



Evaluation of annual total precipitation in the transboundary Euphrates–Tigris River Basin of Türkiye using innovative graphical and statistical trend approaches

Meral Buyukyildiz¹

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Abstract

The Euphrates–Tigris River Basin (ETRB), one of the largest river basins in the Middle East, is also among the most risky transboundary basins in the world. ETRB has a critical importance for the region both politically and economically due to its location. Evaluating the increasing regional impacts of climate change is even more important for the sustainable management of water and soil resources, especially in transboundary basins such as ETRB. Türkiye is one of the most important riparian countries of the ETRB and the Türkiye part of ETRB constitutes the headwater of the basin. In this study, the temporal variability of the annual total precipitation data for the period 1965–2020 of eighteen stations located in the Türkiye part of the ETRB was investigated. Classical Mann–Kendall (MK) test was used to statistically determine the monotonic trend of precipitation. In addition to the MK method, analyses were carried out with three innovative trend methods, which have the ability to interpret trends both statistically and graphically. These innovative trend methods are Şen innovative trend analysis (Şen-ITA), Onyutha trend test (OTT) and trend analysis with combination of Wilcoxon test and scatter diagram (CWTSD). The results obtained show that there is a decreasing trend in annual total precipitation in ETRB according to all trend methods generally used for the examined period. In addition, the results obtained from the relatively new OTT and CWTSD methods show strong consistency with the results of the other two methods. The advantages such as performing numerical and visual trend analysis with innovative OTT and CWTSD methods, identifying trends in low–medium–high value data and detecting sub-trends have shown that these methods can be used as an alternative to the widely used MK and Şen-ITA.

Keywords Climate change · Euphrates–Tigris basin · Onyutha trend test · Şen innovative trend analysis · Transboundary river basin · Wilcoxon test

Introduction

Climate change is a very complex and critical issue that interacts with many sectors such as drinking and utility water, agriculture, food, industry, health, tourism, natural disasters and ecosystem. The importance of water is quite high in almost all sectors where climate change interacts. The scarcity of water, its non-substitutability, industrialization, urbanization, population growth, increase in irrigated agricultural lands, technological innovations, climate changes and environmental problems increase the need for

water resources day by day (Akbaş 2015). On the other hand, water resources are rapidly decreasing due to factors such as pollution and climate change in parallel with population growth.

Many studies on climate change are carried out by researchers all over the world, and the spatial and temporal variability of the hydrological cycle components is examined (Bouklikha et al. 2021; Saphioğlu and Güçlü 2022; Koycegiz and Buyukyildiz 2019; Zerouali et al. 2022; Özel et al. 2004; Zhu et al. 2020). For this purpose, various trend methods are used, both parametric and nonparametric, as well as providing statistical and graphical evaluation. For the past few decades, methods such as Mann–Kendall (MK), sequential Mann–Kendall (SMK), Spearman’s rho (SRho), Sen’s t , Sen’s slope, linear regression (LR) and cumulative sum (CS) have been common in determining trends in hydro-meteorological time series (Makwana et al. 2020; Koycegiz

✉ Meral Buyukyildiz
mbuyukyildiz@ktun.edu.tr

¹ Department of Civil Engineering, Konya Technical University, Konya, Türkiye

and Buyukyildiz 2021; Patakamuri et al. 2020; Shahid 2011; Yenigun et al. 2008; Yue et al. 2002). Rahman et al. (2017) examined the annual, monthly and dry season precipitation trends of Bangladesh and found no significant trend in annual mean precipitation and dry season precipitation for the whole country, while increasing and decreasing trends were obtained in long-term monthly precipitation. Ahmad et al. (2015) analyzed the trends in monthly, seasonal and annual precipitation of 15 stations in the Swat River Basin in Pakistan for the period 1961–2011 using MK and SRho tests, and determined a mixture of increasing and decreasing trends. Fathian et al. (2015) investigated temporal monotonic trends in temperature, precipitation and river flow time series in the Urmia Lake Basin using MK, SRho and Sen's *T* tests.

In recent years, besides classical methods, some innovative approaches have been used in trend analysis. With the innovative trend analysis (Şen-ITA) developed by Şen (2012), the trend in hydrometeorological data can be evaluated graphically, as well as determining whether there is a trend in the low, medium and high values of the time series. Innovative polygon trend analysis (IPTA), an improved version of the Şen-ITA method, was proposed by Şen et al. (2019). Another trend analysis method developed by Şen (2020) is probabilistic innovative trend analysis (PITA), in which probability distribution functions play a role instead of statistical parameters. Şen et al. (2022) proposed a method called cross-empirical trend analysis (CETA) to determine the trends of hydrometeorological time series records at different levels within the variation range. Another innovative trend method is the nonparametric cumulative sum of rank difference (CSD) method proposed by Onyutha (2016a). The CSD method is an approach to graphically determine both the trend of the hydrometeorological variables in the full series and the sub-trends (Onyutha 2016a, 2016b). Recently, an alternative trend analysis method, which includes the combination of Wilcoxon test and scatter diagram (CWTSD), which provides both graphical and statistical interpretations, has been proposed by Saphroğlu and Güçlü (2022). In recent years, there are many studies investigating the variability of hydrometeorological data using innovative analysis methods, some examples of which are given above, as well as classical methods (Serinaldi et al. 2020; Ceribasi et al. 2021; Hırca et al. 2022; Koycegiz and Buyukyildiz 2022; Ahmed et al. 2022; Alashan 2018; Ali et al. 2019; Cengiz et al. 2020; Onyutha 2021; Şen et al. 2022).

Determining the temporal and spatial variability of hydro-meteorological parameters is of great importance especially for transboundary basins. Especially with climate change, the issue of transboundary waters among water problems occupies the political and economic agenda more than in the past (Colvin et al. 2015; Akbaş 2015; Abel et al. 2019). There are many “transboundary” rivers in Türkiye's

territory, such as the Asi, Aras, Meriç, Çoruh, Euphrates and Tigris. The Euphrates and Tigris Rivers, the two main rivers of the Euphrates–Tigris River Basin (ETRB), one of the largest river basins in the Middle East, originate in Türkiye and are key water resources for riparian countries (Rougé et al. 2018). The water issue has the potential to cause more serious problems in the Middle East compared to other regions. The ETRB is among the most risky transboundary basins in the world and has a critical importance for the region both politically and economically (Mianabadi et al. 2022; Yoffe et al. 2003; Daggupati et al. 2017). The main reasons for this are that the need for water is high, water resources are scarce, and the region has an unstable structure where historically continuous conflicts have occurred (Akbaş 2015). Türkiye, the upper riparian country of the ETRB, contributes 89 and 51% to the flow of the Euphrates and Tigris, respectively (FAO, 2009). Especially in the Turkish part of the ETRB, it is estimated that precipitation and snowfall in the basin will decrease by 30–40% by the end of the century (IPCC 2013). The amount of precipitation has an important role in the feeding of surface and underground water resources. Precipitation directly or indirectly affects water resources, water availability and management of water resources (Hu et al. 2017). For this reason, temporal analysis of precipitation in the Türkiye part, which is the upstream of the ETRB, is of great importance for both upper riparian Türkiye and other riparian countries.

