



Assessment of meteorological drought trends in the Euphrates Basin, Turkey

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Abstract

In this study, it was aimed to determine the meteorological drought trends in the Euphrates Basin by using rainfall-based Standardised Precipitation Index (SPI), Statistical Z Score Index (ZSI), Rainfall Anomaly Index (RAI) and rainfall and temperature-based Standardised Precipitation Evapotranspiration Index (SPEI) and Reconnaissance Drought Index (RDI). Mann-Kendall (MK) and Modified Mann-Kendall (MMK) tests were applied during the monthly and annual periods to determine drought trends. The trend analysis results of meteorological drought indices are mapped in 90% ($z > 1.65$) and 95% ($z > 1.96$) confidence intervals. According to the analyses applied, it was determined that the trend analysis results of SPI, ZSI and RDI indicate almost the same results. In addition, SPEI was found to be more sensitive in detecting drought trends compared to other indices. Moreover, it has been concluded that the Euphrates Basin is at great risk of meteorological drought due to the dominance of decreasing drought trends and trends in the basin. Making a drought management plan and going into alarm in endangered areas is recommended to prevent existing risks.

Keywords Drought analysis · Drought index · Mann-Kendall test · Precipitation · The Euphrates Basin

Introduction

As the accumulation of greenhouse gases in the atmosphere increases rapidly due to various human activities, it creates an additional positive heating force on the earth's energy balance, making the global climate warmer and more changeable. Climate change also causes significant variations in the frequency, severity, spatial distribution, length and timing of extreme weather and climate events such as drought and flooding (Türkeş 2013). In an evaluation of thirty-one hazards that are effective in the world, it was determined that drought was the most significant of them by evaluating the degree of

severity, length of the event, total areal extent, loss of life, economic loss, social effects and long-term impacts (Wilhite 2000). Drought is defined as the decrease in the values of hydrological and meteorological variables such as precipitation, humidity, flow, reservoir level, groundwater level below the average values in a region. Drought has negative consequences on water resources, agriculture, animal husbandry, health, industry, energy, tourism and economy (Hagman et al. 1984; Wilhite 2002; Xu et al. 2015). Therefore, it is crucial to monitor the future drought events that are expected to become more severe and determine the spatial effect levels and drought trends. In addition, revealing the regional drought characteristics and trends forms the basis of drafting the drought management plan.

Drought indices are indicators employed to determine and monitor drought conditions. Many drought indices have been developed worldwide to monitor and evaluate drought and take necessary measures against it; some have found widespread use while others have not proven valid. The Deciles Index (DI), Erinc Index (EI), Palmer Drought Severity Index (PDSI), Thornthwaite Index (TI), Standardised Precipitation Index (SPI), Standardised Precipitation Evapotranspiration Index (SPEI) and Aydeniz method are the indices that have found vast application areas both in the world and in Turkey

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(Dogan et al. 2012; Li et al. 2017; Katipoğlu et al. 2020; Katipoğlu et al. 2021). These indices characterise drought events and form a key component of creating drought management plans (Wilhite 2005).

Several studies in the literature examine the temporal and spatial changes of droughts. The highlights of these; Jha et al. (2011) investigated spatial-temporal trends of the SPI for the Indian landmass. It was determined that the regional Kendall test indicated a significant positive trend for June while significant negative trends in July and August. Rahmat et al. (2012) applied trend analysis of the SPI in Victoria, Australia, by using the Mann–Kendall and Spearman's rho trend tests. A statistically significant downward trend was found for all stations. Almazroui et al. (2012a, b) determined significant increasing trend of surface temperatures and decreasing rainfall in Saudi Arabia. It is thought that this warming trend will also affect precipitation and possibly drought. Dabanlı et al. (2017) used SPI to identify spatio-temporal changes of droughts in various periods in Turkey. Rahman and Dawood (2018) analysed spatial precipitation variability and drought assessment using SPI in Pakistan's Khyber Pakhtunkhwa province. The Mann–Kendall test was used for the trend of SPI values. As a result, dry periods and regions with negative trends were determined. Raude et al. (2018) calculated the Standardised Precipitation Index (SPI) and Effective Drought Index (EDI). They applied the Mann–Kendall trend test to determine drought's spatial, temporal and trend distribution in Kenya's upper Tana River basin. As a result, it was revealed that the drought trend in the southeastern parts of the basin increased at significant levels of 90% and 95%. Ye et al. (2019) used the trend-free pre-whitening Mann–Kendall test and a distinct empirical orthogonal function to analyse drought trends and spatial-temporal changes. Bhunia et al. (2019) used the Mann–Kendall test to calculate trends of SPI values. Zarei (2019) used the Mann–Kendall test, Spearman's rho test and the *b* slope of linear regression to perceive the spatial and temporal patterns of drought in the south of Iran. As a result, it was found that drought trends occurred most often in winter and annual time scales. Mehr and Vaheddoost (2020) applied the Spearman rank-order correlation and the innovative Şen method to investigate the drought trends at each station. Jin et al. (2020) used the Mann–Kendall and innovative Şen methods to analyse trends of SPEI values in the Zoige Wetland. Mekonen et al. (2020) tried the Mann–Kendall test and Şen's slope estimator to investigate droughts' trends and reveal the magnitude of change. Qaisrani et al. (2021) used SPI and SPEI values monitoring drought and detecting drought trends. The Mann–Kendall test and Sen's slope estimation were applied to determine trends. As a result, an increasing trend in severity was seen from lower to higher timescales (1, 3, 6, 9 and 12 months).

This study aims to analyse drought in the Euphrates Basin and investigate the distribution of drought trends in the basin with various meteorological drought indices (SPI, SPEI, ZSI, RAI, RDI). These indices have been preferred because they can be used in multiple time scales to determine drought dynamics, ease of calculation and the limited number of meteorological parameters (Katipoğlu et al. 2020). The importance of drought will inevitably increase gradually soon due to the increasing effects of climate change. Therefore, it is necessary to monitor trends with various drought indices. The results obtained from this study will help various authorities and decision-makers develop drought mitigation measures and drought management and mitigation strategies.

Materials and methods

Study area and data

This study selected 16 meteorological stations with regular databases of at least 30 years, located within or near the Euphrates Basin (Table 1). The chosen period was between 1966 and 2017, the most prolonged standard period for these stations. The data used in the study were obtained from the Turkish State Meteorological Service (Fig. 1).

