



Streamflow trends in the Tigris river basin using Mann–Kendall and innovative trend analysis methods

VEYSEL GUMUS* , YAVUZ AVSAROGLU  and OGUZ SIMSEK 

Department of Civil Engineering, Harran University, 63050 Sanliurfa, Turkey.

**Corresponding author. e-mail: gumus@harran.edu.tr*

MS received 17 March 2021; revised 31 May 2021; accepted 15 September 2021

In this study, the trend of monthly mean and annual streamflow values of 16 streamflow gauge stations in the Tigris basin, which holds 13% water potential for Turkey, is determined. The monotonic trends are calculated using non-parametric Mann–Kendall (MK) test. To remove serial correlation from time series, a modified ‘pre-whitening’ method is used. The trend slopes are determined by Sen’s slope method. Moreover, innovative trend analysis (ITA) method is also used to determine trends of low, medium and high streamflow values. As a result of the study, trend indicators, namely, Z values of MK tests and D values of the ITA method are compared and it has been observed that the trend directions by MK and ITA are generally similar. Nevertheless, only the negative D values calculated by ITA are mostly higher than the negative Z values calculated by MK. The ITA results of the annual mean streamflow show 80% of the stations show a strong decrease in trend for high values. Most of the significant trends found by MK are obtained in a decreasing direction, and the linear slopes are mostly determined in the range of $\pm 2\%$ per year. According to the spatial analysis, the significant decreasing trends are generally located in the middle region of the basin.

Keywords. Tigris basin; trend analysis; Mann–Kendall method; innovative trend analysis; spatial analysis.

1. Introduction

Determining the changes of streamflow, which are considered as critical components of the hydrological cycle in a basin, is necessary for the effective and efficient management of water resources in the basin (Dey and Mishra 2017). Knowing the changes of streamflow values is particularly used in the design of dams and hydroelectric power plants for the action plans dealing with flood and drought incidents. The trends of time series of streamflow data are normally used to determine these changes.

Various methods such as Mann–Kendall (MK) test, innovative Sen method, Sen slope, Spearman’s rho tests are used to evaluate the change of time

series. Non-parametric tests are preferred by many researchers to determine the monotonic trends of different parameters among these methods. The changes in the streamflow values in a region can be determined with the non-parametric tests, which are distribution-free methods. There are many studies to determine the trends of hydro-meteorological data with non-parametric tests in the literature. For example, using the MK method, Lins and Slack (1999) evaluated trends for streamflow values at 395 stations in the United States. Yenigün *et al.* (2008) conducted trend analysis for streamflow values of the Euphrates basin, Turkey; Zamani *et al.* (2017) determined the trend of a semi-arid region in Iran; Langat *et al.* (2017)

studied the trend of streamflow and precipitation data in Kenya; Gumus (2019) determined the trend of precipitation and temperature data in Seyhan and Ceyhan basins, Turkey; Du *et al.* (2019) analysed the trend for streamflow data in China's Xiang river basin and Li *et al.* (2020) calculated the trend of streamflow data in China's Hanjiang river basin.

The frequently used non-parametric monotonic trend tests can only provide whether the trend is statistically significant or not and its direction. In addition, it is possible to determine in which range (low, medium, high) there is an increase or decrease trend using the innovative trend analysis (ITA) method, which was proposed by Şen (2012). There are several studies where the trends of hydro-meteorological data in different regions are determined by the ITA method. For instance, to determine trends by ITA, Elouissi *et al.* (2016) used rainfall data in Albania, Kişi *et al.* (2018) studied streamflow data in north Turkey, Cui *et al.* (2017) and Wu and Qian (2017) used precipitation data from different regions of China, Gedefaw *et al.* (2018) used annual and seasonal precipitation changes in the Amhara state region of Ethiopia, Kuriqi *et al.* (2020) analysed the change of streamflow data in Central India, Caloiero *et al.* (2020) performed the temporal variation of precipitation values in the southern regions of Italy, Ashraf *et al.* (2021) examined trends of monthly, seasonal and annual streamflow time series in the upper Indus river basin (UIRB), which is one of the world's largest transboundary river in Pakistan. As is known, the ITA method has been very useful to determine the trend of hydro-meteorological data for different regions globally due to its ability to evaluate the changes occurring in a data set.

Determining the trends of river flow is very important for the effective and efficient use of water resources in a region. This situation is especially important for Turkey, which has many transboundary rivers (Ozis *et al.* 2020). The majority of the trend studies of river flow in Turkey are mostly done at a macro scale level (Kahya and Kalaycı 2004; Cigizoglu *et al.* 2005; Kalayci and Kahya 2006; Topaloğlu 2006; Kişi *et al.* 2018) and gives comprehensive information for the whole country. Kalayci and Kahya (2006) determined trends of the streamflow values between 1964 and 1994 in Turkey by the MK method, and only three stations located on the Tigris basin are considered in the analysis and a significant trend could not be determined. Cigizoglu *et al.* (2005) conducted trends of streamflow values by the MK trend test

for 96 streamflow gauging stations (SGS), and only five stations located in the Tigris basin. As a result of the study, a significant decreasing trend is determined in the west of Turkey for monthly mean streamflow data, however, a significant trend could not be determined in the Tigris basin. Ay *et al.* (2018) determined the trend of the streamflow data for only one station in the Tigris basin using the ITA method. In this station, a decreasing trend was observed in low, medium and high streamflow values with limited data range (2002–2011). Topaloğlu (2006) used streamflow data between 1968 and 1997 in Turkey for a total of 84 stations to calculate trends by the MK analysis method. In the study, only two stations from the Tigris basin are considered and a significant decreasing trend is determined in one station. The crucial effect of serial correlation on the non-parametric trend test is not included in these studies, the trend slopes of streamflow are only considered in a limited number of studies (e.g., Kahya and Kalaycı 2004).

This is a novel study as there is no comprehensive study considering both monthly and annual data for the Tigris basin, Turkey. Also, in addition to the MK test, the ITA method is used to determine trend characteristics in detail, and these two methods are compared for the first time in literature in the study area. Therefore, in the current study, streamflow data, which has 24–62 years range taken from 16 observation stations of the Tigris–Euphrates river basin (TERB), the largest basin in the Middle East (Daggupati *et al.* 2017) whose source point is located in Turkey, are used. Unlike the previous studies, more stations with current data are used. Furthermore, serial correlation effect removed from time-series before the MK test and linear slopes are determined by Sen's slope method. Moreover, trends of low, medium and high values are determined by the ITA method and compared with monotonic trend results in the Tigris basin.

2. Study area and data

TERB is one of the largest basins in the Middle East with a total area of 879,790 km² and 46% of it is located in Iraq, 22% in Turkey, 19% in Iran, 11% in Syria, 1.9% in Saudi Arabia, and 0.03% in Jordan (Bozkurt and Sen 2013). This basin includes the two major rivers, the Euphrates and the Tigris. The Tigris river is 1900 km long and it rises in southeast Turkey. In this study, a trend analysis is

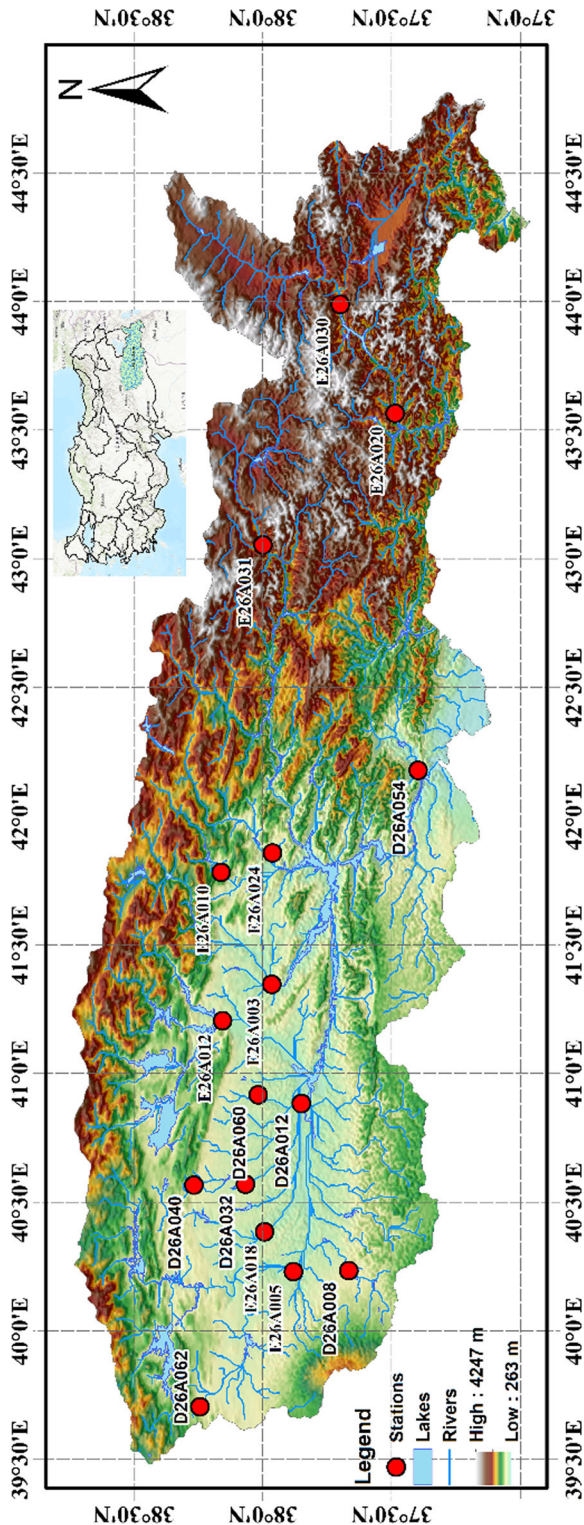


Figure 1. Study area.

conducted by using monthly mean streamflow data from 16 streamflow gauge stations in the Tigris basin (figure 1), which holds 13% water potential of Turkey (22.26 km^3) (DSI 2016).

