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METEOROLOGICAL AND HYDROLOGICAL DROUGHT ANALYSIS OF THE KIZILIRMAK BASIN

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Abstract: Global climate variation revealing its effects intensely after the Industrial Revolution, have increased extremely with the rise in the number and variation of flood and drought problems worldwide within the years from1990 to 2000. Our country is strongly suffering from this climate variation and its undesired consequences increasing every year. Extreme temperature values, serious flood, and drought problems occuring in some regions have begun to produce considerable damages on daily human life. As a result of the decrease in the discharge of streams, the lack of freshwater resources have become a serious problem which have been considered to be solved with the derivation of fresh water resources for natural life and for other human purposes. Drought conditions of the basin were analyzed using hydrological and meteorological data of Kızılırmak Basin. Standardized precipitation index (SPI) expressing meteorological drought with rainfall parameter and streamflow drought index (SDI) expressing hydrological drought with current parameter were calculated. Droughts were observed in the basin and it was understood that these two indices give harmonious results.

Keywords: Kızılırmak basin, Drought, SPI, SDI, Climate change

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1. Introduction

As a result of the increase in the world population, urbanization, climate changes, deforestation, and desertification, drought reaches dimensions that threaten society, the environment and countries. Droughts have economic and social dimensions. It is closely related to the economy, health, psychology and trade of the society. Although drought is increasing its impact in the world, its scope has not yet been fully understood and its effects have not been adequately evaluated. As a natural consequence of this, a precise definition of drought cannot be made. The definitions made are in terms of meteorological, hydrological, agricultural, geographical or industrial, energy production, water supply, maritime and recreation areas according to occupations. (Şen, 2001). Drought in the International Convention to Combat Desertification; It is defined as a natural event that adversely affects land and resource production systems and causes serious hydrological imbalances as a result of precipitation falling significantly below the recorded normal levels (WMO, 1997).

Climate change on a global scale shows its effects locally in the form of different disasters such as floods, floods, droughts, and storms. It is known that there has been an increase in the number of natural disasters with the effect of global climate change, which has been the subject of many articles in recent years. The increase in natural disasters can also pave the way for technological disasters. At this point, it was stated that community education and resilience are important. It is seen that the increasing effect of the disasters affects the society economically and socially. In this context, regardless of the cause and type of the disaster, it is clear that it should be managed holistically, as in the modern disaster management approach (Çelik et al., 2020; Gunduz, 2022; Usta, 2023).

Priority regions affected by climate change in Türkiye, according to IPCC reports; Mediterranean, Aegean, Eastern and Central Anatolia regions. However, flood disasters in the Central Black Sea region in recent years are the biggest indicator of climate change in this region. The drought in the summer months has reached extraordinary situations such as the inability to provide water from drinking water networks in the city centers. Drought; It is a disaster that occurs less frequently than other natural disasters such as earthquakes and floods, develops slowly unlike other natural disasters, covers larger areas and threatens the lives of more living things. According to the generally accepted principles in precipitation-related climate classifications, places with an average annual precipitation of less than 250 mm are defined as arid climates, and places between 250 and 500 mm are defined as semi-arid climates. (Kömüşçü and Erkan, 2000). Knowing the number of rainy days in terms of precipitation characteristics is important in terms of drought possibilities. In most of Türkiye, the number of rainy days is low and varies between 60 and 175 days on average according to the regions. The highest values are on the strip extending along the Black Sea coast in the north of the country, and the number of rainy days in this belt reaches up to 138 and 141 in places. On the other hand, since the precipitation in the Mediterranean Region belongs to a certain period of the year, the sum of the precipitation amount and the number of rainy days is not high. In Türkiye, a significant part of Central and Eastern Anatolia falls into the semi-arid area. The number of rainy days falls below 100 in the Central Anatolia and Eastern Anatolia Regions, which constitute the semi-arid regions of Türkiye. There are no areas in Türkiye that can be considered seriously arid due to precipitation alone. However, Salt Lake and its surroundings in Central Anatolia show characteristics close to the border of being an arid region with annual precipitation of close to 300 mm (Kömüşçü et al., 2003). When the drought trends are evaluated for Türkiye, the sudden decrease in precipitation in the Sahel and the Subtropical belt that started in the 1960s began to be effective in the Eastern Mediterranean Basin and Türkiye with the 1970s. Significant decreasing trends in precipitation and drought events were more evident in the winter season. Aegean, Mediterranean, Marmara and Southeastern Anatolia Regions were affected the most by the dry conditions between the early 1970s and the early 1990s (Turkes, 1996). The most severe and widespread drought events in Türkiye; It happened in the 1971-1974 period and in 1983, 1984, 1989, 1990, 1996 and 2001. It has been observed that these drought events and water shortages, which are effective in many regions of Türkiye, have reached a critical point not only in terms of agriculture and energy, but also in terms of water resources management including irrigation, drinking water, other hydrology systems and activities. The last drought events that occurred in the period of December 2006 – August 2007 were especially effective in the Marmara, Aegean and Central Anatolian regions of Türkiye, as well as in the Western Mediterranean and Western-Central Black Sea regions (Turkes, 1996, 2007, 2017; Komuscu, 2001; Kapluhan, 2013; Akturk and Yildiz, 2018). One of the first studies on drought in Türkiye was carried out by Tanoğlu (1943) in 1943. A drought map was created by applying De Martonne's drought index to temperature and precipitation values. Erinç (1949 and 1950), using the monthly precipitation, temperature and evaporation values, the drought degree of Türkiye and arid areas were determined by Thornthwaite method. Central Anatolia Region and Iğdır Basin are described as semi-arid climate zone. Tumertekin (1956) examined the number of dry months in Türkiye with the indices he calculated according to the De Martonne and Thornwaite formulas. In another study (Tumertekin, 1957), he created a map showing the distribution of drought by using the De Martonne index. Çelenk (1973) used Erinç and Crowe's formulas and De Martonne and Thornthwaite formulas to determine drought in order to compare. Sırdaş and Şen (2003) obtained the drought amplitude, duration and severity values for different cut-off levels by using the SPI method. Operational drought monitoring for Türkiye, minimum and maximum drought magnitudes, maps were created to describe the extent of areal drought. Pamuk et al. (2004) stated that the climate of the Aegean Region has two extreme groups, between these two groups formed by Uşak, Afyon, Kütahya and Gediz, the Coastal Aegean belt is drier during the precipitation period, and the Inner West Anatolian Region is more humid; In the summer period, they reached the conclusion that the Inner West Anatolian Section is drier and the Coastal Aegean is more humid.

