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Trend Assessment of Drought Periods in the Elmalı District of Antalya

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ABSTRACT

This study aims to determine the distribution and trends of 3 and 6-month drought periods in the Elmalı district of Antalya, located in the Mediterranean region, between 1970 and 2023. For this purpose, time series with durations of 3 and 6 months were created first. The time series was divided into four 3-month periods (P3A, P3B, P3C and P3D) and two 6-month periods (P6A and P6B). The Agricultural Standardised Precipitation Index (aSPI) and the Reconnaissance Drought Index (RDI) were used in the study to determine the time-series agricultural drought indices. Reference evapotranspiration values used for determining the moisture deficit in the RDI method were calculated using the Penman-Monteith equation. The Mann-Kendall trend analysis test was applied to determine the trend of the 3 and 6-month index values obtained using the drought index methods. According to the results from both index methods, it was determined that The Elmalı district experienced a high number of severe agricultural droughts during 1972–1973, 1982–1985, 1988–1992, 2006–2007, 2015–2017, and 2020–2021, each for a 3-month period. For the 6-month periods, significant increases in drought severity were observed in the years following 2015. Based on these results from the Mann-Kendall trend test, statistically significant change was observed in the index values in the 3 and 6-month time series of both index methods. However, a decrease close to critical threshold value (p: 0.05) was found in the aSPI-3 times series, specifically in the P3B period of aSPI-3 and RDI-3 and P6A period of aSPI-6.

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Introduction

Among the most significant impacts of climate change are regional droughts. In particular, in countries with a Mediterranean climate, temperatures are expected to increase, precipitation levels to decrease, and the frequency of droughts to increase. Since a large part of Turkey's land area is under the influence of the Mediterranean climate, the country is among those most affected by it.

Antalya, province in the Mediterranean Region, is one of Turkey's most important cities, both for agriculture and tourism. The drought risk associated with climate change that awaits the Mediterranean Region will inevitably have adverse effects on Antalya's water resources and agricultural production. With a land area of 20177 km², Antalya is a significant and large city (General Directorate of Mapping, Ministry of National [HGM], 2023). According to data from the State Hydraulic Works (DSİ), the province's annual surface water flow was 12.9 km³/year. Its groundwater potential was 1.2 km³/year in 2023. A critical role in this sector. Therefore, taking preventive measures climate change is of great importance.

Many drought-related studies have been conducted in Antalya province in the Mediterranean region. For example, Dinç et al. (2016), Bacanlı and Akşan (2019), Mehr and Attar (2021), Sekendur (2022), Ceyhunlu (2023), Durmuş and Bulut (2023), and Pekpostalcı et al. (2023) carried out research aiming to determine the impact of changes in precipitation or moisture deficit on drought in Antalya. According to the studies conducted by these researchers, it has been determined that the severity of drought in Antalya province is generally close to normal or mild (Bacanlı and Akşan, 2019). However, they have also found that the severity of drought can increase seasonally. For example, in the studies conducted by Dinç et al. (2016) and Ceyhunlu (2023), it was suggested that droughts caused by insufficient rainfall may increase during the winter season in Antalya.

This study aimed to conduct agricultural drought analyses for the Elmalı district by utilising meteorological data from 1970 to 2023. For this purpose, the Agricultural Standardised Precipitation Index (aSPI) and the

Reconnaissance Drought Index (RDI) methods were used to identify drought periods. Elmalı district constitutes 7% of Antalya's surface area and is the 6th-largest district of the province in terms of land area (Aydın, 2019). It is particularly significant among Antalya's districts in terms of cereal and fruit production (TÜİK, 2024).

The study seeks to determine the distribution and trends of dry and wet periods in Elmalı between 1970 and 2023 using 3-month (aSPI-3 and RDI-3) and 6-month (aSPI-6 and RDI-6) time series. In addition, four 3-month periods (P3A, P3B, P3C and P3D) and two 6-month periods (P6A and P6B) were defined for the time series. To identify trends during the 3- and 6-month drought periods and their sub-periods, the Mann-Kendall test was applied.

