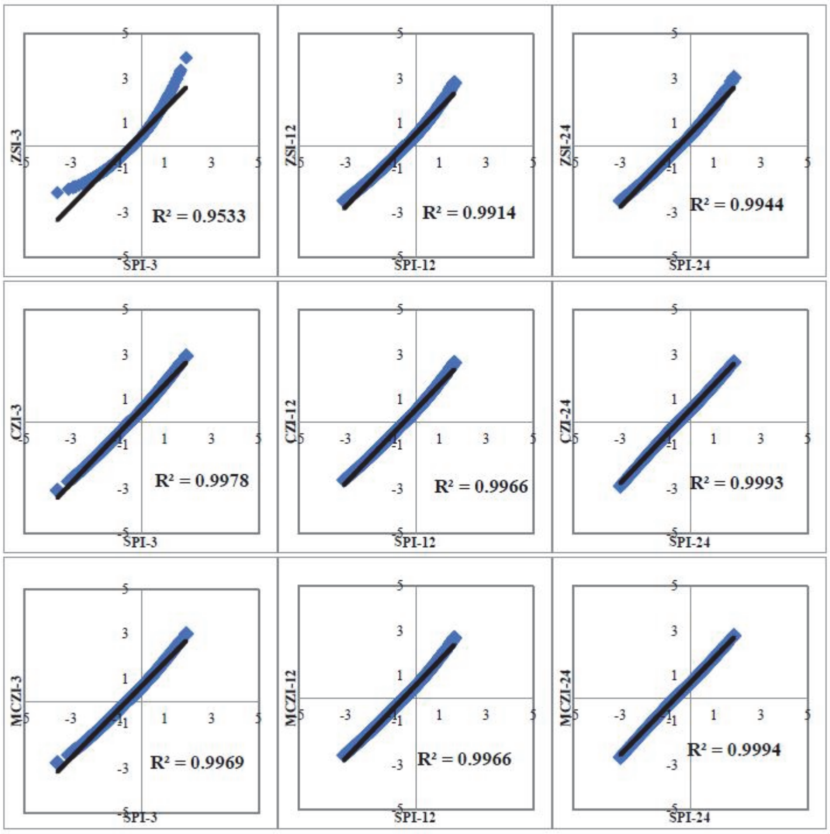

Fig. 8. Scatter diagram of Samsun station.

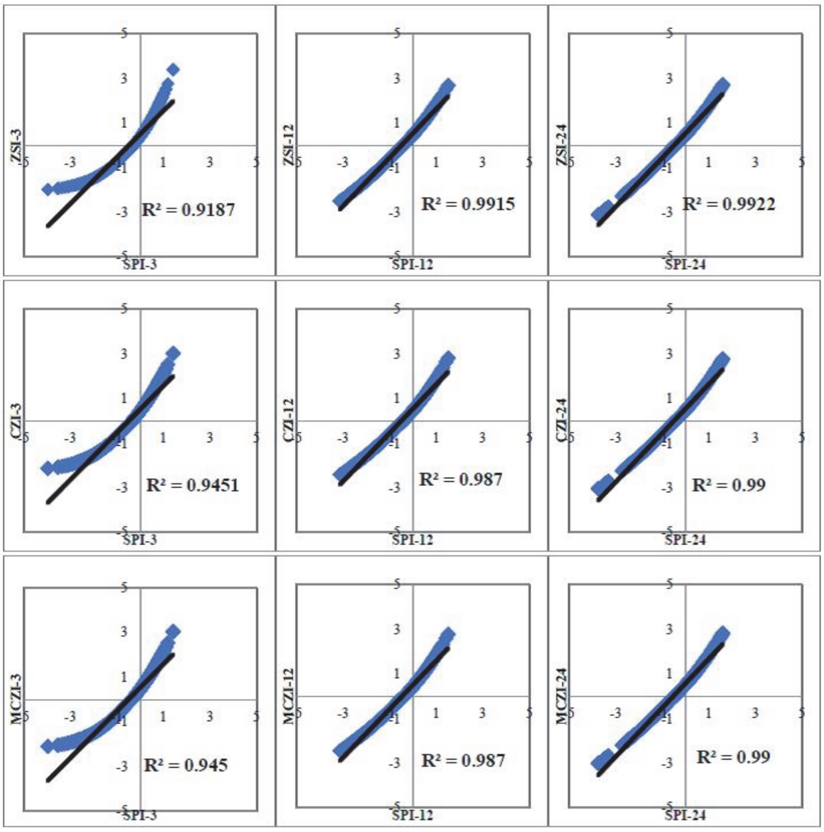

Fig. 9. Scatter diagram of Tokat station.

It was seen that the correlation values in *Tables 7–9* ranged from 0.9585-0.9997, and the indices in scatter diagrams of the stations in *Figs. 6–9* were in very good agreement with each other. The highest correlation value was found in Samsun (0.9989) between SPI-CZI for the 3-month index values, and SPI-CZI and the SPI-MCZI pairs for the 12- and 24-month index values. For the 12-month results, the correlation value of the indices for Amasya reached 0.9990; and the 24-month index values reached the highest correlation value of 0.9997 for the specified index pairs for Corum and Samsun. When the duration of the indices increased, it was found that the correlation values also increased, and the indices were more compatible with each other.

5. Conclusion

In the present study, drought analysis was made for the Yesilirmak Basin, which is one of the basins of Turkey with water potential and drought risk. The data for 4 meteorological stations selected from the basin between 1970 and 2014 were obtained from the Turkish State Meteorological Service. Four different meteorological drought indices (ZSI, CZI, MCZI, and SPI), which required precipitation data were calculated in three time scales (3-month, 12-month, and

24-month); and drought quantities (intensity, duration) were examined. Also, the relation of the indices with SPI, which was selected as the reference index, was investigated and evaluated.

As seen in time series tables and scatter diagrams, high correlation values were obtained between SPI and ZSI, and CZI and MCZI with graphs compatible with each other; and as the time intervals increased, the duration of droughts also increased in all indices. Droughts with similar intensities were detected at the same time periods for the stations included in the study. The dates of the most severe droughts were determined by four droughts indices to have a different but single date for each station and each period. Although all four indices showed similar time periods as dry periods, it was found that SPI indicated dry periods earlier than ZSI, CZI, and MCZI; and these periods lasted longer. In this way, it was concluded that SPI detected droughts earlier. These three indices, which were applied successfully to determine droughts in the Yesilirmak Basin, are recommended to be applied in detailed drought analyses that will be made in the basin as an alternative to SPI.

Drought analyses are very important for relevant ministries in basin action plans prepared separately for each basin by public institutions such as General Directorate of State Hydraulic Works (DSI) and local governments. Drought analysis will be made more realistically to show future water potentials in terms of sustainable integrated basin management.

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