The Euphrates valley is fed mainly from the snowmelt of Turkey's northern and eastern parts together with Iran and Iraq's mountainous areas. The Euphrates, which has the largest drainage area of West Asia and Turkey, is West Asia's longest river. Originating from the mountains in the Ağrı and Erzurum regions of Eastern Anatolia, its two main

Table 1 Meteorological stations is used in the study.

Station number/name	Latitude	Longitude	Altitude (m)
17762/Kangal	39.24	37.38	1521
17094/Erzincan	39.75	39.48	1216
17096/Erzurum	39.95	41.19	1758
17740/Hıms	39.37	41.69	1715
17165/Tunceli	39.11	39.54	981
17099/Ağrı	39.72	43.05	1646
17780/Malazgirt	39.14	42.53	1540
17204/Muş	38.75	41.50	1322
17776/Solhan	38.96	41.05	1366
17203/Bingöl	38.88	40.50	1139
17666/İspir	40.48	40.99	1223
17688/Tortum	40.30	41.54	1576
17692/Sarıkamış	40.33	42.60	2102
17690/Horasan	40.04	42.17	1540
17716/Zara	39.89	37.75	1338
17265/Adıyaman	37.75	38.28	672

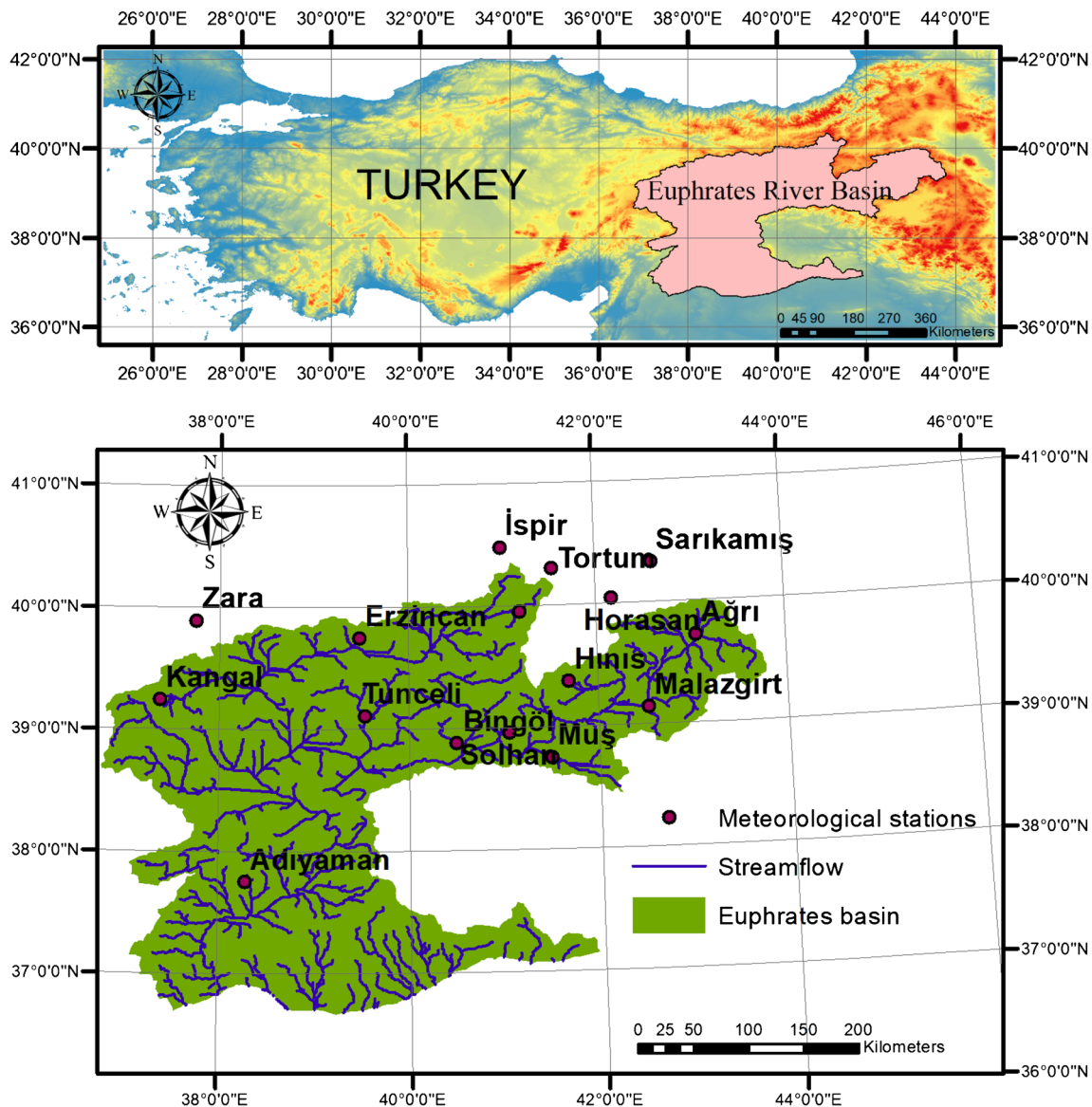


Fig. 1 Location map of meteorological observation stations used in the study

branches, the Murat and Karasu, are fed by dozens of tributaries (Fig. 1).

Analysis of drought indices

There are various indicators to describe drought, which is a complex process. Drought indices are widely used to reveal arid conditions. Meteorological, hydrological and climatic events can be interpreted according to the parameter used in the index. Drought indices are essential in revealing and evaluating the severity, duration, beginning, ending and spatial dimensions of droughts and determining the magnitude of drought disasters (Hayes 2000).

Geomorphological, climatological, hydrological, natural and environmental factors are the most important criteria for selecting the most suitable drought index for a region. It is also

essential to consider the agricultural activities, the climatic situation and the state of water resources and water structures. Some indices are used to monitor droughts, while others are recommended to detect past droughts. For these reasons, explaining the droughts according to several different drought indexes and comparing the results provide more clear findings. For this reason, in the presented study, the results of various drought indices such as SPI, ZSI, RAI, SPEI and RDI, which are accepted in national and international studies, were compared. SPI, ZSI and RAI are calculated only according to monthly total rainfall data. In contrast, SPEI and RDI are calculated using monthly total precipitation and monthly average temperature values, thus considering the potential evapotranspiration values and the climate water balance. In addition, selected indices are calculated in monthly and annual periods and used as inputs for trend analysis.

