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Araştırma Makalesi / Research Article

Meteorological and Hydrological Drought Assessment in Ankara Province

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Abstract

In recent years, the effects of global warming have been felt more and more each day. Considering the climate zone in which our country is located, the issue of drought becomes critical. Therefore, it is important to be able to analyze the components of drought and determine their effects on water resources. In this study, it was aimed to determine the relationship between the two drought types by determining meteorological and hydrological droughts for Ankara province. For this purpose, meteorological droughts of 1, 3, 6 and 12 months were determined using the Standard Precipitation Index (SPI) and precipitation data. Then, hydrological drought was determined by the Streamflow Drought Index (SDI) using the total flow rates coming to the dams in Ankara province. The relationship between meteorological and hydrological droughts was both interpreted by examining the analysis results and determined by determining the correlation coefficients. It has been determined that hydrological drought follows meteorological drought by an average of 1-3 months. For both types of drought, a severe drought danger is not expected in the studied region.

Anahtar kelimeler: *Drought Analysis, Hydrological Drought, Meteorological Drought*
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Ankara İlinde Meteorolojik ve Hidrolojik Kuraklık Değerlendirmesi

Öz

Son yıllarda küresel ısınmanın etkileri gün geçtikçe daha fazla hissedilmektedir. Ülkemizin yer aldığı iklim kuşağı da düşünüldüğünde kuraklık konusu kritik hale gelmektedir. Bu nedenle kuraklığın bileşenlerini analiz edebilmek ve su kaynakları üzerindeki etkilerini belirleyebilmek önemlidir. Bu çalışmada Ankara ili için meteorolojik ve hidrolojik kuraklıklar tespit edilerek iki kuraklık türü arasındaki ilişkinin belirlenmesi amaçlanmıştır. Bunun için, Standart Yağış İndeksi (SYİ) ile yağış verileri kullanılarak 1, 3, 6 ve 12 aylık meteorolojik kuraklıklar tespit edilmiştir. Daha sonra Ankara ilindeki barajlara gelen toplam debiler kullanılarak Akım Kuraklık İndeksi (AKİ) ile de hidrolojik kuraklık belirlenmiştir. Meteorolojik ve hidrolojik kuraklıklar arasındaki ilişki hem analiz sonuçları incelenerek yorumlanmış hem de korelasyon katsayıları belirlenerek tespit edilmiştir. Hidrolojik kuraklığın meteorolojik kuraklığı ortalama 1-3 ay kadar geriden takip ettiği tespit edilmiştir. Her iki kuraklık türü için de çalışılan bölgede şiddetli bir kuraklık tehlikesi beklenmemektedir.

Keywords: *Kuraklık Analizi, Hidrolojik Kuraklık, Meteorolojik Kuraklık*

1. Introduction

In recent years, the negative effects of climate change are one of the major problems faced by our world and our country. Drought is one of the most important events caused by global climate change. In its most general definition, drought; It is the presence of less water than needed in a region or less than the average amount of water in the region. The emergence of extreme temperatures and decreasing precipitation, population growth and increased water use pose a major problem for living things, regardless of the severity and duration of the drought (Menteşe & Akbulut, 2023). Since Turkey is located in a semi-arid region in the world, the danger of drought is one of the important problems of our country. For this reason, basic parameters such as severity, time and duration of drought need to be known. For this purpose, many researchers in our country and around the world have conducted studies on drought (Deniz Öztürk & Ünlü, 2022; Wable et al., 2019; Wu et al., 2021).

