

Comprehensive evaluation of trend analysis of extreme drought events in the Ceyhan River Basin, Turkey

Musa Esit

Adiyaman University, Turkey

Mehmet Ishak Yuce 

Gaziantep University, Turkey

Abstract

The investigation of extreme meteorological drought events is crucial for disaster preparedness and regional water management. In this study, trends in extreme drought events, namely annual maximum drought severity (AMDS) and annual maximum drought duration (AMDD), were examined for the Ceyhan Basin. The analyses of extreme events were conducted using the standard precipitation index (SPI) index for multiple-time scales of 1, 3, 6, 9, and 12 months for 23 meteorological stations located in the Ceyhan Basin, Turkey. The Wallis-Moore and Wald-Wolfowitz methods were employed to determine the homogeneity of the data sets, whereas trend analyses were conducted using Mann-Kendall and Spearman Rho tests. The magnitude of trends was defined by Sen's slope and linear regression, and change points were detected using the standard normal homogeneity test, Buishand's range test, and Pettitt's test. Although increasing trends were detected in most of the stations, only in nine of them, statistically significant results were noted at a significance level of 95%. The results of this paper provide valuable information to water resource management decision-makers in the Ceyhan River Basin for evaluating the effect of droughts and preparing for drought mitigation measures to avoid future drought risks.

Keywords

Climate change, drought severity, drought duration, trend, Ceyhan Basin.

Submitted 16 February 2022, revised 27 June 2022, accepted 15 September 2022

DOI: 10.26491/mhwm/154573

1. Introduction

Droughts are recurrent natural disasters characterized by a significant rainfall deficit, leading to water scarcity, streamflow depletion, crop damage, and groundwater reduction. They can be classified as meteorological, hydrological, agricultural, and socio-economic droughts (Dracup et al. 1980; Wilhite, Glantz 1985). Various parameters must be considered when defining the temporal and spatial scales and the regional characteristics of droughts (Tallaksen, Lanen 2004). More than 130 published drought definitions can be categorized in several ways, as noted by Wilhite and Glantz (1985). Some of the most commonly used definitions of droughts have been listed by Tate and Gustard (2000) and Demuth and Bakenhus (1994). Droughts have negative impacts on social life, the economy, and the environment, although these impacts are difficult to detect. Several indices have been developed to identify and analyze droughts, of which the most commonly used one is the standard precipitation index (SPI) (McKee et al. 1993; Ganguli, Reddy 2014). Other indices, such as the Palmer drought severity index (PDSI) (Palmer 1965), the surface water supply index (SWSI) (Shafer, Dezman 1982), and the crop moisture index (CMI) (Palmer 1968), are also widely applied to detect drought events.

Several drought trend studies have been conducted all over the world (Piccarreta et al. 2004; Xu et al. 2011), and the hydrological time series of precipitation, temperature, soil moisture, and evapotranspiration

at the catchment scale have been widely investigated (Villarini et al. 2009; Burn et al. 2010; Gocic, Trajkovic 2013; Zhang et al. 2015). As a consequence of global warming and climate change, water resources, the environment, agricultural activities, and industrial production have been significantly affected (Shi, Xu 2008). However, the detection of changes in climate and hydrological time series is complex and challenging but has become an important issue because of the role of such changes in water resources management and drought analysis. According to the report of the Intergovernmental Panel on Climate Change (Houghton et al. 1996), in the 20th century, global land precipitation has increased by 2% on average. The impact of climate change on the maximum and minimum temperatures of Gombe City in northeastern Nigeria has shown an increasing trend (Alhaji et al. 2018). Asfaw et al. (2018) investigated trends in the precipitation and temperature parameters for the Woleka Basin in northern Ethiopia and found that the number of dry years increased. Although the mean and minimum temperatures presented an increasing trend, an insignificant trend was observed for the maximum temperature values. Keskin et al. (2015) studied monthly and annual water levels in Lake Eğirdir in Turkey, using Mann-Kendall and Sen's slope tests. Based on their results, the annual water level was reduced by approximately 0.026 m. Karabulut et al. (2008) analyzed trends in rainfall and temperature data in the Samsun region between 1931 and 2006 and noted statistically significant trends in summer temperatures. Although there are numerous investigations on trends in hydrometeorological parameters and climate change (Cannarozzo et al. 2006; Yu et al. 2006; Kampata et al. 2008; Zhong, Li 2009; Kumar, Jain 2010; Santos et al. 2011; Yuce et al. 2015, 2018), only few studies have performed trend analyses in drought events (duration and severity) (Tabari et al. 2012; Ganguli, Reddy 2014; Spinoni et al. 2014; Dashtpajardi et al. 2015; Zhang et al. 2015; Yuce et al. 2022).

As of the beginning of 2021, most of Turkey is facing a severe drought. An increase in the number of dry days is inevitable after several low-rainfall seasons. In 2019, the summer and autumn months were largely devoid of rain, resulting in decreased reservoir water levels. The year 2020 was the driest of the last 5 years, with particularly little rainfall in the latter half of the year, according to a NASA report¹. This study will investigate the presence of any systematic changes in extreme drought events, using historical hydrometeorological data in the Ceyhan River Basin, which plays a critical role in the agricultural and hydropower production of the country. If the presence of any trend is detected, its magnitude and change point in the time series will be studied in detail. Furthermore, the trends of extreme drought events, such as the annual maximum drought severity (AMDS), defined as the largest cumulative severity value for each year, and the annual maximum drought duration (AMDD), which is described as the length of the maximum drought duration for each year, will be investigated. Notably, these two parameters are independent of one another. Here, the length of the AMDS may not be the same as the length of the AMDD within 1 year. Hence, AMDS and AMDD will be evaluated as different time series in statistical analysis tests. Both parameters of the extreme events are calculated by using the SPI method for multiple-time scales of 1, 3, 6, 9, and 12 months.

¹ <https://earthobservatory.nasa.gov/images/147811/turkey-experiences-intense-drought>

2. Study area and data

The Central Taurus Mountains are located in the northern and northwestern parts of the Ceyhan River Basin, with two different mountain ranges, namely the Bolkar Mountains and the Tahtalı Mountains starting from the west. The Ceyhan River Basin is situated in the Mediterranean Climate Zone, which is characterized by dry summers and mild, wet winters. The rainiest months are December, January, and February, and the driest months are June, July, and August. The total length of the Ceyhan River is around 425 km, with an annual discharge of 82.9 m³/s and a basin yield of 10.7 L/h/km³. The maximum total annual rainfall of the catchment is recorded in Kozan with at least 842 mm, and the lowest total annual rainfall is recorded in Elbistan with 395.7 mm (Eris et al. 2019; Yuce et al. 2019). The highest average annual temperature is 19.3°C in Kozan, whereas the lowest average annual temperature is 8.9°C in Göksun (Uzunkol, Kızılelma 2016).

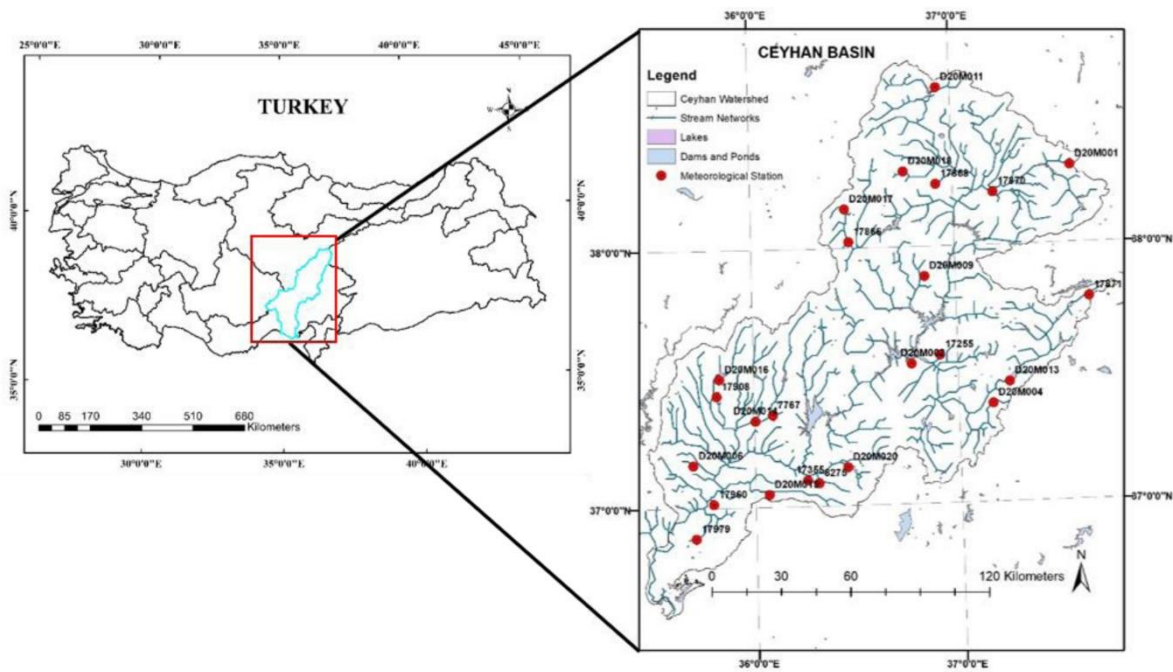


Fig. 1. Locations of the meteorological stations in the Ceyhan Basin.

For this study, we used long-term monthly precipitation data. To evaluate the *SPI* index, the precipitation data of 11 out of 23 meteorological stations were obtained from the General Directorate of Meteorology of Turkey (MGM), whereas the data of the other 12 stations were obtained from the General Directorate of the State Hydraulic Works of Turkey (DSI). The locations of 23 meteorological stations are displayed in Figure 1. The selected monthly precipitation time series with recorded lengths ranging from 15 years (station 7767) to 54 years (station 17255) for the period from 1963-2016 were employed in the analysis. This is a significant amount of data for extreme drought investigation in this basin. The statistical characteristics determined from the monthly precipitation time series for each gauging station are presented in Table 1. The mean, standard deviation, coefficient of variation (Cv), coefficient of skewness (Cs), and lag-one autocorrelation coefficient (r_1) were evaluated by using the observed monthly precipitation time series.