The drought indices in this study were chosen because they evaluate meteorological drought in various time scales, detect the precipitation change in a region, reveal historical drought characteristics, simplicity of calculation and standardised indicators.

Standard Precipitation Index (SPI)

The Standard Precipitation Index (SPI) is one of the most famous meteorological drought indices for recognising and observing drought using monthly precipitation data (McKee et al. 1993). This index is advantageous because it only needs precipitation data to observe drought on multiple time scales (1, 2, 3, 6, 9, 12, 24 months). In calculating the SPI index, the long-term precipitation time series are adapted to a gamma probability distribution and converted to a standard normal distribution (McKee et al. 1993).

The probability density function of the gamma distribution is defined by Eq. (1).

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} X^{\alpha-1} e^{-\frac{x}{\beta}} \quad \text{for } X > 0 \quad (1)$$

Here, where $x > 0$, α is a shape parameter, β is a scale parameter and x is a precipitation amount.

Fitting the distribution to the data requires α and β to be estimated. The maximum likelihood function is given by Eq. (2).

$$\alpha = \frac{1}{4A} \left(1 + \sqrt{1 + \frac{4A}{3}} \right) \quad \text{ve } \beta = \frac{\bar{X}}{\alpha} \quad (2)$$

$$\text{Here, } A = \ln(\bar{X}) - \frac{\sum \ln(x)}{n} \quad (3)$$

n = number of precipitation observations.

The cumulative probability is given by Eq. (4).

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

Although this approach is simple, it is not practical to use for large numbers of data. As Edwards and McKee (1997) used, the approximate conversion provided by Abramowitz and Stegun (1965) is an alternative and was calculated by Eqs. (5) and (6) respectively (Sigdel and Ikeda 2010).

$$Z = \text{SPI} = - \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad \text{for } 0 < H(x) \leq 0.5; \quad (5)$$

$$t = \sqrt{\ln \left(\frac{1}{(H(x))^2} \right)}$$

$$Z = \text{SPI} = + \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad \text{for } 0.5 < H(x) \leq 1; \quad (6)$$

$$t = \sqrt{\ln \left(\frac{1}{(1-H(x))^2} \right)}$$

Here, the values of coefficients c and d are as follows:

$$c_0 = 2.515517, c_1 = 0.802853, c_2 = 0.010328 \\ d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308$$

Standard Precipitation and Evapotranspiration Index (SPEI)

The Standard Precipitation and Evapotranspiration Index (SPEI) method is a widely used method proposed by Vicente-Serrano et al. (2010). Temperature and precipitation values are used in the calculation of this index. It is recommended to eliminate the deficiencies in the SPI index and consider the effects of climatic warming. In obtaining the SPEI values, the potential evapotranspiration (PET) values calculated through the temperature values are also used. For PET calculation, the Thornthwaite (1948) equation is recommended and described by Eq. (7), which only needs the selected station's monthly average temperature and latitude.

$$PET = 16 K \left(\frac{10T}{I} \right)^m \quad (7)$$

Here, T is the average temperature ($^{\circ}\text{C}$), and K is a correction coefficient. I is the annual thermal index calculated as the sum of the 12-month index values. These values can be calculated as in Eqs. (8) and (9).

$$m = 0.49 + 0.0179 I - 0.0000771 I^2 + 0.000000675 I^3 \quad (8)$$

$$i = \left(\frac{T}{5} \right)^{1.514} \quad (9)$$

K is the correction coefficient and can be calculated using Eq. (10). This value depends on latitude and month.

$$K = \left(\frac{N}{12} \right) \left(\frac{NDM}{30} \right) \quad (10)$$

Here, NDM is the number of days the month, and N is the maximum number of sun hours, calculated using Eq. (11).

$$N = \left(\frac{24}{\pi} \right) \bar{\omega}_s \quad (11)$$

where $\bar{\omega}_s$ is the hourly angle of the sun rising, which is calculated using Eq. (12).

$$\bar{\omega}_s = \arccos(-\tan \phi \tan \delta) \quad (12)$$

where φ is the latitude in radians and δ is the solar declination in radians, $\delta = 0.4093 \sin\left(\frac{2\pi j}{365} - 1.405\right)$ is the solar declination in radians and J is the average Julian day of the month.

When the value of PET is known, the difference (D) between precipitation (P) and PET in the relevant month is calculated by Eq. (13).

$$D_i = P_i - PET_i \tag{13}$$

where P_i is the precipitation values (mm), PET_i is the PET values (mm), D_i is a measure of the climatic water balance fitted to the three-parameter log-logistic distribution (Vicente-Serrano et al. 2010). Then, the SPEI is calculated by converting the distribution to the standard normal distribution. In this study, SPEI values were obtained with the R Studio software ‘spei’ code.

Rainfall Anomaly Index (RAI)

Rainfall Anomaly Index (RAI), this index proposed by Van Rooy (1965), uses precipitation’s deviation from normal values to reveal the variation in precipitation. P_i values indicate precipitation, (\bar{P}): the average of precipitation in a long time series, (\bar{M}): the average of the ten highest values and (\bar{X}): the average of the ten smallest values. Positive and negative anomaly states of RAI values are calculated as in Eqs. (14) and (15), respectively.

If $P_i > \bar{P}$

$$RAI = +3 \left[\frac{P_i - \bar{P}}{\bar{M} - \bar{P}} \right] \tag{14}$$

If $P_i < \bar{P}$

$$RAI = -3 \left[\frac{P_i - \bar{P}}{\bar{X} - \bar{P}} \right] \tag{15}$$

Reconnaissance Drought Index (RDI)

Reconnaissance Drought Index (RDI) is a meteorological indicator mainly used for the characterisation and monitoring of droughts. This indicator can be calculated in three forms: initial value (α_k), normalised RDI (RDI_n) and standardised RDI (RDI_{st}). The initial value (α_k) within a year for a reference period of k months. This value (α_k) can be obtained from the ratio of precipitation values to potential evapotranspiration. These values can be calculated employing Eq. (16) (Tsakiris and Vangelis 2005; Zarch et al. 2011).

$$\alpha_k = \frac{\sum_{j=1}^{j=k} P_j}{\sum_{j=1}^{j=k} PET_j} \tag{16}$$

Here, P_j is the precipitation value of month j and PET_j is the evapotranspiration value of month j . Normalised RDI values (RDI_n) can be calculated by Eq. (17). In this equation, $\bar{\alpha}_k$ is the average of the initial values.