Although there are many parameters related to drought, the most basic factor affecting drought is lack of precipitation. Drought types are classified according to the nature of the data used in drought analysis. According to current drought classifications, the most general types of drought are meteorological, hydrological and agricultural drought. The majority of research has concentrated on examining only meteorological or hydrological droughts among drought types (Moccia et al., 2022; Wang et al., 2022). Varol and Ulusoy (2023) determined meteorological droughts by calculating the precipitation data and SPI values of Isparta and Antalya stations for the Karacaören dams in the Antalya basin. They found that the drought analysis results of the two stations were similar to each other. Additionally, by examining the SPI data and the volume and level changes of the dam lake, they stated that the drought analysis results were compatible with the level and volume values of the dam lake. Evci and Kuş Şahin (2021) conducted SPI analysis for 1, 3, 6, 12 and 24 month time intervals in the Salda lake basin for the years 1981-2019. When SPI values were examined, it was determined that the longest droughts, in which mild drought prevailed in the region, occurred between 1989 and 1995. Menteşe and Akbulut (2023) applied drought analysis to the precipitation data of Bilecik and Bozüyük stations between 1964 and 2021. It has been determined that droughts occur in both summer and winter seasons at both stations, but there is no serious danger of drought. Turhan et al. (2022) interpreted the drought by determining SDI values at 3 different stations in the Arsuz Plain for the years 1990-2015. Tuğrul and Hınıs (2022) determined NYI values to determine hydrological drought around Konya Apa Dam for the years 1955-2020 and found evidence of extreme drought in the results. Keskiner and Şimşek (2023) made meteorological drought analysis for Isparta, Eğirdir and Seydişehir stations. It is predicted that Seydişehir station may be exposed to severe droughts compared to other stations.

Since meteorological drought directly affects hydrological and agricultural drought, it is also important to determine the relationship between them. For this reason, many researchers have carried out studies that consider drought types together and examine the relationship between them (Li et al., 2022; Lin et al., 2023; Minh et al., 2024; Sarwar et al., 2022). Aktürk and Yıldız (2018) examined the effects of droughts caused by lack of rainfall in the Çatalan dam basin on river flow, reservoir volume and ground moisture. Özgün et al. (2020) analyzed the precipitation data of Bursa province for the years 1982-2013 with SPI and compared the drought with the flow rate data of Doğancı Dam. In their results, correlation analysis of drought analysis and dam discharge was performed and it was seen that the relationship was positive. As a result of the correlation analysis, they determined that the effect of precipitation in one month is greatest in the next two months. Yılmaz and Yılmaz (2022) made drought analysis for Kırklareli province with the Multivariate Drought Index Method (ÇDKİ). In their studies, they used the variables of monthly total precipitation, monthly average flow, monthly average temperature, monthly average relative humidity and monthly number of rainy days. They compared the ÇDKİ results with SPI and SDI and determined that the ÇDKİ results provide a more comprehensive analysis. Çetin and Kumanlıoğlu (2023) analyzed meteorological drought with SPI and SPEI and hydrological drought with SRI in the Medar basin. They predicted that there would be a severe drought in the basin in the future.

In this study, firstly, hydrological drought analysis was carried out with SPI using precipitation data from Ankara province. Then, the total flow amounts to 8 dams in Ankara were calculated. Using these data, hydrological drought analysis was performed with SDI. Time scales of 1, 3, 6 and 12 months were used in both SPI and SDI analyses. The study also aimed to reveal the relationship between hydrological and meteorological droughts. For this purpose, whether the index values affect each other on the same time scales was examined with the help of correlation analysis. According to the results obtained, it has been determined that droughts are observed from time to time in Ankara province, but there is no danger of severe drought hydrologically and meteorologically. It was determined that the relationship between meteorological and hydrological droughts was positive and moderate.

2. Data and Methods

2.1 Study area and data

Ankara, located in the center of Turkey, was chosen as the study area. For SPI, General Directorate of Meteorology Ankara station number 17130 data was used. The location information of the station is 39°58'21" N and 32°51'49" E. 1991-2023 water year data was used. The data provided for SDI was obtained from the tables of water amounts coming to the dams published by the General Directorate of Ankara Water and Sewerage Administration. The dams in question are Çubuk II, Kızılırmak-

Kesikköprü, Kurtboğazı, Çamlıdere, Eğrekkaya, Akyar, Kavşakkaya and Elmadağ-Kargalı dams. The dam locations and the location of the rainfall station are shown in Figure 1. The graph of the annual total precipitation and the amount of water coming to the dams is given in Figure 2. Statistical parameter information for the data used in the study is available in Table 1.

