Bilecik Şeyh Edebali Üniversitesi Fen Bilimleri Dergisi
Bilecik Seyh Edebali University Journal of Science
10(1), 82-94, 2023
DOİ: 10.35193/bseufbd.1146214
e-ISSN: 2458-7575 (https://dergipark.org.tr/tr/pub/bseufbd)

Araştırma Makalesi - Research Article

Temporal Analysis of Meteorological and Hydrological Drought in the Middle Mediterranean Basin

Orta Akdeniz Havzası'nda Meteorolojik ve Hidrolojik Kuraklığın Zamansal Değişimi

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Geliş / Received: 20/07/2022 ***Revize / Revised: 25/11/2022*** ***Kabul / Accepted: 25/11/2022***

ABSTRACT

In this study, Mann-Kendall (M-K) trend test was used to observe the temporal variation of precipitation, temperature, and flow data of Manavgat Stream, Köprüçay and Dim Stream sub-basins in the Middle Mediterranean Basin. Also, meteorological drought analysis by using Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI), and hydrological drought analysis by using Streamflow Drought Index (SDI) were performed for this study region. M-K trend test was re-applied to define the temporal variation of standardized meteorological and hydrological drought values obtained in 3-, 6-, 9- and 12-months periods.When the trend analysis results were examined, there was an increasing trend in all stations for the SPI method in the 12-month period, while a decreasing trend was observed in the Manavgat and Alanya stations in the RDI method. In the SDI method, a decreasing trend was detected in all periods.The temporal relationship of these drought indices was tried to be explained for the processes in which significant changes were observed according to the trend test. Therefore, the relationships between flow data and SPI as well as RDI were examined at different lag times. When the relationship between flow values of Dim and Manavgat Stream and both SPI and RDI values was examined, it was obtained a high correlation for four-month delay.

Keywords- Middle Mediterranean Basin, Standardized Precipitation Index, Reconnaissance Drought Index, Streamflow Drought Index, Trend Analysis

ÖZ

Bu çalışmada, Orta Akdeniz Havzası'nda bulunan Manavgat Nehri, Köprüçay ve Dim Çayı alt havzalarına ait yağış, sıcaklık ve akım verilerinin zamansal değişimini gözlemlemek için Mann-Kendall (M-K) trend testi kullanılmıştır. Aynı zamanda, bu bölge için Standartlaştırılmış Yağış İndeksi (SYİ) ve Keşif Kuraklık İndeksi (KKİ) ile meteorolojik kuraklık, Akım Kuraklık İndeksi (AKİ) ile hidrolojik kuraklık analizleri gerçekleştirilmiştir. 3-, 6-, 9- ve 12- aylık periyotlarda elde edilen standartlaştırılmış meteorolojik ve hidrolojik kuraklık değerlerinin zamansal değişimini tanımlayabilmek için M-K trend testi tekrarlanmıştır. Trend analizi

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sonuçları incelendiğinde 12 aylık periyotta SYİ yöntemi için tüm istasyonlarda artan trend varken, KKİ yönteminde ise Manavgat ve Alanya istasyonunda azalan trend görülmüştür. AKİ yöteminde tüm periyotlarda azalan trend tespit edilmiştir.Trend testine göre anlamlı değişimlerin gözlendiği süreçler için bu kuraklık indekslerinin birbirleriyle olan zamansal ilişkisi ortaya konulmaya çalışılmıştır. Bunun için, akış verileri ile SPI ve ayrıca KKI arasındaki ilişkiler farklı gecikme sürelerinde incelenmiştir. Dim ve Manavgat Çayı için SYİ ve KKİ ile akım değerleri arasındaki ilişki irdelendiğinde 4 ay gecikme ile yüksek korelasyon elde edilmiştir.

Anahtar Kelimeler- Orta Akdeniz Havzası, Standartlaştırılmış Yağış İndeksi, Keşif Kuraklık İndeksi, Akım Kuraklık İndeksi, Trend Analizi

I. INTRODUCTION

Drought is defined as the scarcity of water due to the lack of precipitation in a region. Although drought is one of the most difficult natural disasters to predict, it often develops slowly and occurs in over a long period of time [1]. Drought, which is considered a common feature of the climate, is a recurrent event. This phenomenon occurs not only in arid regions, but in all climatic zones [2]. Drought is examined in three parts as meteorological, agricultural, and hydrological drought that occurs sequentially over time. Some indices are used in the determination of these drought types. There are various studies related to Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI) which are used for the determination of meteorological drought. SPI is an index developed by McKee et al. [1] to determine the time interval, region, severity, and frequency of drought. Aktürk et al. [3] presented a drought analysis study in the Kırıkkale province of Turkey with the use of SPI and SPEI methods for the 1963-2018 period. They obtained high correlations between the two indices for the same time scale and concluded that SPI and SPEI methods are applicable in the detection and monitoring of drought in the study area. Akturk et al. [4] employed the SPI method to examine drought characteristics in the Kızılırmak river basin of Turkey for the 1960–2017 period. They determined that the basin was under the impact of widespread droughts across the country during the study period. Katipoğlu et al. [5] used the average precipitation and temperature values for 3- and 12- months periods in 52 years (1966-2017) of Erzincan station located in the Euphrates Basin in Turkey. They analyzed these data using SPI, RDI, Statistical Z-Score Index (ZSI), Rainfall Anomaly Index (RAI) and Standardized Precipitation Evapotranspiration Index (SPEI) methods. According to the analysis results, it was seen that the precipitation-based SPI and ZSI methods were in accordance with each other. Also, temperature-based SPEI and RDI were similar in themselves. It has been observed that the RAI method is more effective than other methods in detecting extreme drought or rainy periods. SPEI and RDI have been shown to be superior to other indices because they reflect the water climate changes on the analysis. Jehanzaib et al. [6] conducted drought analyzes for South Korea using SPI, SPEI, Standardized Runoff Index (SRI) indices for different time intervals. It has been observed that the possibility of the transformation of meteorological drought into the hydrological drought increases under the effect of climate change. Çavuş and Aksoy [7] conducted SPI analysis on the precipitation data obtained from the Adana meteorology station located in the Seyhan river basin of Turkey. For the years 1960-2016, analyzes were made for 1-, 3-, 6-, 9-, 12- and 24- months periods. Eris et al. [8] conducted analyzes for 13 different stations in the KüçükMenderes river basin of Turkey using Dimensionless Precipitation Anomaly Index (DPAI), SPI, SPEI methods between 1960 and 2018. According to the analysis results, it was observed that there was a severe and extreme drought in the basin. In addition, they indicate that it was determined that drought intensity increased, and its frequency decreased over time. Çavuş and Aksoy [9] examined the spatial drought for the Seyhan River Basin in the Eastern Mediterranean region of Turkey. SPI was derived from monthly precipitation data on a 12- month period for 19 meteorology stations on the river basin. In terms of the lack of precipitation, it was determined that there was a moderate and severe drought in the Seyhan River Basin. It was observed that the coastal part of the basin was affected more by the drought, while the northern part was less affected. Aksever [10] examined a SPI drought analysis by using precipitation data between 1975 and 2018 for the Kaklık Plain in the Denizli province of Turkey. According to the analysis, it was found that 13 months were dry in this time interval. Gümüş et al. [11] conducted a drought analysis with SPI by using monthly precipitation data from the stations in the Sanlıurfa province of Turkey for 78 years. For the data of the last 30 years, they found that the drought frequency increased. Efe and Özgür [12] conducted monthly and annual drought analyzes for the Konya Province in Turkey by using SPI and Percentage of Normal Index (PNI) with the precipitation data obtained from 20 stations for 1972-2013 years.They determined dry in most of the stations in April especially in recent years according to the SPI method. According to the PNI method,they found that drought recurs frequently in the summer months, especially in August in the majority of the stations. Another meteorological drought method is the RDI proposed by Tsakiris and Vangelis [13]. In this method, potential evapotranspiration (PET) data and precipitation data were used. Malakiya and Suryanarayana [14] used the RDI and SPI methods to assess drought in Amreli region in India. They tried to determine drought categories based on 35-year data including precipitation and PET values. For both methods, more meaningful results were obtained for the 12- month period, and it was stated that moderate drought category was seen more frequently in the region. Kousari et al. [15] conducted drought analysis for Iran with the RDI, nonparametric Mann-Kendall (M-K) method and Sen's trend test. According to their outcomes, the RDI results showed a decreasing trend, especially in long periods of 12-, 18- and 24- months. They stated that decreasing trend in RDI time series means the increasing trend in drought severities. Tsakaris et al. [16] used the RDI, SPI and decimal slices methods for regional drought assessment in Mornos and Nestos basins in Greece. According to their analysis,decimal slices methodsgave similar results with the SPI and RDI methods. However, they stated that the RDI method was more suitable for sensitive areas and regions that climate change occurs.