$$RDI_n(k) = \frac{\alpha_k}{\bar{\alpha}_k} - 1 \tag{17}$$

Standardised RDI values (RDI_{st}) can be calculated by Eq. (18). Here, $y_k = \ln \alpha_k$. Moreover, \bar{y}_k is the arithmetic mean of values of y_k and $\hat{\sigma}_k$ is the standard deviation (Tsakiris and Vangelis 2005). RDI_{st} is used to assess better drought severity and a more straightforward interpretation of results (Tigkas et al. 2012).

$$RDI_{st}(k) = \frac{y_k - \bar{y}_k}{\hat{\sigma}_k} \tag{18}$$

Z Score Index (ZSI)

The Z score or standard score is a dimensionless statistical indicator used to identify droughts. One of its most important advantages is that it can only be calculated with precipitation data and does not fit the distribution. As seen in Eq. (19), it is obtained by dividing the difference of precipitation data from the mean by the standard deviation within the specified period (Wu et al. 2001).

$$ZSI = \frac{P_i - \bar{P}}{\sigma} \tag{19}$$

Threshold values and corresponding categories of all drought indices used in the study are shown in Table 2.

Mann-Kendall test

The Mann–Kendall (MK) test, also known as Kendall’s tau statistics, is a widely used method for determining trends of hydro-meteorological time series (Zhang et al. 2001; Yue et al. 2002). The S statistic of the MK test is the sum of the negative and positive values obtained by Eq. (20). The value of this equation ($x_j - x_k$) is calculated using the signum function in Eq. (21).

Table 2 Drought classification

SPI-SPEI-ZSI-RDI	RAI	Category
$0 \leq \text{Index}$	$0 \leq \text{Index}$	Wet term
$-1 < \text{Index} \leq 0$	$-1.2 < \text{Index} \leq 0$	Mild drought
$-1.5 < \text{Index} \leq -1.0$	$-2.1 < \text{Index} \leq -1.2$	Moderate drought
$-2 < \text{Index} \leq -1.5$	$-3 < \text{Index} \leq -2.1$	Severe drought
$\text{Index} \leq -2.0$	$\text{Index} \leq -3$	Extreme drought

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \tag{20}$$

$$\text{sgn}(x_j - x_k) = \begin{cases} +1 & \text{if } (x_j - x_k) > 0 \\ 0 & \text{if } (x_j - x_k) = 0 \\ -1 & \text{if } (x_j - x_k) < 0 \end{cases} \tag{21}$$

Asymptotically, the test statistic S variance has a normal distribution and a mean of zero. It is calculated by Eq. (22).

$$\text{Var}(S) = \frac{n(n-1)(2n+5)}{18} \tag{22}$$

If there are equal observations in the time series, variance can be calculated by Eq. (23).

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)}{18} \tag{23}$$

Here, n is the data length of the series, k is the number of connected groups of the series and the t value is the number of elements whose numerical values are equal in the examined subset. The MK test, whose variance is determined, is essential by calculating the standard normal variable z with the Eq. (24) and comparing it with the critical z value.

$$z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if } S < 0 \end{cases} \tag{24}$$

The value of $Z_{\alpha/2} = Z_{0.025}$ was determined as 1.96 for the significance level $\alpha = 0.05$ (95% confidence interval) from the standard normal distribution table to evaluate the trend analysis results. If the selected α significance level is $|z| \leq z_{\alpha/2}$, the H_0 hypothesis is accepted: there is a significant trend in the time series. Otherwise, H_0 is rejected, meaning that there is no significant trend in the time series. If the calculated S value is positive, an increasing and a negative decreasing trend exist. This method is helpful because it allows missing data and does not require compliance with a particular data distribution (Yu et al. 1993).

According to Yue and Wang (2004), data should be distributed randomly in the MK test. However, hydro-meteorological time series show statistically significant serial correlation, which generally affects the power of the test. Therefore, it is necessary to examine whether there is a serial correlation before applying the test. For this, the confidence limits of the lag-1 value should be checked with the autocorrelation graph in the 95% confidence interval or Eq. (25).

$$\frac{-1.96}{\sqrt{n}} < r_1 < \frac{+1.96}{\sqrt{n}} \tag{25}$$

Here, r_1 is lag 1, which shows the autocorrelation coefficient, and n is the number of observations. If the calculated values fall below the 0.05-significance level, our data series is assumed to consist of independent variables. Otherwise, our data series shows a serial correlation. If significant autocorrelation is determined in our series, the modified Mann–Kendall (MMK) test developed by Hamed and Rao (1998) is one of the most useful methods.

Results

This study used standardised drought indicators (SPI, ZSI, RAI, SPEI, RDI) based on precipitation and temperature to determine drought. Katipoğlu et al. (2020) should be examined to obtain detailed information on the calculation, evaluation and comparison of meteorological drought indicators used in this study with various statistical analyses.

Trend analysis results

In serial correlation analysis, the autocorrelation of the 95% confidence interval was examined before drought indices of selected stations were subjected to the MK trend test. The r_1 value of the drought indices was evaluated as autocorrelated if it was out of the confidence interval at the 95% confidence interval $(-1.96/\sqrt{N}, +1.96/\sqrt{N})$. Trend analysis was applied with the MMK test of the autocorrelated drought indices and the MK test of the autocorrelated indices. Hamed and Rao (1998) proposed that the MMK test was applied to the stations where autocorrelation was determined. Since this method does not involve any preliminary analysis to data, the data structure was not changed.

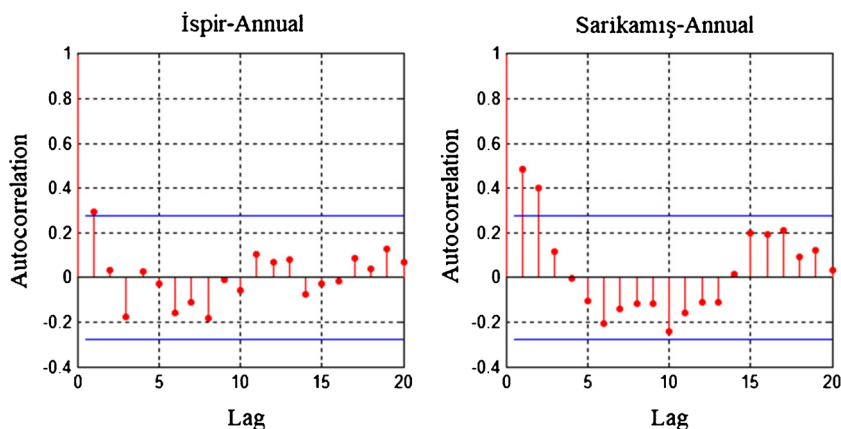
This study applied trend analysis methods (MK and MMK) with the MATLAB 2014a software, and trend results were mapped in the ArcMap 10.5 geographic information systems (GIS) environment.