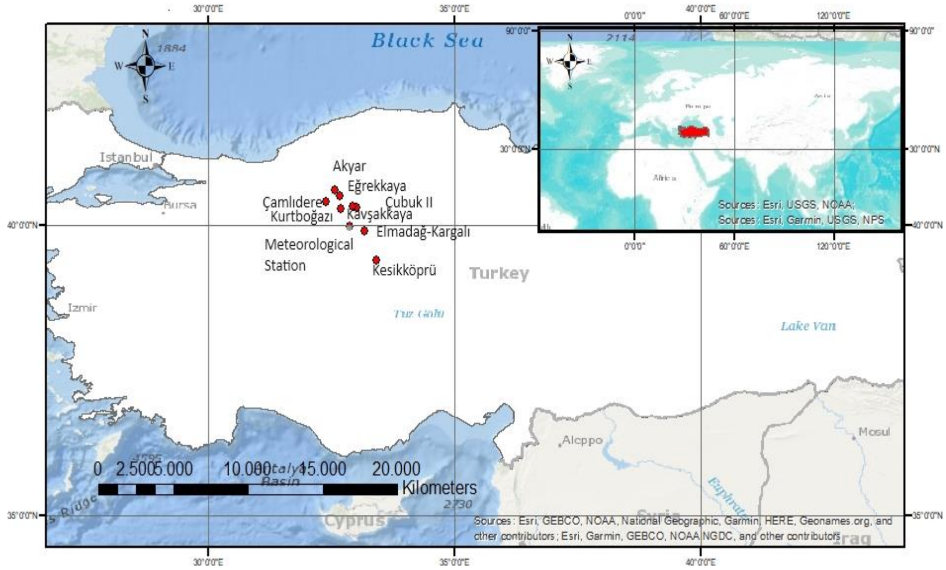

Figure 1. Map of meteorological stations and dams

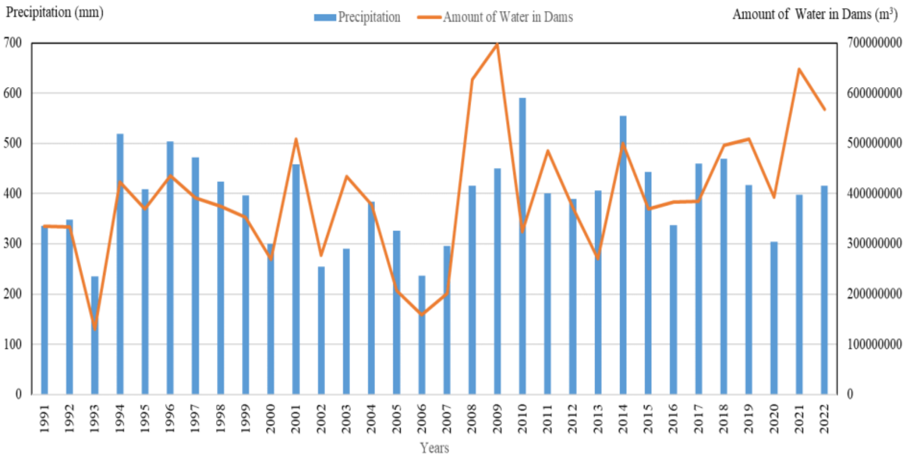

Figure 2. Graph of rainfall and water amount in dams

Table 1. Statistical parameters of the data used in the study

		Aut	Win	Spr	Sum	Yearly
Precipitation Data	Min	0,00	1,30	1,60	0,00	237,40
	Max	167,60	116,90	110,00	133,70	604,60
	Mean	27,87	38,87	47,05	24,58	415,11
	Standart Deviation	25,20	23,02	26,26	28,89	90,23
	Skewness	2,10	0,67	0,40	1,94	-0,18
	Kurtosis	8,70	0,49	-0,72	3,91	-0,34
Streamflow Data	Min(10^6)	1,00	1,32	8,57	0,88	128,86
	Max(10^6)	70,75	260,87	249,10	100,52	697,06
	Mean(10^6)	5,89	35,39	78,32	11,78	390,38
	Standart Deviation	7,67	39,06	53,36	16,91	134,65
	Skewness	6,70	2,63	0,76	3,24	0,26