Hydrological drought appears as the lack of underground and surface water resources with the effect of meteorological drought in a region in the next stage. Mishra and Singh [17] drew attention to the consequences such as hydrological drought, the deterioration of water quality in the region, the decrease in agricultural yield, the decrease in stream flows and the adverse effects on morphology. Many studies have been carried out for the determination of hydrological drought with the Streamflow Drought Index (SDI) applied to standardize the stream flow data. In the SDI method proposed by Nalbantis [18], volumetric flow data were used. Malik et al. [19] conducted a drought analysis the SDI method using data from two stations located at the top of the Ramganga River basin in India between 1975 and 2007.They stated that there was no severe and extreme drought for both stations. They identified that the frequency of moderate drought was high for both stations. Gümüş [20] conducted a drought analysis with the SDI method using a 52-year data set taken from four different stations in the Asi River basin. According to the results of the analysis, he determined the year 2000 was a severe drought year, while the year 2001 was an extreme drought year. Tabari et al. [21] conducted a drought analysis with the SDI method using data from 1975-2009 for 14 stations located in the northwest of Iran. According to the SDI results, they found that there was drought in each station. In addition, they observed that extreme drought occurred for 12-years between 1997 and 2009.

The precipitation, temperature and flow data used in meteorological and hydrological drought analysis are randomly changing variables that may increase or decrease over time. TheM-K test, one of the special methods used in the study, is a non-parametric test that examines the increase or decrease trend of a time dependent variable. Yıldız et. al [22] analyzed drought severity, trend and results with SPI, 12- month period over a 48-year period in the Susurluk Basin of Turkey. Innovative trend analysis and M-K tests were used to determine the trends of SPI values. Malik et. al [23] used M-K and graphical Şen-Innovative Trend (ŞIT) tests to determine the Effective Drought Index (EDI) trend of 13 meteorological stations in India. The results obtained by examining the trend that could not be detected and observed by the MK method in the EDI data series showed the superiority of the ŞIT method. Kişi and Ay [24] used Şen's [25] innovative water parameters method and M-K test. They conducted trend analysis for 4 stations selected across the Kızılırmakriver basin. They found that the two methods were compatible with each other. Büyükyıldız and Berktay [26] examined the trend of monthly total precipitation data of Sakarya Basin by using the Sen, Spearman Rho and seasonal M-K tests in addition to the M-K test. For the precipitation data obtained from 25 stations, decreasing trends with a significance level of 0.05 were determined at the half of the stations while an increasing trend was observed in the remaining part. Yue and Wang [27] applied the cross-correlated M-K Rank Correlation test to approximately 100-year precipitation data of 22 stations for three different geographic regions in Canada.

In this study, meteorological and hydrological drought analysis, which is of great importance for the water resources planning and monitoring, was carried out by using the monthly average flow, monthly average precipitation, and temperature data. The Manavgat Stream, Dim Stream and Köprüçay stations in the Middle Mediterranean Basin in Turkey were selected as the study area. The SPI and RDI methods were used for the meteorological drought and the SDI was used for the hydrological drought analyses. The temporal variation was investigated by applying the M-K test to historical precipitation, temperature, flow records and calculated PET values, as well as the standardized drought indices obtained by the RDI, SPI and SDI methods for 3-, 6-, 9- and 12- month periods.The relationship between meteorological and hydrological drought was investigated using SPI, RDI and flow values for different lag times.

II. METHOD

A. Study Area and Data

The study area includes the Manavgat stream, Köprüçay stream and Dim stream sub-basins which are located in the Middle Mediterranean Basin**.**The Mediterranean climate is effective in this region, where the annual average precipitation is 881.7 mm, the annual average temperature is 18.1 °C and the relative humidity is 60.6% [28]. The Manavgat stream, which originates from the Taurus Mountains is 93 km long. It flows into the Mediterranean Sea through Manavgat district center [29]. The Köprüçay stream originates from the Taurus Mountains near Isparta Sütçüler and flows into the Mediterranean Sea through narrow and deep canyons near Serik. Likewise, the Dim stream originates from the Taurus Mountains and flows into the sea in Alanya. The map of the study area is given in Figure 1.