In this study, it is aimed to examine the temporal variability of the annual total precipitation of the eighteen stations located in the Turkish part of the ETRB during the 1965–2020 periods. The variability in precipitation time series has been realized by using classical and innovative trend methods, which have the ability to determine both monotonic trends and sub-trends, as well as provide statistical and graphical evaluation. The trend methods used include some or all of these features. This study is important in terms of both detecting the temporal variation of precipitation in the transboundary ETRB, which is very important for the Middle East, and revealing the analytical power of the graphical–statistical trend methods (and comparing them with classical trend method) which are quite new in the literature.

Materials and methods

General explanations about the ETRB

ETRB, one of the most risky basins in the world, is also one of the largest transboundary river basins in the Middle East. The total area of the ETRB is 879 790 km² (13% of the Middle East) and covers six riparian countries (Fig. 1). Only Saudi Arabia and Jordan, which are riparian to the

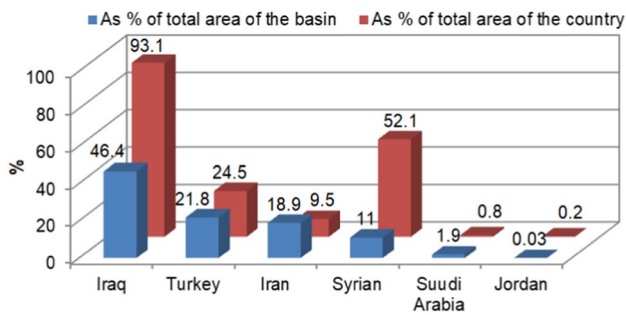


Fig. 1 The riparian countries in the ETRB (FAO 2009)

Euphrates, have a small and arid part of the basin. Iran is riparian only to the Tigris (FAO 2009). The two main rivers of the ETRB are the Tigris and Euphrates Rivers originating in Türkiye.

The source of the Euphrates is the Murat River, which originates in Ağrı Diyaradin in eastern Türkiye, and the Karasu River, which originates in Erzurum Dumludağ. The Euphrates River, after Türkiye (upper riparian), passes through Syria (middle riparian) and Iraq (lower riparian) lands, respectively. In Southern Iraq, the Euphrates and Tigris merge to form the Shatt al-Arab River and then discharge into the Persian Gulf. The Tigris River, which originates in the Southeastern Taurus Mountains in Türkiye, flows southward and forms the Türkiye-Syria border for 40 km from Türkiye’s border city, Cizre. The Tigris River merges with the Habur River outside Türkiye and then passes into Iraq. It merges with the Zap River (in Mosul) and with the Piyale River originating from Iran near Baghdad and joins

with the Euphrates River (Shatt al-Arab) 64 km above Basra and discharge into the Persian Gulf. The region between two rivers is called Mesopotamia. The Euphrates River is 3000 km long (1230 km in Türkiye), and the Tigris River is 1850 km long (400 km in Türkiye). Türkiye’s contribution to the annual flow volume of the Euphrates River is 89%, while its contribution to the annual flow volume of the Tigris River is 51% (FAO 2009; Bozkurt and Sen 2013; Mueller et al. 2021; Yurddaş 2018; Akkaya 2022; Gülsever 2006).

Study area and data

In this study, the part of the ETRB on Türkiye territory was used as the study area (Fig. 2). The study area is one of the twenty-five basins of Türkiye, located in the east of Türkiye, and consists of two parts, the Euphrates and the Tigris. The Tigris Basin covers approximately 7% of Türkiye’s surface area, while the Euphrates Basin covers 16%. The Euphrates Basin covers two meteorological regions (Southeastern Anatolia Region and Eastern Anatolia Region). In parts of the Southeastern Anatolia Region, the summers are hot and dry, and the winters are relatively cold due to the continental climate. In the parts of the Eastern Anatolia Region, the winters are quite cold and the summers are cool. The annual average precipitation in the basin increases significantly from Southeastern Anatolia in the south to the Black Sea in the north. While very little of the precipitation in parts of the Southeastern Anatolia region is due to snowfall, a significant part is due to rain (Yurddaş 2018; Akkaya 2022).

The Tigris Basin also includes various climatic characteristics. The effect of the Mediterranean climate seen in the

Fig. 2 Locations of precipitation measurement station in ETRB



Southwest parts of the Upper Tigris Sub-Basin is moderated to a certain extent by cutting the cold winds coming from the Southeast Taurus Mountains in the north of the basin. A harsher climate prevails in the central parts of the basin. In the Zap Şemdinli Sub-Basin of the Tigris Basin, the continental climate is dominant and the winters are quite cold and the summers are cool. During the summer months, especially in the Southeastern Anatolia Region, drought is at its peak. The annual average precipitation in the basin increases significantly from Southeastern Anatolia to the north toward the Black Sea. A large part of the precipitation falling in the Eastern Anatolia region during the winter months falls as snow. Due to the low average temperatures in this region, the precipitation falling in the winter months is stored as snow in the high mountains for a long time (Akkaya 2022; Gülsever 2006).

Annual precipitation data were obtained from the Türkiye State Meteorological Service. Annual total precipitation data of 18 stations for the period 1965–2020 were used. The information about the stations used, and the statistical characteristics of the annual total precipitation during 1960–2020 period are presented in Table 1. The annual total precipitation values in the basin vary between 146.3 mm and 1992.8 mm. The station with the lowest annual average precipitation value is Malatya with 381.1 mm, and the highest station is Bitlis with 1211.1 mm. The annual maximum (minimum) precipitation values belong to the lowest Erzurum (Diyarbakır) and the

highest Tunceli (Bitlis) stations. Standard deviation (SD) values vary between 76 (Erzincan) and 273.5 (Bitlis). In Table 1, excess kurtosis (C_k) and skewness values (C_s) of the observed precipitation for each station are also given. A kurtosis value greater than 3 (excess kurtosis = $C_k > 0$) indicates that the tails of the observed data are thicker and longer than the normal distribution, and the central peak is higher and sharper (Leptokurtic distribution). If Kurtosis is less than 3 (excess kurtosis = $C_k < 0$), it is an indication that the tailedness is lighter or that there are no (or few) outliers (platykurtic distribution). If the skewness value (C_s) is between ± 0.5 , it is highly symmetrical, between ± 0.5 and 1 indicates moderately skewed, and > 1 (< -1) indicates that the time series is much skewed (Hawkins 1980; Friedman and Vandersteel 1982; Aawar et al. 2019). As illustrated in Table 1, skewness is positive (skewed to the right) at all stations except Diyarbakır. While the C_s values of Mardin, Ağrı, Muş, Erzurum, Siirt, Batman and Diyarbakır stations are between ± 0.5 and there is a fairly symmetrical distribution (close to the normal distribution), the precipitations of the other stations, except for Tunceli station, generally have moderate skewness. Observed precipitation of Tunceli station is much skewed with the value of $C_s = 2.31$ (> 1). The C_k values of Kilis, Adıyaman, Mardin, Erzurum, Muş, Ağrı, Siirt and Batman stations are less than zero (negative) and platykurtic. The C_k values of other stations are greater than zero and leptokurtic. Especially Tunceli station precipitation values tend to have very thick tails and a large number

Table 1 Geographical features and annual precipitation characteristics of stations in ETRB