Drought analysis in the Kızılırmak Basin, which is the subject of this study, has also come to the fore in studies in the literature (Bacanli et al., 2011; Yildiz 2014; Oguzturk et al., 2015; Arslan et al., 2016; Beden et al., 2020; Çıtakoglu and Minarecioglu, 2021; Akturk et al., 2022). The Kızılırmak Basin was chosen as the study area in order to examine an important problem of the region and to serve the region. This study is a preliminary study that should be done in the basin regarding the drought that has started to make itself felt as a result of global climate change in recent years. Considering both precipitation and flow parameters, the necessity of considering drought not only as a lack of precipitation is discussed. In this context, it is aimed that this study will fill an important gap and contribute to the region. In terms of sustainable integrated watershed management, the future water potentials of the basin will be revealed in a more realistic way with drought analysis under the influence of climate change. Standard Precipitation İndex (SPI) and Streamflow Drought İndex (SDI) methods were used in the drought analysis of the basin.

2. Materials and Methods

2.1. Study Area

The Kızılırmak River is the longest river that originates in Türkiye and empties into the sea from Türkiye. Its length is 1355 km. Its main tributaries are Delice River, Devrez and Gökırmak. Kızılırmak, named after the color of its water and known as Halys, which means salty river in ancient times, has hosted civilizations established in Anatolia. The river originates from the southern slopes of Sivas Kızıldağ in the easternmost part of Central Anatolia, flows first to the west and southwest, and then forms an arc. It flows to the west, then to the northwest, passing the Salt Lake in the northeast. It then heads north and north east. Delice River joins and flows to the northwest by drawing zigzags. It flows with the Devrez River and turns to the Northeast. While passing through the provinces of Sivas, Kayseri, Nevşehir, Kırşehir, Kırıkkale, Ankara, Aksaray, Çankırı, Çorum and Samsun respectively, it collects the waters of many streams and streams and pours into the Black Sea from Bafra. There are eight dams on the river. These are the Yamula Dam, which was established in Sarıoğlan, Yemliha town in Kayseri, Kesikköprü, Hirfanlı and Kapulukaya dams near Ankara, and Altınkaya and Derbent dams near Bafra. The Obruk Dam was built on the river and it started to hold water in 2007. The country's surface is divided into 25 drainage basins in order to identify, develop and use water resources, which are one of the most important and non-renewable natural resources of Türkiye (Erkek and Ağıralioğlu, 1998). The map showing the basins and geographical locations is given in Figure 1.

Figure 1. Turkish hydrological basins (T.C. Orman ve Su İşleri Bakanlığı, 2015).

The Kızılırmak Basin is located in the eastern part of Central Anatolia and the Black Sea. The Kızılırmak Basin, with a total area of 78180 km^2, is the second largest basin in Türkiye. 15043 km^2 of Kızılırmak Basin is forest area. The basin accounts for 3.48% of Türkiye's average annual flow, with an average flow volume of 6.48 km^3/year. The climate in the Kızılırmak Basin, which draws a wide arc in Central Anatolia, varies greatly. Most of the springs between Kastamonu and Sivas are semi-arid; North of Kastamonu, east of Sivas and Yozgat section have arid-less humid climate. The whole basin is first degree mesothermal and is located in the zone of temperate climates closest to cold climates. Summers in the basin are dry. More than half of the precipitation falls in the winter and spring months. Precipitation distribution varies according to proximity to the sea and landform characteristics. The middle part of the basin, far from the sea, is the driest part of the basin. This place receives precipitation between 300-400 mm. The Bafra plain and the ridges and peaks of the mountains here receive 1000 mm of precipitation. On the slopes of the mountains facing Central Anatolia, precipitation falls to 500 mm. Except for the coastal part, summers are hot and winters are cold in the basin. From Bafra to the south, the temperature decreases as the altitude increases. Yozgat, Sivas and the east of the basin are the coldest parts. The average temperature here is below 10 degrees. Except for the cold eastern part and the warm northern coastline, the average annual temperature in the centers is between 10-12°C (Uçgun, 2010).

Within the scope of this study, precipitation stations located on the Kızılırmak Basin, which is a very important water resource for Türkiye, will be used. These stations are; Tomarza, Gemerek, Sivas, Cicekdagi, Keskin, Kirikkale, Bala, Kulu, Urgup, Corum, Osmancik, Tosya, Kastamonu, Ilgaz, Bafra and Sarkisla. The characteristics of precipitation observation stations are given in Table 1, and the basic statistical values of precipitation records are given in Table 2.

The flow observation stations to be studied are Yamula, Söğütlühan and Bulakbaşı in the Kızılırmak basin. The characteristics of the flow observation stations are given in Table 3, and the basic statistical values of the flow records are given in Table 4.

While determining the stations used in the study, attention was paid to the absence of any water intake structures in the measurement area and upstream. Thus, the estimated data obtained were reached in a near-accurate manner. Since Yamula dam started to hold water in 2004, flow records of Yamula for 2004 and later years were not included in the study. The locations of precipitation and flow observation stations on the basin are shown in Figure 2.

Table 1. Geographical features of precipitation observation stations.