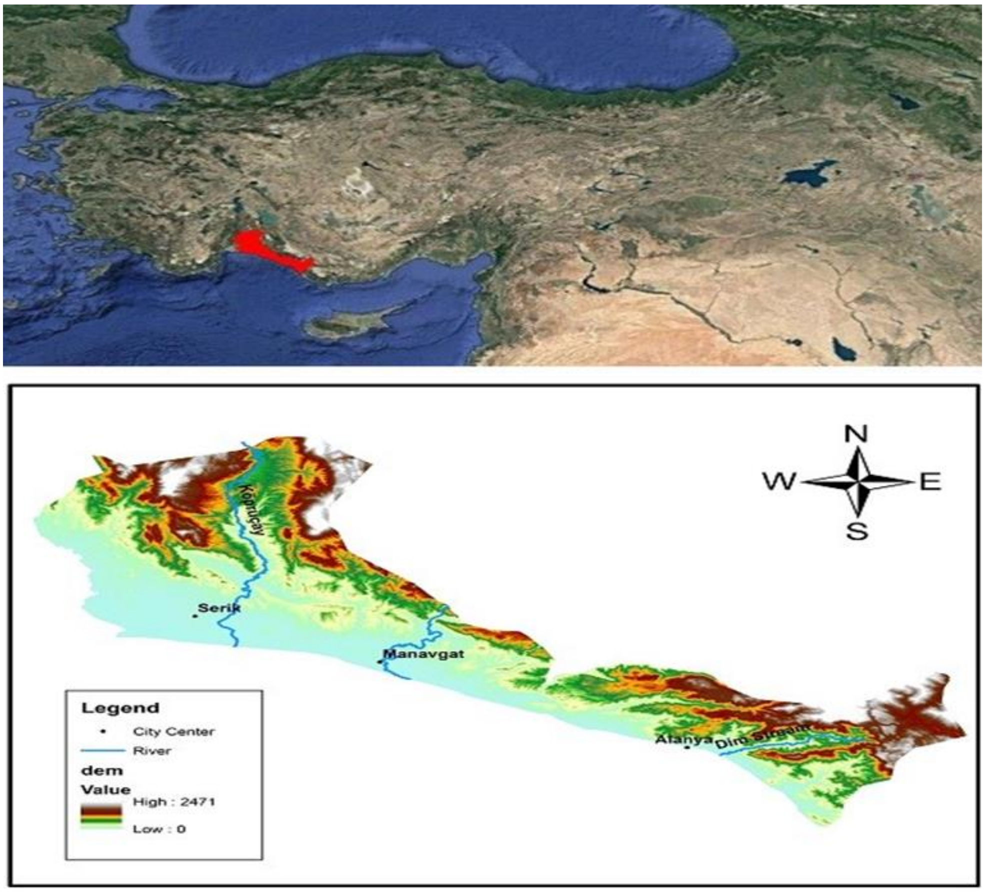

Figure 1. The map of study area

For the meteorological drought analysis, monthly total precipitation, maximum, minimum and average temperature values of Manavgat, Serik and Alanya meteorology stations were taken from the Turkish State Meteorological Service. Also, for the hydrological drought analysis, monthly flow values of Manavgat Stream, Köprüçay and Dim Stream were obtained from the General Directorate of State Hydraulic Works. These data included values between 1972-1994 for Köprüçay, 1963-2002 for Manavgat River and 1963-1998 for Dim Stream. Some statistical values of historical data were summarized in Table 1 and Table 2.

Table 1. Statistical values of precipitation and temperature data

Name of Station	Time Intervals	Precipitation (mm)				Temperature (℃)			
		Max.	Average	Min.	Standard Deviation	Max.	Average	Min.	Standard Deviation
Manavgat	1963-2002	780.8	92.04	0	47.57	30.3	18.49	7.7	0.13
Serik	1972-1994	603.4	93.48	0	48.03	29.9	18.40	6.8	0.24
Alanya	1963-1998	710.4	93.06	0	47.41	30.5	18.87	8.3	0.14

Table 2. Statistical values of flow data (m^3/s)

Name of Station	Time Intervals	Max.	Average	Min.	Standard Deviation
Manavgat Stream	1963-2002	0.084	0.020	0.0000	0.006
Köprüçay	1972-1994	0.100	0.023	0.0080	0.007
Dim River	1963-1998	0.080	0.011	0.0009	0.005

B. Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is a multiscale probability index that calculates precipitation deviation during wet and dry periods and allows drought monitoring at different periods [1]. This index is accepted as the starting point for the meteorological drought monitoring by the World Meteorological Organization. It is widely used because it is simple and uses only monthly precipitation data [30].

With this index, calculations are made for a continuous monthly precipitation data set for at least 30 years at different periods. Each of the precipitation data sets is considered to fit the Gamma function. Thus, the relationship between precipitation and the probability of its occurrence can be determined [31].

SPI is obtained by subtracting the mean of precipitation from the amount of precipitation within the specified time interval or period and dividing it by the standard deviation [32]. SPI is calculated as in Equation (1).

$$SPI = \frac{X_i - \overline{X_t}}{S_x} \tag{1}$$

Here, X_i is the amount of precipitation, X_t is the mean precipitation in the time interval t, and S_x is the standard deviation of the precipitation. The classification of SPI values is given in Table 3.

Table 3. Classification of SPI values [1]

SPI Value	Classification
≥2.00	Extremely humid
1.50 – 1.99	Humid
1.00 – 1.49	Moderately humid
- 0.99 – 0.99	Milddrought
- 1.00 – - 1.49	Moderate drought
- 1.50 – - 1.99	Severe drought
≤- 2.00	Extremedrought

C. Reconnaissance Drought Index

Since the calculation approaches applied for each basin differ from each other, the results are unique for each basin [33]. Reconnaissance Drought Index (RDI) is a method based on precipitation and potential evapotranspiration data [13-16]. Reconnaissance drought index is calculated by Equation (2).

$$a_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}} i = 1(1)N \text{ and } j = 1(1)k \tag{2}$$

where P_{ij} and PET_{ij} represent precipitation and potential evapotranspiration values, respectively. N parameter indicates the number of years of data set. Equation (2) is used to calculate the RDI initial value. RDI_n value is calculated as follows.

$$RDI_n^{(i)} = \frac{a_k^{(i)}}{\overline{a_k^{(i)}}} - 1 \tag{3}$$

In Equation (3), $\overline{a_k^{(i)}}$ represents the mean of the $a_k^{(i)}$ parameter. RDI_{st} refers to the standardized index and is calculated as follows.

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \overline{y}}{\widehat{\sigma_y}} \tag{4}$$

Where $y^{(i)}$ is the ln $(a_k^{(i)})$, $\overline{y}$ is the arithmetic mean value. $\widehat{\sigma_y}$ is the standard deviation value [34].

1)Thornthwaite method:

According to the method proposed by Thornthwaite and Matter [35], the PET value (mm/month) is calculated according to Equation (5) by using the daily average temperature (T) values.

$$PET = 16\left(\frac{10T}{I}\right)^{a} \tag{5}$$

where *a* is given by a third- order polynomial in the heat index(*I)* as below.

$$I = \sum_{i=1}^{12}\left(\frac{T}{5}\right)^{1.514} \tag{6}$$

$$a = 0.675 \times 10^{-6} I^{3} - 0.771 \times 10^{-4} I^{2} + 0.017921 + 0.49239 \tag{7}$$

The PET value for different values of T is calculated according to Equation (8).

$$PET = \begin{cases} 0 & T < 0\,°C \\ 16\left(\frac{10T}{I}\right)^{a} & 0°C \leq T < 25.5°C \\ -425.85 + 32.24 - 0.43T^{2} & T \geq 26.5°C \end{cases} \tag{8}$$

The number of days in a month (θ), thedaylightduration (in hours) on fifteenthday of themonth (h), and latitude are required to calculate the PET correction (Equation 9) [36].

$$PET = PET\left(\frac{\theta}{30}\right)\left(\frac{h}{12}\right) \tag{9}$$

D. Streamflow Drought Index

Streamflow Drought Index (SDI) was proposed by Nalbantis [37] for the analysis of hydrological drought characteristics (duration, severity, and intensity) on multiple time scales. The SDI calculation method is like the SPI method developed by [1]. The only difference is streamflow values that used instead of precipitation values [37].