Station number	Station name	Longitude (N)	Latitude (E)	Annual total precipitation (mm)					
				Mean (mm)	Max.(mm)	Min (mm)	Standard deviation (SD)	Excess kurtosis (C_k)	Skewness (C_s)
17,262	Kilis	36.7084	37.1120	490.8	814.4	290.7	138	-0.27	0.61
17,261	Gaziantep	37.0585	37.3510	567.4	994	325.1	141.6	0.33	0.54
17,270	Şanlıurfa	37.1608	38.7863	453.9	854.7	196.4	151.5	0.44	0.87
17,265	Adıyaman	37.7553	38.2775	715	1169.9	418.5	194	-0.57	0.53
17,275	Mardin	37.3103	40.7284	661.4	1193.9	252.6	220	-0.26	0.47
17,199	Malatya	38.3367	38.2173	381.1	597.4	252	83.6	0.39	0.84
17,201	Elazığ	38.6443	39.2561	411.3	733	205.6	101.4	0.91	0.61
17,165	Tunceli	39.1058	39.5408	852.9	1992.8	521.2	270.5	6.77	2.31
17,094	Erzincan	39.7523	39.4868	375.2	626	238.4	76	1.06	0.78
17,096	Erzurum	39.9529	41.1897	406.9	593.3	253.8	77.8	-0.22	0.28
17,208	Bitlis	38.4750	42.1625	1211.1	1899	738.2	273.5	0.34	0.57
17,203	Bingöl	38.8847	40.5007	948.9	1579.1	596.6	197.8	1.14	0.81
17,204	Muş	38.7509	41.5023	762.2	1085.5	479.3	144.8	-0.43	0.08
17,099	Ağrı	39.7253	43.0522	522.2	779.6	330	104.8	-0.28	0.23
17,280	Diyarbakır	37.8973	40.2027	492.9	768.6	146.3	127.1	0.18	-0.08
17,210	Siirt	37.9319	41.9354	698.8	1046.4	430.8	159.6	-0.42	0.28
17,282	Batman	37.8636	41.1562	486.7	802.2	240.1	127.1	-0.36	0.40
17,285	Hakkari	37.5745	43.7388	773.4	1192.1	450.3	164.9	0.05	0.61

of outliers with $C_k=6.77 (>0)$. This station has a very high standard deviation compared to other stations (except Bitlis) with $SD=270.5$ value.

Trend methods

Şen innovative trend analysis (Şen-ITA)

In this method proposed by Şen (2012), the current time series is divided into two equal parts and the data in each sub-series are ordered from smallest to largest (or from largest to smallest). The first sub-series are on the horizontal axis, and the second sub-series are on the vertical axis, in a Cartesian coordinate system. According to the graph obtained, the trends in the time series are evaluated (Fig. 3). If the data points fall on the 1:1 straight line (45°), there is no trend. If the points are in the lower (upper) triangle area of the 1:1 straight line, there is a decreasing (increasing) trend (Şen 2012). Different trend classes that may occur according to this method are illustrated in Fig. 3.

The difference between the y and x values of a point shows the magnitude of the decreasing and increasing trend, and the absolute value of this difference is the horizontal and vertical distance from the 1:1 straight line (Wu and Qian 2017). The overall trend of a time series is determined by the mean differences. Şen-ITA trend indicator is calculated with the following equation.

$$D = \frac{1}{n} \sum_{i=1}^n 10 \frac{(y_i - x_i)}{\bar{x}} \tag{1}$$

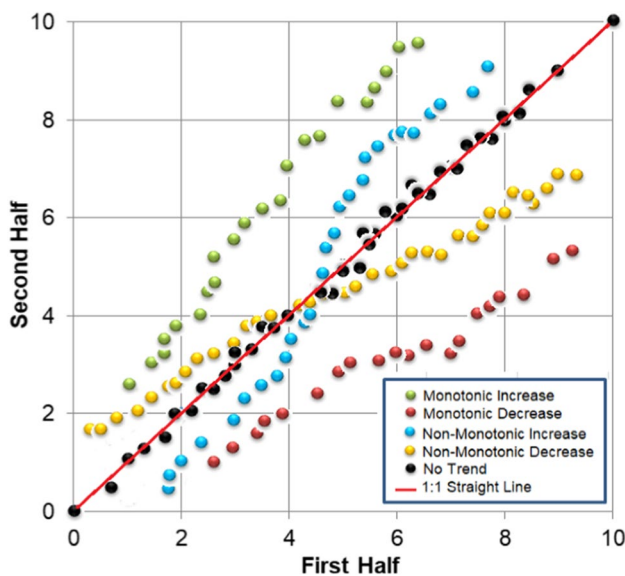


Fig. 3 Possible trend situations according to Şen-ITA

where D is the trend indicator. The positive (negative) value of D shows the increasing (decreasing) trend. n represents the number of data in each sub-series and \bar{x} represents the mean of the first sub-series. (Nisansala et al. 2020, Wu and Quian 2017; Ahmad et al. 2018; Gujree et al. 2022).

Trend analysis with combination of Wilcoxon test and scatter diagram (CWTSD)

In this method proposed by Saplıoğlu and Güçlü (2022), trend evaluation is performed using a combination of scatter diagram and Wilcoxon test (Wilcoxon 1945). In this method, N time series (x_1, x_2, \dots, x_N) is divided into two equal parts ($n=N/2$ numbers) as in Şen-ITA. Contrary to Şen-ITA, the two sub-series obtained are marked mutually in the Cartesian coordinate system, the first sub-series ($X_i=x_1, x_2, \dots, x_{N/2}$) on the x-axis and the second sub-series ($Y_i=x_{N/2+1}, x_{N/2+2}, \dots, x_N$) on the y-axis, without any order. If the distribution of the data on the obtained graph is more in the region below (above) the 1:1 straight line, it can be interpreted visually that there is a decreasing (increasing) trend. If the distribution of unsorted data is approximately equal in the region above or below the 1:1 straight line, it is considered that there is no trend (Fig. 4). The visual difference between the two scatter diagrams obtained using non-ordered two sub-series (NO-ITA) and ordered two sub-series (Şen-ITA) is shown in Fig. 4.

The numerical trend evaluation of the distribution of the data on the graph obtained by using non-ordered two sub-series is made using the Wilcoxon test. In the Wilcoxon test, firstly, the differences between the values of non-ordered two sub-series (X_i : First sub-series and Y_i : Second sub-series) are calculated algebraically (Eq. 2).