Trend analysis of the SPI

The prerequisite for trend analysis is that the data do not have serial correlation. For this, as seen in Fig. 7, the presence of serial correlation in monthly and annual drought indices was examined visually with the help of an autocorrelation function graph. These graphs concluded that the index was autocorrelated since the lag-1 value exceeded the horizontal line (95% confidence limits). While the MMK test is applied to indices that are autocorrelated, the MK test is applied to indices that are not autocorrelated.

For evaluating trend analysis results, $Z_{\alpha/2} = Z_{0.25}$ was determined as 1.96 for the $\alpha = 0.05$ (5%) significance level of the

Fig. 2 RDI values of stations showing lag-1 autocorrelation



standard normal distribution table. If the Z values ($-1.96, 1.96$) are within the confidence interval, the null hypothesis ‘ H_0 : No trend’ is accepted at the level of significance of $\alpha = 0.05$. If the Z values ($-1.96, 1.96$) are outside the confidence interval, ‘ H_0 : No trend’ is rejected, meaning that a trend is present. Therefore, the Z values shown in bold for the SPI values in Table 8 reveal that there are significant trends.

The fact that the Z values are less than zero indicates the decreasing trend in the SPI series, and those larger than zero indicate an increasing trend. Since the SPI is an index based solely on precipitation, the trend can be explained by the increase and decrease in precipitation mainly due to climate change.

Table 3 Trend analysis results of RDI values

RDI–Mann–Kendall test (Z values)	
Station	Annual
Sarıkamış	-1.54
Zara	-1.29
Tortum	-1.37
Solhan	-0.94
Hınıs	0.15
İspir	-0.50
Horasan	-1.62
Kangal	-2.31
Erzincan	-1.22
Erzurum	2.41
Tunceli	-0.95
Ağrı	-1.33
Malazgirt	-0.81
Muş	-1.59
Bingöl	-1.76
Adıyaman	-1.62

Note: bold characters indicate trends at 5% significance level

Table 8 shows no decreasing trend at the 95% confidence interval in February, March, May, June, July, August, September, October and November. However, significant decreasing trends were observed at Sarıkamış in January, Bingöl in April and the Zara, Tortum, Kangal and Tunceli stations in December. When annual SPI trend analysis results were evaluated, no decreasing trend was observed at the 95% confidence interval.

Trend analysis of the SPEI

Before analysing the monthly and annual SPEI values, the serial correlation of the index values was examined visually with the help of the autocorrelation function graph (Fig. 8).

The Z values shown in the bold character of SPEI values in Table 9 show significant trends. The fact that the Z values are less than zero indicates the decreasing trend in the SPEI series, and the larger than zero indicates the increasing trend. Since SPEI is an index based on precipitation and evaporation-transpiration, significant decreasing trends can be mainly explained by the decrease in precipitation and the increase in evaporation-transpiration values due to global warming. It is concluded that SPEI detected more downward droughts than rain-based indices due to evaporation and transpiration.

Table 9 shows no decreasing trend in February, March, May, September, October and November at the 95% confidence interval. However, significant decreasing trends were observed at the station in January (1), April (1), June (2), July (3), August (10), December (4) and the annual index (3).

Trend analysis of the ZSI

Before analysing the monthly and annual ZSI values, the serial correlation of the index values was examined visually with the help of the autocorrelation function graph (Fig. 9).

The Z values shown in the bold character of ZSI values in Table 10 show significant trends. The Z values are less than zero indicates the decreasing trend in the ZSI series, and larger

Table 4 Decreasing tendency percentages observed at all stations regardless of the 95% confidence interval

Decreasing tendency values (%)													
Index	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
SPI	68.8	62.5	43.8	43.8	68.8	68.8	31.3	87.5	18.8	31.3	87.5	87.5	75.0
ZSI	68.8	62.5	50.0	50.0	68.8	62.5	43.8	87.5	18.8	25.0	87.5	81.3	75.0
RAI	68.8	68.8	43.8	37.5	68.8	68.8	37.5	87.5	25.0	25.0	87.5	87.5	75.0
SPEI	68.8	68.8	75.0	43.8	81.3	87.5	87.5	93.8	56.3	31.3	87.5	93.8	87.5
RDI	-	-	-	-	-	-	-	-	-	-	-	-	87.5

Note: bold characters show the largest percentages

than zero indicates the increasing trend. Drought trend results are the same as SPI since the ZSI calculation procedure is based on a precipitation standardisation process like SPI.

Table 10 shows no decreasing trend at the 95% confidence interval in February, March, May, June, July, August, September, October and November. However, significant decreasing trends were observed in Sarıkamış stations in January, Bingöl in April and Zara, Tortum and Kangal stations in December. When annual SPI trend analysis results were analysed, no decreasing trend was observed at the 95% confidence interval.

Trend analysis of the RAI

Before analysing the monthly and annual RAI values, the serial correlation of the index values was examined visually with the help of the autocorrelation function graph (Fig. 10).

The Z values shown in the bold character of RAI values in Table 11 show significant trends. The fact that the Z values are

less than zero indicates the decreasing trend in the RAI series, and larger than zero indicates the increasing trend.

Table 11 shows no decreasing trend at the 95% confidence interval in February, March, May, June, July, August, September, October and November. However, significant decreasing trends were observed in Sarıkamış in January, Bingöl in April and Zara, Tortum and Kangal stations in December. When annual SPI trend analysis results were analysed, no decreasing trend was observed at the 95% confidence interval.

Trend analysis of the RDI

Before analysing the annual RDI values, the serial correlation of the index values was examined visually with the help of the autocorrelation function graph (Fig. 2).

The Z values shown in the bold character of RDI values in Table 3 show significant trends. The Z values are less than zero indicates the decreasing trend in the RDI series, and larger than zero indicates the increasing trend.