In this method, the stream cumulative flow is calculated by Equation (10) [38].

$$Q_{i,j} = \sum_{j=1}^{3k} q_{i,j} i \qquad i = 1,2,3, \ldots \quad j = 1,2,3, \ldots, 12 \quad k = 1,2,3,4 \tag{10}$$

Here, $Q_{ij}$is cumulative, q_{ij}*i.* is hydrological year and *k.* is the total flow in the reference period. *j* defines the months in a hydrological year (*j = 1*Octoberand *j = 12*September). The *k* value is the drought periods (*k = 1*, October-December, *k = 2*, October-March, *k = 3*, October-June, *k = 4*, October-September). SDI value for each hydrological year for period *k* is calculated by Equation (11).

$$SDI_{i,k} = \frac{Q_{i,k} - \overline{Q_k}}{S_k} \qquad i = 1,2,3, \ldots \quad k = 1,2,3,4 \tag{11}$$

Here $\overline{Q_k}$ is the mean of the cumulative volume of flow for the reference period *k* and over a long period, and S_k is the standard deviation value. $\overline{Q_k}$ is considered the threshold level [39]. Hydrological drought conditions are defined in Table 4 based on SDI.

Table 4. Hydrological drought conditions according to SDI [40]

Criterion	Definition
SDI ≥ 0	No drought
-1 ≤ SDI ≤ 0	Mild drought
-1.5 ≤ SDI ≤ -1	Moderate drought
-2 ≤ SDI ≤ -1.5	Severe drought
SDI ≤ -2	Extreme drought

E. Mann-Kendall Trend Test

Mann-Kendall (M-K) trend test, known as Kendall's Tau statistics, is highly preferred in determining the trends of the time series [41, 42]. M-K test is nonparametric and independent of data distribution. While the M-K test statistic is expressed as *S*, it is calculated as follows.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(x_j - x_i) \tag{12}$$

The trend in a time series is investigated by the null hypothesis According to Equation (12), the hypotheses are ranked in $i = 1,2, ..., n\text{-}1$ and x_j. Also, the hypothesis is applied to x_i time series. Each of the data points (x_i) is taken as a point compared with the rest of the x_j data points. This is expressed in Equation (13).

$$sgn(x_j - x_i) \begin{cases} if\,(x_j - x_i) > 0\,, & then \quad +1 \\ if\,(x_j - x_i) = 0\,, & then \quad 0 \\ if\,(x_j - x_i) < 0\,, & then \quad -1 \end{cases} \tag{13}$$

The variance value of the S parameter is calculated according to Equation (14).

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18} \tag{14}$$

In Equation (14), t_i is accepted as the number of nodes up to the sample *i*, and the significance of the M-K test whose variance is determined by Equation (14) is confirmed by comparing it with the critical *z* value calculated by Equation (15) with the standard normal variable *z* [21].

$$z = \begin{bmatrix} If\ S > 0, & then & \frac{S-1}{\sqrt{Var(S)}} \\ If\ S = 0, & then & 0 \\ If\ S < 0, & then & \frac{S+1}{\sqrt{Var(S)}} \end{bmatrix} \tag{15}$$

If the *S* value calculated according to Equation (15) is positive, it is an increasing trend and if it is negative, it is a decreasing trend. In addition, M-K test provides convenience to the user as it is a method that can be used even if there is any deficiency in the data set [43].

III. APPLICATION

In this study, firstly, M-K tests were applied to historical precipitation, temperature data, and potential evapotranspiration values which were calculated by depending on precipitation and temperature. Then, the M-K test was applied to the standardized drought indices calculated using SPI, RDI and SDI in the 3-, 6-, 9- and 12-month periods by DrinC software.

In SPI, the calculation of the index in 12-month and shorter periods is quite complicated because precipitation data do not conform to the normal distribution. After establishing a probability relationship from historical records, the probability of the occurrence of any observed precipitation data and its deviation from the normal distribution whose mean is zero (0) and standard deviation is one (1) can be calculated. Precipitation data are generally found to be compatible with the Gamma probability distribution. The conformity of the precipitation data of the stations to the Gamma probability distribution was investigated to determine the precipitation probabilities observed in periods less than 12- month. Thus, the cumulative probabilities of observed precipitation data can be determined.

A. M-K Test of Historical Records

In addition to historical precipitation, temperature, and flow data, the M-K test was applied by using potential evapotranspiration (PET) values calculated according to the Thornthwaite method to obtain RDI values used in monitoring meteorological drought. M-K test results were given in Table 5.

Table 5. M-K test results of historical records

Period	**Station**	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**
Prec.	**Manavgat**	-0.69	0.79	-0.77	-0.11	-0.21	1.43	-0.61	1.16	-0.27	**1.86**	-0.14	-0.94
	Serik	-0.58	0.32	1.06	0.37	-0.53	**1.69**	-0.95	-0.16	-1.41	**1.28**	0.33	0.16
	Alanya	-0.63	1.37	-0.21	-0.63	-0.37	0.85	-0.79	1.06	-0.03	**1.09**	0.20	-0.44
Temp.	**Manavgat**	**2.40 ***	**2.24 ***	1.00	1.19	0.00	-0.68	0.23	**2.08 ****	**2.89 *****	**3.72 *****	**4.27 *****	**3.48 *****
	Serik	**1.85**	0.90	1.03	1.38	-0.13	-0.34	0.03	1.17	**2.30 ***	1.53	**2.99 ****	**1.99 ***
	Alanya	**2.25 ***	0.64	0.33	**1.87**	0.94	-0.08	1.16	**2.20 ***	**2.35 ***	**4.29 *****	**3.94 *****	**5.12 *****
PET	**Manavgat**	**1.83**	0.92	-0.83	0.15	-1.06	**-2.06 ***	-0.94	**1.36**	**2.74 ****	**3.76*****	**4.37*****	**3.30 *****
	Serik	**1.48**	0.05	0.42	0.85	-0.85	-1.53	-0.63	0.74	**2.11 ***	1.53	**3.12 ****	**1.90**
	Alanya	**1.76**	-0.18	-1.24	0.37	-0.61	**-1.89**	0.26	**1.92**	**2.25 ***	**4.18 *****	**3.99 *****	**5.16 *****
Flow	**Manavgat Str.**	**-2.10 ***	1.39	-0.17	-0.77	-0.55	**-1.71**	0.22	-0.52	-1.11	-0.99	-1.47	**-2.23 ***
	Köprüçay	**-2.03 ***	0.13	0.13	-0.66	-0.82	-0.50	-0.61	-0.45	-1.00	-1.37	-1.08	-1.32
	Dim Str.	1.36	**2.08 ***	0.53	-0.67	-0.78	-1.62	-0.26	-0.53	**-1.70**	**-1.68**	-0.18	-0.61

The values given in Table 5 are the z statistics obtained from the M-K test. The z statistics represent different α confidence intervals. The *, **, and *** signs which were seen next to the values are the significance levels of α for 0.05, 0.01, and 0.001 confidence intervals, respectively. In other words, when the confidence intervals are narrower, the more meaningful the test results are obtained. On the other hand, negative (-) values indicate the decreasing trend, positive (+) values indicate the increasing trend over time.