2.2 Standart precipitation index

Although there are many factors in determining drought in a region, the most basic factor affecting drought is rainfall. For this reason, the majority of the many methods used to determine drought are based on rainfall conditions. The standard precipitation index was developed by McKee and colleagues (1993) to define and track drought. The standard precipitation index method is one of the most frequently used methods in examining meteorological drought events (Türkeş, 2012). DPI is calculated by dividing the difference of precipitation from the average within the specified time period by the standard deviation (Equation 1).

$$SPI = \frac{X_i - X_i^-}{\sigma} \quad (1)$$

SPI is the standard precipitation index, X_i is the precipitation amount, X_i^- is the precipitation average and σ is the standard deviation. SPI evaluates the rainfall data based on the probability distribution using the gamma function. Since the precipitation data does not follow a normal distribution on a small scale, its statistical distribution is converted to a normal distribution and then the normalized data is used. (Thom, 1958; McKee et al., 1995). The gamma function is calculated with equation (2).

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(a)} x^{a-1} e^{\frac{x}{\beta}} \quad (2)$$

a defines the shape variable (a >0), β the scale variable (β >0), x defines the amount of precipitation ($x > 0$) and $\Gamma(a)$ defines the gamma function. Maximum likelihood solutions are used to estimate a and β (Equation 3), (Equation 4) and (Equation 5).

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (3)$$

$$\beta = \frac{\bar{x}}{\alpha} \quad (4)$$

$$A = ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad (5)$$

is the number of precipitation observations. These parameters obtained using the observed time series are then used to find the total probability density function of an observed value in any month. In this case, the cumulative probability distribution function is defined by Equation 6.

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

The gamma function is undefined for x = 0 and the precipitation distribution may contain zero (0) values. In this case, the cumulative probability distribution is calculated with Equation 7 and Equation 8.

$$H(x) = q + (1 - q)G(x) \quad (7)$$

$$q = m * n \quad (8)$$

q refers to the probability for a zero value. If m is the number of days without rain in a rainfall series, this percentage is found with Equation (8). The total probability value H(x) is converted into a standard normal random variable Z, which has a mean of zero (0) and a variance of one (1), representing the SYI value. H(x) is the value of SYI. The drought classification of the values obtained with SYI is as shown in Figure 3 (Guttman, 1999; Özfidaner and Topaloğlu, 2020).

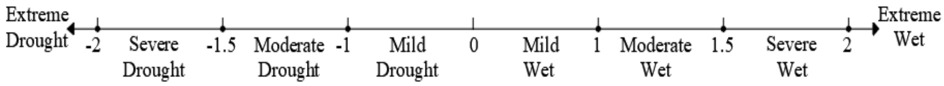

Figure 3. Classifiation values of SPI

2.3 Streamflow drought index

The method that allows examining hydrological drought using monthly flow data was developed by Nalbantis (2008). The index value, which is an indicator of hydrological drought, is calculated with the cumulative flow totals as stated in Equation 9.

$$V_{i,k} = \sum_{j=1}^{3k} Q_{i,j} \quad i = 1,2,\ldots \quad j = 1,2,\ldots.,12 \quad k = 1,2,3,4 \quad (9)$$

$Q_{i,j}$ is the flow data, i is the year, j is the month, and k is the 3-month periods within the water year. According to this; $k = 1$ October-December, $k = 2$ October-March, $k = 3$ October-June, $k = 4$ October-September. After the cumulative flow total is determined, the flow drought index is calculated with Equation 10.

$$SDI_{i,k} \frac{V_{i,k} - V_k^{-}}{\sigma_k} \quad k = 1,2,3,4 \quad (10)$$

V_k^- represents the mean value of cumulative volumes, σ_k represents the standard deviation of cumulative volumes. The drought classification of the calculated SDI values is expressed with the graph given in Figure 4.