The altitude is over 4000 m in the east of the Tigris basin; however, it goes down to 263 m in the west. Thirteen of the stations out of the 16 studied are located below 1000 m altitude. Only three of them (E26A020, E26A030, E26A031) located in the eastern part of the basin are higher than 1000 m altitude. Especially in the western part of the basin, agricultural activities are more than those in the east. Additionally, the anthropological effects are considered for the determination of stations studied. The observation periods of streamflow and station information are given in table 1. Long-term streamflow values at the stations vary between 0.48 and $116.64 \text{ m}^3/\text{s}$. Stations having high streamflow are mostly located on the main tributaries of the Tigris river, while the stations of low streamflow are located on the side tributaries.

3. Methods

3.1 Trend analysis

Globally, non-parametric tests are frequently used to determine the monotonic trends of different hydro-meteorological data (Yenigün *et al.* 2008; Gumus 2019). The most important problem in non-parametric methods is the serial correlation effect. Therefore, the serial correlation effect should be removed before calculating the monotonic trends. In literature, different techniques were applied to remove this effect from the dataset. A few examples are trend-free pre-whitening (TFPW), MK test (Yue *et al.* 2002), modified Mann–Kendall test (MMK) (Hamed and Rao 1998) and the MK test by considering long-term persistence (LTP) and Hurst coefficient (MK4) (Kumar *et al.* 2009; Zamani *et al.* 2017). TFPW procedure removes only lag-1 autocorrelation from series before MK test, MMK test takes into consideration complete serial correlation from dataset and MK4 considers LTP and Hurst coefficient. In addition, a modified version of TFPW based on a hypothesis by Salas (1980) was used to remove serial dependence from the dataset. This method first checks for serial correlation and TFPW is applied only if serial correlation exists. The original data set is used for trend analysis if there is no serial correlation effect. In this study, modified TFPW procedure, which is

Table 1. *Geographical characteristics and observation periods of the stations.*

Station no.	Station name	Coordinates (latitude–longitude)	Precipitation area (km ²)	Elevation (m)	Observation period	Long-term mean streamflow (m ³ /s)
D26A008	Pamukluk Deresi-Dilaver Köprüsü	40°14'0''(E)–37°40'0''(N)	648	702	1974–2015	1.88
D26A012	Başnik Çayı-Salat	40°53'0''(E)–37°51'0''(N)	1060	525	1980–2015	4.00
D26A032	Pamuk Çayı-Karahan Köprüsü	40°34'11''(E)–38°4'0''(N)	305	738	1980–2010	1.88
D26A040	Mehmediyan Çayı-Tepecik	40°34'0''(E)–38°16'0''(N)	79	800	1979–2015	0.48
D26A054	Kızılsu-Kasrik Boğazı	42°10'41''(E)–37°23'49''(N)	650	400	1981–2015	10.36
D26A060	Başköy Çayı-Kıbrıs	40°55'0''(E)–38°1'0''(N)	157.9	594	1989–2015	0.62
D26A062	Sallar Çayı-Yolköprü Köyü	39°42'16''(E)–38°14'36''(N)	51.6	852	1989–2015	0.76
E26A003	Garzan Çayı-Beşiri	41°20'45''(E)–37°57'54''(N)	2450.4	545	1946–2002	48.5
E26A005	Dicle Nehri-Diyarbakır	40°13'47''(E)–37°52'48''(N)	5655.2	570	1956–1997	71.3
E26A010	Bitlis Çayı-Baykan	41°46'57''(E)–38°09'41''(N)	640.4	910	1955–2016	18.23
E26A012	Batman Çayı-Malabadi Köprüsü	41°12'16''(E)–38°09'16''(N)	4105.2	597	1965–2016	116.64
E26A018	Ambar Çayı-Köprübaşı	40°23'03''(E)–37°59'31''(N)	976	595	1969–1998	7.68
E26A020	Zap Suyu-Üzümcü	43°33'56''(E)–37°29'11''(N)	5270.3	1072	1971–2012	56.28
E26A024	Kezer Çayı-Pmarca	41°51'26''(E)–37°57'41''(N)	1169.6	530	1972–2016	19.73
E26A030	Zap Suyu-Teknisyenler	43°59'18''(E)–37°41'55''(N)	4161.5	1425	1986–2011	35.35
E26A031	Çatak Çayı-Tüliran	43°03'16''(E)–37°59'54''(N)	2455	1482	1988–2011	25.44

mostly utilised to determine the trend of the hydro-meteorological data (He *et al.* 2015; Gibrilla *et al.* 2018; Suhaila and Yusop 2018; Gumus 2019; Mumo *et al.* 2019) is applied before the MK test. In the modified TFPW, the lag-1 correlation coefficient (r_1) is checked whether it falls in the range of equation (1) or not (Mohsin and Gough 2010; Gocic and Trajkovic 2013). If the lag-1 correlation coefficient, r_1 , is out of the range, the data set is considered to be under the serial correlation effect.

$$\frac{-1 - 1.645\sqrt{n} - 2}{n - 1} \leq r_1 \leq \frac{-1 + 1.645\sqrt{n} - 2}{n - 1}. \quad (1)$$

In case of serial correlation, the ‘pre-whitening’ method (Storch and Navarra 1995) is used to remove this effect from the time series. The ‘pre-whitened’ time series is obtained by applying ($x_2 - r_1x_1, x_3 - r_1x_2, \dots, x_n - r_1x_{n-1}$) process, then the trend analysis is performed for a new time series (Gocic and Trajkovic 2013; Gumus 2019).

3.1.1 MK method

MK test is a non-parametric test that is frequently used to determine statistically significant trends in hydro-meteorological data (Mann 1945; Kendall 1948). In this test, the existence of a trend in a time series is checked by ‘ H_0 : no trend’ (null hypothesis)

(Yenigün *et al.* 2008). In this method, S test statistic and $sign$ function are used as per equations (2 and 3). Then, variance of S , and Z test statistics are determined with equations (4 and 5), respectively.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(x_j - x_i), \quad (2)$$

$$\text{sign}(x_j - x_i) = \begin{cases} +1 & x_j > x_i, \\ 0 & x_j = x_i, \\ -1 & x_j < x_i \end{cases} \quad (3)$$

$$\text{var}(S) =$$

$$\left[n(n - 1)(2n + 5) - \sum_{i=1}^m t_i i(i - 1)(2i + 5) \right] / 18, \quad (4)$$

$$Z = \begin{cases} \frac{S - 1}{\sqrt{\text{var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S + 1}{\sqrt{\text{var}(S)}} & S < 0. \end{cases} \quad (5)$$

In these equations, n shows the number of data, x shows the data at times i and j , the number of repeated observations in the data set m and the

value of t_i indicates the observations repeated in a series of length i .

Z value is used to determine a statistically significant trend. At α significance level, there is no significant trend in case of $|Z| < Z_{\alpha/2}$ and statistically there is a trend in case of $|Z| \geq Z_{\alpha/2}$. Besides, according to positive/negative values of S , it can be concluded that the trend is in the increasing or decreasing direction.

3.1.2 Sen's slope estimator

The linear slope of the trend can be determined by the method suggested by Sen (1968). The linear slope value (Q_i) is calculated by using equation (6).

$$Q_i = (x_j - x_k)/(j - k) \quad (i = 1, \dots, N). \quad (6)$$

In equation (6), the data number is indicated with N , data at times j and k are indicated by x_j and x_k , respectively. The obtained Q_i values are in ascending order, and the median value (Q_{median}) is evaluated as a change of the relevant observations per unit time. An increasing trend is shown with a positive Q_{median} value, whereas a decreasing trend is shown with a negative Q_{median} value.

3.1.3 Innovative trend analysis

The ITA method was first suggested by Şen (2012). In this method, data series of the hydrological variable is ordered from the start date of the observation to the date of the last observation. Then, the time series is divided into two equal parts and these two new series are ordered from low to high according to the hydro-meteorological data. Finally, the first part of the data series (y_1) is placed on the X -axis and the second part of the data series (y_2) is placed on the Y -axis (figure 2).

If the data points are scattered closer to the bisector line on the graph, it can be said that there is no trend. However, if the scatter is below the line, then there is a decreasing trend. If the scatter is above the line, it is attributed to an increasing trend.

In this study, to determine the existence of trend for ITA, it is assumed that, if most of the data are in the range of $\pm 5\%$ in the scatter plot, there is no trend, if data fall in the ± 5 – 10% range, there is a strong trend, if most of the data exceeded $\pm 10\%$ line there is a very strong trend.

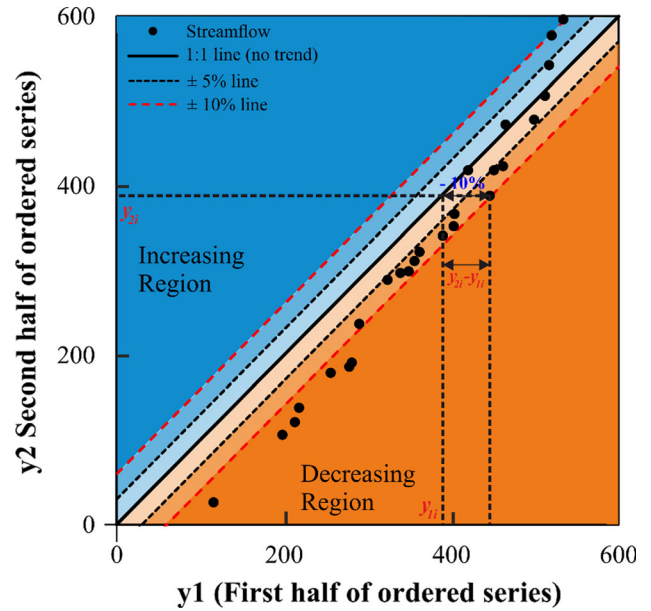


Figure 2. Illustration of the ITA method.