Materials and Methods

Study Area and Climatic Characteristics

The study area is the Elmalı district of Antalya, which is located in the Mediterranean Region. The central coordinates of Elmalı are approximately 36° 44' 14" N latitude and 29° 54' 44" E longitude (MGM, 2024a). To the east of the district lies Tilkicik Hill, to the west Topdağı Hill, to the north Elmalı Mountain, and to the south the Elmalı Plain. The district's elevation above sea level ranges between 1015 and 1050 meters (Elmalı District Governorship, 2023). Elmalı covers a total area of 1433 km², of which 466.07 km² is used for agricultural purposes. Of this agricultural land, 65.2% is cultivated with field crops, 24.3% with fruit, beverage, and spice crops, 9.1% with vegetables, and 1.3% consists of fallow lands (TÜİK, 2024).

This study used the data from the Turkish State Meteorological Service (MGM) to determine drought and trend analyses for the Elmalı district. For this purpose, daily and monthly data on precipitation, mean temperature, maximum temperature, minimum temperature, relative humidity, wind speed, and sunshine duration were obtained from the Antalya Regional Directorate of Meteorology, specifically from meteorological station no. 17952 in Elmalı, covering the period 1970–2023. The long-term averages of selected meteorological variables obtained from the station are presented in Table 1. Examination of the data shows that the highest average temperatures occur in July and August at 24.1°C, while the lowest average temperature is 3.0°C in January. In terms of total long-term precipitation, January and December recorded the highest averages with 83.6 mm, while September recorded the lowest with 8.4 mm.

Reference Crop Evapotranspiration (ETO)

The FAO (Food and Agriculture Organization) developed the FAO-56 Penman-Monteith method to determine reference crop evapotranspiration. The calculation of this Method is performed using Equation 1 (Allen et al., 1998).

$$ET_{0-PM} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

In the equation:

ETO is the Reference Evapotranspiration estimated by the Penman-Monteith equation (mm day^{-1}), Δ is the slope of the saturation vapor pressure curve (KP °C^{-1}); Rn is the net radiation at the crop surface (MJ/m^{2}d) (MJ m^2 d^{-1}); G is the soil heat flux (MJ/m²/day) (MJ m^2 day^{-1}), γ is the psychrometric constant (KP °C^{-1}); T is the mean air temperature °C; U2, is the wind speed measured at 2 m height (m s^{-1}), es is the mean saturation vapor pressure (KPa); ea is the actual vapor pressure (kPa).

The calculations of the FAO-56 Penman-Monteith method were carried out using the EXCEL program.

The Standardised Precipitation Index (SPI) method, developed by McKee et al. (1993), is based on series of total precipitation. However, since it relies solely on total precipitation, it does not fully reflect the impact of drought or wetness on the soil, water balance in agricultural areas (Tigkas et al., 2019). Therefore, precipitation rather than total rainfall was used in this study to assess the effect of drought on agriculture. To calculate adequate precipitation, Equation 2, developed by the USDA Soil Conservation Service (USDA-SCS), was applied (Tigkas et al., 2019).

$$P_e = 1.9443p^{0.82416} - 4.56 \quad (2)$$

In the equation, p represents total precipitation.

Table 1. Average meteorological data over many years of Elmalı District (MGM, 2024b)

Month	Precipitation (mm)	Average Temperature (°C)	Maximum Temperature (°C)	Minimum Temperature (°C)	Wind Speed (m s^{-1})	Relative Humidity (%)
January	83.6	3.0	8.1	-2.1	1.4	60.6
February	60.8	4.3	10.0	-1.4	1.6	58.8
March	51.0	7.5	13.8	1.3	1.8	56.1
April	32.8	11.8	18.4	5.2	2.0	54.9
May	27.5	16.2	23.4	9.1	1.8	53.6
June	26.3	20.6	28.2	13.0	1.9	51.0
July	10.4	24.1	32.0	16.2	1.9	48.1
August	9.7	24.1	32.1	16.1	1.7	47.4
September	8.4	20.5	28.6	12.4	1.6	49.8
October	33.8	15.0	22.5	7.6	1.5	54.2
November	49.3	9.3	15.8	2.9	1.4	57.5
December	83.3	4.7	9.8	-0.5	1.4	61.6

In the next step, the effective precipitation values obtained were used to calculate the Agricultural Standardised Precipitation Index (aSPI) values. The calculation of aSPI follows in the same standardisation approach as SPI. Afterwards, the standardised values are transformed into a normal distribution (Tigkas et al., 2019). In this study.the gamma distribution was used to determine the distribution. Since zero ("0") mm of rainfall was recorded in some months in the Elmalı region between 1970 and 2023, the gamma distribution was used instead of the log-normal distribution. Accordingly, the probability density function is given in Equation 3.