State	Station	Period	Longitude-Latitude	Altitude(m)
Kayseri	Tomarza	1975–2010	38°45'22'' N/35°79'12'' E	1402
	Gemerek	1975 - 2014	39°18'50'' N/36°08'05'' E	1182
Sivas	Sivas	1975–2014	39°74'37'' N/37°00'20'' E	1294
	Şarkışla	1975–2009	39°33'31'' N/36°44'08'' E	1253
Kırşehir	Çiçekdağı	1975–2010	39°60'67'' N/34°42'35'' E	900
Kırıkkale	Keskin	1977–2012	39°66'82'' N/33°61'18'' E	1140
	Kırıkkale	1975–2014	39°84'33'' N/33°51'81'' E	751
Ankara	Bala	1975–2013	39°55'46'' N/33°10'89'' E	1250
Konya	Kulu	1975–2012	39°07'88'' N/33°06'57'' E	1005
Nevşehir	Ürgüp	1979–2012	38°62'18'' N/34°91'44'' E	1068
Çorum	Çorum	1975–2014	40°54'61'' N/34°93'62'' E	776
	Osmancık	1976–2012	40°97'87'' N/34°80'11'' E	419
Kastamonu	Tosya	1975–2011	41°01'32'' N/34°03'67'' E	870
	Kastamonu	1975–2013	41°37'10'' N/33°77'56'' E	800
Çankırı	Ilgaz	1975–2012	40°91'56'' N/33°62'58'' E	885
Samsun	Bafra	1975–2012	41°55'15'' N/35°92'47'' E	103

Table 2. Basic statistical information of precipitation observation stations records.

Station	Mean	Std. Dev.	Skewness	Max.	Min.
Tomarza	397.56	26.13	0.77	129.4	0
Gemerek	420.85	28.28	1.04	159.9	0
Sivas	457.84	29.24	0.80	139.2	0
Şarkışla	319.19	22.94	1.21	135.1	0
Çiçekdağı	357.19	24.34	1.23	171.1	0
Keskin	445.14	29.49	0.91	145.9	0
Kırıkkale	390.66	26.68	0.91	138.2	0
Bala	312.43	26.95	1.27	158.7	0
Nulu	450.33	38.56	2.58	312.1	0
Ürgüp	373.88	25.65	0.89	138.3	0
Çorum	446.57	29.01	1.45	220.1	0
Osmancık	380.63	23.91	1.00	124.3	0
Tosya	481.41	28.09	0.91	156.4	0
Kastamonu	496.02	31.41	1.97	278.4	0
Ilgaz	443.47	28.35	1.16	188.2	0
Bafra	797.07	45.97	1.47	343.9	0

Table 3. Geographical features of streamflow observation stations.

State	Station	Period	Longitude-Latitude	Altitude(m)
Sivas	Söğütlühan	1963 2009	39°43'59'' N/36°58'59'' E	1243
Kayseri	Yamula	1939 - 2003	38°89'02'' N//35°25'86'' E	995
Sivas	Bulakbaşı	1972-2009	39°87'80'' N//37°56'30'' E	1298

Table 4. Basic statistical information of streamflow observation stations records.

Station	Mean	SD	Skewness	Max.	Min.
Söğütlühan	1174.15	127.88	2.30	892.17	7.72
Yamula	2121.34	208.15	2.25	1295.48	14.20
Bulakbaşı	423.72	54.25	2.50	365.99	0.17

SD= standard deviation

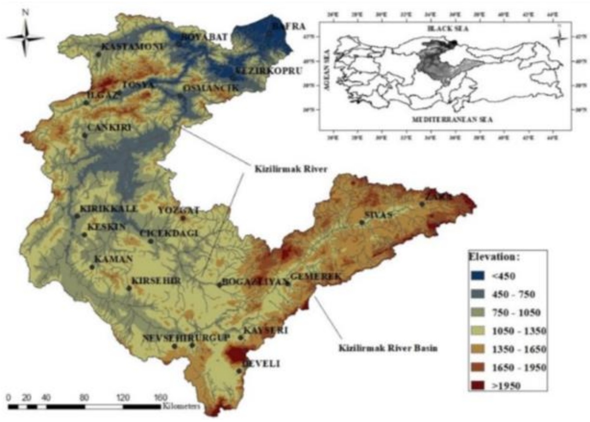

Figure 2. Study area (Akturk et al., 2022).

2.2. Standard Precipitation Index (SPI)

SPI developed by McKee et al., (1993, 1995). SPI is used for the modelling of rainfall and is obtained by dividing the difference between the precipitation and mean of precipitation in a specific period by the standard deviation (equation 1) and the SPI classes are shown in Table 5 (McKee et al., 1993). The advantages of SPI are that it quickly determines the drought months and can be calculated in different time periods (Sirdas and Sen, 2003).

$$SPI = \frac{x_J - \mu}{\sigma} \quad (1)$$

Table 5. Drought classification by SPI

SPI	Drought category	State
SPI ≥0.0	No Drought	0
-1.00 ≤ SPI < 0.00	Mild Drought	1
-1.50 < SPI ≤ -1.00	Moderately Drought	2
-2.00 < SPI ≤-1.50	Severe Drought	3
SPI ≤ -2.00	Extremely Drought	4

Thom (1958) proposed Gamma distribution for historical precipitation time series (Yacoub and Tayfur, 2020). Probability density function of Gamma distribution is defined as equation 2 (Yacoub and Tayfur, 2020);

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta}; x, \alpha, \beta > 0 \qquad (2)$$

Where x is the amount of rainfall, Γ(α) is the gamma function and α is shape, β is scale parameter. Shape and scale parameters can be estimated as equation 3 (Bacanli, 2017; Yacoub and Tayfur, 2020);

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

Here, n refers to the number of rainfall observations, with cumulative probability distribution function given below equation 1 (Bacanli, 2017);

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

Then cumulative probability function is calculated for a given period (1, 2, 6, 9, 12, 24 months). If the precipitation series have zero values, then cumulative probability becomes as follows equation 5;

$$H(x) = q + (1 - q)G(x) \qquad (5)$$

The cumulative probability value H(x) is converted into a Z variable with the standard normal random value showing the SPI with a mean value of zero and variance that equals to 1 (Abramowitz and Stegun, 1965; Yacoub and Tayfur, 2017). H(x) is the value of the SPI. Normalization of the SPI values enables the prediction of temporal and spatial variations in the precipitation series for that station (McKee et al., 1993; Guttman, 1999).