The difference between the y_2 and y_1 values of a point is the distance to the 1:1 line and the trend indicator is calculated as follows:

$$D = \frac{1}{n} \sum_{i=1}^n 10 \frac{(y_{1i} - y_{2i})}{\bar{y}_1}, \quad (7)$$

where D is the trend indicator, its sign indicates the direction of the trend (+ is increasing, – is decreasing), n is the number of data in each sub-series, \bar{y}_1 is the mean of the first sub-series. In the aforementioned calculation, the obtained D values are also multiplied by 10 to compare the calculated values of D by the MK test (Wu and Qian 2017; Nisansala *et al.* 2020).

4. Results and discussion

The modified TPFW procedure is applied to streamflow data before the MK test. Figure 3 provides the lag-1 serial correlation coefficients (r_1) of the monthly and annual streamflow data (208 total time series for 16 stations). The red bold lines in figure 3 represent the probability limits on the correlogram for an independent series of r_1 , which is calculated using equation (1). The majority (74%) of the calculated lag-1 correlation coefficients in time series are positive. At stations E26A020 and E26A030, positive lag-1 correlations are determined in all-time series. At station D26A062, 31% of the time series have negative lag-1 correlation coefficient. While calculated lag-1

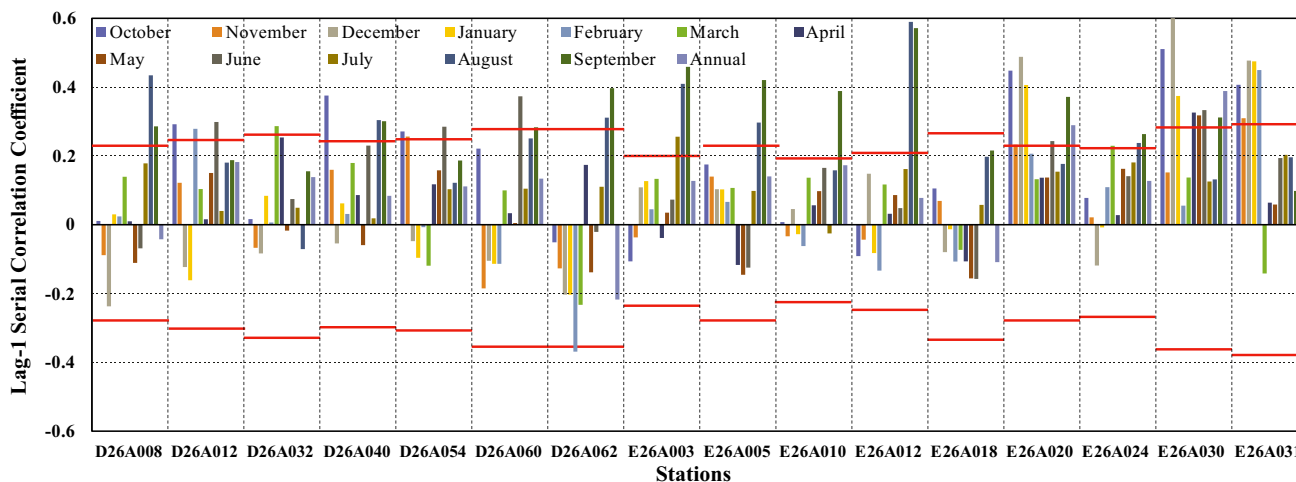


Figure 3. Lag-1 serial correlation coefficient for the monthly and annual streamflow data of stations (the bold red line represents the probability limits on the correlogram for an independent series, r_1).

correlation coefficients at all stations in September are positive, 56% of the stations in December are negative. According to Salas (1980), the series correlation effect is determined in 23% of the time series. Lag-1 correlation coefficient of these series is outside the range given in equation (1) (exceeding the red bold line). Station E26A030 has the highest serial correlation effect with 62%. The serial correlation effect of these time series has been removed using the ‘pre-whitening’ method, and monotonic trends of pre-whitened data series are determined. In addition, linear trend slopes with Sen’s slope and D values with ITA method are calculated. The results obtained from the analyses are given in table 2. According to the MK test results, which are shown in table 2, it is seen that most of the significant trends obtained are in a decreasing direction and a significant trend is determined for six months and the annual mean streamflow values at stations D26A012 and D26A032. In addition, there is an increasing trend at station E26A012 for three months, at station E26A005 for two months and at stations D26A008, D26A060, E26A003 and E26A030 for one month. A significant (increasing or decreasing) trend could not be determined for both monthly and annual mean streamflow values at stations E26A010, E26A024, E26A031 and D26A062. Sen’s slope results show that the maximum linear slope of increase is determined as $0.4875 \text{ (m}^3/\text{s)/year}$ at E26A005 (for November) and the maximum linear slope of decrease is determined as $-3.1459 \text{ (m}^3/\text{s)/year}$ at station E26A012 (for April). When the trend slopes of the annual mean streamflow values are examined, there is a change of $-0.8871 \text{ (m}^3/\text{s)/}$

year at E26A012 station and $-0.0362 \text{ (m}^3/\text{s)/year}$ at station D26A012. At stations D26A008 (for August) and D26A060 (for May), which showed a significant increase in trend, the increasing slope remained quite limited. Although some of the trend slope values in table 2 are relatively high, in the next section, the percentage of slope, which is calculated by the slope values divided by the long-term mean values, will be used to assess the trend’s slope.

It is mostly observed that the $|D| \geq Z_{\alpha/2}$ condition is also fulfilled when the $|Z| \geq Z_{\alpha/2}$ condition is fulfilled by the MK method when the Z and D values are compared. While $|Z| \geq Z_{\alpha/2}$ condition is fulfilled in eight time-scales only in three stations, $|D| \geq Z_{\alpha/2}$ condition is not fulfilled. However, $|Z \text{ or } D| \geq Z_{\alpha/2}$ condition is fulfilled in all significant trend-determined time scales except for these eight time-scales. A monotonic significant trend is not found in some stations, but it is observed that the $|D| \geq Z_{\alpha/2}$ situation occurred. The reason for this condition is the occurrence of trend in certain values (low, medium or high) by the ITA method. For example, in station E26A030, $|D| \geq Z_{\alpha/2}$ condition has occurred, while a significant trend is not determined by the MK method for the annual mean streamflow data, but there is a decreasing trend only at high values in this station.

The monthly and annual mean streamflow values are calculated for 16 stations in the Tigris basin, and the station-based distributions of Z and Sen’s slope values for all time scales are given in figure 4. In this figure, the bars and the left y -axis indicate the Z value, the line and the right y -axis

Table 2. Trend analysis results of stations (D of ITA, Z of MK, SS of Sen's slope).