$$g_{(x)} = \frac{1}{\beta^{\alpha}\tau(\alpha)} x^{a-1} e^{-\frac{x}{3}} \quad (3)$$

In the equation,

α is equal to the shape parameter (α > 0), β is the scale parameter (β > 0), x is the effective precipitation value (x > 0), τ(α) is the gamma function. The calculations of the α and β parameters are defined in Equation 4 (Tigkas et al., 2019).

$$\alpha = \frac{1+\sqrt{1+\frac{4A}{3}}}{4A}, \ \beta = \frac{\overline{X}}{\alpha} \quad (4)$$

In the equation:

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

where n represents the number of observations. The cumulative probability of a precipitation event (G(x)) is given in Equation 5. After substituting t=x/β, the formula takes the form shown in Equation 6 (Tigkas et al., 2019).

$$G_{(x)} = \int_0^x g(x)dx = \frac{\int_0^x t^{\alpha-1} e^{-\frac{x}{3}} dx}{\beta^{\alpha}\tau(\alpha)} \quad (5)$$

$$G_{(x)} = \frac{\int_0^x t^{\alpha-1} e^{-t} dt}{\tau(\alpha)} \quad (6)$$

Since the gamma distribution is defined as x=0, to account for the cumulative probability of zero effective precipitation (q), Equation 7 is applied (Edwards and McKee, 1997).

$$H_{(x)} = q + (1-q)G_{(x)} \quad (7)$$

For the calculation of aSPI, the cumulative probability distribution was transformed into a normal distribution using Equation 8, 9 (Abramowitz and Stegun, 1965).

$$aSPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), \quad 0 < H_x \leq 1.0 \quad (8)$$

$$t = \sqrt{\ln\left(1/(H_x)^2\right)}$$

$$aSPI = t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}, \quad 0.5 < H_x \leq 1.0 \quad (9)$$

$$t = \sqrt{\ln\left(1/[1-(H_x)^2]\right)}$$

$c_0 = 2.515517,\ c_1 = 0.802853, c_2 = 0.010328$

$d_1 = 1.43278,\ d_2 = 0.189269,\ d_3 = 0.001308$

The classification of drought and wetness magnitudes for aSPI was based on the drought classification proposed by McKee et al. (1993), as presented in Table 2. Additionally, the DrinC software was used for the computation of aSPI values. The Drought Index calculation (DrinC 1.7) software was produced by Tigjas et al. (2022) at the National Technical University of Athens.

Table 2. Drought classification based on index values of the aSPI method (MGM, 2024c).

aSPI	Drought Class/Category
> 2.00	Exceptional Humid (ExH)
1.60 – 1.99	Extreme Humid (EH
1.30 – 1.59	Very Humid (VH)
0.80 – 1.29	Moderate Humid (MoH)
0.51 – 0.79	Mild Humid (MH)
0.50 - (-0.50)	Near Normal (NN)
(-0.51) - (-0.79)	Mild Drought (MiD)
(-0.80) - (-1.29)	Moderate Drought (MD)
(-1.30) - (-1.59)	Severe Drought (SD)
(-1.60) - (-1.99)	Very Severe Drought (VSD)
< (-2.00)	Exceptional Drought (ED)

Reconnaissance Drought Index (RDI)

The calculation of the Reconnaissance Drought Index (RDI) begins with the computation of the initial RDI value (αk). This value could be calculated for the entire year, for each month of the hydrological year, or by grouping monthly intervals. The calculation of αk is performed using Equation 10 (Tsakiris et al., 2007).

$$\propto_0^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} ET_{ij}}, i = 1 - N \quad (10)$$

In the equation, Pij and PETij represent, respectively, the total precipitation and potential evapotranspiration of the *j* month of the *i* year. N represents the total number of years with available data.

The second step consists of calculating the Normalised RDI (RDIn) values, which are obtained using Equation 11 (Tsakiris et al., 2007).

$$RDI_n^{(i)} = \frac{\alpha_0^{(i)}}{\overline{\alpha_0}} \quad -1 \quad (11)$$

In the equation, $\overline{\alpha_k}$ represents the arithmetic mean of the αk values calculated for N years. In the third step of this method, the standardisation of RDI (RDIst(i)) is carried out following a procedure similar to that used in the calculation of SPI. The standardisation of RDI is defined in Equation 12 (RDIst(i)) (Tsakiris et al., 2007).

$$RDI_{st}^{(i)} = \frac{y_k^{(i)} - \overline{y_k}}{\sigma_{yk}}, \qquad y_k = \ln\left(\alpha_0^i\right) \quad (12)$$

In the equation, yk¯ denotes the arithmetic mean of the y_k values, while σ_{yk} represents the standard deviation of $y_k^{(i)} - \overline{y_k}$.