Table 1. Statistical parameters of observed rainfall stations; S.D., standard deviation; Cv, coefficient of variance; Cs, skewness; r1, kurtosis.

Station	Earliest record year	Latest record year	Latitude	Longitude	Mean (mm)	St. Dev.	Cv	Cs	r1
7767	1998	2012	37.3575	36.0907	65.64	55.53	0.85	1.06	0.26
8275	1964	1995	37.0901	36.3094	85.75	83.87	0.98	1.28	0.39
17255	1963	2016	37.5760	36.9150	60.39	65.57	1.09	1.27	0.50
17355	1986	2016	37.1021	36.2539	69.10	63.75	0.92	1.12	0.33
17866	1963	2011	38.0240	36.4823	51.19	46.29	0.90	1.07	0.39
17868	1970	2011	38.2405	36.9190	35.31	31.16	0.88	0.99	0.34
17870	1963	2011	38.2038	37.1982	33.30	28.87	0.87	0.97	0.33
17871	1993	2011	37.7867	37.6532	60.15	66.40	1.10	1.55	0.46
17908	1963	2011	37.4337	35.8188	70.24	58.79	0.84	1.11	0.23
17960	1964	2011	37.0153	35.7955	59.00	58.64	0.99	1.43	0.33
17979	1964	2011	36.7687	35.7903	67.54	70.99	1.05	1.55	0.33
D20M001	1963	2009	38.3000	37.5833	29.13	26.70	0.92	1.12	0.31
D20M002	1980	2005	37.5458	36.7747	58.40	66.96	1.15	1.51	0.42
D20M004	1970	1988	37.3833	37.1666	41.15	41.77	1.02	0.96	0.42
D20M006	1963	1974	37.1666	35.7000	53.98	60.21	1.12	1.85	0.30
D20M009	1963	2009	37.8833	36.8500	78.89	81.62	1.03	1.28	0.44
D20M011	1963	1996	38.6166	36.9333	32.32	29.73	0.92	1.28	0.27
D20M013	1968	2015	37.4666	37.2500	50.28	54.04	1.07	1.36	0.41
D20M014	1973	2015	37.3352	36.0056	90.27	78.25	0.87	1.15	0.25
D20M015	1976	2015	37.0500	36.0666	76.15	66.45	0.87	1.12	0.28
D20M016	1977	2015	37.5000	35.8333	78.27	69.64	0.89	1.25	0.25
D20M017	1980	2003	38.1520	36.4654	65.48	65.48	1.00	1.43	0.33
D20M018	1982	2002	38.2918	36.7604	25.09	28.13	1.12	2.29	0.19

3. Methodology

3.1. Standardized Precipitation Index

The *SPI* method, developed by McKee et al. (1993), is used to evaluate the level of deficiency in precipitation on different time scales ranging from 1 to 48 months. It is the most well-known and used index among many other indices to identify meteorological drought events and is based on fitting precipitation data to a probability distribution function (PDF). Gamma is the most suitable probability density distribution function for climatological data (Ganguli, Reddy 2014; Zhang et al. 2015). The dry period is considered to be the period in which the index is less than or equal to -1 . The *SPI*, which is classified based on values presented in Table 2, is determined by Equation 1:

$$SPI = \frac{X_{ij} - X_{im}}{\sigma} \quad (1)$$

where X_{ij} is the monthly precipitation amount and X_{im} and σ are the mean and standard deviation of precipitation evaluated from the all-monthly time series, respectively.

Table 2. *SPI* classification (McKee et al. 1993); *SPI* = Standardized Precipitation Index.

<i>SPI</i> value	Category
≥ 2	Extremely wet
1.50 to 1.99	Very wet
1.0 to 1.49	Moderately wet
0.99 to 0	Normal
0 to 0.99	Near normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Severely dry
≤ -2	Extremely dry

3.2 Homogeneity test

3.2.1 Wallis-Moore and Wald-Wolfowitz

The Wallis and Moore phase frequency test (Wallis, Moore 1941) is used to detect deviations of time series for randomness in the sequence of values. The test is based on sign differences (- or +), while the first and last phases named sequence of signs are not accounted thus the number of phases is identified. If $n \geq 10$ and continuity correction is applied, a fairly good test may be based on the hypothesis that the data are normally distributed, when $n \geq 25$, the correction is not used (Wallis, Moore 1941). The z test statistic is calculated as follows:

$$E[H] = \frac{1}{3}(2n - 7) \quad (2)$$

$$var[H] = \frac{1}{90}(16n - 29) \quad (3)$$

$$z = (H - E[H]) / \sqrt{\left(\frac{1}{90}(16n - 29)\right)} \quad (4)$$

where h is the number of phases, although the first and last phases are not taken into account. The z -statistic is normally distributed. A continuity correction of -0.5 is added to the denominator for $n \leq 30$.

The Wald-Wolfowitz test, which is also known as Runs test, measures the randomness of the data and examines whether an observation influences the subsequent observation. Time series data are cut from a certain level that could be the mean, medium, or mode to determine if each value in the series is lower or higher than this level. The number of passes from one data to the other above or below a certain level is called the run number, it is small if it is below or above long periods. Such series may not have homogeneity (Wald, Wolfowitz 1940). The result of the test is z , the number of data N , the number of runs r , the number of values below the medium level Na , the number of values above the medium level Nu ; the equations are as follows:

$$E[r] = \frac{2Na*Nu}{(Na+Nu)} + 1 \quad (5)$$

$$V[r] = \frac{2Na*Nu(2Na*Nu-N)}{(N-1)N^2} \quad (6)$$

$$z = \frac{r-1-E[r]}{\sqrt{V[r]}} \quad (7)$$

3.3. Trend Analysis

3.3.1. Mann-Kendall Test

The Mann-Kendall test is a non-parametric test to determine the trend in the hydrometeorological variable in a time series (Mann 1945; Kendall 1975; Helsel et al. 2002). It is the most preferred statistical method for time series since it is not fitted to any distribution. The application of the Mann-Kendall test statistic Z is expressed as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(x_j - x_k) \quad (8)$$

where n is the number of the data, x_j and x_k are the data point in years j and k ($j > k$), and t_i is the length of the tied rank group.

$$\text{sgn}(x_j - x_k) = \begin{cases} 1 & (x_j - x_k) > 0 \\ 0 & (x_j - x_k) = 0 \\ -1 & (x_j - x_k) < 0 \end{cases} \quad (9)$$

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_i^r t_i(t_i-1)(2t_i+5)}{18} \quad (10)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & S < 0 \end{cases} \quad (11)$$

A positive Z value indicates an increasing trend, whereas a negative value indicates a decreasing trend. Critical test statistical values are 1.645, 1.97, and 2.57 for different significance levels of 90%, 95%, and 99%, respectively (Yu et al. 1993).

3.3.2. Spearman's Rho Method

Spearman's rho test is a commonly employed nonparametric method to investigate the presence of trends (Lehmann, D'Abrera 1975; Sneyers 1990). Its statistics r_s and Z (standardized test statistics) are computed as follows:

$$r_s = 1 - \frac{[6 \sum_{i=1}^n (Rx_i - i)^2]}{n(n^2-1)} \quad (12)$$

$$z = r_s \sqrt{\frac{n-2}{1-r_s^2}} \quad (13)$$

where R_{xi} (rank statistic) is obtained by sorting the data, and n is the length of the time series. Negative z values show decreasing trends, whereas positive z values indicate increasing trends. At the 90% significance level, for $z > \pm 1.645$, the null hypothesis of no trend is rejected.

3.4. Trend Slope

3.4.1. Linear Regression Method

Regression analysis is a statistical method used to predict the relationships between one dependent variable and one or more independent variables. It forms the basis of complex estimation methods and is used to evaluate the strength of the relationship between variables and to model the relationship between them. The dependent variable is usually represented by Y , and the independent variables are denoted by X (Gocic, Trajkovic 2013). The linear regression formula is given as follows:

$$Y = a + bX \quad (14)$$

where a is the intercept, and b is the slope of the line. A positive b value indicates increasing trends, and a negative a value indicates decreasing trends.

3.4.2. Sen's Slope Estimator

Sen's slope test (Sen 1968) is a non-parametric test that calculates the slope of the trend in a data set; it is used for equiponderant time series. For each data point, the slope difference is calculated per changing time. The slope of the trend can be estimated by the median of all slopes between data pairs in the same season (Helsel et al. 2002). All slope pairs are ranked from smallest to largest, and if the calculated number of slopes (n) is odd, the median slope gives the slope S . If n is even, the two median slopes are averaged. Here, Q represents data, n is the length of the data, and T is time. The slope of n pair of data is predicted as follows:

$$S = \frac{Q_2 - Q_1}{T_2 - T_1} \quad (15)$$

$$S = \begin{cases} \frac{S_{n+1}}{2} & n = \text{even} \\ S_{\frac{n}{2}} & n = \text{odd} \end{cases} \quad (16)$$

3.5. Tests for Change Point Detection

Considering the importance of climatic variability in terms of water availability, increasing irrigation demand, crop yields, and other factors, it is crucial to identify and evaluate the trends in the monthly, seasonal, and annual historical data series. Change point detection is substantial to evaluate the period in which a significant change occurs in a time series. In this study, the standard normal homogeneity test (SNHT), Buishand's range test (BRT), and Pettitt's test (PT) were employed to detect change points in the time series.