Time scale	D26A008	D26A012	D26A032	D26A040	D26A054	D26A060	D26A062	E26A003	E26A005	E26A010	E26A012	E26A018	E26A020	E26A024	E26A030	E26A031
October	Z 1.395	-2.13 (†)	-0.816	-0.667	-0.652	0.167	-1.042	0.916	2.569 (†)	1.470	-0.545	0.357	-0.775	-0.108	-0.817	-0.687
	D 8.176	-5.852	-2.801	-2.274	-5.035	-2.477	-7.953	-0.418	6.021	0.408	-1.036	0.055	-1.154	-1.844	-3.027	-2.461
November	SS 0.0004	-0.0059	-0.0038	-0.0024	-0.0368	0.0002	-0.0028	0.0184	0.1731	0.0127	-0.052	0.0046	-0.0586	-0.0023	-0.1733	-0.2189
	Z 0.954	-3.61 (†)	-2.006 (†)	-1.818 (†)	-2.372 (†)	0.709	-0.417	1.68 (†)	2.623 (†)	0.231	-1.389	1.499	-0.618	-1.418	-1.675 (†)	-0.317
	D 23.477	-6.118	-1.154	-2.572	-6.329	-1.051	-1.051	6.627	6.069	1.296	-4.274	7.050	-0.887	-3.144	-2.816	-2.349
December	SS 0.0016	-0.0724	-0.012	-0.0033	-0.1897	0.0031	-0.0028	1.405	0.4875	0.0047	-0.474	0.0223	-0.0425	-0.0603	-0.2672	-0.2353
	Z -0.249	-2.384 (†)	-1.768 (†)	-2.891 (†)	-1.250	-0.375	-0.146	1.074	0.856	-0.626	2.423 (†)	0.571	-1.404	-0.616	-1.611	-0.739
	D 2.679	-4.932	-6.272	-3.716	-3.717	-3.688	-1.997	0.770	1.437	-0.781	-5.160	3.193	-1.423	-2.329	-3.196	-2.620
January	SS -0.0024	-0.0683	-0.0291	-0.006	-0.139	-0.0012	-0.0014	0.1261	0.4423	-0.0273	-1.3952	0.0304	-0.08	-0.0318	-0.2593	-0.1882
	Z 0.022	-1.022	-1.360	-1.373	-0.852	0.167	1.022	-0.441	-0.347	0.000	-0.379	0.535	-0.955	-0.0605	-2.265 (†)	-0.370
	D 2.066	-1.739	-2.830	-1.197	-2.708	4.493	12.779	-1.947	-2.776	0.386	-1.216	-1.752	-0.605	1.549	-2.607	-2.082
February	SS 0.0016	-0.0569	-0.0513	-0.007	-0.1866	0.0019	0.0171	-0.0617	-0.2409	0	-0.6172	0.0882	-0.06	0.093	-0.1765	-0.1323
	Z 0.195	0.426	-1.088	-0.667	0.028	-0.208	1.499	-1.205	0.000	0.304	-1.460	0.839	-0.748	0.655	-1.301	-0.053
	D 1.637	2.115	-1.925	-0.116	-1.082	2.488	1.977	-1.475	0.781	-0.411	-2.610	0.128	-0.655	-0.902	-1.593	-1.343
March	SS 0.0051	-0.0774	-0.0774	-0.0063	0.02	-0.0133	0.054	-0.2637	0	0.0176	-1	0.2064	-0.05	0.0898	-0.11	-0.149
	Z -2.233 (†)	-1.076	-1.085	-1.583	-1.307	-1.167	0.167	-0.847	-0.672	1.166	-1.523	0.375	1.431	1.204	1.896 (†)	-0.149
	D -3.071	-0.655	-3.092	-3.895	-1.643	1.419	-1.248	-1.710	-1.710	-0.395	-1.438	0.277	0.846	1.407	4.500	1.339
April	SS -0.1077	-0.0689	-0.1311	-0.021	-0.2524	-0.0325	0.0038	-0.2983	-0.6154	0.1222	-1.5744	0.1225	0.425	0.3	0.6294	-0.0316
	Z -1.647 (†)	-0.913	-2.023 (†)	-0.798	-1.307	0.459	0.083	-0.620	0.704	0.850	2.052 (†)	0.143	-0.650	-0.528	-1.191	0.471
	D -3.247	-2.032	-2.032	-0.626	-2.669	1.977	-2.828	-0.498	-1.107	-0.147	-1.037	-2.317	0.223	-0.768	-3.685	0.118
May	SS -0.0441	-0.0601	-0.1171	-0.0081	-0.225	0.0078	0.0024	-0.382	0.7	0.15	-3.1459	0.0914	-0.4667	-0.2232	-1.7368	0.1455
	Z -1.062	-1.893 (†)	-1.938 (†)	-0.745	-1.477	2.085 (†)	-0.125	-2.685 (†)	0.325	-1.136	2.675 (†)	-0.500	-0.726	-0.460	-0.771	0.174
	D -3.637	-4.133	-4.076	-2.362	-3.368	9.467	-4.937	-2.630	-1.941	-1.680	-1.502	-1.452	0.288	-1.925	-3.135	-0.435
June	SS -0.0061	-0.0749	-0.0432	-0.0026	-0.1692	0.0161	-0.0018	-1.2313	0.15	-0.1457	-2.6652	-0.05	-0.5807	-0.1235	-0.9158	0.356
	Z -0.932	-1.802 (†)	-1.802 (†)	-0.889	-0.978	0.485	0.479	-1.838 (†)	-0.304	-1.598	2.509 (†)	0.232	-1.741 (†)	-1.517	-0.397	-0.620
	D -6.667	-5.344	-3.871	-2.716	-5.419	31.194	-0.785	-1.849	-1.114	-1.592	-2.341	-1.272	-0.742	-2.555	-3.978	-2.094
July	SS -0.0007	-0.0334	-0.0124	-0.0015	-0.0333	0.008	0.0034	-0.2583	-0.0546	-0.0475	-0.9955	0.0083	-1.225	-0.0917	-0.7087	-0.4313
	Z 1.048	-2.453 (†)	-1.500	-0.851	-1.875 (†)	0.104	1.126	-0.827	-0.206	-0.595	2.352 (†)	-1.356	2.124 (†)	-0.783	-0.882	-1.018
	D 0.769	-5.787	-4.820	-5.424	-5.078	2.661	2.661	-1.243	-0.410	-1.406	4.409	-3.366	-0.859	-2.008	-4.426	-2.967
August	SS 0.0001	-0.011	-0.0031	-0.0009	-0.0209	0.0001	0.0025	-0.0284	-0.016	-0.0067	0.2882	-0.012	-0.5278	-0.0231	-0.3341	-0.615
	Z 2.242 (†)	-1.493	-1.254	-0.545	-1.125	-0.104	1.278	-2.184 (†)	0.528	-1.373	3.574 (†)	-2.38 (†)	-2.482 (†)	-0.637	-0.441	-0.496
	D 25.000	-5.096	-3.980	-2.632	-4.976	-2.317	5.741	-2.699	1.299	-0.675	26.123	-5.673	-1.144	-2.311	-3.645	-2.188
September	SS 0.0001	-0.0043	-0.0001	-0.0005	-0.0133	-0.0001	0.0009	-0.036	0.0233	-0.0073	0.4755	-0.0124	-0.2611	-0.0227	-0.0718	-0.17
	Z 1.001	-1.651 (†)	-1.697 (†)	-0.272	-1.052	1.234	1.543	-1.095	1.067	-0.006	1.673 (†)	-1.589	-1.718 (†)	-0.799	-0.631	-0.248
	D 11.818	-5.485	-6.360	-2.177	-6.022	3.622	4.746	-1.542	2.411	0.567	12.955	-3.421	-0.358	-1.684	-2.732	-1.631
Annual	SS 0.0002	-0.0056	-0.0011	-0.0001	-0.0126	-0.0013	0.0016	-0.01	0.0871	0.0005	0.0073	-0.0073	-0.1296	-0.0139	-0.0456	-0.620
	Z -0.650	-1.512	-1.938 (†)	-1.138	-1.505	0.750	-0.250	-1.466	0.022	-0.158	2.138 (†)	0.464	-1.112	0.000	-0.958	-0.620
	D -0.556	-2.003	-2.954	-2.173	-2.841	1.394	-0.160	-1.125	-0.691	-0.544	-1.643	-0.539	-0.217	-0.936	-3.016	-1.306
	SS -0.0087	-0.0456	-0.0362	-0.0046	-0.1024	-0.0018	0.0071	-0.2034	0.0059	-0.0079	-0.8871	0.0211	-0.2535	0.001	-0.3604	-0.1952

* Significant trend at the 10% significance level.

† Significant trend at the 5% significance level.

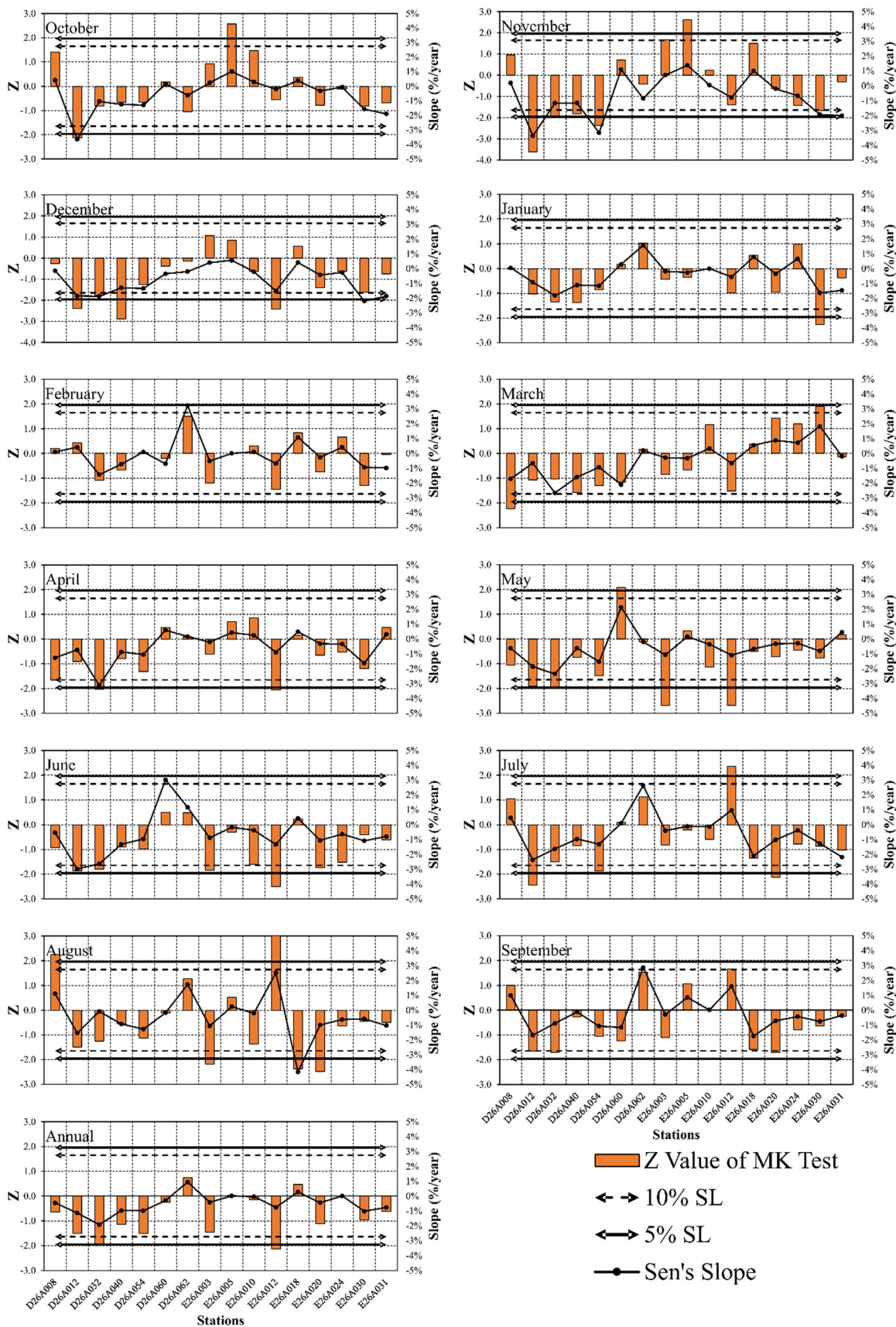


Figure 4. Distribution of Z and Sen's slope values.