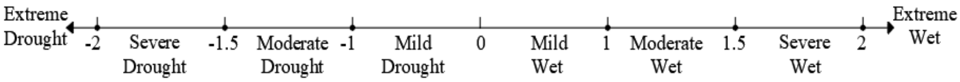

Figure 4. Classifiation values of SDI

2.4 Pearson correlation coefficient

The correlation coefficient (r), which provides information about the relationship between two variables, is calculated with Equation 11. The correlation coefficient takes values between 0 and 1. While its numerical value expresses the strength of the relationship between two variables, its sign indicates that the variables increase or decrease in the same direction.

$$r = \frac{n\sum XY - \sum X \sum Y}{\sqrt{\left[n\sum X^2 - \left(\sum X\right)^2\right]\left[n\sum Y^2 - \left(n\sum Y\right)^2\right]}} \quad (11)$$

If the calculated r value is in the range of (0-0.2), there is a very weak relationship, in the range of (0.2-0.39), there is a weak relationship, in the range of (0.4-0.59), there is a moderate relationship, in the range of (0.6 -0.79) is interpreted as a high level of relationship, and a range of (0.8-1) is interpreted as a very high level of relationship.

3. Results

All meteorological drought (SPI) index values can be found in Figure 5, and all hydrological drought (SDI) index values can be found in Figure 6. In the graphs presented, it can be determined which drought class the index values belong to. The incidence of extreme droughts decreases as the time scale increases.

It is seen in the graphs that both meteorological and hydrological drought index values sometimes reach the extreme drought level. However, when examined in whole time interval, it is possible to say that there is no danger of extreme drought for Ankara province.

In determining hydrological and meteorological droughts in Ankara province; SPI and SDI values were calculated for time scales of 1, 3, 6 and 12 months. SPI and SDI values in terms of severity, duration and frequency, as well as the formation dates of the minimum index values, are given in Table 2. When this table is examined; Both SPI and SDI analyzes showed that there was an inverse relationship between drought severity and duration and frequency. However, although the years in which minimum index values occur vary, they are predominantly seen between 2000 and 2010.