3.5.1. Standard Normal Homogeneity Test

The statistic of the SNHT (Alexandersson 1986), (T_k), is used to compare the average of the first n year with the average of the last ($n - k$) year with n data points (Vezzoli et al., 2012; Jaiswal et al., 2015). The T_k equation is as follows:

$$T_k = kZ_1^2 + (n - k)Z_2^2 \quad (17)$$

Z_1 and Z_2 can be calculated as follows:

$$Z_1 = \frac{1}{k} \sum_{i=1}^k \frac{(X_i - \bar{X})}{\sigma_X} \quad (18)$$

$$Z_2 = \frac{1}{n-k} \sum_{i=k+1}^n \frac{(X_i - \bar{X})}{\sigma_X} \quad (19)$$

Here, \bar{X} and σ_X are mean and standard deviation, respectively. The year in which T_k reaches the maximum value is considered as the point of change. The significant critical values for SNHT are given in Table 3.

Table 3. Critical values for different change point detection test statistics.

Number of Observations	Buishand Range Test			Pettitt Test		Standard Normal Homogeneity Test		
	1%	5%	10%	1%	5%	1%	5%	10%
20	1.6	1.43	1.1	71	57	9.56	6.95	6.07
30	1.7	1.5	1.12	133	107	10.45	7.65	6.6
40	1.74	1.53	1.13	208	167	11.01	8.1	6.92
50	1.78	1.55	1.14	293	235	11.38	8.45	7.15
70	1.81	1.59	1.17	488	393	11.89	8.8	7.47
100	1.86	1.62	1.22	841	677	12.32	9.15	7.77

3.5.2. Buishand's Range Test

The adjusted partial sum, S_k , is computed as follows:

$$S_k = \sum_{i=1}^k (X_i - \bar{X}) \quad (20)$$

When the series is homogeneous, the value of S_k fluctuates around zero. The test captures data showing sensitivity to break in the middle of distorting the homogeneity of the time series. If there is a change in K year, it reaches the maximum or minimum value around the year $k = K$ (Buishand 1982). The significant change can be computed by evaluating the rescale-adjusted range R :

$$R = \frac{\text{Max}(S_k) - \text{Min}(S_k)}{\bar{X}} \quad (21)$$

3.5.3. Pettitt's Test

PT is a non-parametric method (Pettitt 1979) to determine change detection in a time series. It is commonly used to calculate the occurrence of an unexpected change in hydrometeorological records (Sneyers 1990; Smadi, Zghoul 2006). The null hypothesis indicates that the series has an independent and random distribution, whereas the alternative hypothesis indicates a sudden change. The U_k test statistic is expressed as follows:

$$U_k = 2 \sum_{i=1}^k r_i - k(n+1) \quad k = 1, \dots, n \quad (22)$$

The U_k test results are presented graphically. In case of a break in $k = K$ year, the test statistic is at maximum or minimum values. Significant critical values are given in Table 3.

$$K = \max|U_k| \quad (23)$$

4. Analysis of Results

4.1. Homogeneity Analyses

The precipitation data of 23 meteorological stations in the Ceyhan River Basin were analyzed by the *SPI* drought index for time scales of 1, 3, 6, 9, and 12 months. The AMDS and AMDD time series for station 17355 are illustrated in Figure 2. These graphs do not show any statistically significant trend in the data and provide only a rough view of the variation of the data over time.

The Wallis and Moore phase-frequency test and the Wald-Wolfowitz test were employed for the analysis of extreme drought events (AMDS and AMDD), verifying the homogeneity for different time scales. The results of these two tests were compared to achieve an accurate homogeneity and randomness in the time series. If the outcomes of both tests suggest homogeneity in the time series, the presence of homogeneity is accepted. When only one of the methods suggests homogeneity of the time series, the results are defined as doubtful; if both methods suggest no homogeneity in the data set, it is labeled as non-homogeneous. The homogeneity test results for the AMDS and the AMDD time series of 23 meteorological stations for time scales of 1, 3, 6, 9, and 12-month are presented in Table 4.

In the AMDS time series, for *SPI* 1-month time scale, the data of 19 out of 23 stations indicated homogeneity by both tests, whereas stations 17871, 17979, and D20A011 presented homogeneity by one of the methods. Only station 17908 showed non-homogeneity by both tests for the significance level of 90%. For the same time scale, stations 8275, 17355, 17870, 17908, and D20A016 presented homogeneity by one of the methods, and only station D20A006 illustrated non-homogeneity by both methods; the data for the remaining stations were homogeneous in the AMDD time series. The AMDS time series were homogenous in all stations for the *SPI* 3-month time scale, apart from station 17960, which presented homogeneity by the Wald-Wolfowitz test. Although the AMDS time series presented homogeneity by one of the methods at 10 stations (17866, 17870, 17960, 17979, D20A002, D20A009, D20A011, D20A013,

D20A015, and D20A016), the data at only one station (8275) showed non-homogeneous characteristics. The data at the other stations showed homogeneous features.

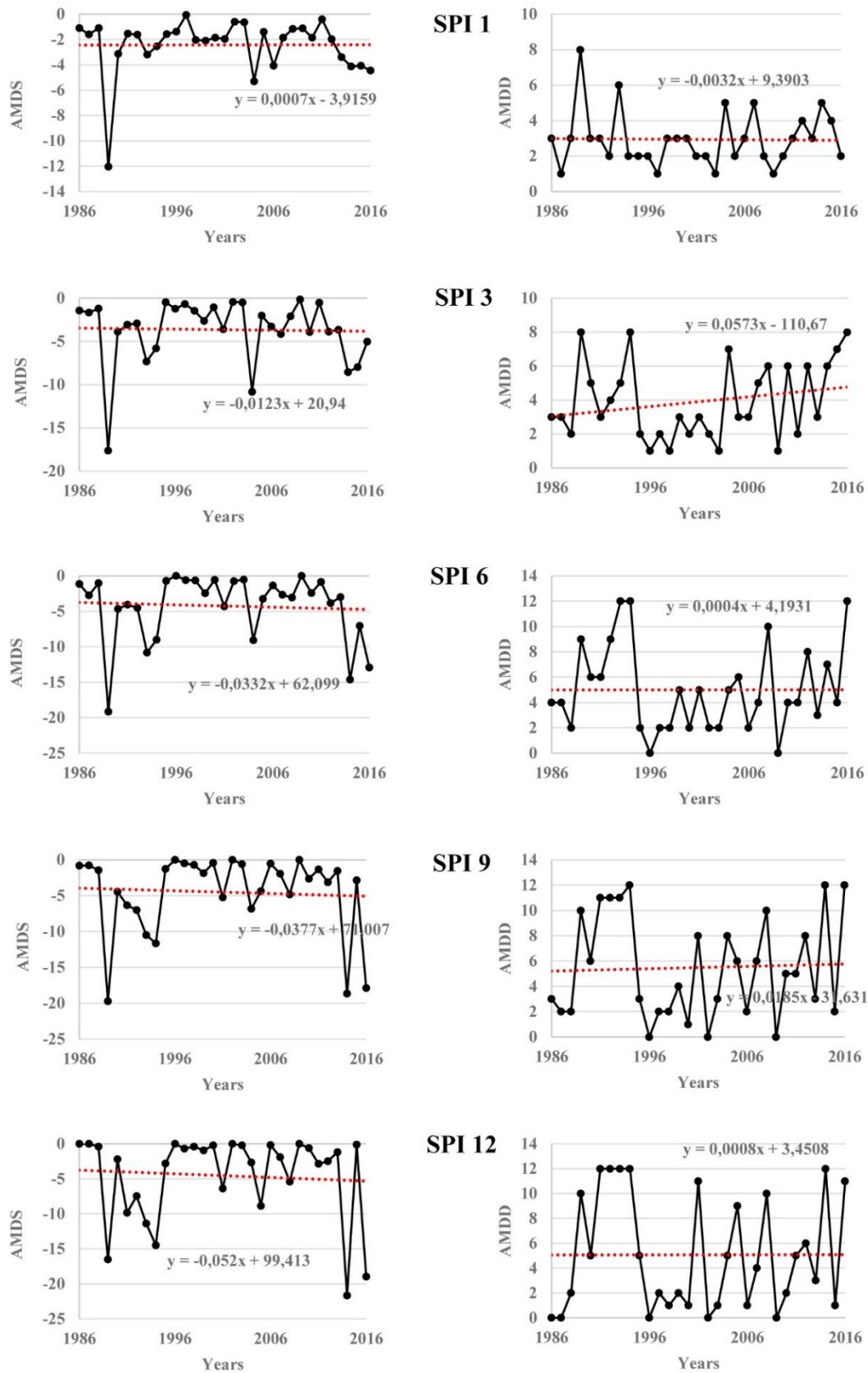


Fig. 2. The extreme drought events' both AMDS and AMDD time series of station 17355 at different time scales.

The *SPI* 6-month time scale AMDS time series presented homogeneity by one of the methods at stations 8275, 17868, and D20A002, whereas the other stations indicated homogenous data sets. The AMDD time series displayed non-homogenous features at stations 8275 and D20A013, homogeneous features by one of the methods at stations 17868, D20A016, and D20A017, and the data sets at the other stations were homogeneous by the two tests. With the increase in the length of the time scales, the number of non-homogenous stations also increased. For instance, three and five stations were non-homogenous for the *SPI* 9-month time scale and the *SPI* 12-month time scale, respectively. Station 17868 in both AMDS and AMDD as well as stations D20A001 and D20A016 in the AMDD time series were non-homogenous for the *SPI* 9-month time scale. Station 17868 in AMDS, stations D20A011 and D20A013 in both AMDS and AMDD, and stations D20A009 and D20A016 in the AMDD time series were non-homogenous for the *SPI* 12-month time scale.

Table 4. Homogeneity test results for extreme drought events at different time scales.