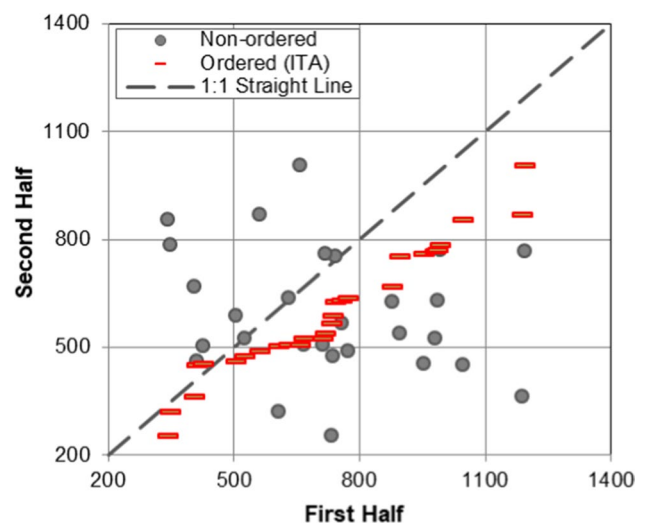


Fig. 4 Distinctions between Şen-ITA (ordered data) and NO-ITA (non-ordered data) methods

$$D_i = X_i - Y_i \tag{2}$$

After taking the absolute value of the series obtained by taking the difference (Eq. 3), their rank is determined from the smallest to the largest. The signs of the differences to which they belong to the rank values are given.

$$|D_i| = |X_i - Y_i| \tag{3}$$

Rank values are collected separately according to their signs. The sum of the “+” and “-” marked ranks are determined as T^+ and T^- , respectively. On the other hand, T^+ and T^- must always equal the sum of all N rows (i.e., $T^+ + T^- = n(n + 1)/2$). The absolute value of T^+ and T^- is taken and the smaller value is chosen as the Wilcoxon test statistic value (T_W). The T_W value is compared with the Wilcoxon critical table value (T_o) at α significance level. If $T_W \leq T_o$, the null hypothesis is rejected (trend exists). Otherwise, the null hypothesis is accepted (no trend). When the number of samples is relatively large ($n > 20$), the Wilcoxon test statistic Z_W value is calculated with the following equation using the normal distribution approach.

$$Z_W = \frac{T_W - \mu_T}{\sigma_T} \tag{4}$$

where μ_T and σ_T represent the mean and standard deviation, respectively, and are calculated by the equations below. n is the number of data in each sub-series.

$$\mu_T = \frac{n(n + 1)}{4} \tag{5}$$

$$\sigma_T = \sqrt{\frac{n(n + 1)(2n + 1)}{24}} \tag{6}$$

Trend evaluation according to the obtained Z_W value is made by comparing the $Z_{critical}$ value at the α significance level obtained from the standard normal distribution table, as in the MK test statistic (Adeniyi and Dilau 2015; Saplıoğlu and Güçlü 2022; Lee and Kang 2015; Karagöz, 2019).

Onyutha trend test (OTT)

The Onyutha trend test (OTT) has been proposed to detect temporal sub-trends, unlike many trend analysis methods in the literature (Onyutha 2016a, 2016b, 2021). OTT is applied to rescaled nonparametric series. It is necessary to obtain the a_j and q_k series in order to allow the sub-trends to be investigated graphically. The a_j and q_k series are calculated with the help of the following equations.

$$a_j = \sum_{i=1}^j e_{y,i} \quad 1 \leq j \leq n \tag{7}$$

$$q_k = \sum_{j=1}^k a_j \quad 1 \leq k \leq n \tag{8}$$

In the above equation, e_y is expressed as the rescaled and standardized series of the natural time series (Onyutha 2021). The temporal variability of the a_j series can be expressed as an analogy to the limit Markov process. The breaks in this series indicate a temporal change. Hurst exponent (HE) was used in addition to the a_j series to examine the temporal variability (Hurst 1951). Observation of the graphical subtrend analysis is provided by plotting the q_k series against the observation period. Confidence interval limits (CILs) are set to determine the presence of a significant trend. In this study, 95% significance level was taken into account. In addition, standardized test statistics (Z) and trend statistics (T) should be calculated for statistical analysis of the trend. CILs, Z and T are determined with the help of the following equations (Onyutha 2021).

$$CIL_s = \mp \left| Z_{\alpha/2} \right| \times \sqrt{V^F(T)} \tag{9}$$

$$Z = \frac{T}{\sqrt{V(T)}} \text{ and } T = \sum_{j=1}^n \sum_{i=1}^j e_{y,i} \tag{10}$$

$V(T)$ is the variance of the test statistic. The q_k series is sufficient to investigate the sub-trends that occur with the occurrence of a temporal break. However, Z statistics are calculated by shifting the determined time windows in order to examine the changes in the study period in more detail. In this study, the time window was determined as 10 years. Calculated Z values are plotted against the number of data. Thus, the presence of sub-trends in periods when temporal break does not occur can be examined. For detailed information about OTT, please see Onyutha (2016a; 2016b; 2021).

Mann–Kendall (MK) test

The Mann–Kendall (MK) test (Mann 1945; Kendall 1975), recommended to be used in trend analysis by the World Meteorological Organization (WMO), is a nonparametric rank-based test and independent of the distribution of data (Mitchell et al. 1966; Mianabadi et al. 2022). MK test statistic (Z) is calculated with the following equations.

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

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

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

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

In the above equations, n is the number of data. X_i and X_j represent data values at i and j times, respectively. In Eq. 14, where k is the number of the tied groups in the data set and t_i is the number of data points in the i^{th} tied group. According to the standardized MK test statistic (Z_{MK}) value calculated by Eq. 11, the evaluation of the trends is done at the α significance level. In this study, $\alpha = 0.05$ was used. The $Z_{critical}$ value obtained from the standard normal distribution table for $\alpha = 0.05$ is 1.96. If $|Z_{MK}| > Z_{1-\alpha/2}$, the null hypothesis (H_0) is rejected and the alternative hypothesis (H_1) is accepted. There is a significant trend at the α significance level in the time series examined according to the H_1 hypothesis. If the Z_{MK} (or S) value is negative, it indicates the presence of a decreasing trend, and if it is positive, it indicates the presence of an increasing trend (Mianabadi et al. 2022; Makwana et al. 2020).

Before applying the MK method, it should be checked whether there is a serial correlation in the time series. If there is a serial correlation at a certain level of significance in the time series, it should be eliminated and the MK test should be applied later (Von Storch and Navarra 1995). In the literature, some methods are used to eliminate the serial correlation determined in the time series (Von Storch and Navarra 1995; Yue et al. 2002; Hamed and Rao 1998). In this study, the pre-whitening procedure suggested by Von Storch and Navarra (1995) was applied to the time series with serial correlation. Details of the processing steps of the pre-whitening procedure are available in many studies in the literature (Gümüř 2019; Gocic and Trajkovic 2013; Chatterjee et al. 2016).

Results and discussion

The spatial distribution and box plots of the annual total precipitation data for the 1965–2020 period of the eighteen meteorological stations in the ETRB are illustrated in Fig. 5. According to Fig. 5a, the annual mean precipitation has higher values in the east of the ETRB. Ten of the eighteen stations have outliers (Fig. 5b). However, all of the outliers are seen on the upper side, except for Diyarbakır station. There are large outliers only for Tunceli station, the others are usually mild outliers. The large outliers at Tunceli station coincide also with the high kurtosis value of this station in Table 1.