In this study, when determining the distribution of RDI values, the log-normal method produced errors in monthly and 3-month time series where precipitation in the summer months was zero. Therefore, the Delta probability distribution method was adopted. This method was applied in the same way as described for the Standardised Precipitation Index (SPI). Additionally, the DrinC software was used for the computation of RDI values.

Mann–Kendall (MK) Trend Analysis Test

This method is considered a monotonic test and is commonly used to determine whether a statistically significant trend exists in hydro-meteorological data (Mann, 1945; Kendall, 1948; Avsaroğlu et al., 2021). The test is based on the null hypothesis (H_0: no trend) within a time series. The test statistic is calculated through the S statistic and the sign function, as presented in Equations 13 and 14. Subsequently, the variance of S and the Z test statistic are computed using the formulas provided in Equation 15 and Equation 16, respectively (Mann, 1945; Kendall, 1948; Avsaroğlu et al., 2021).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(X_j - X_i) \quad (13)$$

$$sign(X_j - X_i) = \begin{cases} +1, X_j > X_i \\ 0\ X_j = X_i \\ -1\ X_j < X_i \end{cases} \quad (14)$$

$$var(S) = \frac{[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i i(i-1)(2i+5)]}{18} \quad (15)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, S > 0 \\ 0, S = 0 \\ \frac{S+1}{\sqrt{var(s)}}, S < 0 \end{cases} \quad (16)$$

In these equations, n represents the number of data points, x denotes the observed values at time i and j, i refers to the repeated observations within a series of length t.

The Z value is used to determine the statistical significance of a trend. If Z; $Z < \alpha/2$ at a given significance level (α), the null hypothesis cannot be rejected, indicating no significant trend. If Z; $Z \geq \alpha/2$, the presence of a statistically significant trend is confirmed. Moreover, the sign of the S statistic reveals the direction of the trend: a positive S value indicates an increasing trend, a negative S value indicates a decreasing trend. The Mann–Kendall test equations in this study were computed using the XLSTAT 2025 statistical software package.

Results and Discussion

Analysis of 3-Month Drought Periods

Figure 1 presents the distribution of aSPI-3 and RDI-3 values for the years 1970–2023, calculated using meteorological data from the Elmalı district. The distribution of 3-month index values for both methods falls predominantly within the Near Normal (NN) category. In addition, no statistically significant linear trend is observed in the 3-month values of either index method (Figure 1). The distribution reveals that 33% of aSPI-3 values fall within the NN category, 29% indicate drought periods, and 38% indicate wet periods. Similarly, 40% of RDI-3 values fall within the NN category, while 31% represent drought periods and 29% represent wet periods. These results suggest that the classification levels of the two indices are relatively close. Furthermore, findings by Bacanlı and Akşan (2019), Dinç et al. (2014), Erkul and Altunbaş (2023), and Mahnamfar and Nigussie (2023) reported that SPI-3 and SPEI-3 values in Elmalı district and Antalya province are generally close to the NN category. The results of these studies are consistent with the findings of this research, indicating a parallel relationship between the aSPI-3 and RDI-3 methods.

Between 1970 and 2023, the Elmalı district experienced 3-month drought periods (aSPI-3 and RDI-3) during 1972–1973, 1982–1985, 1988–1992, 2006–2007, 2015–2017, and 2020–2021. According to both index methods, the frequency of high-intensity 3-month droughts increased, particularly in the years following 2015. These results are consistent with the study conducted by Türkeş (2012), which reported similar drought periods across Turkey between 1970 and 2010. Additionally, Durmuş and Bulut (2023) found that in the Western Mediterranean Region, SPEI values indicated severe droughts in 1981, 1985, 1989, 1990, 2000, 2007, and 2008.