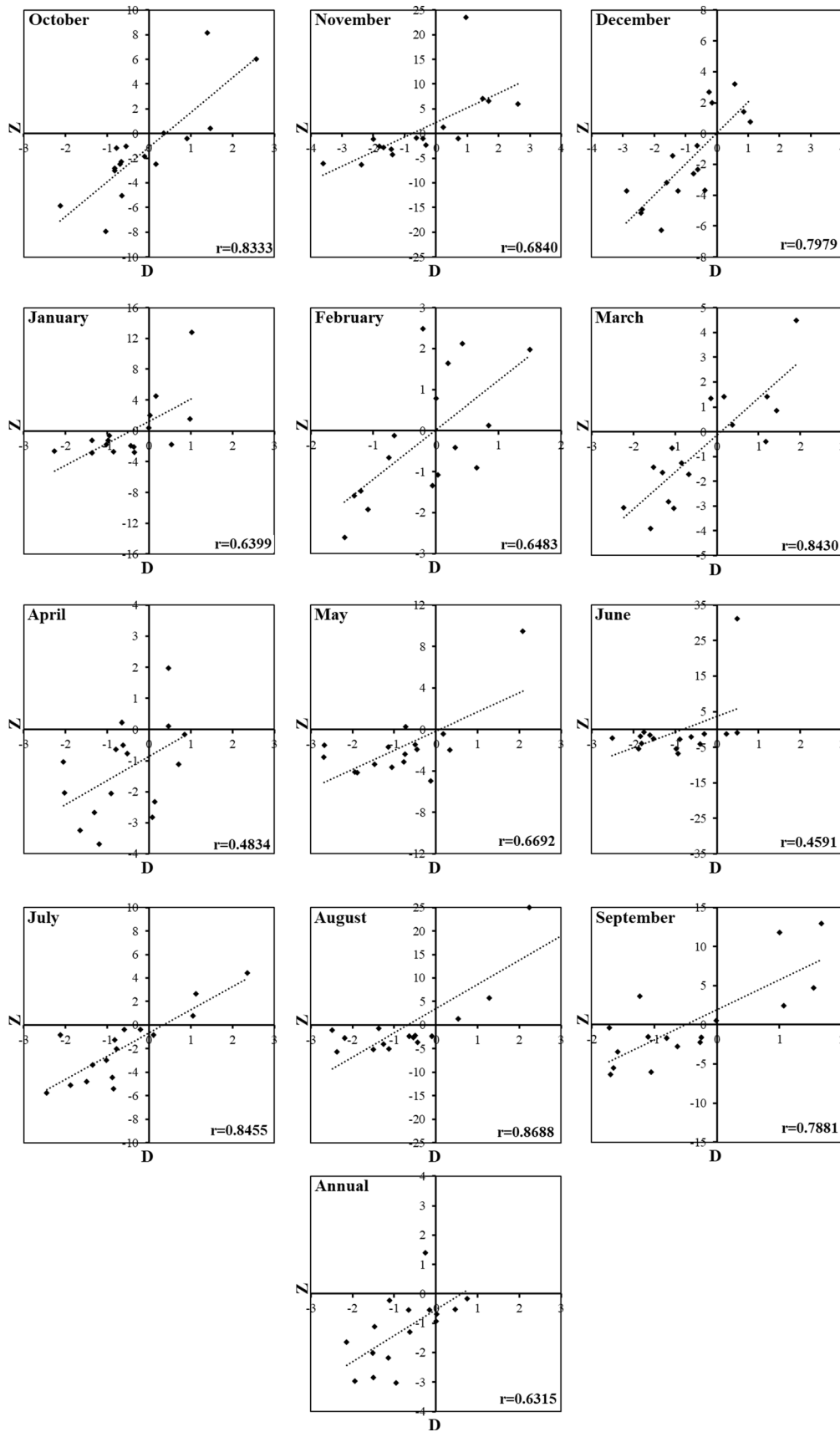


Figure 5. Scatter plot of Z and D values.

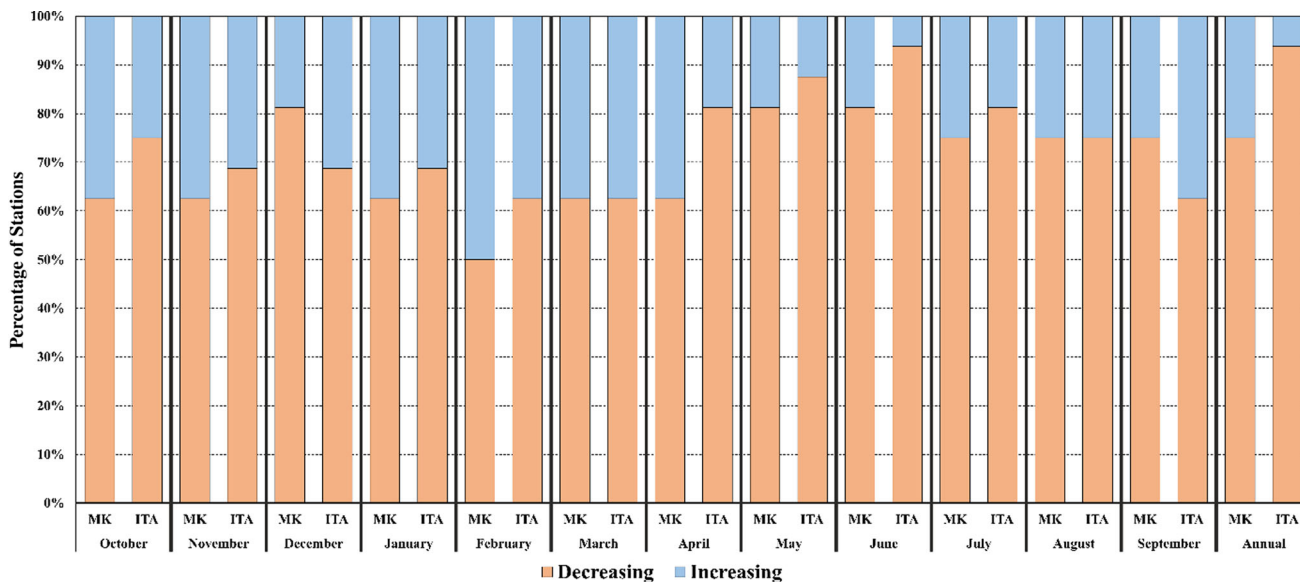


Figure 6. Percentage of trend directions of the stations with MK and ITA.

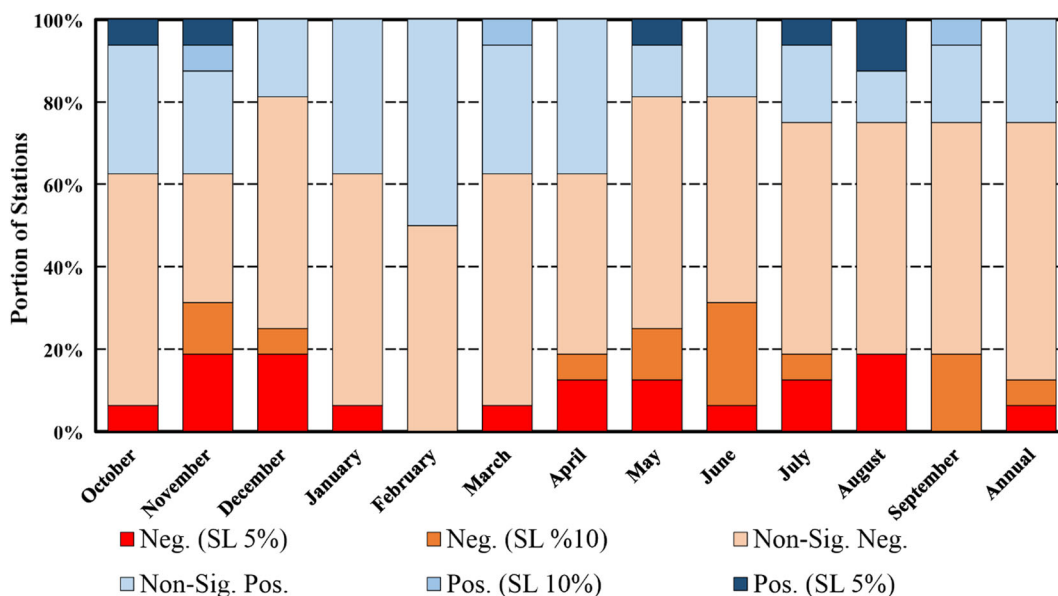


Figure 7. Percentage of stations having positive and negative trends based on the MK test.

indicate the percentage of Sen’s slope values. The percentage of the trend slope is calculated by dividing Sen’s slope values by the long-term mean streamflow value (annual or monthly). This is because the flow rates measured in some main tributaries are quite high compared to the flow rates measured in the side tributaries, thus ensuring integrity for interpretation. The statistically significant trend intervals of the *Z* values obtained from the MK test are indicated as solid horizontal and dashed horizontal lines for 5% and 10% significant levels, respectively. Accordingly, a

significant trend is determined on different stations at 5% significant level (SL) in all months except February and September in the whole basin. The most decreasing trend at 5% SL is observed for three stations in November, December and August. However, at 10% SL, the number of stations that show the trend is five in November and June, and four in December. At 5% SL, the maximum increasing trend is determined at two stations in August, and the number of stations with significant trends is determined two even when the confidence interval is increased. Considering the significant