The trends of the annual total precipitation data for 56 years (1965–2020 periods) of the eighteen stations in the ETRB were first analyzed graphically. For this purpose, Şen-ITA, NO-ITA and OTT tests were used. The Şen-ITA method (based on ranking each sub-series in a bi-divided

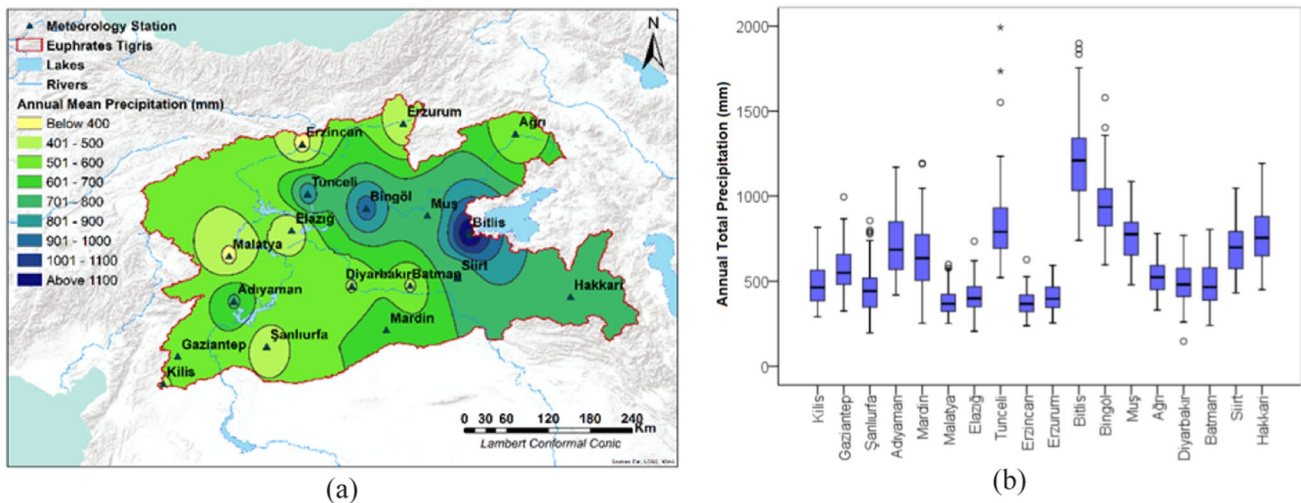


Fig. 5 Spatial distribution and box plots of annual precipitation

time series) and the NO-ITA method (which does not require ranking the same sub-series) from these three methods that provide visual trend evaluation are shown in the same coordinate system for each station.

The annual total precipitation data for the period 1965–2020 (56 years) are divided into two sub-series, the period 1965–1992 (first half) and the period 1993–2020 (second half). The graphs obtained by applying the Şen-ITA and NO-ITA procedures to the two sub-series obtained for each station are presented in Fig. 6. According to both Şen-ITA and NO-ITA, it is seen that most of the points are located in the triangle region below the straight line (1:1), especially in the graphs of Kilis, Mardin, Şanlıurfa, Elazığ, Ağrı, Bingöl, Malatya, Bitlis, Batman and Hakkari stations. Therefore, as a result of visual inspection at these stations, it can be said that there is a decreasing trend in annual total precipitation according to both methods. From the graphs of Adiyaman and Gaziantep stations, according to both methods, we can say that the points are slightly more intense in the upper triangle region than in the lower triangle region; therefore, there is a slight increase trend in these stations. At other stations, according to both Şen-ITA and NO-ITA, the points are distributed approximately equally in two triangular regions and on the 1:1 straight line. This situation makes it difficult to evaluate whether there are positive or negative trends in these stations. From the graphs given in Fig. 6, a statistical evaluation of the trends cannot be made according to both methods. Wilcoxon test applied to non-ordered data was used to statistically evaluate trends at $\alpha = 0.05$ significance level in NO-ITA. Şen-ITA trend indicator ($D_{\text{Şen-ITA}}$) was applied for statistical evaluation of Şen-ITA graphs.

For the numerical trend evaluation, the MK test was also applied to the annual total precipitation data of eighteen stations. Serial correlations were examined before applying the MK test. The autocorrelation coefficients (r_1) calculated for this purpose are given in Table 2. According to Table 2, the r_1 values of Bitlis, Tunceli and Hakkari stations are greater than the critical autocorrelation coefficient ($= 0.244$) at the $\alpha = 0.05$ significance level, and there is a serial correlation in the precipitations of these stations. Pre-whitening procedure was applied to the annual total precipitation of these stations and then the MK test was applied. Since there was no serial correlation in the precipitation of other stations, the MK test was applied directly.

Wilcoxon test statistic (Z_{Wil}), Şen-ITA indicator ($D_{\text{Şen-ITA}}$), MK test statistic (Z_{MK}), OTT statistic (Z_{OTT}) and Hurst exponent (HE) values obtained for eighteen stations are given in Table 3. Bold values in Table 3 indicate that the null hypothesis (H_0) is rejected at $\alpha = 0.05$ significance level and there is a trend, while other values indicate the absence of a trend. Negative values in Z_{MK} , Z_{Wil} , Z_{OTT} and $D_{\text{Şen-ITA}}$ values represent a decrease and positive values represent an increase. The results obtained in all methods are generally

coherent with each other in terms of the direction of the trend. According to Table 3, statistical indicators of all methods used generally show a decreasing trend in annual total precipitation. However, most of these decreasing trends are insignificant at the $\alpha = 0.05$ significance level. Significant decreasing trends were determined according to some methods in only five of the eighteen stations. Significant decreasing trends were obtained in the Kilis and Şanlıurfa stations with the values of $Z_{\text{OTT}} = -2.78$ and $Z_{\text{OTT}} = -2.29$, respectively, in the Onyutha method, while at the Bitlis station with the value of $Z_{\text{Wil}} = -1.98$ in the Wilcoxon method. In Mardin and Malatya stations, there is a significant decreasing trend according to both MK and Wilcoxon methods. Z_{MK} and Z_{Wil} statistics at Mardin (Malatya) stations were $Z_{\text{MK}} = -2.16$ (-2.10) and $Z_{\text{Wil}} = -2.46$ (-2.03), respectively. On the other hand, an insignificant positive trend was obtained in annual total precipitation in some methods (italic values in Table 3). These insignificant positive trends were generally obtained with the Şen-ITA trend indicator ($D_{\text{Şen-ITA}}$) and are inconsistent with other methods. $D_{\text{Şen-ITA}}$ statistics at Gaziantep, Adiyaman, Erzincan, Muş and Diyarbakır stations indicate an insignificant increasing trend with values of 0.61, 0.37, 0.05, 0.05 and 0.01, respectively. In Adiyaman ($Z_{\text{MK}} = 0.01$) and Tunceli ($Z_{\text{MK}} = 0.17$) stations, on the other hand, an insignificant increasing trend was obtained with MK test, and this is inconsistent with other methods (except for Şen-ITA in Adiyaman). However, for Şen-ITA and NO-ITA, the trend interpretations made by visual inspection in Fig. 6 and the numerical trend results of these two methods in Table 3 are generally compatible with each other.

In addition to the temporal variability of the precipitation time series, Hurst exponent (HE) was also used in this study to examine the memory of the long-term time series. The HE values calculated for the eighteen stations in the ETRB are given in Table 3. According to Table 3, the stations where the HE value is closest to 0.5 are Siirt and Erzurum. Compared to other stations, it is seen that the a_j series of Siirt and Erzurum have a curve that shows noiseless oscillation around zero. It is seen that the inconsistency in the time series of stations with $\text{HE} < 0.5$ (Diyarbakır, Tunceli, Şanlıurfa, Hakkari, Adiyaman, Gaziantep, Kilis, Elazığ, Bingöl, Muş, Erzincan, Batman) is also reflected in the a_j series (Fig. 7). The sudden ups and downs in the a_j series can be shown as a sign that the general trend in the time series is inconsistent with the behavior of the sub-trends. At stations with $\text{HE} > 0.5$ (Mardin, Malatya, Erzurum, Bitlis, Ağrı, Siirt), it was observed that the time series showed consistency compared to other stations in the long term. For example, the decreasing trend at Ağrı and Bitlis stations shows itself more strongly in temporal variability. This is observed from the convex curves occurring in the a_j series.