2.3. Streamflow Drought Index (SDI)

The SDI method was developed by Nalbantis (2008). It is hypothesized that a series of monthly streamflow volumes, ($Q_{i,j}$) is available, with i refering to the hydrological year and j denoting the month in that year, that is, October- September (Gumus and Algin, 2017). Based on this, cumulative volumes are shown in equation 6;

$$V_{i,k} = \int_{j=1}^{3k} Q_{i,j}\, ; i = 1,2, \ldots ,12; k = 1,2,3,4 \qquad (6)$$

Here, $V_{i,k}$ refers to the cumulative streamflow volume of ith hydrological year, and Nth reference period (Nalbantis, 2008; Nalbantis and Tsakiris, 2009). Based on the cumulative streamflow volumes, $V_{i,k}$, the SDI is defined for the ith hydrological year, as follows equation 7;

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V_k}}{S_k}; i = 1,2, \ldots, k; k = 1,2,3,4 \qquad (7)$$

From the mean (V_k), and standard deviation (S_k), of the cumulative stream flow volume, the SDI for Nth reference period within ith hydrological year can be calculated via Equation 7, with the truncation level set at V_k, although other values can be used.

The SDI has five categories ranging between extreme wet and extreme drought, as given in Table 6 (Nalbantis, 2008).

Table 6. Drought classification by SDI

State	Drought category	SDI
0	No Drought	SDI ≥ 0.00
1	Mild Drought	-1.00 ≤ SDI < 0.00
2	Moderately Drought	-1.50 ≤ SDI < -1.00
3	Severe Drought	-2.00 ≤ SDI < -1.50
4	Extremely Drought	SDI < -2.00

3. Results and Discussion

3.1. SPI Results

In this study, SPI analysis was performed for the determination of meteorological drought in the Kızılırmak Basin. SPI values were calculated for each station and graphics were prepared. Since the graphics of all stations used take up too much space, the results of 3, 6, 12 and 24 SPI of Tomarza are given in Figure 3 as an example.

When the graphs are examined, it is seen that the most severe droughts are seen in the 3 and 6-month time series, while the drought Intensities are relatively less in the 12-month time series, but the dry periods are intense. Serious droughts were not observed in the 24-month time series, and the number of these droughts, which are seen as mild severe, is less than in other time series. As it can be understood from here, droughts are observed in almost every time series, even if the severity is classified according to the time series in places where drought is seen. Whether the time series is short or long period does not generally change whether drought is seen or not, but it causes the severity to be described as mild in long periods. When the SPI graphs of the other stations given in Annex-1 are examined, similar results are seen. While the SPI values vary between 0 and -3 in the 3, 6 and 12 month periods, they vary between 0 and -1 in the 24 month period. The most intense periods of drought in the basin are between 1982-1987, 1990-1997 and 2000-2008.

Table 7 gives information about the longest drought periods seen at precipitation stations. According to the table, the longest period when the SPI value fell below 0 was chosen as the maximum drought period, the sum of the SPI values in the longest period represents the degree of drought, the maximum drought severity is the minimum value of the SPI values of the time period, the drought frequency is the number of drought recurrences in the time series.

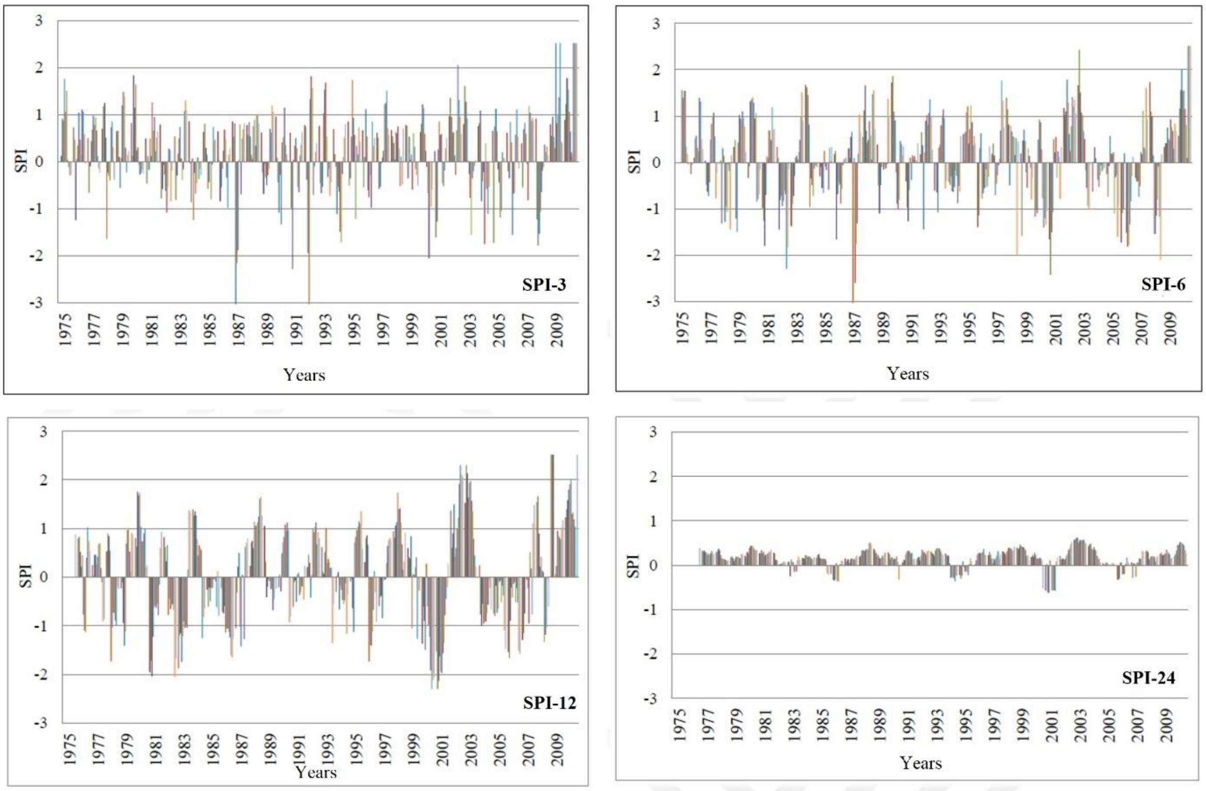

Figure 3. Temporal distribution of SPI results for Tomarza.