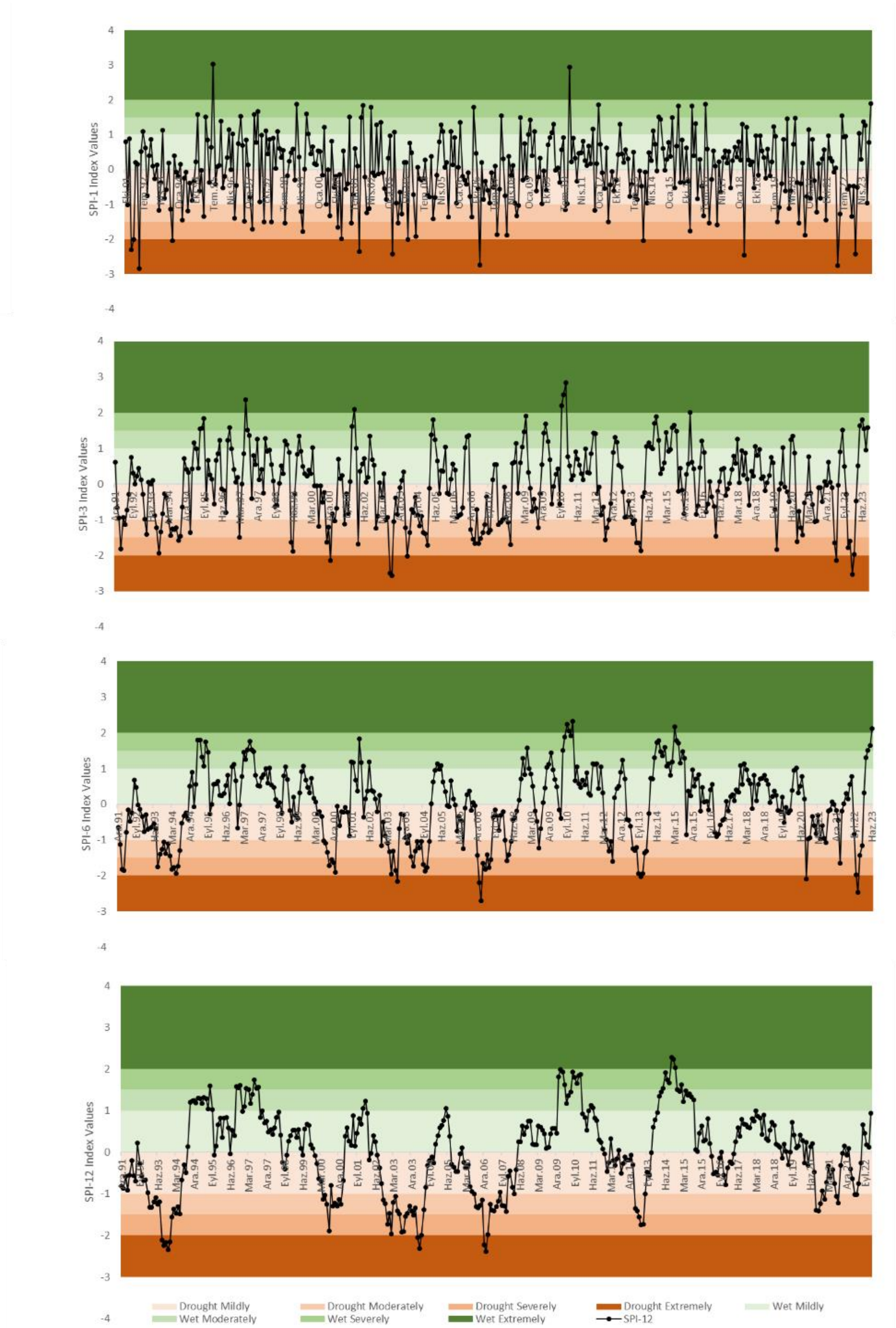

Figure 5. SPI values for 1, 3, 6 and 12 months

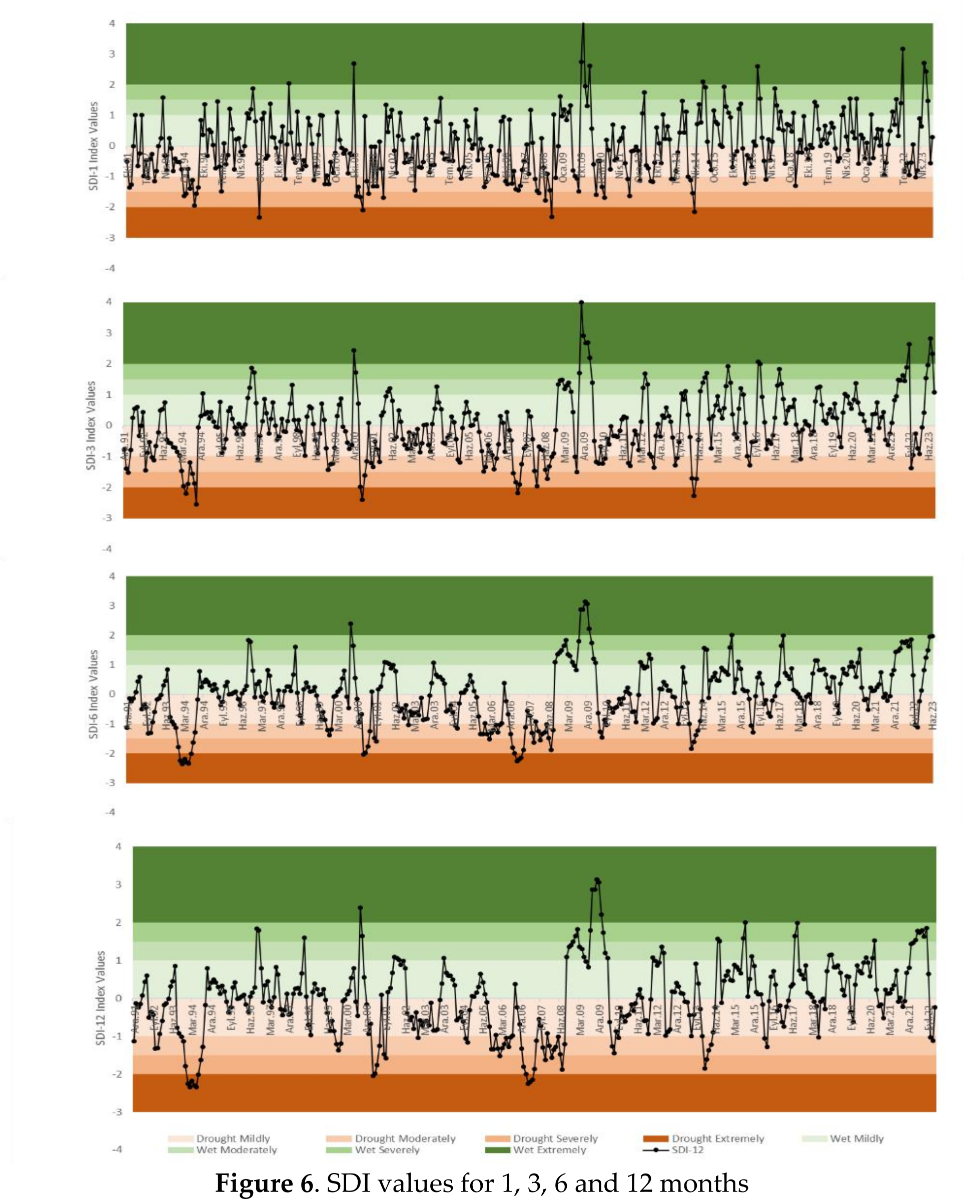

Figure 6. SDI values for 1, 3, 6 and 12 months

Considering the index values of the same time scales, the drought and humidity occurrence percentages are shown in Table 3. It was determined that the percentages of total drought and total humidity occurrence for the 1991-2023 year period were half. While extreme drought or extreme humidity occurrences were observed at levels of 1%-5%, mild drought and mild humidity occurrences were observed at levels of 30%-40%.

Table 2. Severity, duration, frequency of occurrence and minimum index values for SPI and SDI

	Severity	Duration	Frequency	Minimum Index Value	Date of Occurence
SPI-1	Drought Mildly	121	64	-0,99	08/2009
	Drought Moderately	28	17	-1,49	11/1996
	Drought Severely	19	5	-1,99	01/2001
	Drought Extremely	12	7	-2,84	05/1992
SPI-3	Drought Mildly	110	34	-0,99	05/2003
	Drought Moderately	42	10	-1,49	03/1997
	Drought Severely	23	1	-1,97	02/2023
	Drought Extremely	6	-	-2,56	06/2003
SPI-6	Drought Mildly	111	27	-0,99	08/2012
	Drought Moderately	39	4	-1,47	06/2004
	Drought Severely	27	1	-1,97	01/2023
	Drought Extremely	6	-	-2,71	05/2007