According to the M-K test results of PET values, an increasing trend was observed in Manavgat and Alanya stations in May, June, July, August, September, and October, while a decreasing trend was observed in both in March. At the Serik station, the most significant test result was obtained in August for the increasing trend observed in June, July, August, and September. In general, there was an increasing trend in temperature values in all months of the year. Especially in the period between May and October, this increase was in significant level for all three stations. Although the flow data generally showed a decreasing trend, the most significant results were seen in October for Manavgat Stream and Köprüçay stations and in November for Dim Stream.

B. M-K Test for Meteorological and Hydrological Droughts

To observe the change of meteorological and hydrological drought in the region over time, the standard values of SPI, RDI, and SDI were calculated at 3-, 6-, 9- and 12-month periods, and the M-K test was applied for these indices. In Tables 6, 7, and 8, these test results were given for SPI, RDI, and SDI, respectively.

Table 6. M-K test results of SPI values

Period	Station	October	November	December	January	February	March	April	May	June	July	August	September
3-month	**Manavgat**	0.87	0.17	-0.71	-0.24	0.06	**1.24**	0.94	0.40	-0.33	1.05	0.20	1.58
	Serik	1.21	0.74	0.85	0.85	1.06	**1.90**	-0.74	-0.05	-0.42	0.29	-0.48	0.00
	Alanya	**1.54**	0.72	-0.31	-1.02	-0.56	0.19	0.12	0.10	**1.27**	0.38	0.69	0.75
6- month	**Manavgat**	0.48	0.10	0.01	-0.05	0.03	**1.27**	0.78	0.43	1.57	0.64	0.13	-0.27
	Serik	1.16	0.95	0.95	0.63	0.69	**1.69**	-0.85	-0.42	0.11	0.63	0.37	-0.05
	Alanya	0.59	0.12	-0.01	-0.93	-0.45	0.59	0.10	1.19	1.08	1.21	0.40	0.12
9- month	**Manavgat**	0.22	0.08	-0.22	-0.20	0.05	**1.64**	0.59	0.13	-0.31	0.06	-0.17	-0.15
	Serik	1.00	1.16	0.90	0.74	0.63	0.90	0.37	0.00	0.00	0.48	0.40	0.42
	Alanya	0.72	0.31	0.07	-0.89	-0.01	1.29	1.46	0.69	0.23	0.20	0.26	0.12
12- month	**Manavgat**	0.06	0.10	0.64	0.06	0.20	0.06	0.20	0.01	-0.10	-0.24	-0.22	-0.29
	Serik	**1.00**	0.79	0.32	0.53	0.32	0.37	0.53	0.21	0.48	0.53	0.48	0.42
	Alanya	**0.91**	0.12	0.56	0.31	0.15	0.53	0.34	0.34	0.26	0.20	0.34	0.42

In Table 6, while the SPI values for the Manavgat and Serik stations showed an increasing trend in the 3- and 6- months periods in March, an increasing trend was observed at the Manavgat station in the 9 months period in March. In addition, an increasing trend was observed at the Serik and Alanya stations in 12 months period in October. In the 3- months period, an increasing trend was observed in June and October at the Alanya station. In parallel with the increasing trend in historical precipitation data given in Table 5, a general increase was observed in the SPI values while there was no significant decreasing trend.

Table 7. M-K test results of RDI values

Period	Station	October	November	December	January	February	March	April	May	June	July	August	September
3- month	**Manavgat**	0.76	0.43	-0.13	0.20	0.85	**1.36**	0.76	0.15	-0.42	0.98	-0.03	1.27
	Serik	0.90	0.53	0.37	0.58	1.16	**1.80**	-0.79	-0.05	-0.53	0.16	-0.53	-0.26
	Alanya	**1.13**	0.89	-0.04	-0.80	-0.18	0.18	-0.18	-0.01	1.16	0.16	0.29	0.37
6- month	**Manavgat**	0.78	0.71	0.06	-0.03	-0.20	0.69	0.50	0.10	1.29	0.10	-0.27	-0.48
	Serik	0.79	**1.32**	1.06	0.42	0.90	1.48	-0.74	-0.58	-0.21	0.32	-0.26	-0.26
	Alanya	**0.78**	0.53	0.12	-1.02	-0.97	-0.04	-0.45	0.78	0.75	0.59	0.01	-0.31
9- month	**Manavgat**	0.31	-0.27	-0.83	-0.66	-0.45	1.36	-0.06	-0.36	-0.78	-0.36	-0.13	-0.29
	Serik	0.74	0.74	0.42	0.05	0.32	0.85	0.16	-0.37	-0.26	0.11	0.00	0.05
	Alanya	**0.59**	0.10	-0.50	-1.59	-0.75	0.72	0.80	0.10	-0.48	-0.75	-0.34	0.10
12- month	**Manavgat**	-0.45	-0.71	-0.20	-0.48	-0.50	-0.41	-0.45	-0.55	-0.48	-0.62	-0.76	-0.90
	Serik	0.48	0.21	0.37	0.11	-0.53	0.05	0.05	-0.05	0.05	0.00	0.00	-0.05
	Alanya	-0.07	-0.56	0.04	-0.20	-0.56	-0.20	-0.40	-0.40	-0.18	-0.20	-0.42	-0.40

As can be seen in Table 7, an increasing trend was observed with the RDI method, which is similar to the SPI method, in March at the Serik and Manavgat stations for the 3-month period. There is an increasing trend for November at the Serik station in the 6-month period. The same upward trend was also observed at Alanya station in October. Especially at the Serik station, there is a trend parallel to the increase in historical temperature and PET values in both SPI and RDI methodsfor 12- month period. Since the upward trend in both temperature and PET values at Serik station was lower than that of Manavgat and Alanya stations, decreasing trends were observed in the RDI. When the 12-month period was analysed, an increasing trend was seen in SPI values at Manavgat, Serik and Alanya stations. In the same period, a decreasing trend was observed in RDI values at Manavgat and Alanya stations. The decreasing trend seen in RDI is thought to be due to more significant increases in temperature values in Manavgat and Alanya. In RDI method, unlike SPI, PET values are also used depending on the air temperature as well as the precipitation parameter. For this reason, it has been observed that there are trend differences between the two indices.