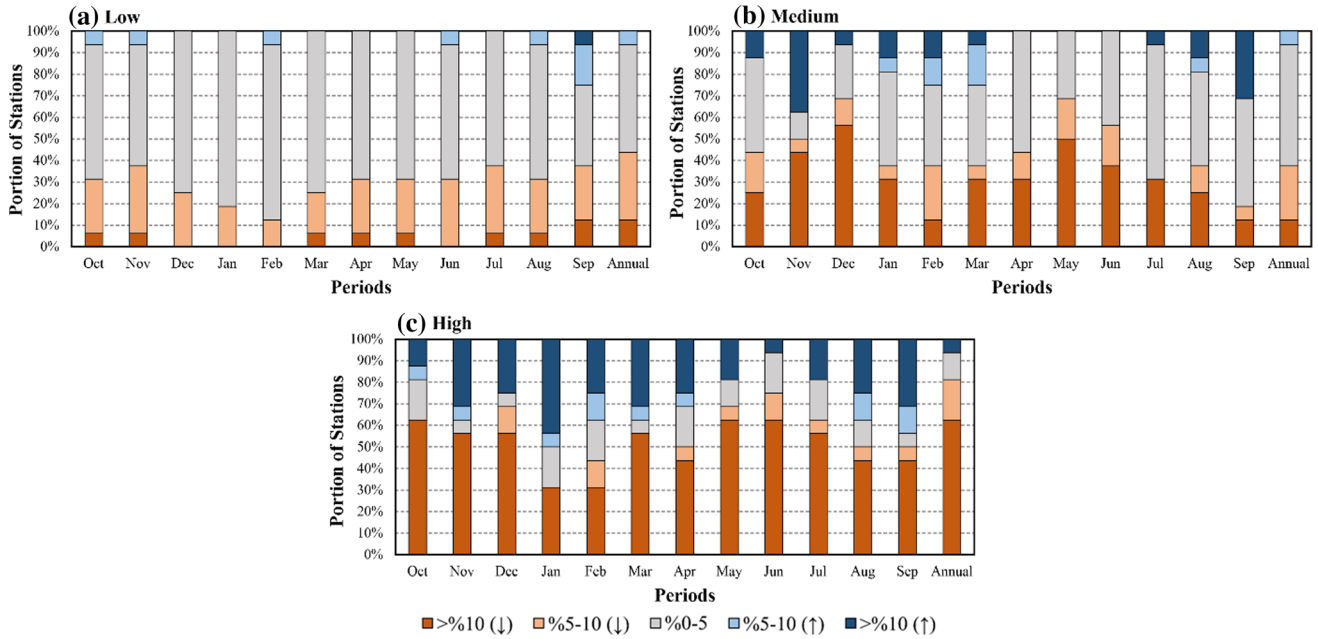


Figure 8. Percentage of stations having positive and negative trends based on the ITA. (a) Low, (b) medium, and (c) high.

increasing trends in the summer months, significant increasing trends are determined for station E26A012 in July and August, and for station D26A008 in August. As observed in the results of the precipitation trend analysis studied by Sezen and Partal (2020), an increasing trend is determined in the region where station E26A012 is located. It is possible that the increase in streamflow values is also due to this. Station D26A008 shows quite low streamflow values for long-term years as can be observed by the mean streamflow values ($1.88 \text{ m}^3/\text{s}$) given in table 1. Therefore, in this river, which is mostly dry in summer (mean streamflow value is $0.008 \text{ m}^3/\text{s}$ in August), the streamflow rate would increase significantly even as a result of the mixing of the water used for irrigation or a low-intensity rainfall into the river flow especially in recent years. Hence, it is evaluated that there is a significant increasing trend occurrence in August at station D26A008. In addition, it is seen that the amount of change is mostly in the range of $\pm 2\%$ for the slope values shown in figure 4. According to the results for all monthly time scales, it is determined that the number of stations that has an increasing trend is less than the number of stations that has a decreasing trend.

Figure 5 shows the correlation between the D values calculated according to the ITA method and the Z values calculated by the MK method. As shown in this figure, there is a very high correlation

between Z and D values in October, March, December, July and August. However, the correlation is very low in June and April, and it is acceptable for the other months and annual time scales. It can be interpreted that this inconsistency is because one of them tends to decrease while the others show an increase in the evaluation made for three different data sets (low, medium, high) using the ITA method. The correlation coefficients of Z and D determined in this study for streamflow are similar to the correlation coefficients between Z and D values calculated for precipitation values in different regions (Wu and Qian 2017; Nisansala *et al.* 2020). Therefore, it is evaluated that D values of the ITA method can be used as indicators to determine a trend for streamflow data.

The distribution of trend directions determined according to Z values calculated by the MK method, and D values calculated by ITA are given in figure 6. It is observed that the trend directions given by both methods are mostly similar to each other, but the negative D values calculated by the ITA method are more than the negative Z values calculated by the MK method except for September, March and August. It can be said that especially in the high correlation found for the months (e.g., March and August) in the scatter plot (figure 5) gives a very consistent result in terms of trend directions.

The distribution of trends determined by the MK test at the Tigris basin is shown for all time

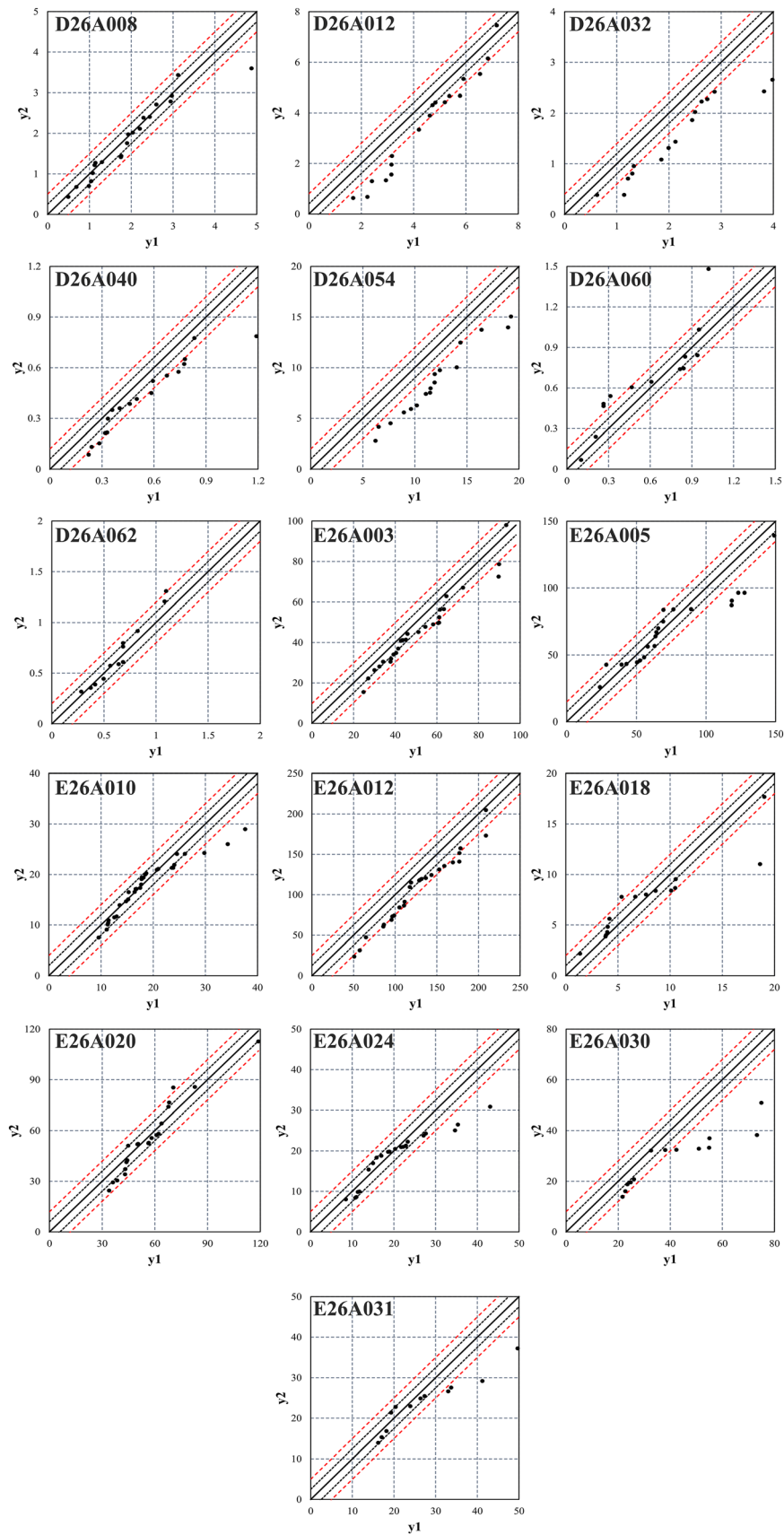


Figure 9. Results of ITA for annual streamflow values at the 16 stations.