SPI-12	Drought Mildly	98	20	-0,97	11/1992
	Drought Moderately	56	3	-1,49	03/1994-04/2003
	Drought Severely	12	-	-1,99	03/2004
	Drought Extremely	9	-	-2,38	11/2006
SDI-1	Drought Mildly	143	55	-0,99	08/1992-07/2009
	Drought Moderately	45	15	-1,49	09/1995-09/2009
	Drought Severely	14	1	-1,95	08/1994
	Drought Extremely	4	-	-2,34	05/1997
SDI-3	Drought Mildly	135	38	-0,98	02/1994
	Drought Moderately	40	8	-1,49	01/2006
	Drought Severely	15	1	-1,98	03/2001
	Drought Extremely	5	-	-2,55	08/1994
SDI-6	Drought Mildly	140	27	-0,99	05/2013
	Drought Moderately	25	4	-1,47	06/2001-04/2008
	Drought Severely	22	2	-1,99	12/2006
	Drought Extremely	7	-	-2,35	12/1993
SDI-12	Drought Mildly	121	14	-0,98	08/2013
	Drought Moderately	15	3	-1,49	03/1994
	Drought Severely	23	1	-1,98	05/2006
	Drought Extremely	18	-	-2,7	03/2007

Table 4 shows the correlation analysis results of SPI and SDI index values by month. The relationship type was determined to be positive in all calculated months and time intervals. To evaluate in terms of relationship level; A mostly moderate relationship was determined between SPI and SDI values. As the time interval in the index results increases, the correlation analysis results provide significantly better results.