Table 7. Maximum drought periods for precipitation stations

Station	P	F	D	LDP	MED	DE
Bafra	3	65	13	1984/10-1985/09	-2.83	-11.82
	6	38	17	2006/07-2007/11	-2.60	-16.03
	12	25	39	2005/12-2008/11	-2.66	-26.99
	24	15	9	1982/05-1983/01	-0.49	-1.65
Bala	3	35	13	1986/03-1987/03	-4.12	-22.71
	6	22	22	2001/02-2002/11	-5.46	-11.71
	12	25	26	1988/10-1990/11	-3.68	-27.39
	24	5	62	1986/03-1991/04	-1.38	-33.13
Çiçekdağı	3	61	12	1994/04-1995/03	-3.13	-10.77
	6	34	26	1981/08-1983/09	-3.07	-21.83
	12	26	28	2006/05-2008/08	-2.42	-17.62
	24	13	12	2008/01-2008/12	-0.51	-4.31
Çorum	3	64	8	1976/03-1976/10	-2.75	-9.25
	6	41	16	1993/08-1994/11	-2.90	-11.50
	12	30	27	2006/11-2009/01	-2.29	-30.07
	24	12	22	1994/06-1996/03	-0.64	-1.45

P= period, F= frequency, D= duration (Month), LDP= longest dry period, MED= most extreme drought, DE= degree

Table 7. Maximum drought periods for precipitation stations (continuing)

Station	P	F	D	LDP	MED	DE
Gemerek	3	65	12	2002/11-2003/10	-3.08	-12.34
	6	44	16	1994/05-1995/08	-3.23	-7.54
	12	31	19	1994/04-1994/10	-3.35	-3.64
	24	9	12	1994/11-1995/10	-0.41	-2.22
Ilgaz	3	55	13	1975/09-1976/09	-2.25	-9.10
	6	38	30	2006/03-2008/08	-2.36	-18.88
	12	22	34	2006/04-2009/01	-2.41	-33.55
	24	15	23	2007/03-2009/01	-0.78	-9.72
Kastamonu	3	70	11	2007/02-2007/12	-2.66	-12.71
	6	42	31	1975/06-1977/12	-2.78	-18.64
	12	27	29	2006/04-2008/08	-2.85	-39.80
	24	14	23	1994/06-1996/04	-0.92	-1.51
Keskin	3	63	9	1994/02-1994/10	-4.99	-9.05
	6	30	41	1991/11-1995/03	-2.55	-31.83
	12	16	47	1992/04-1996/02	-2.14	-31.89
	24	10	35	1992/12-1995/10	-0.47	-6.09

P= period, F= frequency, D= duration (Month), LDP= longest dry period, MED= most extreme drought, DE= degree

Table 7. Maximum drought periods for precipitation stations (continuing)

Station	P	F	D	LDP	MED	DE
Kırıkkale	3	67	8	1979/03-1979/10	-3.14	-6.23
	6	45	21	1993/06-1995/02	-2.57	-10.38
	12	24	61	1992/04-1997/04	-2.55	-69.13
	24	20	52	1992/09-1996/12	-0.77	-14.02
Kulu	3	48	8	1989/02-1989/09	-5.43	-3.79
	6	40	9	2004/02-2004/10	-5.59	-4.58
	12	23	60	2004/04-2009/03	-3.33	-36.54
	24	18	62	2005/04-2010/05	-0.93	-9.14
Osmancık	3	65	11	1986/02-1986/12	-3.73	-7.27
	6	32	25	2006/12-2008/12	-2.38	-25.68
	12	23	39	1976/12-1980/02	-2.06	-15.15
	24	12	15	1994/06-1995/08	-0.77	-2.66
Sivas	3	67	11	1984/02-1984/12	-1.90	-7.10
	6	43	13	1993/11-1994/11	-2.74	-7.12
	12	26	14	2004/03-2005/04	-0.29	-2.86
	24	8	1	1979/12-1979/12	-0.35	-0.35
Tomarza	3	58	7	2008/02-2008/08	-3.05	-6.54
	6	38	14	1982/03-1983/04	-3.69	-13.64
	12	24	42	2004/02-2007/07	-2.30	-27.98
	24	17	10	1994/06-1995/03	-0.36	-2.70
Tosya	3	69	11	2007/02-2007/12	-2.39	-13.86
	6	38	25	2006/12-2008/12	-2.56	-33.75
	12	24	41	1992/02-1995/06	-2.60	-34.66
	24	13	24	2007/03-2009/02	-0.89	-12.45
Ürgüp	3	52	6	1984/07-1984/12	-3.56	-2.40
	6	32	18	2003/03-2004/08	-2.06	-6.93
	12	25	25	2003/07-2006/05	-2.48	-19.96
	24	12	23	2004/07-2006/05	-0.71	-1.68
Şarkışla	3	51	11	1994/02-1994/12	-2.96	-7.63
	6	34	31	1993/01-1995/07	-2.82	-25.79
	12	22	47	1920/04-1996/02	-3.63	-60.73
	24	7	38	1993/04-1996/05	-0.76	-10.08

P= period, F= frequency, D= duration (Month), LDP= longest dry period, MED= most extreme drought, DE= degree

When Table 7 is examined, it is understood that generally the longest and most severe drought periods are observed in the 12-month time period. Since 3-month periods express seasonality and are a relatively short period of time, and 24-month periods are a rather long period of time, they will reflect relatively less drought severity and droughts less frequently; values were found to be more decisive.

Considering the need for agricultural water, the development of plants, periods of intense water consumption, the construction of water structures and the measures to be taNen regarding drought, it is also important to determine the seasonal drought situation. It is possible to examine the seasonal distributions of droughts by looking at the results of the 3-month SPI assessment. As an example, seasonal SPI graphs for Tomarza station are shown in Figure 4. Seasonal drought distributions of other stations are given in Table 8.