Station	Tests	<i>SPI</i> 1		<i>SPI</i> 3		<i>SPI</i> 6		<i>SPI</i> 9		<i>SPI</i> 12	
		AMDS	AMDD	AMDS	AMDD	AMDS	AMDD	AMDS	AMDD	AMDS	AMDD
7767	WM	-0.109	0.762	-0.109	1.415	0.762	0.109	0.109	1.415	0.762	0.762
	WW	-0.023	1.023	0.601	-0.369	1.607	1.513	2.246	1.815	2.161	1.714
	Result	H	H	H	H	H	H	D	D	D	D
8275	WM	1.727	3.453	0.863	3.453	2.590	1.727	1.727	1.727	1.295	0.432
	WW	0.387	1.238	0.671	2.887	1.331	1.710	0.103	0.837	-0.011	0.608
	Result	H	D	H	N-H	D	N-H	D	D	H	H
17255	WM	0.875	0.547	0.438	0.438	0.219	0.438	0.219	0.219	0.875	0.875
	WW	0.875	0.547	0.438	0.438	0.219	0.438	0.219	0.219	0.875	0.875
	Result	H	H	H	H	H	H	H	H	H	H
17355	WM	0.585	2.341	0.732	0.146	0.293	1.024	0.146	1.024	0.293	1.499
	WW	0.455	0.027	0.309	0.438	0.858	1.039	0.080	0.450	-0.476	0.759
	Result	H	D	H	H	H	H	H	H	H	H
17866	WM	1.957	1.151	1.266	2.187	0.115	1.496	0.806	0.806	0.460	1.496
	WW	-1.505	-1.232	-0.184	0.665	1.381	1.244	1.283	1.930	1.495	1.289
	Result	H	H	H	D	H	H	H	D	H	H
17868	WM	0.499	0.624	1.372	1.746	0.624	1.372	2.120	2.120	2.120	1.746
	WW	0.099	0.312	1.236	0.977	3.192	1.961	3.302	2.038	3.348	1.585
	Result	H	H	H	H	D	D	N-H	N-H	N-H	D
17870	WM	1.266	2.532	0.575	2.877	0.806	1.496	0.806	0.806	1.841	1.841
	WW	-0.988	-0.854	-0.293	0.048	0.217	0.839	0.348	0.603	0.956	1.540
	Result	H	D	H	D	H	H	H	H	D	D
17871	WM	0.095	0.095	0.095	0.474	0.667	-0.095	0.667	-0.095	0.477	0.477
	WW	-2.218	-1.781	-1.531	-1.103	-0.379	0.603	0.910	0.747	2.095	2.133
	Result	D	D	H	H	H	H	H	H	D	D
17908	WM	2.302	0.906	0.806	1.496	0.230	0.230	0.460	1.151	0.460	0.230
	WW	-2.217	-1.924	-1.293	-1.062	-0.166	0.088	0.452	0.511	0.742	0.336
	Result	N-H	D	H	H	H	H	H	H	H	H
17960	WM	0.465	0.233	1.861	2.160	0.116	0.116	0.116	0.582	0.931	0.233
	WW	-1.060	-0.731	-1.440	-0.941	0.116	0.116	1.137	0.989	2.242	1.343
	Result	H	H	D	D	H	H	H	H	D	H
17979	WM	1.861	0.233	0.814	2.155	0.465	0.465	0.116	0.931	0.465	1.603
	WW	-1.273	-1.320	-1.346	-0.790	0.376	-0.471	0.358	0.229	1.829	1.483
	Result	D	H	H	D	H	H	H	H	D	H
D20A001	WM	1.163	1.629	0.465	0.931	0.233	1.629	1.629	2.327	1.629	1.214
	WW	-1.294	-1.493	-1.297	-0.574	-0.276	1.231	0.166	1.945	1.098	2.059
	Result	H	H	H	H	H	H	H	N-H	H	D

D20A002	WM	0.723	0.723	0.723	1.688	0.723	0.723	0.723	0.723	0.241	1.741
	WW	-1.070	-0.054	-0.142	0.224	1.844	0.199	1.867	1.189	2.366	0.952
	Result	H	H	H	D	D	H	D	H	D	D
D20A004	WM	0.477	0.477	0.095	0.477	0.477	1.621	1.621	1.621	0.095	0.477
	WW	0.299	-0.257	-0.097	0.129	0.970	1.265	1.596	1.685	0.927	0.960
	Result	H	H	H	H	H	H	H	H	D	H
D20A006	WM	-0.124	2.849	0.124	1.610	0.124	1.610	1.610	1.610	0.124	0.124
	WW	-1.027	-1.976	-0.951	0.360	0.104	-0.491	0.142	0.053	0.091	-0.351
	Result	H	N-H	H	H	H	H	H	H	H	H
D20A009	WM	0.353	0.353	1.059	1.764	0.353	1.059	1.764	1.282	1.059	2.470
	WW	0.707	0.005	-0.629	0.244	0.484	1.610	0.675	2.166	0.763	2.414
	Result	H	H	H	D	H	H	D	D	H	N-H
D20A011	WM	1.812	0.558	0.975	2.443	0.975	0.975	0.139	1.665	1.812	2.648
	WW	-0.190	0.403	-1.091	-1.233	0.382	0.539	0.822	1.163	1.719	2.297
	Result	D	H	H	D	H	H	H	D	N-H	N-H
D20A013	WM	0.233	0.931	0.582	1.978	0.582	2.676	0.582	1.978	1.978	1.978
	WW	-0.688	0.043	-0.491	0.253	1.180	1.729	1.738	1.273	2.021	2.414
	Result	H	H	H	D	H	N-H	D	D	N-H	N-H
D20A014	WM	0.562	1.601	0.616	0.985	1.355	0.616	0.862	1.601	0.616	0.862
	WW	-0.977	-0.156	-0.549	-0.235	-0.371	0.349	-0.201	1.510	-0.061	1.018
	Result	H	H	H	H	H	H	H	H	H	H
D20A015	WM	1.024	1.279	0.640	0.128	0.640	0.128	0.128	0.640	0.640	0.128
	WW	-0.954	-0.985	-0.952	-1.950	-0.189	0.732	-0.192	1.006	-0.103	1.576
	Result	H	H	H	D	H	H	H	H	H	H
D20A016	WM	0.519	1.815	1.037	1.815	0.648	1.426	1.426	2.204	1.426	2.204
	WW	-0.636	-0.255	-0.496	-0.544	1.628	1.699	1.753	2.184	1.482	2.095
	Result	H	D	H	D	H	D	D	N-H	H	N-H
D20A017	WM	0.420	1.594	0.420	0.084	1.091	2.602	0.084	0.084	0.084	1.091
	WW	-0.044	0.614	-0.176	-0.187	0.187	1.160	-0.375	-0.120	-0.358	0.290
	Result	H	H	H	H	H	D	H	H	H	H
D20A018	WM	0.090	1.173	0.451	1.173	0.451	0.090	1.173	0.090	1.715	-0.090
	WW	-0.095	-0.103	-0.592	-0.373	-0.755	-0.362	0.410	0.056	1.151	0.282
	Result	H	H	H	H	H	H	H	H	D	H

H: Homogeneous, **D:** Doubtful, **N-H:** Non-homogeneous

4.2. Trend Analyses

Trend detection analysis of extreme drought event time series under the influence of climate change is critical to propose and make use of management strategies. Table 5 summarizes the outcomes of the Spearman Rho and Mann-Kendall statistical tests used to detect any trends in the *SPI* 1-,3-,6-,9-, and 12-month time series. The null hypothesis is not rejected at the 90% significance level where $-1.64 < z < 1.64$. The Mann-Kendall and Spearman Rho methods performed similarly in the analysis of trend detection in the extreme drought event time series (Table 5). For the *SPI* 1-month time scale, a significant trend was not detected by both tests in the extreme drought events, except in the data of stations 17868 and D20A014. Although two tests showed a statistically significant increasing trend in the AMDS series of station 17868, the AMDD series of station D20A014 showed a statistically significant decreasing trend. In the *SPI* 3-month time scale, the statistically significant increasing trend was evaluated only in the AMDS series of station 7767 and in the AMDD series of station 8275. In the case of the *SPI* 6-month time scale, the time series at four stations showed statistically significant trends in both test results. The AMDS and AMDD time series at station 7767 showed increasing and decreasing trends, respectively. Statistically

significant increasing trends were observed in the AMDS time series of stations 8275, 17866, and D20A016, whereas decreasing trends were noted in the AMDS time series of station D20A016, with a significance level of 90%. As in the *SPI* 3-month period, similar results were clearly seen for the *SPI* 9-month time scale of stations 7767, 8275, and D20A016. In the time series at five stations, statistically significant trends were determined for the *SPI* 12-month time scale. Increasing trends were perceived in the AMDS time series of stations 7767 and D20A018, whereas decreasing trends were detected in the AMDS time series of stations 8275 and D20A016. Furthermore, both tests demonstrated a statistically significant increasing trend in the AMDD time series of stations 8275 and D20A009.

Table 5. Trend detection results for extreme drought events.