In Fig. 7, the annual total precipitation, a_j and CSD_2 time series for ETRB are given. According to the slopes of the

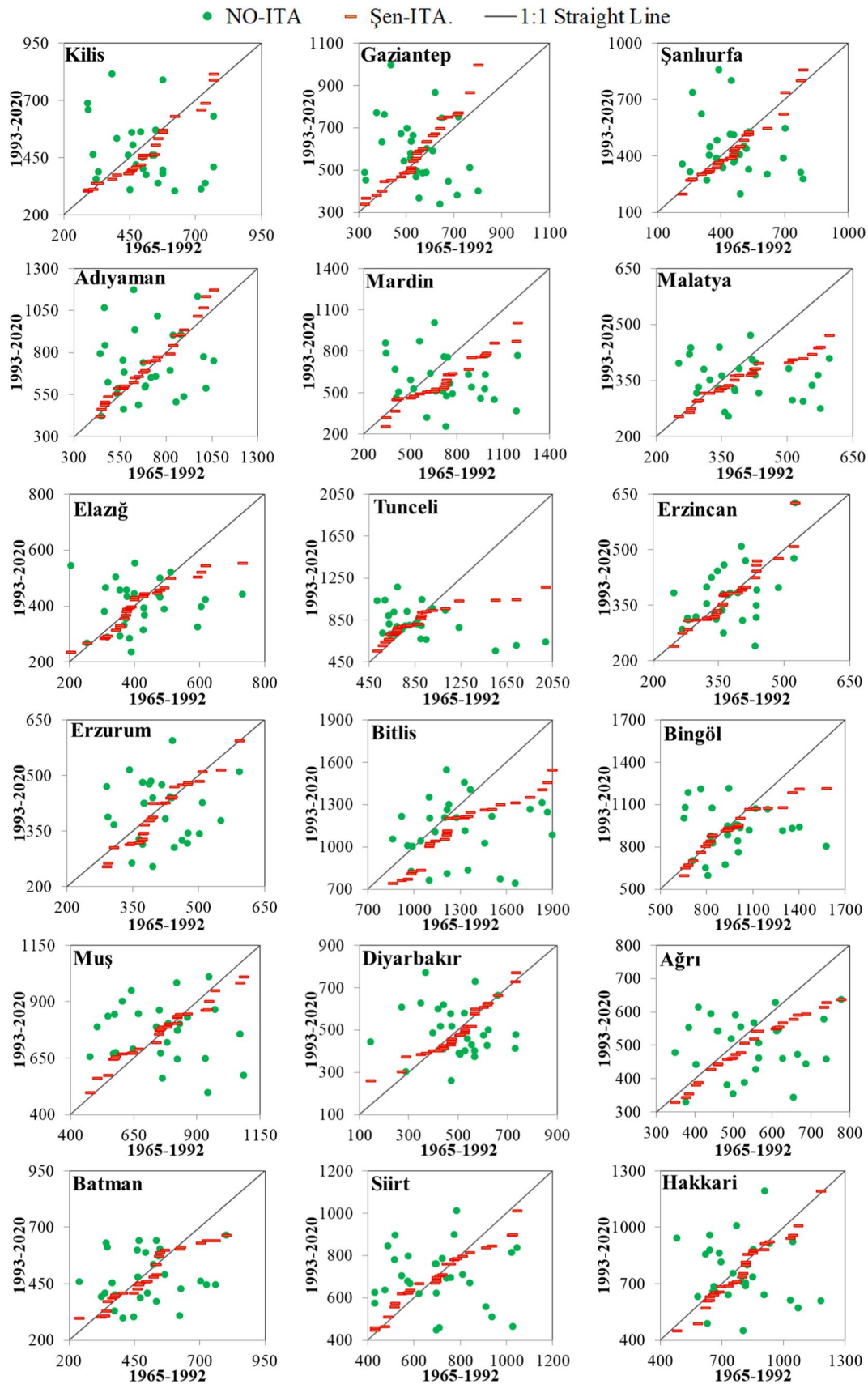


Fig. 6 Şen-ITA and NO-ITA graphs

Table 2 Autocorrelation coefficients for annual total precipitation values

Station name	r_1	Station name	r_1
Kilis	-0.048	Erzurum	-0.066
Gaziantep	-0.057	Bitlis	<i>0.421</i>
Şanlıurfa	-0.038	Bingöl	0.142
Adıyaman	0.006	Muş	0.18
Mardin	0.2	Ağrı	0.15
Malatya	0.028	Diyarbakır	0.045
Elazığ	0.066	Batman	0.138
Tunceli	<i>0.461</i>	Siirt	0.13
Erzincan	-0.037	Hakkari	<i>0.252</i>

Italic values indicate stations with serial correlation at $\alpha=0.05$ significance level

Table 3 Z statistics of different trend analysis methods and H statistics

Station name	Z_{MK}	Z_{Wil}	Z_{OTT}	$D_{\text{Şen-ITA}}$	HE
Kilis	-1.83	-1.00	-2.78	-0.63	0.305
Gaziantep	-0.40	-0.64	-0.47	<i>0.61</i>	0.396
Şanlıurfa	-1.28	-0.82	-2.29	-0.52	0.253
Adıyaman	<i>0.01</i>	-0.30	-0.16	<i>0.37</i>	0.307
Mardin	-2.16	-2.46	-1.77	-1.83	0.572
Malatya	-2.10	-2.03	-1.73	-1.21	0.548
Elazığ	-0.23	-0.89	-0.30	-0.49	0.403
Tunceli	<i>0.17</i>	-0.02	-0.80	-0.79	0.212
Erzincan	-0.47	-0.43	-0.65	<i>0.05</i>	0.339
Erzurum	-0.10	-0.48	-0.14	-0.30	0.519
Bitlis	-1.38	-1.98	-1.71	-1.41	0.609
Bingöl	-0.91	-1.30	-1.52	-0.53	0.327
Muş	-0.38	-1.25	-0.46	<i>0.05</i>	0.457
Ağrı	-0.36	-1.66	-0.24	-0.87	0.736
Diyarbakır	-0.17	-0.23	-0.71	<i>0.01</i>	0.176
Batman	-0.59	-0.64	-0.99	-0.43	0.290
Siirt	-0.14	-0.11	-0.16	-0.08	0.516
Hakkari	-0.48	-0.68	-0.75	-0.39	0.275

linear regression equations given in the precipitation time series in Fig. 7a, there is a decreasing trend in almost all stations (except Gaziantep and Diyarbakır). According to the CSD_z time series in Fig. 7c, while Bitlis, Bingöl and Ağrı stations have a significant decreasing trend in the time series, a CSD_z value exceeding the significance level was not obtained at other stations. In the CSD_z time series (Fig. 7c), decreasing trends are observed in most stations (Kilis, Gaziantep, Urfa, etc.) in the first 10 years of the 1965–2020 period. In addition, there is a decreasing trend in the precipitation data of many stations in the study area in the 1990–2000 periods. It is also observed from the time

series that there are significant decreases in precipitation during these periods. Strong decreasing trends, which are determined based on the linear trend equations given in the time series, are confirmed by the convex curves observed in the a_j series (Kilis, Şanlıurfa, Mardin, Malatya) (Fig. 7b). Although the dominant trend is in the direction of decreasing throughout the basin, increasing trends are also observed from time to time in the lower periods (for example, Gaziantep, 1985–2005). Although there are occasional changes in the time series of stations (Gaziantep, Adıyaman, etc.) where the a_j series oscillates around zero throughout the working period, it is observed that the linear slope is close to zero. It has been determined that the trend directions of the sub-trends are largely compatible at stations where OTT is inconsistent with other methods in terms of the importance level of the overall trend. The fact that the Bitlis station, which has the highest precipitation average in the basin, has a significantly decreasing trend can be considered as a drought signal. In addition, it has been observed that Mardin and Malatya stations, which have relatively low precipitation averages compared to other stations, are also in danger in terms of limited water resources due to the decreasing precipitation trend.