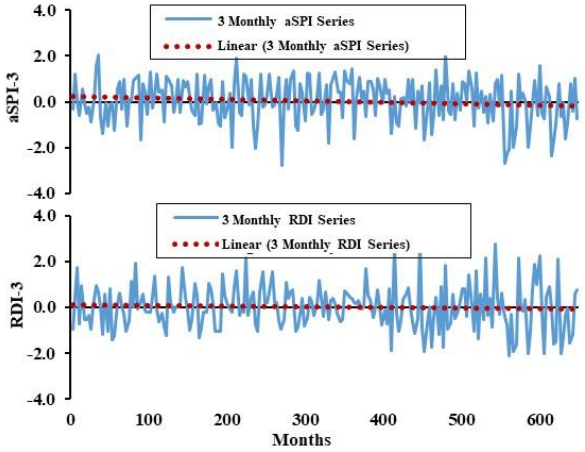

Figure 1. Three-month scale temporal distribution of different index methods.

In this study, the distribution of droughts across different levels over the 20 years from 1970 to 2023 is presented in Table 3. Accordingly, between 1970 and 2023, 70% of the aSPI-3 drought events occurred at Moderate to Severe (MiD+MD) intensity levels, while 30% occurred at Slight, Very Severe, and Extremely Severe (SD+VSD+ED) levels. For the RDI-3 values, 75% of drought events occurred at MiD+MD intensity, and 25% at SD+VSD+ED levels. When examining the 20-year periods and the 14 years between 2010 and 2023 in Table 3, it is observed that the number of drought events in the last 14 years is nearly equal to the total number of droughts in the preceding 20-year periods, which indicates an increase in the frequency of 3-month drought events during the last 14 years.

The study presents the temporal distribution of 3-month droughts based on aSPI-3 and RDI-3 values from 1970 to 2023 in Figure 2. It is observed that the index values for all 3-month periods fall within the Near Normal (NN) category for both methods. However, linear trend was detected in the P3A, P3B, and P3C periods for both aSPI-3 and RDI-3. No significant linear change is observed in the P3D period.

Table 3. Distribution of three-month drought levels according to different index methods.

Method	Years	Drought severities					Total
		MiD	MD	SD	VSD	ED	
aSPI-3	1970-1989	6	11	1	1	2	21
	1990-2009	9	6	3	3	0	21
	2010-2023	5	8	0	3	5	21
	1970-2023	20	25	4	7	7	63
RDI-3	1970-1989	7	14	2	0	0	23
	1990-2009	11	8	0	4	0	23
	2010-2023	3	5	6	1	4	19
	1970-2023	21	27	8	5	4	65

MiD: Mild Drought, MD: Moderate Drought, SD: Severe Drought, VSD: Very Severe Drought, ED: Exceptional Drought.