Similar to this study, Dinç et al. [28] carried out drought analysis of eight meteorological stations in Antalya using SPI. They observed increasing trends at 3-, 6-, 12- and 24-month periods at Alanya and Manavgat stations. Simsek [44] performed trend analysis using 3-, 6- and 12-month SDI values of 29 streamflow-gauging stations in the Mediterranean Basin.It was seen that there was decreasing trend in most of the stations. In addition, there are studies having similar results in nearby regions as [45, 46].

Table 8. M-K test results of SDI values

Period	Station	October	November	December	January	February	March	April	May	June	July	August	September
3- month	Manavgat Stream	0.13	0.00	-0.57	**-1.06**	-0.80	-0.69	-0.34	-0.89	**-1.27**	**-1.43**	**-1.85**	0.24
	Köprüçay	0.00	-0.32	-0.90	-0.79	-1.00	-0.37	-0.53	-0.82	**-1.00**	**-1.21**	**-2.01***	-0.95
	Dim Stream	1.27	0.61	-0.23	**-1.21**	-0.94	-0.72	-0.75	-1.08	**-1.57**	**-1.51**	1.29	1.57
6- month	Manavgat Stream	-0.45	-0.48	-0.80	**-1.04**	-0.83	-0.69	-0.52	**-1.04**	-0.69	-0.22	-0.73	-0.66
	Köprüçay	-0.90	-0.74	-0.74	-0.69	-0.77	-0.37	-0.85	-0.74	-0.69	0.05	-0.69	-1.43
	Dim Stream	0.00	-0.40	-0.64	**-1.32**	-0.94	-0.78	-0.89	**-1.13**	0.75	0.67	0.40	0.10
9- month	Manavgat Stream	-0.64	-0.80	-1.01	**-1.20**	**-1.25**	-0.59	-0.38	-0.87	-0.66	-0.94	-0.92	-0.94
	Köprüçay	-0.85	-0.74	-1.00	-0.79	-0.16	-0.11	-0.32	-0.95	**-1.58**	**-1.27**	**-1.27**	**-1.37**
	Dim Stream	-0.26	-0.20	-0.67	**-1.38**	**-1.48**	0.00	0.23	-0.18	-0.53	-0.53	-0.69	-0.83
12- month	Manavgat Stream	-0.87	-0.80	-0.78	-0.90	-0.97	-0.80	-0.76	-0.94	**-1.04**	**-1.01**	**-1.13**	**-1.29**
	Köprüçay	-0.79	-0.32	-0.58	-0.63	-0.85	-1.00	-1.37	-1.56	**-1.58**	**-1.48**	**-1.21**	**-1.16**
	Dim Stream	-0.18	-0.83	-0.91	-0.50	-0.59	-0.42	-0.78	-0.80	**-1.08**	-0.86	-0.72	-0.69

According to Table 8, there was a decreasing trend for all three flow stations in the 3-, 6-, 9- and 12-month period in June, July, and August. According to the SDI method, the decreasing trend was observed in the summer months, and it supported the occurrence of the hydrological drought in the continuation of the meteorological droughts detected in March in the region. The decreasing trends for the Manavgat and Dim streams in January and for 3-, 6- and 9- month periods showed the effect of hydrological drought in the flows of the region.

In addition, it was considered that hydrological drought may occur in the continuation of meteorological drought, the relationships between monthly flow values of each stream and both SPI and RDI values were examined in different lag times. A high correlation was obtained between meteorological drought indices and flow values in the four-month delay period for the Dim stream as shown in Figs. 2 and 3. In the figures, the highest R^2 values ($0.60 < R^2 < 0.80$) for the 6- and 9- month periods were obtained in December and January. The highest R^2 value was found to be 0.74 for both SPI and RDI in the 9-month period with a delay of four months. This showed that the correlation was strong between the standardized meteorological data in October (i.e.the beginning of the water year) and the flow data in January and December approximately four months later. While this high relationship in the winter months seemed to weaken towards the end of the water year for the 3-month period ($0.00 < R^2 < 0.20$), it increased relatively during the 6-, 9- and 12-month periods after July ($0.20 < R^2 < 0.40$). There was a common similarity at the end of November and in February for all periods with a range of $0.40 < R^2 < 0.60$.

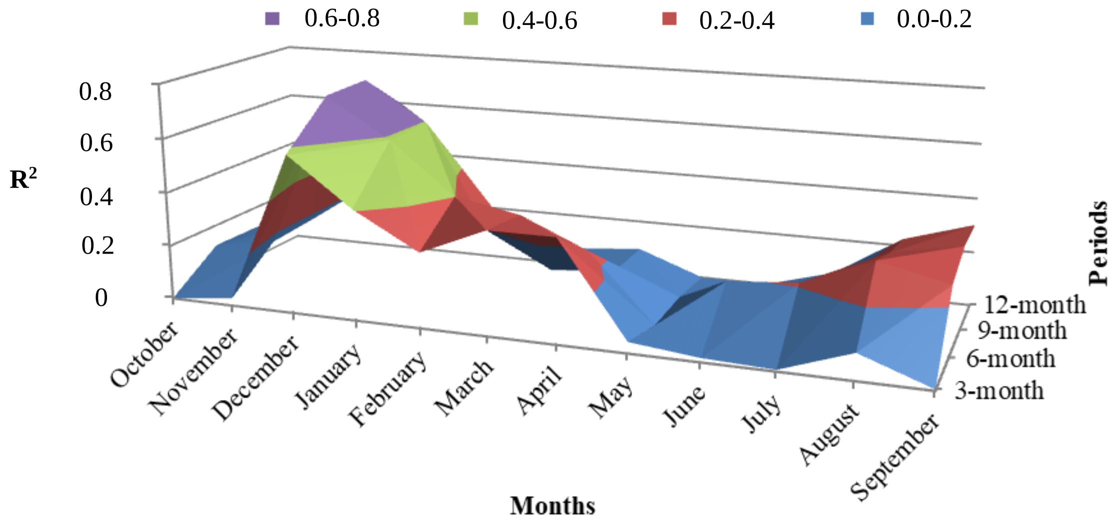

Figure 2. R^2 values between SPI and flow values of Dim Stream for a delay of four months