Table 3. Drought and humidity occurrence percentages

	SPI-1	SPI-3	SPI-6	SPI-12	SDI-1	SDI-3	SDI-6	SDI-12
Drought Extremely	0,03	0,02	0,02	0,02	0,01	0,01	0,03	0,05
Drought Severely	0,05	0,06	0,07	0,03	0,04	0,04	0,04	0,06
Drought Moderately	0,07	0,11	0,10	0,15	0,12	0,10	0,11	0,04
Drought Mildly	0,32	0,29	0,29	0,26	0,37	0,35	0,31	0,32
Wet Mildly	0,38	0,36	0,35	0,38	0,29	0,34	0,37	0,40
Wet Moderately	0,10	0,10	0,10	0,09	0,11	0,09	0,07	0,05
Wet Severely	0,05	0,05	0,05	0,06	0,03	0,04	0,06	0,06
Wet Extremely	0,01	0,01	0,01	0,01	0,03	0,03	0,02	0,01

This is due to the fact that it takes time for the precipitation to flow. In the correlation analysis results, it was determined that the periods with the highest correlation came after the periods when rainfall was abundant.

Table 4. SPI and SDI correlation analysis by months

SPI/SDI	1-month	3-month	6-month	12-month	SPI/SDI	1-month	3-month	6-month	12-month
October	0,19	0,23	0,48	0,56	**April**	0,28	0,43	0,37	0,32
November	0,06	0,21	0,64	0,58	**May**	0,46	0,66	0,43	0,45
December	0,18	0,52	0,55	0,54	**June**	0,68	0,67	0,32	0,45
January	0,54	0,51	0,50	0,28	**July**	0,50	0,44	0,22	0,57
February	0,53	0,33	0,44	0,22	**August**	0,32	0,11	0,23	0,62
March	0,27	0,07	0,38	0,31	**September**	0,34	0,08	0,37	0,61

4. Conclusions

In recent years, the effects of global warming have been felt more and more. The issue of drought is becoming more important day by day due to global warming, extreme temperatures and decrease in precipitation. Especially considering the climate zone in which our country is located, the issue of drought becomes even more critical. It is important to be able to analyze the components of drought and determine their effects on water resources.

In this study, meteorological droughts were determined with SPI using the rainfall data of Ankara province located in the center of Turkey, and hydrological droughts were determined with SDI using the data on the amount of water coming to the dams in Ankara. In calculating SPI and SDI values for Ankara province, time intervals of 1, 3, 6 and 12 months were taken into account. Although severe droughts occur from time to time in both types of drought, it is possible to say that there is no danger of severe drought for Ankara province. The most common drought classes for both precipitation and runoff data are slightly dry and slightly wet. Although the drought and humidity percentages are approximately equal; The number of dry years is less than the number of wet years. It has been observed that the driest years at different time scales occurred in the period between 2000 and 2010.

According to the results of the correlation analysis between meteorological and hydrological droughts, a mostly moderate relationship was detected. One of the reasons why higher correlation coefficients cannot be obtained is that precipitation data is limited to a single meteorological station and flow data consists of the total amount of water arriving at 8 dams. Other reasons are related to climate variability, human activities, land use status and land characteristics.
When the occurrence dates of hydrological and meteorological droughts are examined, they generally occur 1-3 months after meteorological droughts, depending on the calculated time scale and stations.

Conducting studies on drought in a specific region provides the opportunity to be prepared for possible risks. It is especially important to take precautions against dry seasons that are expected to be rainy. Apart from drought analyzes made with existing data, it will also be useful to predict droughts that may occur in the coming years. The results obtained from the study can be used for water resources management.

Declaration of Ethical Standards

The authors declare that they comply with all ethical standards.

Credit Authorship Contribution Statement

Author 1: Resources, Research, Writing – original draft, Visualization, Arrangement
Author 2: Resources, Research, Writing – original draft, Visualization, Arrangement
Author 3: Research, Visualization, Writing – original draft, Analysis and interpretation

Declaration of Competing Interest

The authors have no conflicts of interest to declare regarding the content of this article.

Data Availability

All data generated or analyzed during this study are included in this published article. Data will be made available if deemed necessary.

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