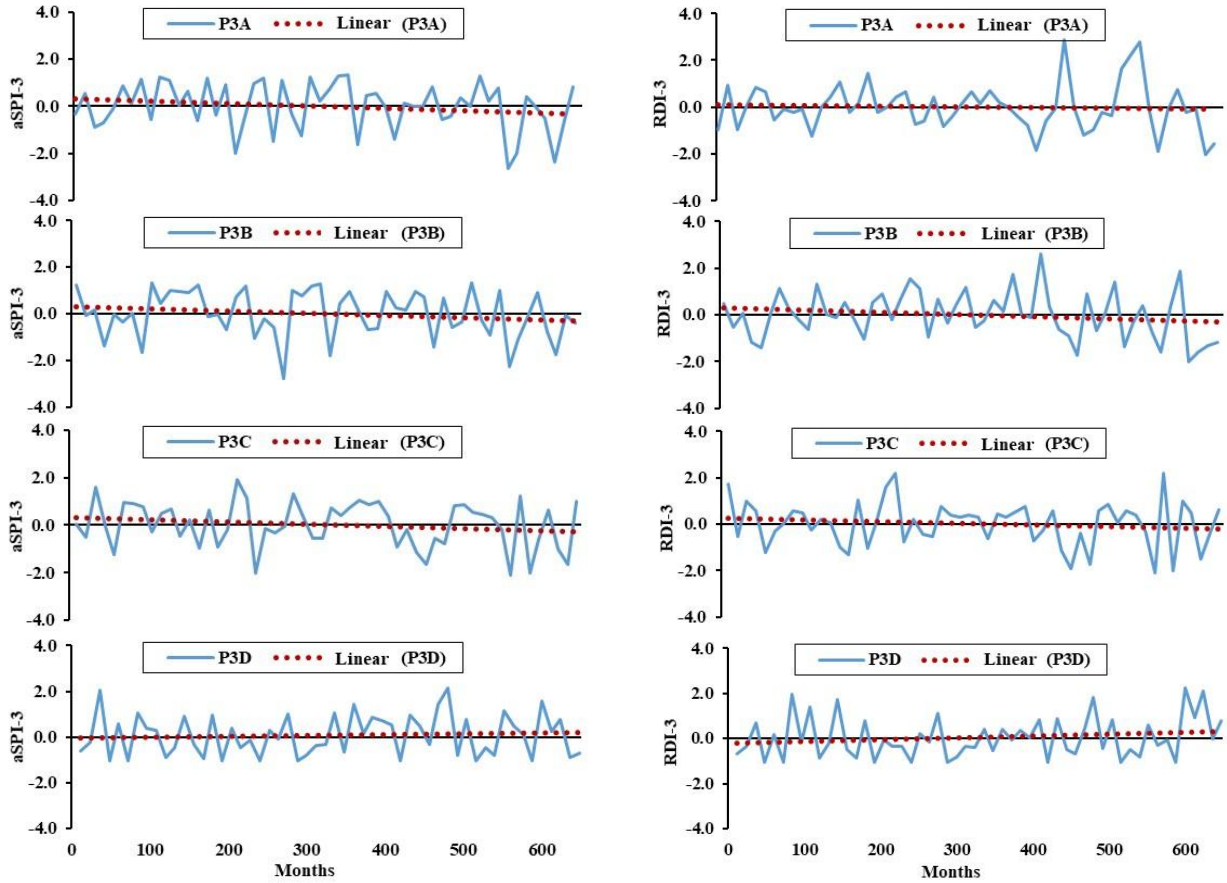

Figure 2. Temporal distribution of the aSPI and RDI index methods over three months.

When 3-month drought periods are examined using different index methods, no statistically significant linear trend is observed. Nevertheless, the frequency of prolonged 3-month droughts has increased after 2015. The occurrence of severe 3-month droughts indicates that plant water consumption rises due to soil moisture deficits. Consequently, more irrigation water will be required to compensate for moisture deficits during these periods. Therefore, it is essential to conserve water resources and implement measures to use available irrigation water more efficiently.

Analysis of 6-Month Drought Periods

The distribution of aSPI-6 and RDI-6 values for the years 1970–2023, calculated using meteorological data from the Elmalı district, is presented in Figure 3. The 6-month index values for both methods are in the Near Normal (NN) category. Additionally, no statistically significant linear trend is observed in the 6-month values for either index method (Figure 3). The distribution reveals that 42% of aSPI-6 values fall within the NN category, 25% represent drought periods, and 33% represent wet periods. Similarly, for RDI-6 values, 42% fall within the NN category, 29% indicate drought periods, and 30% indicate wet periods. These results suggest that the NN category has the highest frequency in both index methods.

Between 1970 and 2023, high-intensity 6-month droughts based on aSPI-6 and RDI-6 were observed twice, during 2015–2017 and 2020–2022. The study indicates an increase in the frequency of severe 6-month droughts after 2015, which parallels the increase observed in 3-month drought events.

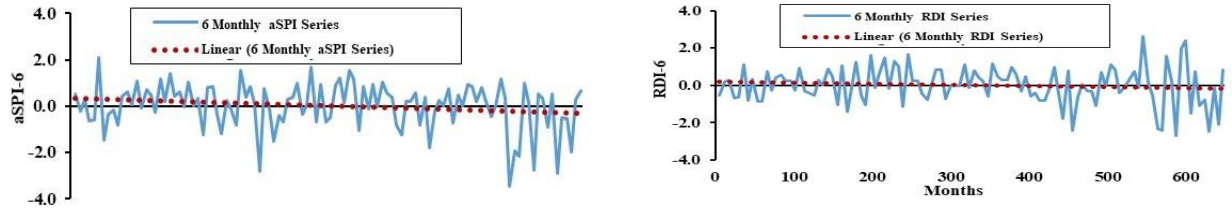

Figure 3. Six-month scale temporal distribution of different index methods.