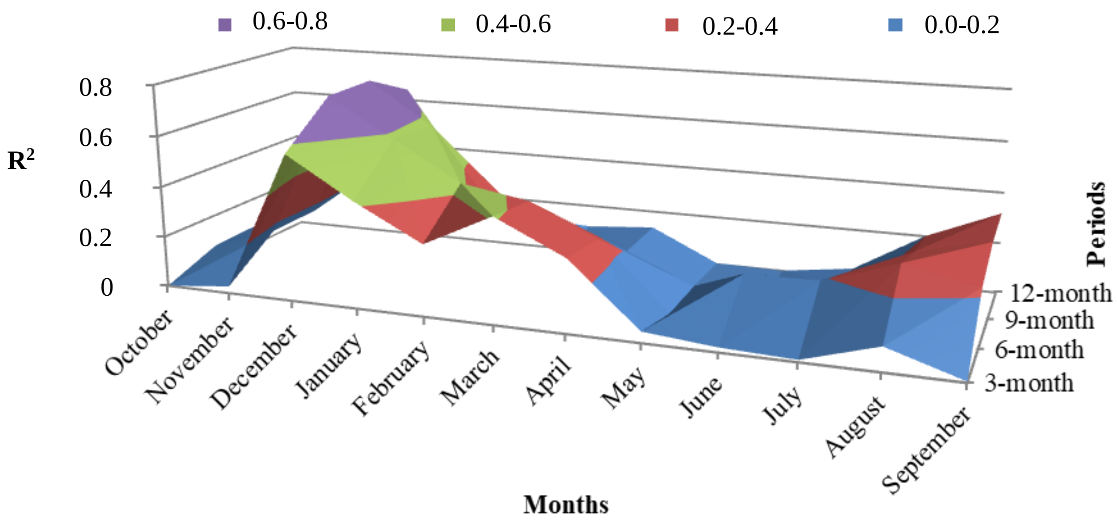

Figure 3. R^2 values between RDI and flow values of Dim Stream for a delay of four months

Also, the relationship between flow values and meteorological drought indices (SPI and RDI) were obtained as 0.58 ($0.40<R^2<0.60$) for 6- months period for the 4-month delay period of Manavgat Stream. For Köprüçay, the lower relationship was found ($0.00 <R^2<0.20$). In the study area, the relationship between flow values and meteorological drought indices showed local differences in different periods.

IV. CONCLUSIONS

The increasing need for domestic, industrial, and irrigation water because of the climate change due to global warming and the population growth requires better planning of non-renewable water resources. For this planning, it is not possible to separate the drought risk which occurs in a long time from the decrease in water resources. The effect of determining hydrological drought that may occur in the case of long-term meteorological drought, defined as lack of precipitation, on sustainable water resources studies is important. M-K trend test has been applied to see the temporal changes of historical precipitation, temperature, flow, and potential evapotranspiration data of Manavgat Stream, Köprüçay, and Dim Stream sub-basins in the Middle Mediterranean Basin, which is important for agricultural production to monitor meteorological and subsequent hydrological drought. In addition, the standard values obtained with the SPI, RDI, and SDI used for the analysis of meteorological and hydrological drought were also tested with the M-K test. According to the M-K test, the increasing and decreasing trends of the precipitation and flow drought indices in the region over time were observed in successive months. It is known that SPI in a 6- month period may be an indicator for the determination of hydrological drought in the continuation of meteorological drought. In addition, a strong correlation was observed between the 6-month SPI values and the flow values for the 4- month lag time. This situation supports that agricultural and hydrological drought may occur after the meteorological drought. Similarly, the parallel changes of precipitation and PET values in the same time intervals show that agricultural drought is compatible with arid and rainy processes in terms of meteorology. As a result of this study, by knowing the relationship between meteorological and hydrological drought with a delay of 4 months, early detection of possible hydrological drought risk will be provided. In this way, it could be recommended to take measures for the optimum use of water resources for the relevant stakeholders.

REFERENCES

[1] McKee, T. B., Doesken, N. J., & Kleist, J. (1993). *The relationship of drought frequency and duration to time scales.* In Proceedings of the 8th Conference on Applied Climatology. 17(22), 179-183.

[2] Dai, M., Huang, S., Huang, Q., Leng, G., Guo, Y., Wang, L., Fang, W., Li, P., & Zheng, X. (2020). Assessing agriculturaldrought risk and its dynamic evolution characteristics. *Agricultural Water Management*, 231, 106003.

[3] Aktürk, G., Zeybekoğlu, U., & Yıldız, O. (2022). SPI ve SPEI yöntemleri ile kuraklık araştırması: Kırıkkale Örneği. *Uluslararası Mühendislik Araştırma ve Geliştirme Dergisi (IJERAD*), 14(2), 762-776.

[4] Akturk, G., Zeybekoglu, U., & Yildiz, O. (2022). Assessment of meteorological drought analysis in the Kızılırmak River Basin, Turkey. *Arabian Journal of Geosciences*,15(9), 1-15.

[5] Katipoğlu, O. M., Acar, R., & Şengül, S. (2020). Comparison of meteorological indices for drought monitoring and evaluating: a case study from Euphrates basin, Turkey. *Journal of Water and Climate Change*, 11(S1), 29-43.

[6] Jehanzaib, M., Sattar, M. N., Lee, J. H., & Kim, T. W. (2020). Investigating effect of climate change on drought propagation from meteorological to hydrological drought using multi-model ensemble projections. *Stochastic Environmental Research and Risk Assessment*, 34(1), 7-21.

[7] Çavus, Y., & Aksoy, H. (2020). Critical drought severity/intensity-duration-frequency curves based on precipitation deficit. *Journal of Hydrology*, 584, 124312.

[8] Eris, E., Çavus, Y., Aksoy, H., Burgan, H. I., Aksu, H., & Boyacıoglu, H. (2020). Spatiotemporal analysis of meteorological drought over Küçük Menderes River Basin in the Aegean Region of Turkey. *Theoretical and Applied Climatology*, 142(3), 1515-1530.

[9] Cavus, Y., & Aksoy, H. (2019). Spatial drought characterization for Seyhan River basin in the Mediterranean region of Turkey. *Water*, 11(7), 1331.

[10] Aksever, F. (2019). Standartlaştırılmış yağış indeksi (SYİ) yöntemi ile kuraklık analizi ve Kaklık (Honaz-Denizli) ovasındaki yeraltısuyu değişimi. *Mühendislik Bilimleri ve Tasarım Dergisi*, 7(1), 152-160.

[11] Gümüş, V., Başak, A., & Oruç, N. (2016). Drought Analysis of Şanlıurfa Station with Standard Precipitation Index (SPI). *Harran Univercity Journal of Engineering*, 1(1), 36-44.

[12] Efe, B., & Özgür. E. (2014). *Drought analysis of Konya and surroundings by standardized precipitation index (SPI) percent of normal index* (PNI). 2nd International Drought and Desertification Symposium, Konya, Turkey. 146-159.

[13] Tsakiris, G., & Vangelis, H. J. E. W. (2005). Establishing a drought index incorporating evapotranspiration. *European Water*, 9(10), 3-11.

[14] Malakiya, A. D., & Suryanarayana, T. M. V. (2016). Assessment of drought using standardized precipitation index (SPI) and reconnaissance drought index (RDI): a case study of Amreli District. *International Journal of Science and Research*, 5(8), 1995-2002.