Station	Tests	<i>SPI</i> 1		<i>SPI</i> 3		<i>SPI</i> 6		<i>SPI</i> 9		<i>SPI</i> 12	
		AMDS	AMDD	AMDS	AMDD	AMDS	AMDD	AMDS	AMDD	AMDS	AMDD
7767	MK	1.683	-1.093	1.683	-0.855	2.474	-2.448	2.428	-1.910	2.138	-1.706
	SR	1.537	-1.131	1.684	-0.974	2.499	-2.497	2.160	-1.935	1.918	-1.628
	Result	N	N	I	N	I	D	I	D	I	N
8275	MK	-0.276	0.685	-0.584	1.755	-1.674	1.947	-1.384	1.704	-1.860	1.874
	SR	-0.297	0.697	-0.534	1.691	-1.595	1.787	-1.409	1.693	-1.762	1.957
	Result	N	N	N	I	N	I	N	I	D	I
17255	MK	0.149	-0.265	0.261	0.008	0.351	-0.196	0.441	-0.565	0.211	-0.479
	SR	0.143	-0.273	0.411	0.079	0.425	-0.259	0.478	-0.506	0.179	-0.419
	Result	N	N	N	N	N	N	N	N	N	N
17355	MK	-1.105	0.283	-0.952	1.211	-0.391	0.242	-0.255	0.377	-0.307	0.309
	SR	-1.203	0.369	-1.014	1.123	-0.370	0.066	-0.234	0.345	-0.474	0.251
	Result	N	N	N	N	N	N	N	N	N	N
17866	MK	-0.060	0.894	-0.681	0.755	-0.534	1.712	-1.036	1.050	-1.529	1.432
	SR	-0.063	0.897	-0.674	0.787	-0.663	1.901	-1.151	1.086	-1.616	1.440
	Result	N	N	N	N	N	I	N	N	N	N
17868	MK	1.767	-1.019	0.900	-0.373	0.293	0.000	-0.163	0.087	0.043	-0.515
	SR	1.667	-1.012	1.009	-0.512	0.282	0.232	-0.179	0.153	-0.020	-0.547
	Result	I	N	N	N	N	N	N	N	N	N
17870	MK	0.448	0.323	0.509	-0.731	0.552	0.409	-0.276	0.772	0.000	0.529
	SR	0.459	0.243	0.413	-0.667	0.498	0.426	-0.333	0.837	0.626	-0.984
	Result	N	N	N	N	N	N	N	N	N	N
17871	MK	1.469	-0.184	0.350	0.606	0.000	0.748	-0.771	0.634	-0.703	0.958
	SR	1.236	-0.257	0.055	0.582	-0.045	0.816	-0.760	0.823	-0.800	1.065
	Result	N	N	N	N	N	N	N	N	N	N
17908	MK	0.620	-0.254	1.121	-1.243	0.992	0.452	-0.173	0.564	-0.476	0.923
	SR	0.620	0.111	1.228	-1.323	0.946	0.469	-0.104	0.531	-0.463	0.836
	Result	N	N	N	N	N	N	N	N	N	N
17960	MK	-0.453	0.009	0.604	-0.579	0.871	-0.729	0.792	-0.626	0.561	-1.433
	SR	-0.513	0.045	0.053	-0.493	0.791	-0.741	0.696	-0.567	0.562	-1.403
	Result	N	N	N	N	N	N	N	N	N	N
17979	MK	-1.129	0.256	-0.044	-0.469	0.836	-1.044	0.818	-1.117	0.873	-0.777
	SR	-1.137	0.264	0.200	-0.445	0.852	-1.000	0.655	-1.185	0.938	-0.689
	Result	N	N	N	N	N	N	N	N	N	N
D20A001	MK	0.756	-0.347	0.053	0.000	0.231	0.072	-0.044	-0.134	-0.250	0.467
	SR	0.831	-0.325	0.159	0.155	0.216	0.126	-0.010	-0.185	-0.221	0.400
	Result	N	N	N	N	N	N	N	N	N	N
D20A002	MK	-1.058	-0.206	-1.236	-0.246	-0.243	-0.178	0.133	-0.621	-0.441	0.155
	SR	-1.250	-0.180	-1.280	-0.203	-0.456	-0.107	-0.175	-0.472	-0.024	0.155
	Result	N	N	N	N	N	N	N	N	N	N
D20A004	MK	1.295	-0.616	0.910	0.146	0.560	-0.543	0.070	-0.035	0.596	0.035
	SR	1.396	-0.644	0.968	0.035	0.514	-0.622	0.246	-0.180	0.775	-0.120

	Result	N	N	N	N	N	N	N	N	N	N
D20A006	MK	0.480	0.287	-0.069	-0.071	-0.206	0.972	-0.754	1.038	-0.630	1.196
	SR	0.255	0.349	-0.162	-0.250	-0.186	0.971	-0.742	0.864	-0.449	1.031
	Result	N	N	N	N	N	N	N	N	N	N
D20A009	MK	-0.578	0.973	-0.604	0.046	-0.569	0.805	-0.991	1.519	-1.584	1.656
	SR	-0.541	0.978	-0.205	0.123	-0.396	0.702	-0.965	1.502	-1.575	1.706
	Result	N	N	N	N	N	N	N	N	N	I
D20A011	MK	-0.030	-0.076	-0.030	0.406	-0.445	0.569	-0.742	0.313	-0.388	0.165
	SR	-0.180	-0.109	-0.020	0.422	-0.442	0.577	-0.883	0.449	-0.560	0.158
	Result	N	N	N	N	N	N	N	N	N	N
D20A013	MK	-0.764	-0.009	-0.098	0.451	-0.018	0.537	-0.463	0.789	-0.602	0.976
	SR	-0.680	-0.083	-0.090	0.446	0.017	0.580	-0.569	0.881	-0.591	0.897
	Result	N	N	N	N	N	N	N	N	N	N
D20A014	MK	1.026	-1.901	1.256	-1.063	-0.345	0.453	-1.057	1.381	-0.744	1.157
	SR	0.949	-1.910	1.181	-1.058	-0.463	0.520	-1.064	1.204	-0.769	1.084
	Result	N	D	N	N	N	N	N	N	N	N
D20A015	MK	-0.350	-0.303	0.105	-0.142	0.245	-0.647	0.478	-0.844	-0.117	0.459
	SR	-0.304	-0.316	-0.013	-0.099	0.305	-0.684	0.471	-0.787	-0.178	0.407
	Result	N	N	N	N	N	N	N	N	N	N
D20A016	MK	-1.476	0.224	-1.694	1.583	-2.762	2.421	-2.407	2.002	-1.947	1.783
	SR	-1.424	0.225	-1.599	1.550	-2.586	2.301	-2.335	1.917	-1.696	1.514
	Result	N	N	N	N	D	I	D	I	D	N
D20A017	MK	-0.819	-0.027	0.050	-1.236	-0.273	0.505	-0.893	0.526	-0.821	-1.706
	SR	-0.776	-0.138	0.123	-1.205	-0.225	0.521	-0.913	0.481	-0.844	0.785
	Result	N	N	N	N	N	N	N	N	N	N
D20A018	MK	-1.300	0.415	-0.151	0.093	-0.091	-0.092	-0.151	0.731	-0.967	1.798
	SR	-1.377	0.418	-0.279	0.340	-0.087	0.029	-0.296	0.921	-1.078	1.714
	Result	N	N	N	N	N	N	N	N	N	I

N: No Trend, D: Decreasing, I: Increasing, MK: Mann-Kendall, SR: Spearman Rho

4.3. Trend Magnitude

Sen's slope estimator and linear regression analysis were employed to determine the slope of trends in the AMDS and AMDD time series. The signs of the slopes were in line with the results of the Spearman Rho and Mann-Kendall tests. The slopes of the trend lines are indicated in bold in the time series where the trend was detected (Table 6). The highest slopes of the trend line, ranging from 0.6 to 0.8 for both tests, were detected in the AMDS time series of station 7767 for the *SPI* 9-month time scale. The other evaluated slopes of the trend were 0.067 in AMDD time series of station 8275 for the *SPI* 3-month time scale, 0.179 in the AMDD time series of station 8275 for the *SPI* 6-month period, 0.106 in the AMDD time series of station 8275 for the *SPI* 9-month period, 0.083 in AMDS time series of station 8275 for the *SPI* 12-month period, and 0.138 in the AMDD time series of station 8275 for the *SPI* 12-month period.

Table 6. Trend Magnitude Test results for all stations.

Station	Tests	<i>SPI</i> 1		<i>SPI</i> 3		<i>SPI</i> 6		<i>SPI</i> 9		<i>SPI</i> 12	
		AMDS	AMDD	AMDS	AMDD	AMDS	AMDD	AMDS	AMDD	AMDS	AMDD
7767	SS	0.132	0.000	0.340	-0.125	0.495	-0.333	0.768	-0.600	0.710	-0.500
	R	0.150	-0.079	0.297	-0.118	0.480	-0.379	0.759	-0.464	0.798	-0.432
8275	SS	-0.007	0.000	-0.032	0.067	-0.091	0.179	-0.076	0.106	-0.071	0.083
	R	-0.018	0.024	-0.045	0.073	-0.129	0.138	-0.149	0.145	-0.189	0.138
17255	SS	0.002	0.000	0.006	0.000	0.010	0.000	0.005	0.000	0.000	0.000
	R	-0.003	-0.003	0.000	0.003	-0.014	0.001	-0.010	-0.020	0.002	-0.027
17355	SS	-0.025	0.000	-0.050	0.050	-0.025	0.000	-0.018	0.000	-0.007	0.000