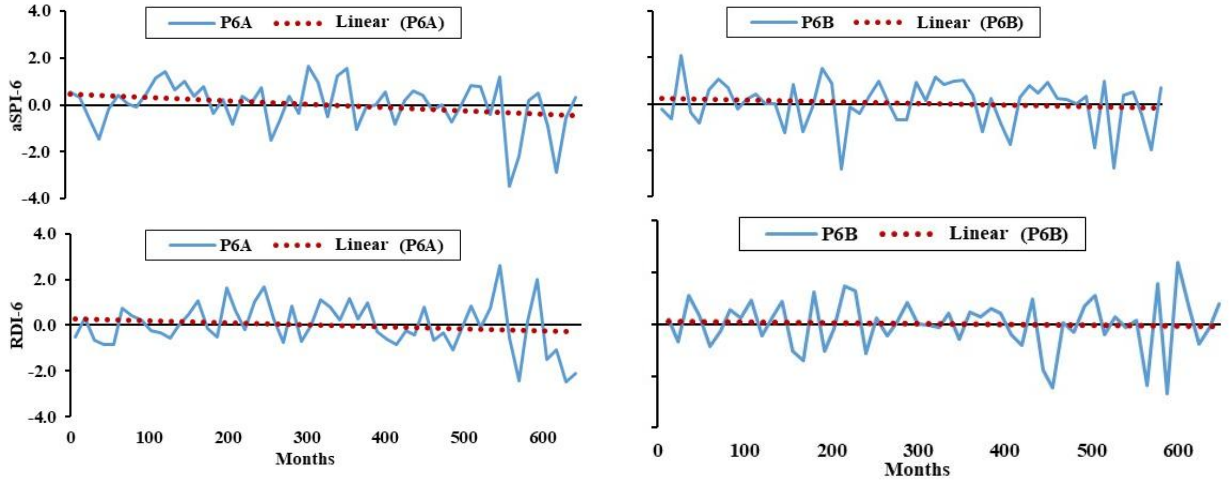

Figure 4. Temporal distribution of the aSPI and RDI index methods over six months.

Table 4. Distribution of six-month drought levels according to different index methods.

Method	Years	Drought severities					Total
		MiD	MD	SD	VSD	ED	
aSPI-6	1970-1989	2	4	1	0	1	8
	1990-2009	4	4	1	1	0	10
	2010-2023	2	1	0	2	4	9
	1970-2023	8	9	2	3	5	27
RDI-6	1970-1989	3	3	0	0	0	6
	1990-2009	2	3	1	0	0	6
	2010-2023	3	0	0	0	0	3
	1970-2023	8	6	1	0	0	15

MiD: Mild Drought, MD: Moderate Drought, SD: Severe Drought, VSD: Very Severe Drought, ED: Exceptional Drought.

The distribution of 6-month droughts across intensity levels over the 20-year period from 1970 to 2023 is presented in Table 4. According to the aSPI-6 values, 63% of drought events occurred at Moderate to Severe (MiD+MD) intensity, while 37% occurred at Slight, Very Severe, and Extremely Severe (SD+VSD+ED) levels. For RDI-6 values, 93% of drought events were at MiD+MD intensity, and only 7% at SD+VSD+ED levels. When examining the 20-year periods and the 14 years between 2010 and 2023, it is observed that the number of drought events in the last 14 years is comparable to that in the previous 20-year periods, indicating an increase in the frequency of 6-month drought events during the last 14 years. Specifically, between 2010 and 2023, aSPI-6 values show a higher number of droughts with SD+VSD+ED intensity compared to RDI-6 values. This can be attributed to the fact that agricultural areas did not effectively benefit from the rainfall events recorded in the six-month time series between 2010 and 2023.

The temporal distribution of 6-month droughts based on aSPI-6 and RDI-6 values between 1970 and 2023 is presented in Figure 4. It is observed that the index values for all 6-month periods are within the Near Normal (NN) category for both methods. However, a linear decreasing trend is detected in the P6A period for both aSPI-6 and RDI-6.

When examining 6-month drought periods according to different index methods, no statistically significant linear trend is observed. However, similar to 3-month drought periods, the frequency of prolonged 6-month droughts has increased after 2015, indicating an increase in the number of long-lasting drought events in recent years. In the next section of the study, the Mann–Kendall trend analysis test is applied to determine whether the observed increases in the frequency of 3 and 6-month drought periods are statistically significant.

Mann–Kendall (MK) Trend Analysis of 3 and 6-Month Drought Periods

The results of the Mann–Kendall trend test applied to the 3 and 6-month time series of aSPI and RDI methods are presented in Table 5. According to the test results, no statistically significant trend is observed for aSPI-3 and RDI-3 values. However, the Tau value for aSPI-3 is very close to the significance threshold (0.05) and is slightly negative.

Table 5. Mann-Kendall Trend analysis of drought indices in different time series of the Elmalı District.