Fig. 3 Drought tendency percentage decreasing according to various drought indices

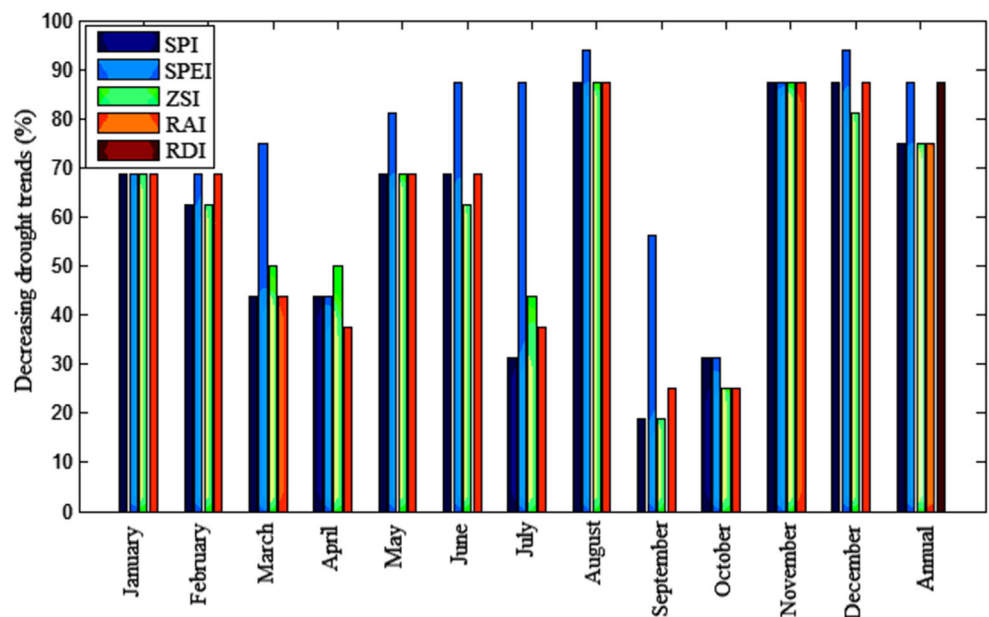


Table 5 Numbers of meteorological drought trends decreasing at the 95% confidence interval

Index	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
SPI	1	-	-	1	-	-	-	-	1	-	-	4	-
ZSI	1	-	-	1	-	-	-	-	-	-	-	3	-
RAI	1	-	-	1	-	-	-	-	-	-	-	3	-
SPEI	1	-	-	1	-	2	3	10	-	-	-	4	3
RDI	-	-	-	-	-	-	-	-	-	-	-	-	1

Table 3 shows that a decreasing trend was observed at Kangal station at the 95% confidence interval. When increasing and decreasing RDI trends are interpreted regardless of their confidence interval, a decreasing trend was observed in 87.5% of stations (except Hınıs and Erzurum).

Comparing trend analysis results

A decreasing tendency in drought indices values shows an increase in drought severity. For this, the tendencies of the drought values calculated with various drought indices are investigated by trend analysis. Table 4 shows the decreasing trend percentages in the monthly and annual periods regardless of the 95% confidence interval of the meteorological drought indices used in the study. In other words, trend percentages calculated for all negative z values are shown.

It is seen in Table 4 and Fig. 3 that all meteorological drought indices give similar results. However, the tendencies percentages of SPI, ZSI and RAI values calculated using only precipitation values are slightly below the percentage values of the SPEI, and RDI calculated using precipitation and temperature values. This indicates that the droughts calculated with the values of SPEI and RDI have increased severity.

Climate change causes a decrease in precipitation and an increase in temperature in some regions of Turkey compared to previous years. It was concluded that this situation caused significant trends in drought indices values based on precipitation and temperature.

In Table 5, it is seen that decreasing trends occurred in the January, April and December values of the SPI, SPEI, ZSI and RAI. In addition, according to the SPEI trend analysis results,

it is seen that this is the index that shows the most decreasing trend, namely, increased drought severity. This demonstrates the necessity of water resource management and drought action plans.

Since PET values are used in the SPEI calculation, climatic effects are also taken into account. When Table 5 is examined, the highest drought trend with 95% confidence interval was obtained according to SPEI. These trends indicate that SPEI values are more effective in revealing drought trends.

It is seen in Table 6 that decreasing trends in the values of SPI, ZSI and RAI occurred in September. In addition, there are a few increasing trends in the annual periods in the SPEI and RDI.

Maps of trend analysis

Maps of precipitation-based indices trends

In this section, precipitation-based SPI, ZSI and RAI values are mapped to increasing and decreasing trends according to confidence intervals of 90% ($z > 1.65$) and 95% ($z > 1.96$). The stations with a decreasing trend in these maps are denoted with a red inverted triangle, and stations with an increasing trend are designated with a triangle (Figs. 11, 12, 13, 14, 15, 16).

Spatial distribution maps similar results in monthly and annual time scale rainfall-based indices were obtained when analysed. A downward tendency in drought indices prevails in the maps for January, February, May, June, August, November, December and annual indices. These maps indicate increasing drought severity in these months (Figs. 11, 12, 13, 14, 15, 16).

Table 6 Numbers of meteorological drought trends increasing at the 95% confidence interval

Index	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
SPI	-	-	-	-	-	-	-	-	1	-	-	-	-
ZSI	-	-	-	-	-	-	-	-	1	-	-	-	-
RAI	-	-	-	-	-	-	-	-	1	-	-	-	-
SPEI	-	-	-	1	-	-	1	-	-	-	-	-	1
RDI	-	-	-	-	-	-	-	-	-	-	-	-	1