In the literature, the temporal and spatial variations of hydrometeorological parameters in the ETRB have been studied by some researchers. The findings obtained in the current study are consistent with other literature findings on precipitation in the ETRB. Yürekli (2015) examined the changes in precipitation of 19 stations in ETRB at seven different time scales and determined a general decreasing trend, and it was stated that these changes were probably due to the effect of the North Atlantic Oscillation (NAO). Sezen and Partal (2020) found positive trends in summer and autumn precipitation and strong negative trends in winter, spring and annual precipitation in the Türkiye part of ETRB. Önol and Semazzi (2009) found that precipitation in the Türkiye part of ETRB showed a strong decrease. Bozkurt and Şen (2013) determined that precipitation data in the ETRB decreased in the mountainous and northern parts of the basin and increased in the southern parts. Daggupati et al. (2017) analyzed the temporal and spatial distribution of streamflow and precipitation data by dividing the ETRB into three sub-regions. A 30, 24 and 16% reduction in precipitation was obtained for zone 1 (on the borders of Türkiye), zone 2 (on the borders of Iran) and zone 3 (on the borders of Syria and Iraq), respectively. It has been stated that the decreasing trend in precipitation, especially in zone 1 and zone 2 (especially for Syria and Iraq, which are riparian countries of the ETRB with a very arid climate), will have very worrying consequences for flows.

It is obvious that the decreasing trends in precipitation obtained both in the current study and in other studies related to the region will significantly affect the flow