Indices	Kendall's Tau	S	Var (S)	P (α) Value	Trend	Şen Slope
aSPI-3	-0.07	-1565.0	1127389.7	0.14	-	-0.001
aSPI-6	-0.07	-400.0	141882.0	0.29	-	0.000
RDI-3	-0.03	-676	1127392.7	0.53	-	0.000
RDI-6	-0.05	-290	141882.0	0.44	-	0.000

Table 6. Mann-Kendall Trend analysis of drought indices in different periods of the Elmalı District.

Indices	Periods	Kendall's Tau	S	Var (S)	P (α) Value	Trend	Şen Slope
aSPI	P_{3A}	-0,08	-117.0	17967.0	0.39	-	-0.008
	P_{3B}	-0.14	-197.0	17967.0	0.14	-	-0.011
	P_{3C}	-0.11	-155.0	17967.0	0.25	-	-0.010
	P_{3D}	0.06	80.0	17900.7	0.56	-	0.004
	P_{6A}	-0.12	-177.0	17967.0	0.19	-	-0.010
	P_{6B}	-0.01	-13.0	17967.0	0.93	-	-0.002
RDI	P_{3A}	-0.08	-115	17967.0	0.39	-	-0.007
	P_{3B}	-0.13	-189.0	17967.0	0.16	-	-0.014
	P_{3C}	-0.03	-43.0	17967.0	0.75	-	-0.003
	P_{3D}	0.16	228.0	17900.0	0.09	-	0.013
	P_{6A}	-0.10	-141.0	17967.0	0.30	-	-0.009
	P_{6B}	-0.02	-3.0	17967.0	0.98	-	-0.001

For the 6-month indices, the results for aSPI-6 and RDI-6 values reveal a decrease very close to the significance threshold (0.05), although not statistically significant. Overall, the trend results for 6-month indices in the Elmalı district are near the threshold, suggesting an increase in 6-month drought index values over time.

The results of the trend analysis for the 3 and 6-month time series of aSPI and RDI methods are presented in Table 6. According to the results, no statistically significant trend is observed for aSPI-3 and RDI-3 during the P3A, P3B, P3C and P3D periods. For both index methods, the values in the P3A and P3B periods are negative and very close to the significance threshold (0.05). Bacanlı and Çukuroğlu (2018) reported that, using the Mann–Kendall trend analysis, precipitation in Antalya between 1965 and 2017 showed decreasing trends in February and December. In the P3D period, values are positive and near the threshold, no significant trend is observed for aSPI-3 and RDI-3 during the same period. In the P6A period, a negative trend near the significance threshold (0.05) is detected, although it is not statistically significant.

Based on the 3 and 6-month trend results from the study, it is observed that long-duration droughts, such as 6-month events, are increasing, suggesting an increase in the number of 6-month droughts. The 3-month time series also reveals that severe droughts occur frequently. These findings indicate that irrigation water in the Elmalı district should be used in a controlled manner, with conservation measures. Furthermore, if prolonged droughts become frequent, the annual flow of water resources supplying the region should also be carefully monitored and assessed.

Conclusion

In this study, the drought index values and their trend analyses indicate that high-intensity 3-month droughts occurred in 1972–1973, 1982–1985, 1988–1992, 2006–2007, 2015–2017, and 2020–2021. The frequency of severe 3-month droughts increased between 2010 and 2023. According to the Mann–Kendall trend test results, aSPI-3 and RDI-3 trends did not show statistically significant decreases; their values were very close to the significance threshold (0.05). These findings suggest that the frequency of 3-month drought periods in the Elmalı district has increased.

Regarding 6-month drought periods based on aSPI-6 and RDI-6 values, both methods indicate that severe droughts have become more frequent after 2015.

The increase in agricultural drought, particularly over 6-month periods, will exacerbate soil moisture deficits in agricultural lands. Consequently, the demand for irrigation water in agriculture is expected to increase. Therefore, it is essential to utilise water resources efficiently and implement conservation measures. Furthermore, given the risk of hydrological drought, water resource flows should be monitored periodically. The number of studies examining the impact of such droughts on agriculture should be increased, and drought analyses should be repeated at regular intervals in the same regions.

Declarations

Ethical Approval Certificate

This research did not involve human or animal no ethical approval was required.

Author Contribution Statement

Samet MORAY prepared and planned the literature review, material and method analysis, findings, and discussion section, and wrote the first draft of the article. Harun KAMAN provided guidance and consulting for the research, encouraged the research, edited the article's conclusion, and reviewed the final version of the text.

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Conflict of Interest

The authors declare no conflict of interest.

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