17866	R	0.001	-0.003	-0.012	0.057	-0.033	0.000	-0.038	0.019	-0.052	0.001
	SS	0.000	0.000	-0.013	0.000	-0.016	0.042	-0.028	0.032	-0.023	0.036
17868	R	-0.002	0.017	-0.021	0.021	-0.025	0.059	-0.033	0.034	-0.050	0.060
	SS	0.024	0.000	0.032	0.000	0.016	0.000	-0.002	0.000	0.000	0.000
17870	R	0.018	-0.021	0.032	-0.012	0.068	-0.007	0.061	0.005	0.079	-0.037
	SS	0.005	0.000	0.013	0.000	0.018	0.000	-0.005	0.010	-0.009	0.000
17871	R	0.019	-0.010	0.021	-0.012	0.024	0.012	0.005	0.023	-0.008	0.023
	SS	0.081	0.000	0.033	0.000	0.017	0.100	-0.081	0.125	-0.073	0.143
17908	R	0.042	-0.004	0.080	0.042	-0.007	0.096	-0.078	0.109	-0.124	0.175
	SS	0.006	0.000	0.030	0.000	0.031	0.000	-0.001	0.000	-0.001	0.000
17960	R	0.005	-0.006	0.031	-0.023	0.026	0.013	-0.003	0.020	-0.018	0.026
	SS	-0.006	0.000	0.014	0.000	0.028	0.000	0.019	0.000	0.010	-0.048
17979	R	-0.015	0.004	0.004	0.001	0.029	-0.022	0.061	-0.045	0.080	-0.072
	SS	-0.010	0.000	-0.001	0.000	0.029	0.000	0.022	-0.028	0.019	0.000
D20A001	R	-0.011	0.003	0.003	-0.008	0.043	-0.026	0.062	-0.037	0.098	-0.046
	SS	0.008	0.000	0.001	0.000	0.008	0.000	0.000	0.000	0.000	0.000
D20A002	R	-0.010	-0.001	-0.041	0.022	-0.009	0.002	-0.005	-0.017	-0.021	0.149
	SS	-0.038	0.000	-0.011	0.000	-0.023	0.000	-0.003	-0.077	0.000	0.000
D20A004	R	-0.025	0.057	-0.029	-0.009	-0.116	0.021	-0.102	-0.049	-0.123	-0.014
	SS	0.062	0.000	0.106	0.000	0.108	0.000	0.016	0.000	0.038	0.000
D20A006	R	0.064	-0.047	0.144	-0.072	0.175	-0.111	0.190	-0.021	0.137	0.044
	SS	0.080	0.000	-0.019	0.000	-0.062	0.367	-0.256	0.438	-0.345	0.500
D20A009	R	0.012	0.042	-0.005	0.038	-0.083	0.245	-0.101	0.329	-0.134	0.378
	SS	-0.005	0.000	-0.002	0.000	-0.021	0.000	-0.023	0.050	-0.025	0.037
D20A011	R	-0.010	0.016	-0.006	-0.002	-0.003	0.016	-0.017	0.060	-0.020	0.066
	SS	-0.001	0.000	-0.001	0.000	-0.027	0.000	-0.029	0.000	0.000	0.000
D20A013	R	-0.014	0.006	-0.008	0.008	-0.013	0.017	-0.033	0.024	-0.097	0.028
	SS	-0.011	0.000	-0.005	0.000	0.000	0.000	-0.006	0.000	0.000	0.000
D20A014	R	-0.010	-0.003	0.003	0.011	0.021	0.010	0.020	0.016	0.012	0.032
	SS	0.014	0.000	0.042	0.000	-0.009	0.000	-0.024	0.054	-0.012	0.000
D20A015	R	0.024	-0.042	0.051	-0.035	0.017	0.018	-0.010	0.051	-0.027	0.057
	SS	-0.006	0.000	0.005	0.000	0.007	0.000	0.017	-0.034	0.000	0.000
D20A016	R	0.007	-0.005	-0.011	-0.006	-0.001	-0.025	0.016	-0.038	-0.001	0.013
	SS	-0.033	0.000	-0.072	0.043	-0.156	0.133	-0.096	0.100	-0.071	0.091
D20A017	R	-0.034	0.011	-0.081	0.050	-0.163	0.125	-0.184	0.111	-0.198	0.115
	SS	-0.034	0.000	0.002	-0.080	-0.034	0.000	-0.042	0.024	-0.034	0.079
D20A018	R	-0.008	-0.016	0.034	-0.084	-0.023	0.020	-0.073	0.047	-0.059	0.065
	SS	-0.050	0.000	-0.026	0.000	-0.051	0.000	-0.018	0.100	-0.127	0.286
D20A018	R	-0.056	0.031	-0.011	0.025	-0.019	-0.014	-0.098	0.106	-0.203	0.227

4.4. Change Point Detection

After determining the presence of a trend as well as its slope in the time series of extreme drought events, SNHT, BRT, and PT were applied to define the point where the change had started. The change point is identified as the point where the change point occurs in SNHT and BRT, which can be depicted graphically. The outcomes of the three methods were compared to assess a precise change point. As two of the three tests presented the same results, that specific point was chosen to be the change point for the particular time series. However, if the outcomes of all three tests were inconsistent, the change point selection was denoted as suspicious (S). The change points for extreme drought events of the AMDS and AMDD time series are presented in Table 7.

Table 7. Change point results of extreme drought events.

Station	Tests	Test criteria	SPI 1		SPI 3		SPI 6		SPI 9		SPI 12	
			AMDS	AMDD	AMDS	AMDD	AMDS	AMDD	AMDS	AMDD	AMDS	AMDD
7767	BRT	R/sqrt(n)min	0.91	1.14	0.99	0.83	1.48	1.09	1.29	1.17	1.34	1.21
		CP	NC	NC	2000	NC	2001	2008	2001	2008	2001	NC
	SNH T	T	3.15	4.97	6.08	3.80	7.08	6.05	7.62	5.68	7.25	4.94
		CP	NC	NC	2000	NC	2001	2008	2001	2008	2001	NC
	PT	U	28	31	59	28	62	61	58	65	68	34
		CP	NC	NC	2000	NC	2001	2004	2001	2008	2008	NC
	Result	NC	NC	2000	NC	2001	2008	2001	2008	2001	NC	
8275	BRT	R/sqrt(n)min	0.99	0.93	1.07	1.49	1.2	1.22	1.06	1.5	1.05	1.4
		CP	NC	NC	NC	1979	NC	1980	NC	1969	1980	1980
	SNH T	T	3.92	3.1	2.31	6.91	4.4	6.7	3.55	6.3	6.2	6.4
		CP	NC	NC	NC	1979	NC	1969	NC	1969	1982	1969
	PT	U	65	65	63	123	59	105	92	102	113	105
		CP	NC	NC	NC	1979	NC	1979	NC	1969	1980	1969
	Result	NC	NC	NC	1979	NC	SC	NC	1969	1980	1969	
17866	BRT	R/sqrt(n)min	0.9	0.93	0.84	0.9	0.94	1.12	0.96	0.95	1.04	1.07
		CP	NC	NC	NC	NC	NC	1984	NC	NC	NC	NC
	SNH T	T	1.3	3.11	2.09	2.38	2.17	7.1	2.17	2.22	2.84	3.49
		CP	NC	NC	NC	NC	NC	1981	NC	NC	NC	NC
	PT	U	102	127	122	135	148	225	185	157	228	195
		CP	NC	NC	NC	NC	NC	1981	NC	NC	NC	NC
	Result	NC	NC	NC	NC	NC	1981	NC	NC	NC	NC	
D20A009	BRT	R/sqrt(n)min	0.83	1.66	0.79	0.82	0.8	0.87	0.82	0.9	0.83	1.14
		CP	NC	NC	NC	NC	NC	NC	NC	NC	NC	1982
	SNH T	T	3.95	5.77	1.76	2.82	2.65	1.89	2.38	3.88	2.01	7.3
		CP	NC	NC	NC	NC	NC	NC	NC	NC	NC	1982
	PT	U	143	130	112	121	115	126	148	130	123	205
		CP	NC	NC	NC	NC	NC	NC	NC	NC	NC	1982
	Result	NC	NC	NC	NC	NC	NC	NC	NC	NC	1982	
D20A014	BRT	R/sqrt(n)min	0.95	1.14	1.068	0.96	1.05	1.53	1.14	1.87	1.23	1.64
		CP	NC	1980	NC	NC	NC	NC	NC	NC	NC	NC
	SNH T	T	2.78	3.4	3.42	5.53	2.17	3.89	2.7	5.5	3.17	5.32
		CP	NC	1975	NC	NC	NC	NC	NC	NC	NC	NC
	PT	U	128	159	134	134	136	157	141	128	116	142
		CP	NC	1999	NC	NC	NC	NC	NC	NC	NC	NC
	Result	NC	SC	NC	NC	NC	NC	NC	NC	NC	NC	
D20A016	BRT	R / sqrt(n)min	0.82	0.97	1.04	0.88	1.22	1.26	1.3	1.65	1.34	0.9
		CP	NC	NC	NC	NC	1988	1988	1988	1988	1996	NC
	SNH T	T	3.95	5.43	5.16	3.48	7.02	7.28	6.93	7.7	6.95	5.3
		CP	NC	NC	NC	NC	1988	1984	1988	1984	1988	NC
	PT	U	116	69	144	120	188	181	193	188	169	158
		CP	NC	NC	NC	NC	1988	1988	1988	1988	1988	NC
	Result	NC	NC	NC	NC	1988	1988	1988	1988	1988	NC	
D20A018	BRT	R/sqrt(n)min	0.77	0.85	0.94	0.82	0.61	0.67	0.83	0.84	1.01	1.04
		CP	NC	NC	NC	NC	NC	NC	NC	NC	NC	1988
	SNH T	T	3.42	1.82	1.68	2.91	1.42	1.64	1.62	1.94	2.99	6.98
		CP	NC	NC	NC	NC	NC	NC	NC	NC	NC	1984
	PT	U	45	34	36	31	22	23	28	42	44	63
		CP	NC	NC	NC	NC	NC	NC	NC	NC	NC	1988
	Result	NC	NC	NC	NC	NC	NC	NC	NC	NC	1988	

NC: No change

All three tests were performed with a significance level of 90%. According to test results, no abrupt changes were found at station 7767 for the *SPI* 1-month period in the AMDS and AMDD time series, the *SPI* 3-month period in the AMDD time series, and the *SPI* 12-month period in the AMDD time series. Changes in the AMDS time series were noted in the year 2000 for *SPI* 3-, in 2001 for *SPI* 6-, 9-, and 12-month time scales. Changes in the AMDD series were found in 2008 for *SPI* 6- and *SPI* 9- at station 7767. We detected no changes in both the AMDS and AMDD time series at station D20A014. Changes were observed in 1981 at station 17866 for the *SPI* 6- in the AMDD time series, in 1982 at station D20A009 for the *SPI* 12- in the AMDD time series, and in 1988 at station D20A018 for the *SPI* 12- AMDD time series (Fig. 3).