[15] Kousari, M. R., Dastorani, M. T., Niazi, Y., Soheili, E., Hayatzadeh, M., & Chezgi, J. (2014). Trend detection of drought in arid and semi-arid regions of Iran based on implementation of reconnaissance drought index (RDI) and application of non-parametrical statistical method. *Water Resources Management*, 28(7), 1857-1872.

[16] Tsakiris, G., Pangalou, D., & Vangelis, H. (2007). Regional drought assessment based on the Reconnaissance Drought Index (RDI). *Water Resources Management*, 21(5), 821-833.

[17] Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology*, 391(1-2), 202-216.

[18] Nalbantis, I. (2008). Evaluation of a hydrological drought index. *European water*, 23(24), 67-77.

[19] Malik, A., Kumar, A., Salih, S. Q., & Yaseen, Z. M. (2021). Hydrological drought investigation using streamflow drought index. *In Intelligent Data Analytics for Decision-Support Systems in Hazard Mitigation.* 63-88.

[20] Gümüş, V. (2017). Akım kuraklık indeksi ile Asi havzasının hidrolojik kuraklık analizi. Gazi University *Journal of Science Part C: Design and Technology*, 5(1), 65-73.

[21] Tabari, H., Nikbakht, J., & Hosseinzadeh Talaee, P. (2013). Hydrological drought assessment in Northwestern Iran based on streamflow drought index (SDI). *Water resources management*, 27(1), 137-151.

[22] Yıldız, M. B., Nacar, S., & Şan, M. (2022). *Assessment of regional drought trends by using improved visualization version of Innovative Trend Analysis and Mann Kendall test*. 14th International Conference on Hydroscience& Engineering Izmir, Turkey. 503-513.
[23] Malik, A., Kumar, A., Pham, Q. B., Zhu, S., Linh, N. T. T., & Tri, D. Q. (2020). Identification of EDI trend using Mann-Kendall and Şen-innovative trend methods (Uttarakhand, India). *Arabian Journal of Geosciences*, 13(18), 1-15.
[24] Kisi, O., & Ay, M. (2014). Comparison of Mann–Kendall and innovative trend method for water quality parameters of the Kizilirmak River, Turkey. *Journal of Hydrology*, 513, 362-375.
[25] Şen, Z. (2017). Innovative trend significance test and applications. Theoretical and applied climatology, 127(3), 939-947.
[26] Büyükyıldız, M., & Berktay, A. (2004). Parametrik olmayan testler kullanılarak Sakarya havzası yağışlarının trend analizi. Selçuk Üniversitesi Mühendislik, *Bilim ve Teknoloji Dergisi*, 19(2), 23-38.
[27] Yue, S., & Wang, C. Y. (2002). Regional streamflow trend detection with consideration of both temporal and spatial correlation. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 22(8), 933-946.
[28] Dinç, N., Aydınşakir, K., Işık, M., & Büyüktaş, D. (2016). Drought analysis of Antalya province by standardized precipitation index (SPI). *Derim*, 33(2), 279-298.
[29] Doğaner, S. (2016) Ovalar, Akdeniz Bölgesi Coğrafyası, academia.edu. Erişim tarihi: 27 Mayıs 2016.
[30] DanandehMehr, A., Sorman, A. U., Kahya, E., & Hesami Afshar, M. (2020). Climate change impacts on meteorological drought using SPI and SPEI: case study of Ankara, Turkey. *Hydrological Sciences Journal*, 65(2), 254-268.
[31] Bhunia, P., Das, P., & Maiti, R. (2020). Meteorological drought study through SPI in three drought prone districts of West Bengal, India. *Earth Systems and Environment*, 4(1), 43-55.
[32] Özfidaner, M., & Topaloğlu, F. (2020). Standart yağış indeksi yöntemi ile Güneydoğu Anadolu Bölgesi'nde kuraklık analizi. *Toprak Su Dergisi*, 9(2), 130-136.
[33] Gürler, Ç. (2017) *Beyşehir ve Konya-Çumra-Karapınar Alt Havzalarında Standartlaştırılmış İndis Yaklaşımı ile Hidrolojik Kuraklık Değerlendirmesi*. Uzmanlık Alan Tezi, Orman ve Su İşleri Bakanlığı Su Yönetimi Genel Müdürlüğü, Ankara.
[34] Tigkas, D., Vangelis, H., & Tsakiris, G. (2013). The RDI as a composite climatic index. *Eur Water*, 41, 17-22.
[35] Thornthwaite, C. W., & Mather, J. R. (1957). Instruction and Tables for Computing Potential Evapotranspiration and for Computing Potential Evapotranspiration and Water Balance. *Drexel Institute of Technologi Laboratory of Climatology*, 10(3).
[36] Rusnam, R., & Yanti, N. R. (2021). Potential evapotranspiration uses Thornthwaite method to the water balance in Padang City. *In IOP Conference Series: Earth and Environmental Science*, 757(1), 1-6.
[37] Malik, A., Kumar, A., & Singh, R. P. (2019). Application of heuristic approaches for prediction of hydrological drought using multi-scalar streamflow drought index. *Water Resources Management*, 33(11), 3985-4006.
[38] Nalbantis, I., & Tsakiris, G. (2009). Assessment of hydrological drought revisited. *Water Resources Management*, 23(5), 881-897.
[39] Jahangir, M. H., & Yarahmadi, Y. (2020). Hydrological drought analyzing and monitoring by using Streamflow Drought Index (SDI)(case study: Lorestan, Iran). *Arabian Journal of Geosciences*, 13(3), 1-12.
[40] Adib, A., & Tavancheh, F. (2019). Relationship between hydrologic and metrological droughts using the streamflow drought indices and standardized precipitation indices in the Dez Watershed of Iran. *International Journal of Civil Engineering*, 17(7), 1171-1181.
[41] Zhang, X., Harvey, K. D., Hogg, W. D., & Yuzyk, T. R. (2001). Trends in Canadian streamflow. *Water Resources Research*, 37(4), 987-998.
[42] Yue, S., Pilon, P., & Cavadias, G. (2002). Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology*, 259(1-4), 254-271.
[43] Yu, Y. S., Zou, S., & Whittemore, D. (1993). Non-parametric trend analysis of water quality data of rivers in Kansas. *Journal of Hydrology*, 150(1), 61-80.
[44] Simsek, O. (2021). Hydrological drought analysis of Mediterranean basins, Turkey. *Arabian Journal of Geosciences*, 14(20), 1-17.
[45] Topcu, E., & Seçkin, N. (2022). Drought assessment using the reconnaissance drought index (RDI): A case study of Eastern Mediterranean, Seyhan, Ceyhan, and Asi basins of Turkey. *Journal of Engineering Research*, 10(2B), 124-141.
[46] Yuce, M. I., & Esit, M. (2021). Drought monitoring in Ceyhan basin, Turkey. *Journal of Applied Water Engineering and Research*, 9(4), 293-314.