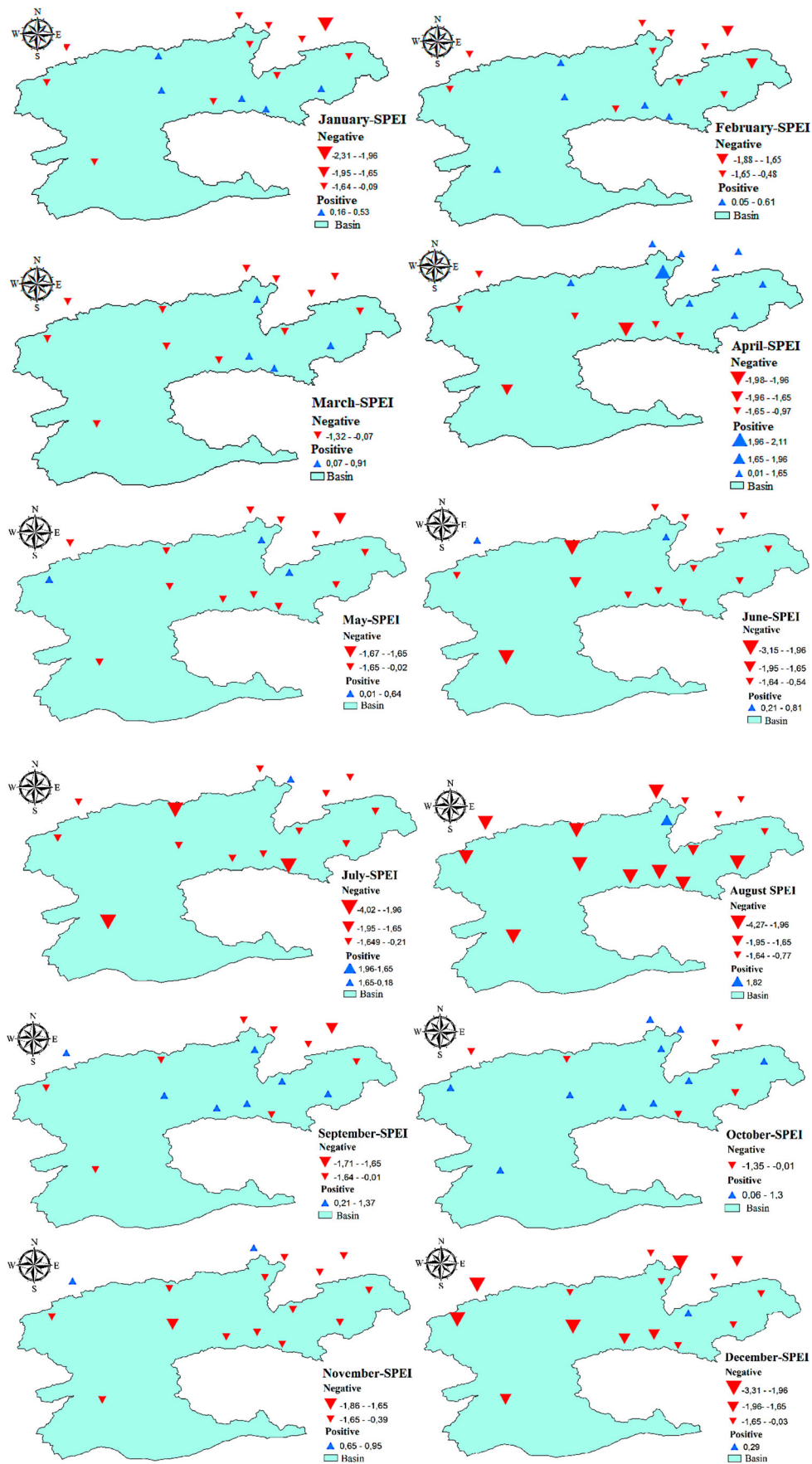
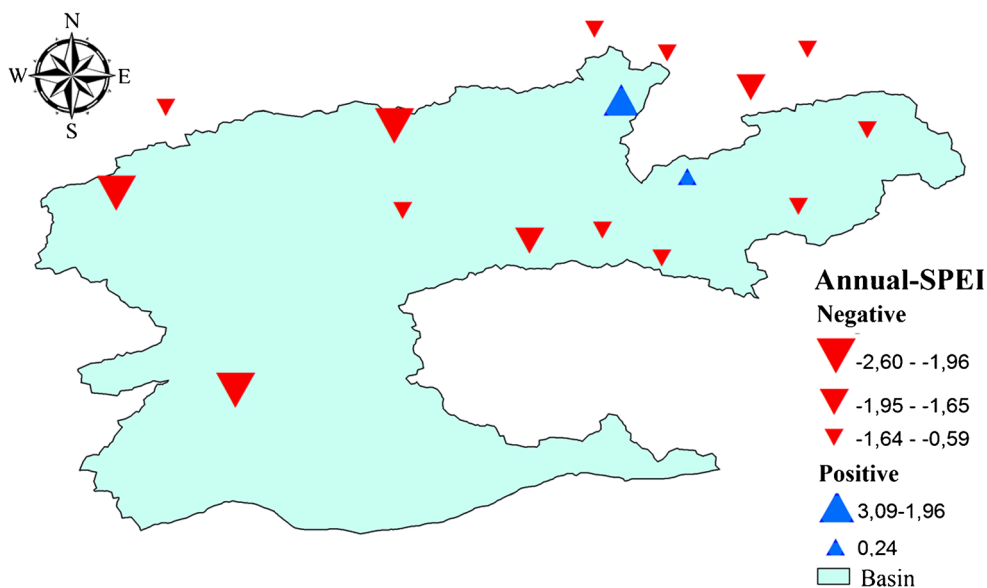


Fig. 4 Spatial distribution of trend analysis results for monthly SPEI values

Fig. 5 Spatial distribution of trend analysis results for annual SPEI values



Maps of precipitation and temperature-based indices trends

In this section, precipitation and temperature-based SPEI and RDI values are mapped to increasing and decreasing trends according to confidence intervals of 90% ($z > 1.65$) and 95% ($z > 1.96$). RDI indices may be undefined due to negative temperature values in the monthly period. For this reason, only annual trend analysis has been used. The downward tendency in drought indices prevails in the maps for January, February, March, May, June, July, August, September, November, December and annual indices. These maps indicate increasing drought severity in these months (Figs. 4, 5, 6).

When the SPEI and RDI trends are compared in the annual period, the same locations show increasing and decreasing

trends. However, SPEI was found to be more sensitive in detecting trends with 95% confidence interval.

Comparison of meteorological drought trend maps

Trend analysis results are compared in Table 7. It was determined that the trend analysis results of the SPI, ZSI and RAI are similar. However, because of the trend analysis of the SPEI, decreasing tendencies were observed to prevail in March, July and September. In addition, the annual drought tendency for all indices shows a decrease, suggesting that the risk of drought may lead to more extraordinary disasters in future years. For this, droughts should be monitored, and risks should be managed by taking precautionary measures.