In general, numerous change points were detected at stations 7767, 8275, and D20A016, with a significance level of 90%. Although there were no changes for the *SPI* 1- month time scales and the *SPI* 3-month time scales at station 8275, the years 1979, 1969, and 1980 were critical for the *SPI* 6- AMDS time series, the *SPI* 9- AMDD time series, and the *SPI* 12- AMDS time series, respectively. At station D20A016, the change point was detected in 1988, which was a critical year for the *SPI* 6-AMDS and AMDD time series, for the *SPI* 9- AMDS and AMDD time series, and for the *SPI* 12- AMDS time series.

5. Discussion and Conclusions

The AMDS and the AMDD trends in extreme drought events were evaluated in this study. The *SPI* drought index was used to assess the extreme events for 23 meteorological stations in Ceyhan Basin over several time scales of 1, 3, 6, 9, and 12 months. The AMDS and AMDD time series are important extreme hydrological drought events in disaster preparedness and the regional management of water supplies. The homogeneity of the extreme drought occurrence time series was investigated using the Wallis-Moore and Wald-Wolfowitz methods, and Mann-Kendal and Spearman Rho trend analyses were carried out. Sen's slope estimator and linear regression analysis were used to assess the magnitude of trends, and the SNHT, BRT, and PT were used to identify the change point that denotes the start of the trend.

The number of stations with non-homogeneous data increased as the *SPI* time scales increased, especially in the AMDS time series. Most of the stations seemed to have homogeneous time series; however, the data in a few stations were homogeneous by one of the methods and non-homogeneous by the other one, with a significance level of 90%.

In the AMDS series, an increasing trend was observed only in the station 7767 data for 3-, 6-, 9-, and 12-month time scales, whereas decreasing trends were detected in station 8275 for the 12-month time scale and in station D20A016 for the 6-, 9-, and 12-month time scales. Nevertheless, in the AMDD time series, increasing trends were noted in station 8275 for the 3-, 6-, 9-, and 12-month time scales, station 17866 for the 6-month time scale, station D20A009 for the 12-month time scale, station D20A016 for the 6- and 9-month time scales, and station D20A018 for the 12-month time scale, whereas decreasing trends were perceived in the station 7767 for the 6- and 9-month time scales and in station D20A014 for the 1-month time scale.

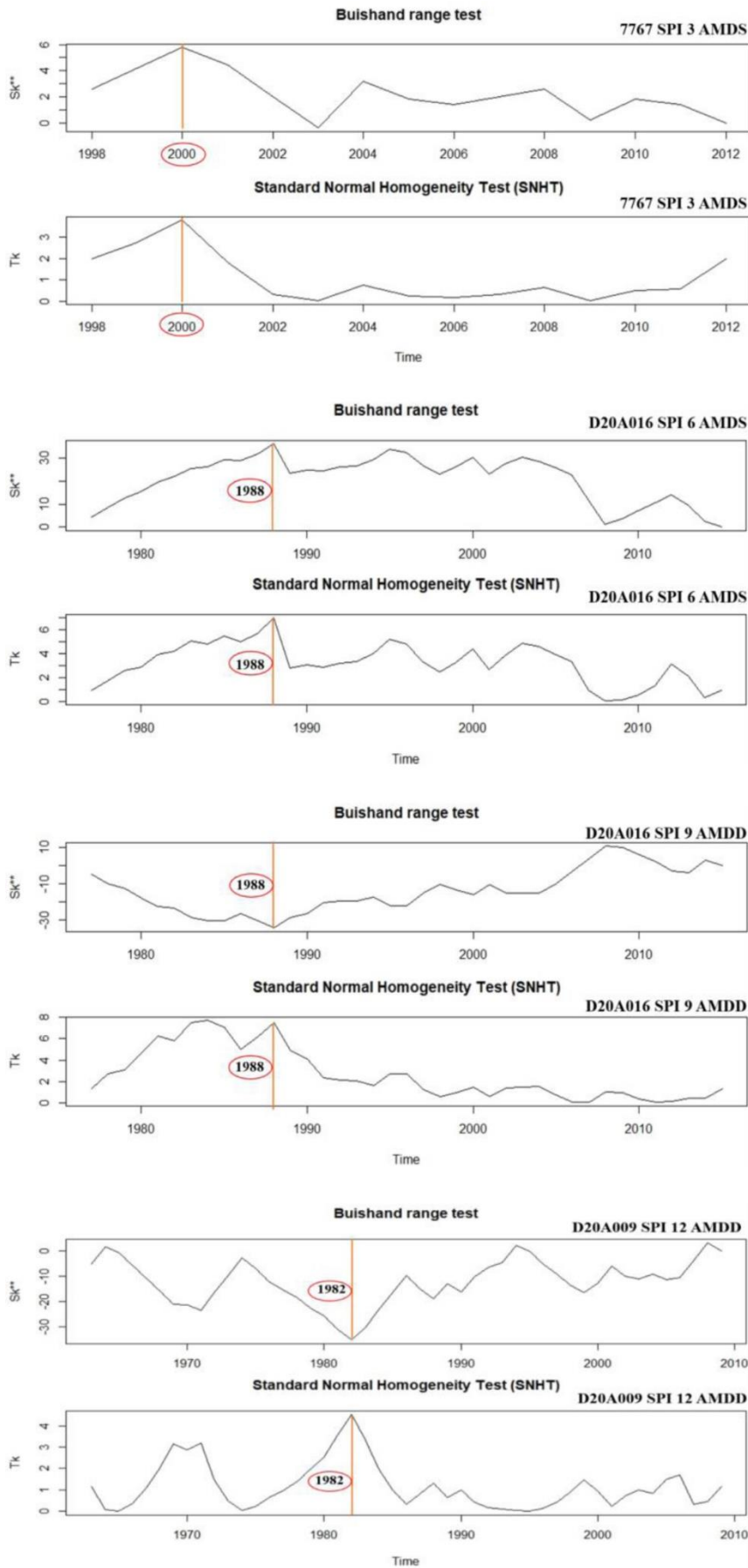


Fig. 3. Change point results for different time scales of *SPI* 3, 6, 9, and 12 months.

These results indicate that the AMDD time series with higher time scales revealed an increasing trend, whereas the AMDS time series showed a decreasing trend, which was statistically significant at the 90% confidence level.

Possible change points started after 1988 for D20A016 and D20A018, whereas the data in stations 7767, 8275, 17866, and D20A009 shifted after late 2000, 1969, 1981, and 1982, respectively. Change point detection tests captured different years in the data of some stations, most likely because of climate type, topography, and hydrological conditions, among others. Investigations on drought and climate change at local scales need to be periodically repeated to assess the impacts of precipitation, temperature, evapotranspiration, and groundwater level on agriculture, water resources and food security, energy production and security, economic growth, ecosystem sustainability, environmental health, and health security. The results of this study are consistent with previous findings. For instance, Dikici and Aksel, (2021) indicated that precipitation is generally decreasing, considering a 50-year period. According to their calculations, the basin faces a severe drought threat in the 20-year return period. Tosunoglu and Kisi (2016) investigated the trends of maximum hydrologic drought variables, annual maximum duration (AMD), and annual maximum severity (AMS) using MK, modified MK, and the recently developed Sen's innovative trend analysis (ITA) techniques. Increasing trends in the severity of the drought at the stations 2316 and 2323 were captured by the modified MK and ITA techniques, respectively. The possibility of future droughts or water shortages in these stations should be considered. The results of this paper provide valuable information to water resource management decision-makers in the Ceyhan River Basin for evaluating the effects of droughts and preparing for drought mitigation measures to avoid future drought risks.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgment

We are grateful to the General Directorate of Meteorology of the Ministry of Agriculture and Forestry in Turkey for providing us with the data used in this study.

Reference

- Alexandersson H., 1986, A homogeneity test applied to precipitation data, *International Journal of Climatology*, 6 (6), 661-675, DOI: 10.1002/joc.3370060607.
- Alhaji U., Yusuf A.S., Edet C.O., Oche C.O., Agbo E.P., 2018, Trend analysis of temperature in Gombe State using Mann Kendall Trend Test, *Journal of Scientific Research and Reports*, DOI: 10.9734/JSRR/2018/42029.
- Asfaw A., Simane B., Hassen A., Bantider A., 2018, Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin, *Weather and Climate Extremes*, 19, 29-41, DOI: 10.1016/j.wace.2017.12.002.
- Buishand T.A., 1982, Some methods for testing the homogeneity of rainfall records, *Journal of Hydrology*, 58 (1), 11-27, DOI: 10.1016/0022-1694(82)90066-X.