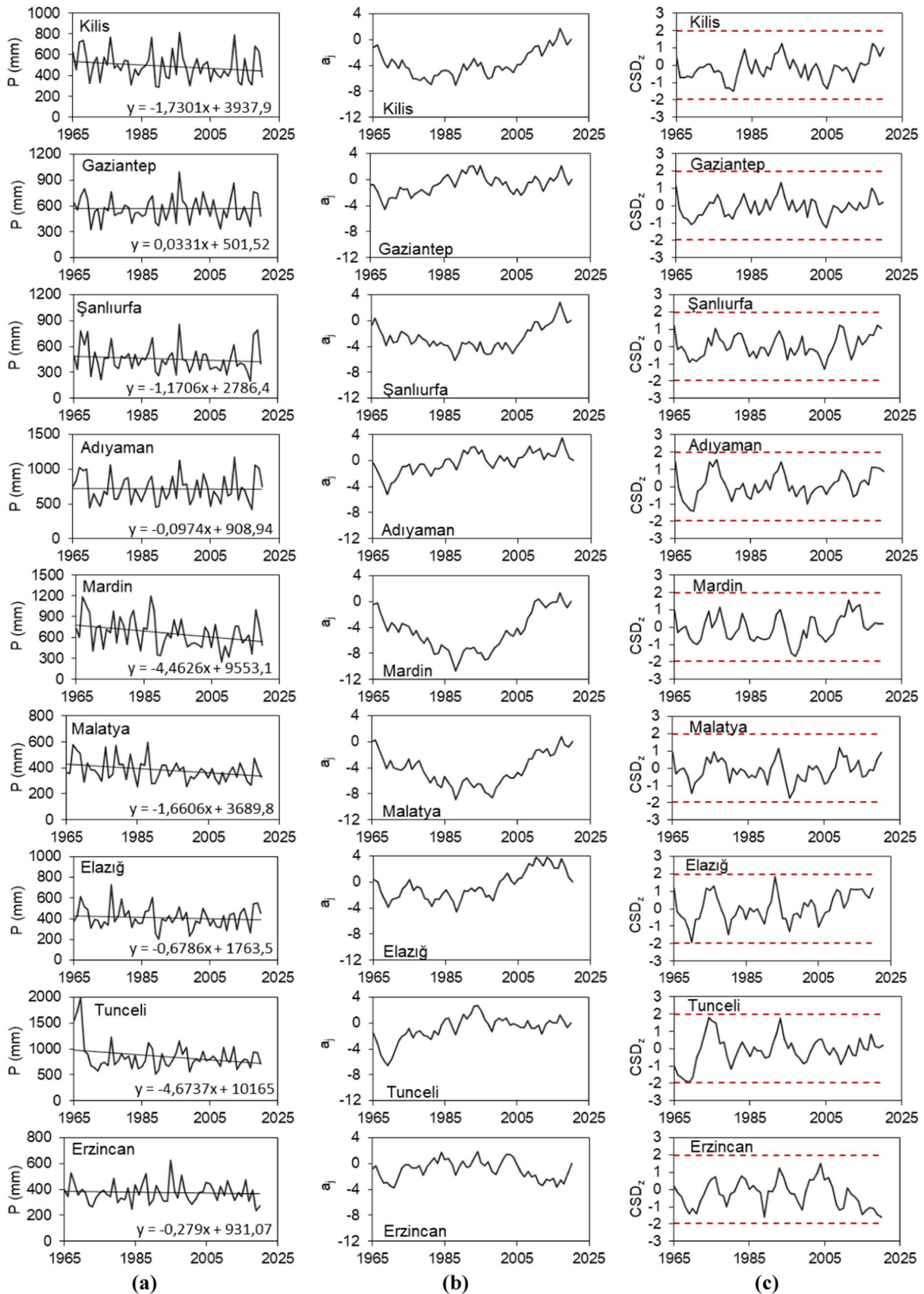


Fig. 7 a Precipitation time, b a_j and c CSD_z series for the ETRB

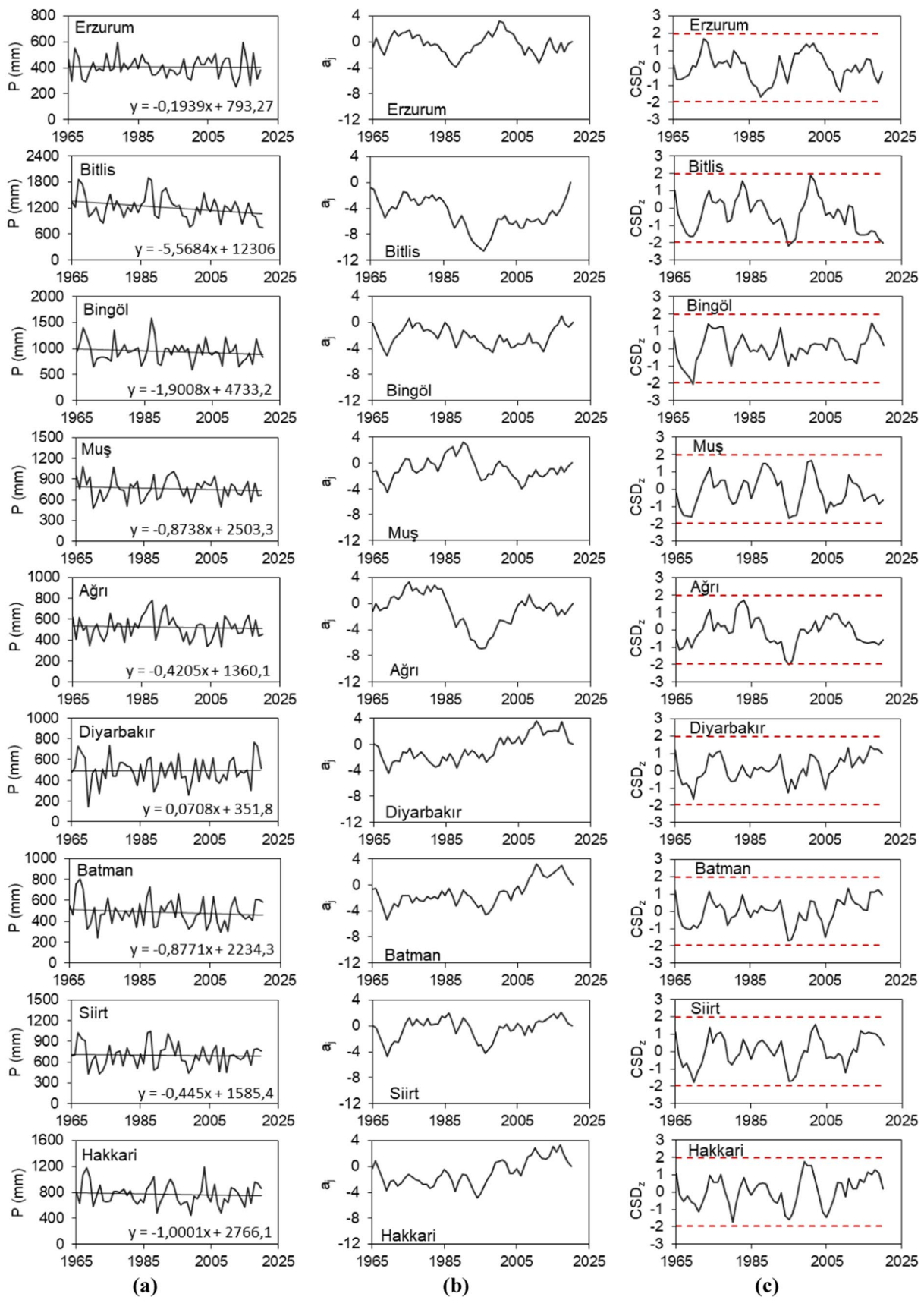


Fig. 7 (continued)

regime of the two main rivers (Tigris and Euphrates) in the basin. The determination of decreasing trends in some studies examining the temporal variability of streamflow in the ETRB is also an indication of this. Ay et al. (2018) analyzed the trend of monthly flow data of two stations in the Euphrates–Tigris Basin with Şen-ITA and MK and found significant decreasing trends in both stations. Topaloğlu (2006), in his study investigating the trend of flow data of a total of 84 stations in Türkiye between the years 1968–1997, handled two stations of the Tigris Basin and determined a significant downward trend in these stations. In another study, the trends of long-term flow values of three stations in the Tigris Basin were analyzed and it was stated that the flow values in the region had a decreasing trend (Yildiz et al. 2016). Gumus et al. (2022) found strong and very strong downward trends for annual mean river flow at 80% of stations in the ETRB. While some studies on ETRB indicate that by the end of the century, snowfall and precipitation (especially in Türkiye, which forms the upstream of the basin) will decrease by 30–40%, it is claimed that this will significantly reduce the surface flow (IPCC 2013; Yilmaz and Imteaz 2011; Bozkurt and Şen 2013; Özdoğan 2011; Şen 2019). At the same time, temperatures are expected to increase in the basin (Alivi et al. 2021).

Considering that the decreases detected in precipitation and snowfall despite the increases in temperature and evapotranspiration in the studies conducted for the past time periods by various researchers on the region, will continue in the future, all riparian countries of the basin (especially in downstream countries such as Iraq and Syria largely rely on upstream water) water shortage, which is a problem even now, will increase in the future and cause serious pressures on water resources (World Bank 2018). Despite the fact that all riparian countries in the basin are struggling with water stress and there is much cooperation with each other, the region is also among the regions where hostile interaction is most common in the world (Rüttinger et al. 2015). In particular, the political instability, fragility and conflicts experienced in Syria for a long time negatively affect the cooperation between riparian countries.

According to the results obtained both in the current study and in other studies, it is obvious that the effects of climate change on both water resources and water-dependent agriculture will increase in ETRB and will trigger problems such as internal migration, poverty and social unrest. As a result, it is inevitable to increase the efforts and cooperation of all riparian countries, whose water security is under great threat in the future, on adaptation to climate change and a more efficient water resources management.

Conclusion

In this study, the temporal variation of the annual total precipitation during 1965–2020 periods of eighteen observation stations in the Turkish section of the transboundary ETRB, which consists of the basins of the Euphrates and Tigris rivers and their tributaries, was investigated. The temporal variability of precipitation was investigated using both statistical and graphical trend methods. As a result of the analyses, a decreasing trend was determined in all trend methods generally used in annual total precipitation for the period studied in ETRB. The results of the CWTSD, Şen-ITA and OTT methods, which allow both statistical and graphical interpretation, are largely in agreement with the MK test results recommended by WMO in terms of the direction of the trend. According to the number of stations, the compatibility between CWTSD, Şen-ITA and OTT methods and MK results is in the order of 89, 100 and 72% for eighteen stations, respectively. According to the four statistical trend indicators used, significant trend formation at $\alpha=0.05$ significance level was obtained in seven of the eighteen stations (OTT for Kilis and Şanlıurfa, MK and Wilcoxon for Mardin and Malatya, Wilcoxon for Bitlis). The high compatibility of the results obtained from the analysis shows that OTT and CWTSD methods, which are relatively new in the literature, can be used as alternative methods to methods such as MK and SRho, which are widely used in trend analysis. OTT and CWTSD methods, unlike classical methods, have the advantage of visual trend interpretation as well as statistical trend interpretation. In addition, OTT provides the opportunity to determine the sub-trends as well as the trends in the whole time series, while the CWTSD method enables trend evaluation according to the size of the data (low, medium, high).

Trend analyses on precipitation and other hydrometeorological parameters in both arid and semi-arid region and transboundary basins such as ETRB will provide significant benefits for water resource management and sustainability in riparian countries, especially in potential areas where water scarcity may increase over time. Especially in transboundary basins such as ETRB, which have a very important geopolitical position and controversial diplomacy, such studies are very important in order to eliminate the negative effects of climate change.

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Declarations

Conflict of interest The corresponding author states that there is no conflict of interest.

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