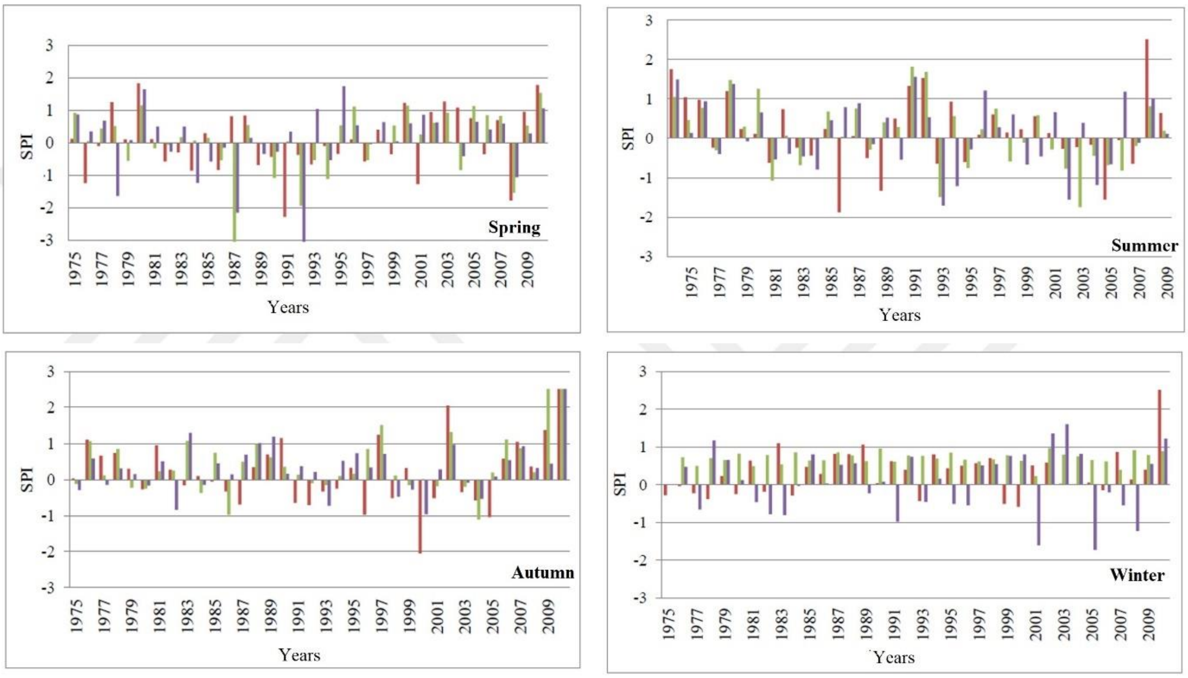

Fıgure 4. Temporal distribution of seasonal drought distributions for Tomarza.

Table 8. Seasonal distributions of droughts for precipitation stations

	State	Tomarza	Gemerek	Sivas	Şarkışla	Çiçekdağı	Keskin	Kırıkkale	Bala	Kulu	Ürgüp	Çorum	Osmancık	Tosya	Kastamonu	Ilgaz	Bafra
	4	0	0	1	1	1	1	1	3	0	1	2	3	2	2	0	4
W	3	2	3	2	2	5	3	0	1	0	0	7	4	6	4	0	3
	2	1	6	4	9	6	7	5	0	0	5	6	7	7	7	1	5
	4	4	3	2	1	1	5	0	2	3	0	3	2	1	1	0	0
Sp	3	4	5	7	7	3	4	2	0	0	1	5	5	6	5	2	5
	2	6	15	17	14	8	12	9	0	4	2	8	7	11	13	14	13
	4	0	2	3	2	5	2	2	3	2	0	5	3	3	2	1	4
S	3	5	6	3	3	1	4	5	0	1	0	2	3	6	4	2	10
	2	5	15	15	7	9	5	13	2	3	3	7	13	13	7	9	11
	4	1	5	4	2	3	3	1	2	3	2	3	3	2	4	1	2
A	3	0	3	4	3	4	5	5	0	1	0	4	5	7	6	2	7
	2	2	7	8	4	7	15	6	4	0	5	10	13	17	8	5	11

W= winter, Sp= spring, S= summer, A= autumn

When the Figure 4 and Table 8 are examined, it is seen that the droughts are more and more severe in the spring period compared to the other seasons, and the observed drought numbers and severity decrease as the summer, autumn and winter seasons go, respectively. When Table 8 examined, the most drought was observed in the spring season at Tomarza, Gemerek, Sivas, Sarkisla, Kulu, Kastamonu, Ilgaz. The most drought was observed in the autumn season at Keskin, Bala, Ürgüp, Çorum Osmancık and Tosya. The most drought was observed in the summer season at Çiçekdağı, Gemerek, Kırıkkale and Bafra. Although the season in which the most drought is seen differs according to the stations, the most drought in the basin was observed in the spring, summer, autumn and winter seasons, respectively.

3.2. SDI Results

According to the hydrologic drought assessment made according to the SDI; Droughts were observed in each of the different periods (3, 6, 9, 12 months) for all three stations. In Table 9, information on the longest drought periods seen at flow stations is given. According to the table, the longest period when the SDI value fell below 0 was chosen as the maximum drought period.

Table 9. Maximum drought periods for streamflow stations

Station	P	F	D	LDP	MED	DE
Söğütlühan	3	48	10	2001/6-2002/3	-0.86	-5.93
	6	42	20	1972/10-1974/5	-1.22	-13.7
	12	16	94	2001/4-2009/1	-1.92	-92.58
	24	7	110	2000/8-2009/9	-1.93	-118.90
Yamula	3	66	20	2000/8-2002/3	-0.95	-12.83
	6	58	29	1972/11-1975/3	-1.30	-21.19
	12	20	94	1955/4-1963/1	-2.14	-71.47
	24	15	56	1956/3-1963/4	-2.18	-83.01
Bulakbaşı	3	39	10	1994/6-1995/3	-0.82	-5.96
	6	34	19	2000/10-2002/4	-1.20	-14.26
	12	21	60	2001/4-2006/3	-2.11	-3.76
	24	10	62	2001/3-2006/4	-2.16	-73.34

P= period, F= frequency, D= duration (Month), LDP= longest dry period, MED= most extreme drought, DE= degree.

Contrary to the results of the SPI, the SDI shows that the severity and duration of droughts increase over long time periods. In both indices, drought frequency observed in long time periods decreased compared to short time periods. The longest and most severe droughts were seen after 2000 and the periods of maximum drought were similar to the SPI. Figure 5 shows the change curves of the SDI of all three flow stations over the 3, 6, 9 and 12 month periods.