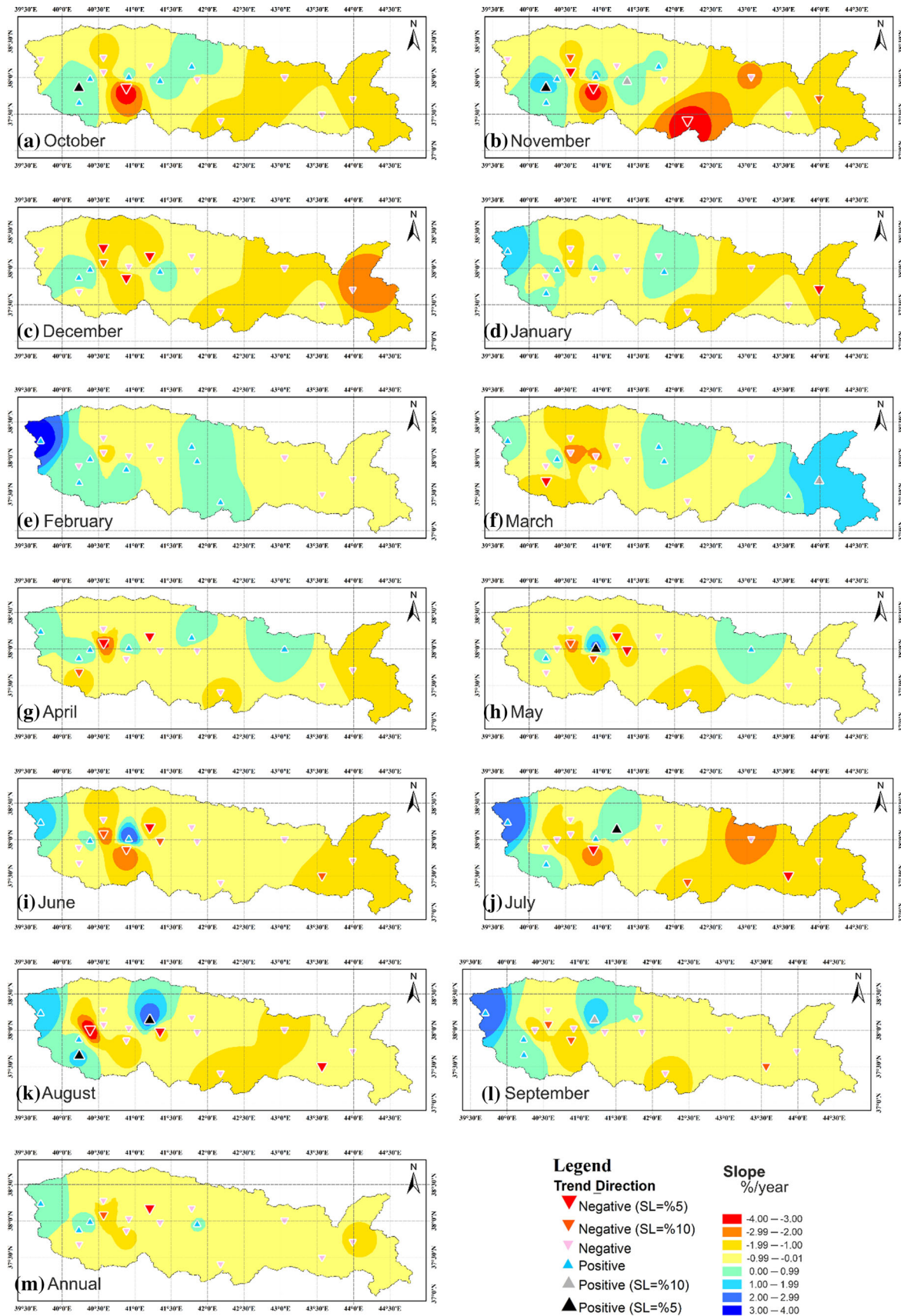


Figure 10. Spatial distributions of the stations based on the Z values and the linear slope.

scales in figure 7. As can be seen from the figure, it is calculated that the streamflow values of the Tigris basin generally tend to decrease. The increasing and decreasing values are relatively equal in February and there is no significant trend except in February. The maximum decrease occurred in December, May and June. It can be said that approximately 30% of the stations showed a decreasing trend in November and June when the decreasing trends (at 5% and 10% SL) are analysed. The stations that show a significant increasing trend remained limited in the basin. In November and August, an increasing trend was determined at 15% of the stations, and a significant increasing trend could not be determined in December, January, February, April, June and annual mean values.

According to the ITA method, the distribution of the stations with 0–5%, 5–10% and more than 10% change in low, medium and high streamflow values is given for all time scales in figure 8. The percentage of stations that shows a decrease of 5% and more in all time scales except February in low streamflow values is around 20–30%, and this rate is 45% in the annual mean. In addition, the number of stations, which tended to decrease more than 10% in low streamflow value, remained limited. In medium streamflow values, unlike low values, the number that tends to decrease more than 10% has increased dramatically. In addition, the number of stations, which tended to increase more than 10% in medium streamflow, is more than 30% in November and September of all stations. The change that occurs in high streamflow values is another remarkable result. Especially in high streamflow values, the case of no trend is little, if any, and it is found that there are more stations with a decreasing trend except for a few months (January and February). It is determined that the number of stations, which decreased by 10% and above in October, June and annual mean streamflow values, is at a high level of 60%.

Figure 9 shows the graphs of the annual mean streamflow values of 16 studied stations according to the ITA method. This graph enables quite different interpretation according to monotonic trends. For example, it can be said that there is no trend at stations D26A008 and D26A062, and higher streamflow values tend to decrease at stations E26A010, E26A024, E26A030 and E26A031. In addition, it can be clearly seen from the graph that station D26A054 shows a strong decrease in

all values, while the medium values increase at station E26A018. Moreover, low streamflow values also show a decreasing trend at stations D26A012 and D26A060. Since it is easy to apply compared to monotonic trend analysis methods with clearer statements in interpreting results, the ITA method can be assessed as highly beneficial in analysing the streamflow values.

While temporal trends in a basin are evaluated on a station basis, it is also useful to give the spatial distribution of changes in order to make a regional evaluated for the entire basin. Therefore, the spatial distributions of Z and Sen slopes calculated at the Tigris basin are given in figure 10. Throughout the basin, the change of Sen slope values for all time scales (monthly and annual) is in the range of $\pm 4\%$ and it is determined that the overall basin has a decreasing trend within the range of 0–2%. The amount of decrease occurred at a high level of 3–4% in October, November and August, and the decrease in these regions is usually significant according to the MK test. Slope values show an increasing trend in the eastern and south-western regions of the basin at all-time scales except in May. Also, it is determined that this increase is between 2% and 4% especially in February, July and September, and this increase was observed only in August at stations with significant trends. It is seen that the stations with a significant decreasing trend are generally located in the middle region of the basin. It is determined that the spatial distribution obtained during the summer months is similar to each other.

Yildiz *et al.* (2016) statistically analysed the trends of long-term streamflow values of three stations in the Tigris basin. As a result of the analysis, it is stated that the streamflow values in the region changed and tended to decrease. From this result, they predicted that the average mean streamflow of the river naturally decreases slightly, and this decreasing trend would go on. With the results of the presented study, it is also observed that the trends tend to decrease throughout the basin. Also, as a result of the trend analysis of rainfall data in the Tigris and Euphrates basins, Turkey conducted by Önoğlu and Semazzi (2009) shows that the rainfall has a strong decrease. Bozkurt and Sen (2013) studied climate change in the Tigris and Euphrates basins, Turkey, and they found that the rainfall data show a decrease in the mountainous and

northern parts of the basin and an increase in the southern parts. Daggupati *et al.* (2017) investigated the spatial and temporal distribution of precipitation and streamflow data of the TERB. In the study which examined separating the TERB into three sub-regions, one of them deals with the Tigris basin, Turkey. As a result of the study, it is stated that annual precipitation values tend to decrease up to 30%. Kahya and Kalaycı (2004) determined the trend of the annual streamflow values of 83 stations in Turkey by using data between 1964 and 1994 by the MK test. In their study, only three stations (E26A003, E26A010, E26A012) from the Tigris basin are evaluated and no significant trends are determined in these three considered stations. However, in the present study, a significant decreasing trend is calculated using the MK method at station E26A012 in the annual mean streamflow, in addition, decreasing trends are also determined using the ITA method in high streamflow values at stations E26A003 and E26A010, and in all (low, medium, high) values at station E26A012. Especially with this presented study, with current data (up to 2016 for some stations), the existence of significant trends that were not determined before is seen in repeated analyses. Ay *et al.* (2018), studied the trend analysis of a station not used in this study in the Tigris basin of Turkey, due to the measurement range being short (2002–2011), using the ITA and MK tests. In this station, which is near to station E26A010 as a location, significant decreasing trends are determined according to both methods. Although the data range is limited in their study, the trend directions determined are similar to the presented study. Al-Hasani (2020) evaluated the trends of streamflow, temperature and precipitation data at nine stations located in the Iraq borders of the Tigris basin. Significant decreasing trends were determined during winter, spring and summer streamflow values in all hydrometric stations. In addition to this, Al-Hasani interpreted that the reduction in streamflow can be linked mainly to the increased dam constructions, and global warming caused less precipitation, and higher temperature. Since the stations he used are all within the borders of the Tigris basin in Iraq, no direct comparison is made with the presented study, which is the upper part of the Tigris basin in Turkey. However, the decreasing trends in streamflow values as a result of his work are found generally similar to the presented

study. In addition, it is stated that there is a decreasing trend in streamflow values and this decreasing trend is due to dams built on rivers and climate change. Since the decrease in precipitation, which is the main component of the streamflow in the Tigris basin, is expected to decrease the streamflow, the results of this study are in parallel with the previous studies. In addition, it is noted that the strong decreasing tendencies determined by the ITA method in medium and high values should be considered as an issue that should be tackled in particular. In this region, it will be useful to evaluate streamflow in particular and precipitation data for different climate change scenarios in order to see the impact of climate change on water resources.

5. Conclusions

In this study, the trends of the monthly and annual mean streamflow data of 16 stations in the Tigris river basin, Turkey are evaluated. Monotonic trends are determined using the MK test, and trends of low, medium and high values determined using the ITA method. Before applying the MK test, the serial correlation effect is removed. The linear trend slopes are calculated using Sen's slope method. The following conclusions may be drawn from this study:

- Z values of the MK test and D values of the ITA method are compared, and it is generally seen that the $|D| \geq Z_{\alpha/2}$ condition occurs when the $|Z| \geq Z_{\alpha/2}$ condition is fulfilled. Additionally, the trend directions found by MK and ITA are similar, but the negative D values calculated by ITA are mostly more than the negative Z values calculated by MK.
- According to the MK test, most of the significant trends are obtained in the decreasing direction. The percentage of changes in linear slopes is mostly determined in the range of $\pm 2\%$. No significant trend is determined in any month or annual mean streamflow in only four of the 16 stations studied.
- It is observed that there is a very high correlation between the Z and D values in some months, this correlation is found low only in June and April. The reason is assessed that each low, medium and high streamflow values shows a different trend in ITA. The number of stations, which tended to decrease more than 10% in

medium values, increased dramatically and they are more than 30% in some months.