Fig. 6 Spatial distribution of trend analysis results for annual RDI values

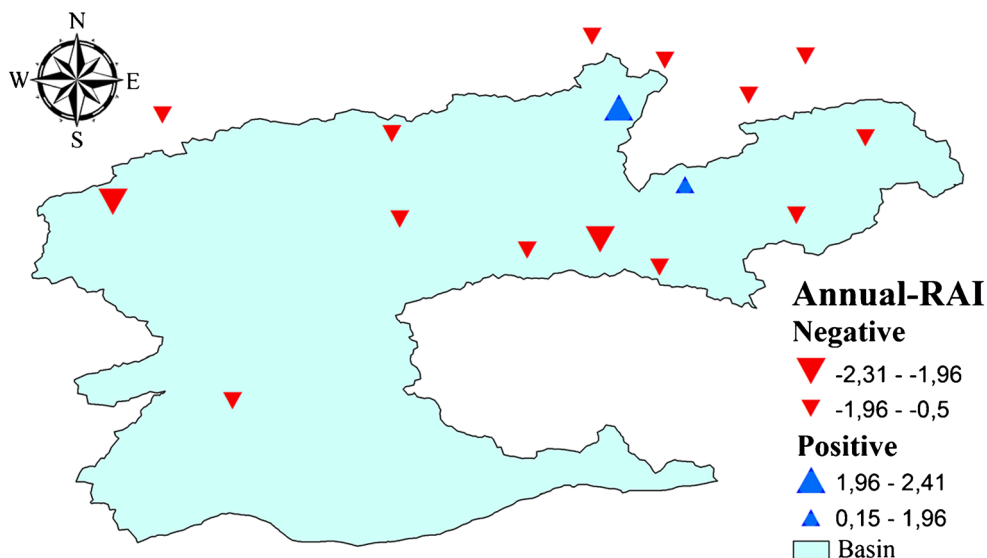


Table 7 Results of trend analysis of meteorological droughts

Index	Period dominated by decreasing tendency
SPI	January, February, May, June, August, November, December and annual
ZSI	January, February, May, June, August, November, December and annual
RAI	January, February, May, June, August, November, December and annual
SPEI	January, February, March, May, June, July, August, September, November, December and annual
RDI	Annual

Discussion

In the Eastern Mediterranean, increasing temperature trends and decreasing precipitation trends have been detected (Evans 2009; Stocker et al. 2013). Sönmez et al. (2005) found that in Turkey, a warming trend that began in the early 1990s has dominated for almost a decade, and annual average temperatures have risen above the average since 1995. In addition, they used SPI to analyse Turkey's spatial and temporal variations of meteorological droughts. In 1999 and 2000, significant droughts were generally associated with a lack of precipitation in winter and spring, the wettest seasons. As a result, on a regional scale, moderate droughts are seen in shorter periods in Southeast and Eastern Anatolia, while severe droughts occur in shorter periods in the non-coastal parts of the country. This situation supports the study in terms of increasing drought trends.

Nikbakht et al. (2013) applied the non-parametric Mann–Kendall and Sen's tests to state temporal trends of the Percent of Normal Index (PNI) in the northwest of Iran. As a result, a downward trend was determined at 12 out of the 14 studied stations. Mathbout et al. (2018) analysed SPI and SPEI values by the MK test; negative drought trends were detected in all stations of Syria. Khanmohammadi et al. (2018) used SPI and RDI values to examine the trends of dry and wet periods by MK and MMK tests in 30 synoptic stations of Iran. The trend analysis results indicated that the variation of dry and wet periods decreased in most stations at a 95% confidence level. Also, the behaviour of the SPI and RDI was roughly the same and the trend line slope of dry and wet periods for the SPI, and RDI indices were negative in 70% and 50% of the stations, respectively. The study's findings conducted in Syria and Iran, which is adjacent to the Euphrates Basin, support the fact that the drought indices have a decreasing trend, as in the present study. Yilmaz (2019) used a recent graphical trend detection method known as the innovative Şen method (ISM) and the MK trend test to analyse drought trends in Southeastern Turkey in the region of the Southeastern Anatolia Project (Turkish acronym: GAP) by using 12- and 24-month SPI values. The results showed that the central GAP region has a significant decreasing trend and a tendency toward heavier droughts in the future. This study conducted in the GAP region concluded, similarly to our study, that decreasing drought trends are widely influential in the region in terms of the

Euphrates Basin. Moreover, as the area is close to the Mediterranean, it was determined that drought trends are dominant in the study area where climate change effects are dominant. Gümüş et al. (2021) analysed the trend of 1-, 3-, 6- and 12-month SPI values at the Diyarbakir station with the Innovative Trend Analysis method. As a result, the drought index values did not change in Diyarbakir station in general. However, extremely arid and very arid indices tended to increase slightly, especially for medium and long-term droughts (SPI-3, SPI-6 and SPI-12). A weak decreasing trend was found. The results obtained are in good agreement with the study.

In this study, considering decreasing drought tendencies and trends prevailing in the basin, it is concluded that possible droughts that may occur in the future due to climate effects are likely to become more severe and cause water problems in the basin and the Middle East. Therefore, this study's results improve the sustainable planning of water resources, the development of water policies and drought preparations for decision-makers and the development of drought risk and adaptation strategies.

Conclusions

This study subjected the trend analysis to the precipitation-based SPI, ZSI and RAI and precipitation and temperature-based SPEI and RDI indices. The results were shown on maps at critical confidence intervals (95% and 90%). It was revealed that the SPEI is more sensitive than the other indices in determining drought trends since it also considers PET values, which can show the increasing climate change effects in recent years. Furthermore, this study determined an increase in drought trends in January, February, May, June, August, November, December and annual periods. These trends show that the Euphrates Basin is at significant risk of drought. For this reason, drought measures should be taken before drought causes a crisis, drought reduction strategies should be applied and water resources should be managed effectively.

The spatial trend changes in the drought indices used in the study show significant regional variation since precipitation depends on many parameters (pressure characteristics, altitude, location relative to the sea, the direction of the mountains, winds, geographical location, topography), the

temperature depends on many parameters (elevation, humidity, slope, aspect, latitude, angle of the sun) and the basin is vast and mountainous. For this reason, a definite relationship could not be established between the spatial characteristics of droughts and geographical features. However, it was concluded that decreasing drought trends prevailed in the region due to the decrease in precipitation and increase in temperatures.

Agricultural development decision-making processes, water resource management strategies and drought hazard mitigation plans can be applied according to the spatial change of drought trends. In addition, examination of the relationship between drought trends and other climate parameters in global warming conditions will be pursued in future studies.

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Declarations

Conflict of interest The authors declare no competing interests.

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