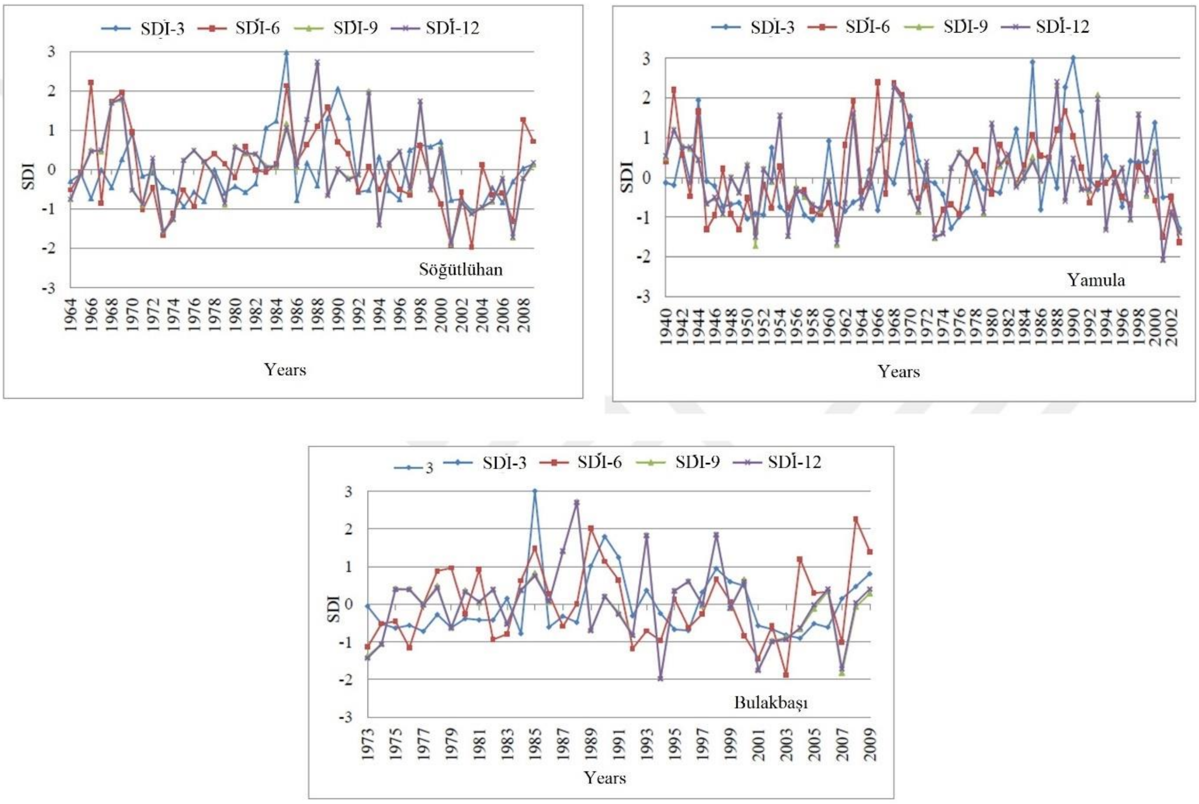

Figure 5. Temporal distribution of SDI results for streamflow stations.

3.3. Combined Evaluation of SPI and SDI Results

In order to understand whether hydrological drought is also seen during periods of meteorological drought and whether these two indices are compatible with each other, the equi-period results of SPI and SDI indices of precipitation and flow observation stations located close to each other were compared.

Sivas (rainfall) and bulakbaşı (flow) were evaluated together. According to SPI, the maximum droughts seen in Sivas are given in Table 8. The change graph of Bulakbaşı's SDI in various time periods is given in Figure 5. According to the SPI results, the average Severity of the drought, which started in the 2nd month of 1984 and lasted for 11 months in a 3-month period, was calculated as -0.66 and was graded as mild drought. Looking at the SDI results for the same time period in similar years, a mild drought that started in the 9th month of 1983 and ended in the 2nd month of 1984, with an average severity of -0.69, was observed for 7 months. There was no drought until the 8th month of 1984, and another mild drought that lasted 4 months with an average severity of -0.48 was seen between the 8th and 11th months of 1984. In the 6-month time period of SPI, the average Severity of the drought, which started in the 11th month of 1993 and lasted for 13 months, was calculated as -0.55 and was characterized as mild drought. When similar years are examined in the 6-month time period of SDI, a drought with an average severity of -0.96 was observed that started in the 10th month of 1992 and continued until the 4th month of 1993, and then another drought that started in the 11th month of 1993 and ended in the 3rd month of 1995. A drought was observed and its average Severity was calculated as -0.84. According to SPI, for the 14-month drought, which started in the 3rd month of 2004 and ended in the 4th month of 2005 and whose severity was calculated as -0.20 in a 12-month period, when the SDI was analyzed in the same time period and similar years, it was observed that the drought started in the 4th month of 2001 and ended in the 4th month of 2006. There was a drought lasting for 60 months, with an average Severity of -0.90, which lasted until the month of May.

Sarkisla (rainfall) and Söğütlühan (flow) were evaluated together. The maximum droughts seen in Sarkisla are given in Table 8. The graph of the change of SDI of Söğütlühan in various time periods is given in Figure 5. According to SPI, the maximum drought in the 3-month period started in the 2nd month of 1994 and lasted for 11 months. When we look at the results of the 3-month period of SDI, the drought that started in the 8th month of 1993 continued until the 4th month of 1994, and there was no drought for the next 2 months, and the drought continued from the 6th month of 1994 to the 3rd month of 1995. During this drought, the average drought Intensity according to SDI was calculated as -0.59, which is in line with the SPI of -0.69 average drought Intensity, and both are characterized as mild droughts. According to the 6-month SPI results, the drought, which started in the 1st month of 1993 and continued for 31 months and ended in the 7th month of 1995, started in the 11th month of 1993 according to the 6-month SDI and continued until the 3rd month of 1995, lasting 17 months and the average drought intensity was calculated as -0.70. The average drought Intensity according to SPI is -0.83, and both indices indicate mild drought during this drought. In the 12-month SPI results, the average Severity of the maximum drought starting in the 4th month of 1992 and continuing for 47 months until the 2nd month of 1996 is -1.29 and moderately dry. When the periods of the SDI results covering this period are examined, there was a drought that started in the 10th month of 1990 and continued until the second month of 1993, lasted for 29 months and the average drought severity was calculated as -0.23. There was no drought until the 4th month of 1994, a new drought was seen in the period from the 4th month of 1994 to the 5th month of 1995 and its average severity was calculated as -1.23. This drought, which lasted for 13 months, was described as moderate drought. In the 3rd month of 1996, a one-month drought of -0.06 intensity was observed and no other drought was observed until the 3rd month of 1997.