- The most remarkable result of ITA is that all stations showed a very strong trend (increase or decrease) in high streamflow values. In addition, strong and very strong decreasing trends are found for the annual mean streamflow at 80% of the stations.
- Spatial analysis of Sen slope values for all time scales (monthly and annual) in the Tigris basin is in the range of $\pm 4\%$, and the overall basin is in a decreasing trend. This amount of decrease occurred in the range of 0–2%. The significant decreasing trends are generally located in the middle region of the basin.

With this study, since it is seen that streamflow values tend to decrease significantly on a monthly and annual basis, it is evaluated that water should be used effectively and efficiently in this basin, which is a transboundary and has different water structures in it, and that the decrease in high and medium streamflow should be monitored in detail in terms of planning. In addition, it is considered that the ITA method can be used as a reliable method in trend analysis because it is easy to apply compared to the monotonic trend analysis methods. In conclusion, the ITA method is beneficial with clearer expressions in interpreting the results.

Acknowledgement

This study was supported by the Harran University Scientific Research Council (HUBAP) with Project Number 18196.

Author statement

Veysel Gumus: Conceptualisation, coding, interpreting results, writing the manuscript; Yavuz Avsaroglu: Performing analysis and writing and discussing results; and Oguz Simsek: Writing the discussion and correcting the proof.

References

- Al-Hasani A A 2020 Trend analysis and abrupt change detection of streamflow variations in the lower Tigris river basin, Iraq; *Int. J. River Basin Manag.*, <https://doi.org/10.1080/15715124.2020.1723603>.
- Ashraf M S, Ahmad I, Khan N M, Zhang F, Bilal A and Guo J 2021 Streamflow variations in monthly, seasonal, annual and extreme values using Mann–Kendall, Spearman's Rho and innovative trend analysis; *Water Resour. Manag.* **35**(1) 243–261.
- Ay M, Karaca Ö F and Yıldız A K 2018 Comparison of Mann–Kendall and Sen's innovative trend tests on measured monthly flows series of some streams in Euphrates-Tigris basin; *J. Indian Inst. Sci.* **34**(1) 78–86.
- Bozkurt D and Sen O L 2013 Climate change impacts in the Euphrates–Tigris basin based on different model and scenario simulations; *J. Hydrol.* **480** 149–161.
- Caloiero T, Coscarelli R and Ferrari E 2020 Assessment of seasonal and annual rainfall trend in Calabria (southern Italy) with the ITA method; *J. Hydroinform.* **22**(4) 738–748.
- Cigizoglu H, Bayazit M and Önöz B 2005 Trends in the maximum, mean, and low flows of Turkish rivers; *J. Hydrometeorol.* **6**(3) 280–290.
- Cui L, Wang L, Lai Z, Tian Q, Liu W and Li J 2017 Innovative trend analysis of annual and seasonal air temperature and rainfall in the Yangtze river basin, China during 1960–2015; *J. Atmos. Sol.-Terr. Phys.* **164** 48–59.
- Daggupati P, Srinivasan R, Ahmadi M and Verma D 2017 Spatial and temporal patterns of precipitation and stream flow variations in Tigris-Euphrates river basin; *Environ. Monit. Assess.* **189**(2) 50.
- Dey P and Mishra A 2017 Separating the impacts of climate change and human activities on streamflow: A review of methodologies and critical assumptions; *J. Hydrol.* **548** 278–290.
- DSI 2016 Strategic action plan for 2017–2021; General Directorate of State Hydraulic Works, Ankara, 100p.
- Du J, Cheng L and Zhang Q 2019 Spatiotemporal variability and trends in the hydrology of the Xiang river basin, China: Extreme precipitation and streamflow; *Arab. J. Geosci.* **12**(18) 1–12.
- Elouissi A, Şen Z and Habi M 2016 Algerian rainfall innovative trend analysis and its implications to Macta watershed; *Arab. J. Geosci.* **9**(4) 1–12.
- Gedefaw M, Yan D, Wang H, Qin T, Girma A, Abiyu A and Batsuren D 2018 Innovative trend analysis of annual and seasonal rainfall variability in Amhara regional state, Ethiopia; *Atmosphere (Basel)* **9**(9) 326.
- Gibrilla A, Anornu G and Adomako D 2018 Trend analysis and ARIMA modelling of recent groundwater levels in the White Volta river basin of Ghana; *Groundw. Sustain. Dev.* **6** 150–163.
- Gocic M and Trajkovic S 2013 Analysis of changes in meteorological variables using Mann–Kendall and Sen's slope estimator statistical tests in Serbia; *Glob. Planet. Change* **100** 172–182.
- Gumus V 2019 Spatio-temporal precipitation and temperature trend analysis of the Seyhan–Ceyhan river basins. Turkey; *Meteorol. Appl.* **26**(3) 369–384.
- Hamed K H and Rao A R 1998 A modified Mann–Kendall trend test for autocorrelated data; *J. Hydrol.* **204**(1–4) 182–196.
- He Y, Ye J and Yang X 2015 Analysis of the spatio-temporal patterns of dry and wet conditions in the Huai river basin using the standardized precipitation index; *Atmos. Res.* **166** 120–128.
- Kahya E and Kalaycı S 2004 Trend analysis of streamflow in Turkey; *J. Hydrol.* **289**(1–4) 128–144.

- Kalayci S and Kahya E 2006 Assessment of streamflow variability modes in Turkey: 1964–1994; *J. Hydrol.* **324**(1–4) 163–177.
- Kendall M G 1948 *Rank correlation methods*; Griffin, London, 202p.
- Kişçi Ö, Guimaraes Santos C A, Marques da Silva R and Zounemat-Kermani M 2018 Trend analysis of monthly streamflows using Şen’s innovative trend method; *Geofizika* **35**(1) 53–68.
- Kumar S, Merwade V, Kam J and Thurner K 2009 Streamflow trends in Indiana: Effects of long term persistence, precipitation and subsurface drains; *J. Hydrol.* **374**(1–2) 171–183.
- Kuriqi A, Ali R, Pham Q B, Gambini J M, Gupta V, Malik A, Linh N T T, Joshi Y, Anh D T and Dong X 2020 Seasonality shift and streamflow flow variability trends in central India; *Acta Geophys.* **68**(5) 1461–1475.
- Langat P K, Kumar L and Koech R 2017 Temporal variability and trends of rainfall and streamflow in Tana river basin, Kenya; *Sustainability* **9**(11) 1963.
- Li S, Zhang L, Du Y, Zhuang Y and Yan C 2020 Anthropogenic impacts on streamflow-compensated climate change effect in the Hanjiang river basin, China; *J. Hydrol. Eng.* **25**(1) 04019058.
- Lins H F and Slack J R 1999 Streamflow trends in the United States; *Geophys. Res. Lett.* **26**(2) 227–230.
- Mann H B 1945 Nonparametric tests against trend; *Econometrica* **13** 245–259.
- Mohsin T and Gough W A 2010 Trend analysis of long-term temperature time series in the Greater Toronto Area (GTA); *Theor. Appl. Climatol.* **101**(3) 311–327.
- Mumo L, Yu J and Ayugi B 2019 Evaluation of spatiotemporal variability of rainfall over Kenya from 1979 to 2017; *J. Atmos. Sol.-Terr. Phys.* **194** 105097.
- Nisansala W, Abeysingha N, Islam A and Bandara A 2020 Recent rainfall trend over Sri Lanka (1987–2017); *Int. J. Climatol.* **40**(7) 3417–3435.
- Ozis U, Harmancioglu N B and Ozdemir Y 2020 Transboundary river basins; *Water Resources of Turkey*, Springer, pp. 399–444.
- Önol B and Semazzi F H M 2009 Regionalization of climate change simulations over the Eastern Mediterranean; *J. Clim.* **22**(8) 1944–1961.
- Salas J D 1980 *Applied modeling of hydrologic time series*; Water Resources Publication, Michigan, 484p.
- Sen P K 1968 Estimates of the regression coefficient based on Kendall’s tau; *J. Am. Stat. Assoc.* **63**(324) 1379–1389.
- Sezen C and Partal T 2020 Wavelet combined innovative trend analysis for precipitation data in the Euphrates–Tigris basin, Turkey; *Hydrol. Sci. J.* **65**(11) 1909–1927.
- Storch H V and Navarra A 1995 Spatial patterns: EOFs and CCA; In: *Analysis of climate variability* (eds) von Storch H and Navarra A, United States, <https://doi.org/10.1007/978-3-662-03167-4>.
- Suhaila J and Yusop Z 2018 Trend analysis and change point detection of annual and seasonal temperature series in Peninsular Malaysia; *Meteorol. Atmos. Phys.* **130**(5) 565–581.
- Şen Z 2012 Innovative trend analysis methodology; *J. Hydrol. Eng.* **17**(9) 1042–1046.
- Topaloğlu F 2006 Trend detection of streamflow variables in Turkey; *Fres. Environ. Bull.* **15**(7) 644–653.
- Wu H and Qian H 2017 Innovative trend analysis of annual and seasonal rainfall and extreme values in Shaanxi, China, since the 1950s; *Int. J. Climatol.* **37**(5) 2582–2592.
- Yenigün K, Gümüş V and Bulut H 2008 Trends in streamflow of the Euphrates basin, Turkey; *Water Manag.* **161**(4) 189–198.
- Yildiz D, Yildiz D and Gunes M S 2016 Comparison of the long term natural streamflows trend of the upper Tigris river; *Imp. J. Interdiscip. Res.* **2**(8) 1174–1184.
- Yue S, Pilon P, Phinney B and Cavadias G 2002 The influence of autocorrelation on the ability to detect trend in hydrological series; *Hydrol. Process.* **16**(9) 1807–1829.
- Zamani R, Mirabbasi R, Abdollahi S and Jhajharia D 2017 Streamflow trend analysis by considering autocorrelation structure, long-term persistence, and Hurst coefficient in a semi-arid region of Iran; *Theor. Appl. Climatol.* **129**(1) 33–45.