- Burn D.H., Sharif M., Zhang K., 2010, Detection of trends in hydrological extremes for Canadian watersheds, *Hydrological Processes*, 24 (13), 1781-1790, DOI: 10.1002/hyp.7625.
- Cannarozzo M., Noto L.V., Viola F., 2006, Spatial distribution of rainfall trends in Sicily (1921-2000), *Physics and Chemistry of the Earth. Parts A/B/C*, 31 (18), 1201-1211, DOI: 10.1016/j.pce.2006.03.022.
- Dashtpajardi M.M., Kousari M.R., Vagharfard H., Ghonchepour D., Hosseini M.E., Ahani H., 2015, An investigation of drought magnitude trend during 1975-2005 in arid and semi-arid regions of Iran, *Environmental Earth Sciences*, 73, 1231-1244, DOI: 10.1007/s12665-014-3477-1.
- Demuth S., Bakenhus A., 1994, *Hydrological Drought – A literature review*, University of Freiburg, Freiburg, Germany.
- Dikić M., Aksel M., 2021, Comparison of drought indices in the case of the Ceyhan Basin, *International Journal of Environment and Geoinformatics*, 8 (2), 113-125, DOI: 10.30897/ijegeo.792379.
- Dracup J.A., Lee K.S., Paulson E.G., 1980, On the definition of droughts, *Water Resources Research*, 16 (2), 297-302, DOI: 10.1029/WR016i002p00297.
- Eris E., Aksoy H., Onoz B., Cetin M., Yuce M.I., Selek B., Aksu H., Burgan H.I., Esit M., Yildirim I., Karakus E.U., 2019, Frequency analysis of low flows in intermittent and non-intermittent rivers from hydrological basins in Turkey, *Water Supply*, 19 (1), 30-39, DOI: 10.2166/ws.2018.051.
- Ganguli P., Reddy M.J., 2014, Evaluation of trends and multivariate frequency analysis of droughts in three meteorological subdivisions of western India, *International Journal of Climatology*, 34 (3), 911-928, DOI: 10.1002/joc.3742.
- Gocic M., Trajkovic S., 2013, Analysis of precipitation and drought data in Serbia over the period 1980-2010, *Journal of Hydrology*, 494, 32-42, DOI: 10.1016/j.jhydrol.2013.04.044.
- Helsel D.R., Hirsch R.M., Ryberg K.R., Archfield S.A., Gilroy E.J., 2002, *Statistical methods in water resources*, Techniques and Methods 4-A3, DOI: 10.3133/tm4A3.
- Houghton J.T., Meiro Filho L.G., Callander B.A., Harris N., Kattenburg A., Maskell K., 1996, *Climate Change 1995: The Science of Climate Change*, IPCC assessment report, available online <https://digitallibrary.un.org/record/223181> (data access 04.10.2022).
- Jaiswal R.K., Lohani A.K., Tiwari H.L., 2015, Statistical analysis for change detection and trend assessment in climatological parameters, *Environmental Processes*, 2 (4), 729-749, DOI: 10.1007/s40710-015-0105-3.
- Kampata J.M., Parida B.P., Moalafhi D.B., 2008, Trend analysis of rainfall in the headstreams of the Zambezi River Basin in Zambia, *Physics and Chemistry of the Earth. Parts A/B/C*, 33 (8-13), 621-625, DOI: 10.1016/j.pce.2008.06.012.
- Karabulut M., Gürbüz M.A., Korkmaz H., 2008, Precipitation and temperature trend analyses in Samsun, *Journal of International Environmental Application and Science*, 3 (5), 399-408.
- Kendall M.G., 1975, *Rank correlation methods*, 4th edition, Charles Griffin, London.
- Keskin M.E., Taylan D., Aslanbaş T., 2015, An investigation of water potential of Lake Eğirdir, Turkey, *Procedia Earth and Planetary Science*, 15, 244-248, DOI: 10.1016/j.proeps.2015.08.060.
- Kumar V., Jain S.K., 2010, Trends in seasonal and annual rainfall and rainy days in Kashmir Valley in the last century, *Quaternary International*, 212 (1), 64-69, DOI: 10.1016/j.quaint.2009.08.006.
- Lehmann E.L., D'Abbrera H.J., 1975, *Nonparametrics: Statistical methods based on ranks*, Springer, Oxford, 479 pp.
- Mann H.B., 1945, Nonparametric Tests Against Trend, *Econometrica*, 13 (3), 245-259, DOI: 10.2307/1907187.
- McKee T.B., Doesken N.J., Kleist J., 1993, The relationship of drought frequency and duration to time scales, [in:] 8th Conference on Applied Climatology, Anaheim, 17-22 January, 179-184.
- Palmer W.C., 1965, *Meteorological drought*, Research Paper No. 45, US Weather Bureau, Washington, DC.
- Palmer W.C., 1968, Keeping track of crop moisture conditions, nationwide: The new crop moisture index, *Weatherwise*, 21 (4), 156-161, DOI: 10.1080/00431672.1968.9932814.
- Pettitt A.N., 1979, A Non-parametric approach to the change-point problem, *Journal of the Royal Statistical Society. Series C: Applied Statistics*, 28 (2), 126-135, DOI: 10.2307/2346729.
- Piccarreta M., Capolongo D., Boenzi F., 2004, Trend analysis of precipitation and drought in Basilicata from 1923 to 2000 within a southern Italy context, *International Journal of Climatology*, 24 (7), 907-922, DOI: 10.1002/joc.1038.

- Santos C.A.C. dos, Neale C.M.U., Rao T.V.R., da Silva B.B., 2011, Trends in indices for extremes in daily temperature and precipitation over Utah, USA, *International Journal of Climatology*, 31 (12), 1813-1822, DOI: 10.1002/joc.2205.
- Sen P.K., 1968, Estimates of the regression coefficient based on Kendall's Tau, *Journal of the American Statistical Association*, 63 (324), 1379-1389, DOI: 10.1080/01621459.1968.10480934.
- Shafer B.A., Dezman L.E., 1982, Development of a surface water supply index (SWSI) to assess the severity of drought conditions in snowpack runoff areas, [in:] *Proceedings of the 50th Annual Western Snow Conference*, Reno, Nevada.
- Shi X., Xu X., 2008, Interdecadal trend turning of global terrestrial temperature and precipitation during 1951-2002, *Progress in Natural Science*, 18 (11), 1383-1393, DOI: 10.1016/j.pnsc.2008.06.002.
- Smadi M.M., Zghoul A., 2006, A sudden change in rainfall characteristics in Amman, Jordan during the mid 1950s, *American Journal of Environmental Sciences*, 2 (3), 84-91, DOI: 10.3844/ajessp.2006.84.91.
- Sneyers R., 1990, On the statistical analysis of series of observations, WMO Technical Note, 192 pp.
- Spinoni J., Naumann G., Carrao H., Barbosa P., Vogt J., 2014, World drought frequency, duration, and severity for 1951-2010, *International Journal of Climatology*, 34 (8), 2792-2804, DOI: 10.1002/joc.3875.
- Tabari H., Abghari H., Talaei P.H., 2012, Temporal trends and spatial characteristics of drought and rainfall in arid and semiarid regions of Iran, *Hydrological Processes*, 26 (22), 3351-3361, DOI: <https://doi.org/10.1002/hyp.8460>.
- Tallaksen L., van Lanen H.A.J., 2004, *Hydrological drought. Processes and estimation methods for streamflow and groundwater*: Elsevier.
- Tate E.L., Gustard A., 2000, Drought definition: A hydrological perspective, [in:] *Drought and Drought Mitigation in Europe*, J.V. Vogt, F. Somma (eds.), Springer Netherlands, Dordrecht, 23-48, DOI: 10.1007/978-94-015-9472-1_3.
- Tosunoglu F., Kisi O., 2016, Joint modelling of annual maximum drought severity and corresponding duration, *Journal of Hydrology*, 543, 406-422, DOI: 10.1016/j.jhydrol.2016.10.018.
- Uzunkol M., Kızılelma Y., 2016, Determination of drought status and trends in the Ceyhan Basin. *The Journal of Academic Social Sciences*, 29 (4), 503-519, DOI: 10.16992/ASOS.1258.
- Vezzoli R., Pecora S., Zenoni E., Tonelli F., 2012, Data Analysis to Detect Inhomogeneity, Change Points, Trends in Observations: An Application to Po River Discharge Extremes, CMCC Research Paper No. 138.
- Villarini G., Serinaldi F., Smith J.A., Krajewski W.F., 2009, On the stationarity of annual flood peaks in the continental United States during the 20th century, *Water Resources Research*, 45 (8), DOI: 10.1029/2008WR007645.
- Wald A., Wolfowitz J., 1940, On a test whether two samples are from the same population, *The Annals of Mathematical Statistics*, 11 (2), 147-162.
- Wallis W.A., Moore G.H., 1941, A Significance Test for Time Series and Other Ordered Observations, National Bureau of Economic Research.
- Wilhite D.A., Glantz M.H., 1985, Understanding the drought phenomenon: The role of definitions, *Water International*, 10 (3), 111-120, DOI: 10.1080/02508068508686328.
- Xu Y., Lin S., Huang Y., Zhang Q., Ran Q., 2011, Drought analysis using multi-scale standardized precipitation index in the Han River Basin, China, *Journal of Zhejiang University-SCIENCE A*, 12 (6), 483-494, DOI: 10.1631/jzus.A1000450.
- Yu P.-S., Yang T.-C., Kuo C.-C., 2006, Evaluating long-term trends in annual and seasonal precipitation in Taiwan, *Water Resources Management*, 20 (6), 1007-1023, DOI: 10.1007/s11269-006-9020-8.
- 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, DOI: 10.1016/0022-1694(93)90156-4.
- Yuce M.I., Esit M., Ercan B., 2018, A relationship between flow discharges, sediment discharge and sub-basin areas in Ceyhan Catchment, [in:] *13th International Congress on Advances in Civil Engineering*, 12-14 September, Izmir.
- Yuce M.I., Esit M., Kalaycioglu V., 2022, Investigation of trends in extreme events: a case study of Ceyhan Basin, Turkey, *Journal of Applied Water Engineering and Research*, DOI: 10.1080/23249676.2022.2113462.
- Yuce M.I., Esit M., Karatas M.C., 2019, Hydraulic geometry analysis of Ceyhan River, Turkey, *SN Applied Sciences*, 1 (7), 763, DOI: 10.1007/s42452-019-0800-1.

Yuce M.I., Esit M., Muratoglu A., 2015, Determining the hydraulic geometry parameters of Seyhan River, American Journal of Engineering, Technology and Society, 2 (4), 77-84.

Zhang Y., Cai W., Chen Q., Yao Y., Liu K., 2015, Analysis of changes in precipitation and drought in Aksu River Basin, Northwest China, Advances in Meteorology, DOI: 10.1155/2015/215840.

Zhong A.H., Li Y.Q., 2009, Spatial and temporal distribution characteristics and variation tendency of precipitation in Mianyang, Sichuan Province, Plateau and Mountain Meteorology Research, 29 (4), 63-69.