Tomarza (precipitation) and Yamula (flow) were evaluated together. The maximum droughts seen in Tomarza are given in Table 8. The change graph of Yamula's SDI in various time periods is given in Figure 5. According to SPI, the maximum drought in the 3-month period was in 2008, and in the 12-month period between 2004 and 2007, however, the SDI was not calculated in 2004 and following years due to the impoundment of the Yamula dam in 2004. According to the 6-month SPI results, the maximum drought started in the 3rd month of 1982 and ended in the 4th month of 1983. The average Severity of this drought, which lasted for 14 months, was calculated as -0.97, rated as mild drought. When the SDI results in the same period and time period are examined, the drought that started in the 10th month of 1982 continued until the 4th month of 1983, and the average severity of the drought lasting for this 6 months was calculated as -0.64, and it was described as a mild drought. Then another drought started in the 9th month of 1983 and continued until the 4th month of 1984. The average severity of this drought, which lasted for 6 months, was calculated as -0.77 and was described as mild drought.

In summary; Considering the results of SDI, although the duration and severity of droughts are relatively less compared to SPI, hydrological droughts in Sivas and Bulakbaşı were more severe and longer lasting than meteorological droughts. In SPI, the Severity and duration of droughts decrease as the duration of the examined time period increases, while the Severity and duration of droughts in SDI can increase with the increase of the examined time period. Hydrological drought was also observed in the periods when meteorological drought was observed in the compared flow and precipitation stations. It has been noticed that hydrological drought is seen intermittently in the time periods where the meteorological drought continues uninterrupted, and the drought start and end times of both indices are close to each other even though they are not exactly the same. Although the hydrological drought sometimes started before the meteorological drought, sometimes later and continued intermittently, the time periods in which the droughts are seen cover each other. Considering that the SDI is based on the water year, unlike the SPI, it is reasonable that the drought start and end times are not exactly the same. As can be understood from here, meteorological and hydrological drought indices give results that are compatible with each other and the effects of meteorological drought can be seen more in a short time.

4. Conclusion

In this study conducted for the Kızılırmak basin, the drought situation was analyzed in terms of hydrological and meteorological. The SPI for meteorological drought was calculated at 3, 6, 12 and 24 month periods. When the SPI results were examined throughout the basin, it was understood that the most severe droughts were seen in the periods of 3 and 6 months, while the drought intensities were relatively less frequent in the 12-month periods. There was generally very little drought in 24-month periods, and all droughts were classified as mild droughts. As the time period examined according to the SPI got longer, the severity and intensity of the drought decreased. By looking at the 3-month time periods of the SPI, seasonal droughts in the basin were examined and it was seen that the most droughts in the basin were experienced in spring, summer, autumn and winter, respectively.

SDI expressing hydrological drought was calculated in 3, 6, 9 and 12 month periods. In the examined time intervals, the greatest droughts were seen in 2000 and later years. Contrary to the SPI results, the severity and duration of drought increased over long time periods in the SDI.

During periods of maximum meteorological drought, hydrological drought was also observed. A meteorological drought that continues uninterrupted for a long time is intermittent in terms of hydrological drought, and the start-end times of the drought are not exactly the same, but the time periods in which the droughts occur are of a nature that covers each other.

Drought is a disaster that starts as a meteorological drought, develops as an agricultural, hydrological drought and continues as a socio-economic drought. The effects of drought are felt the most when the demand for water is the highest and crisis management is carried out during these periods, but since our country has a semi-arid climate, risk management should be done regularly instead of crisis management, and measures related to drought should be taken and these measures should always be developed. The climate of water basins and their surroundings should be monitored regularly.

The measures to be taken in the fight against drought can be listed as follows;

In regions where drought risk is high, the number of meteorological and hydrological stations should be increased and regular measurements should be made. By determining the total water deficiency, water transfers between basins should be made from regions with excess water to regions with water scarcity. With short and long-term forecasts, the amount of water in the water reservoirs should be determined continuously and the available water should be used in a planned way.

The unconscious use of pesticides and fertilizers, low irrigation efficiency or excessive irrigation reduce the existing water quality and quantity. Trainings should be given in schools, institutions and community centers on water conservation and the rational use of water resources, and drought awareness should be created in the society.

As a result of global climate change, drought in the basin is expected to increase even more in the future. In line with this expectation, it is important to identify risks and hazards, take all necessary precautions, take responsibility for disasters and to raise awareness in order to prevent and reduce damages within the scope of the modern disaster management approach.

Water is of great importance for our country in terms of agriculture and energy. Many water structures have been established to be used in irrigation and energy production and investments are still being made in this regard. It is possible for water structures to serve their purpose and to maintain the profitability of investments only if sufficient precipitation falls.

Although it is very important to find the meteorological and hydrological records in the past in order to carry out scientific studies, the measurements; the fact that it is recorded uninterruptedly, simultaneously and for many years has the feature of being data that can be used in scientific studies. In order to shed light on current and future studies, the stations recording the events in nature should be positioned in a way that best reflects the reality and should be capable of making accurate, regular and uninterrupted measurements.

Author Contributions

The percentage of the author(s) contributions is present below. All authors reviewed and approved final version of the manuscript.

	A.U.K.	D.S.O.	U.Z.
C	40	30	30
D	40	30	30
S	40	30	30
DCP	40	35	25
DAI	30	40	30
L	30	40	30
W	30	40	30
CR	40	20	40
SR	30	30	40
PM	40	35	25

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for this study because of there was no study on animals or humans.

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