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Trends in streamflow of the Euphrates basin, Turkey

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Detection of changes over the long term for a series of hydrological variables is an important and critical issue, which is subject to increasing interest. In this study, trend analysis of the streamflow of the Euphrates basin, which is the biggest basin in Turkey, is carried out. The non-parametric trend tests (Mann–Kendall and Spearman's rho) are applied to annual average, minimum and maximum streamflow data of 22 selected stations in the Euphrates basin. All the streamflow records date back over at least 24 years, with lengths in the range 24–44 years. The Mann–Kendal rank correlation test is used to determine the year in which trends begin. The linear slopes of trends are calculated by using Sen's estimator of slope technique. Based on the test's procedures, with respect to annual minimum streamflow, significant decreasing trends are detected for six stations and an upward trend is found for only one station. While no trend appears relating to annual maximum streamflow for any station, a decreasing trend is found with respect to annual mean streamflow for one station. The results are expected to assist water resources managers and policy makers in making better planning decisions in the Euphrates basin.

NOTATION

H_o	null hypothesis
m	number of tied values
n	number of data
Q	Sen's estimator of slope
R	rank of the ith observation in the sample
r_s	test statistic of Spearman's rho
S	Mann–Kendall test statistic
t	test statistic Mann–Kendall rank correlation test
u	standardised variable of the Mann–Kendall rank correlation
u'	backward series of u
x_i	data at time i
Z	standard normal test statistic

1. INTRODUCTION

Observational and historical streamflow data are the most important factors in planning and designing water resource projects. These data have time-dependent characteristics and are affected by many factors such as climatic change and anthropogenic activities. One of the main steps in water resources work is to identify the trends in observed streamflow data and their occurrence in space and time. The detection of a significant trend in streamflow will affect the decisions on water management and policies.

Various streamflow trend studies have been conducted in different parts of world. Burn and Elnur[1] described the development and application of a procedure that identifies trends in hydrological variables. Their study relates to the quantification of trends in hydrological variables and the investigation of the relationship between trends in hydrological variables and the trends in meteorological variables in Canada. Whitfield and Cannon[2] compared hydrological and meteorological data for Canada from two different decades and found the more recent decade to be generally warmer with the occurrence of both increases and decreases in precipitation and streamflow. Trends in flood and low flows in the USA were studied by Douglas *et al.*[3] They found that the cross-correlation of flow records reduces the effective number of samples and low-flow time series exhibit significant temporal persistence. The streamflow trends in the USA have also been studied by Lins and Slack.[4] They evaluated for 395 climate-sensitive stream gauging stations in the conterminous USA using the non-parametric Mann–Kendall test. Yue *et al.*[5] examined impacts of serial and cross-correlation on Canadian streamflow trend detection. Birsan *et al.*[6] analysed mean daily streamflow records from 48 watersheds in Switzerland with an undisturbed runoff regime for trends with the Mann–Kendall non-parametric test in three study periods. Their results indicated that mountain basins are the most vulnerable environments from the point of view of climate change, because of their watershed properties, which promote fast runoff and because of their fundamental vulnerability to temperature changes that affect rainfall, snowfall, and snow and ice melt. Some of the other examples which include trend study in streamflow are Zhang *et al.*[7], Marengo *et al.*[8], Burn *et al.*[9,10] and Zhang *et al.*[11] Among streamflow trend studies in Turkey, Kahya and Kalayci[12] examined trends in streamflow obtained from 26 basins over Turkey and found significant trends appearing in the western and southeastern parts of the country. The direction of those trends is, in general, downward. But they did not detect any trend in the basins located in eastern Turkey. Kalayci and Kahya[13] evaluated trends in monthly streamflow data for 11 stations in the Sakarya basin (located in northwestern Turkey) and found downward trends for each month in all stations except one. Topaloğlu[14] investigated 15 streamflow variables, including annual minimum, mean, maximum and monthly streamflows, for a network of 75 streamflow gauging stations in seven geographical regions of Turkey. He found significant decreasing trends in the Marmara, Aegean, Mediterranean and Central Anatolia regions. Bayazit *et al.*[15] studied trend analysis of streamflow in Turkey. They found a significant downward trend in mean streamflow, floods and low streams in the west, south, middle and Trakya regions of Turkey. The same authors also carried out further work on the existence of trends in maximum, mean, and low flows of Turkish rivers using the parametric t-test and non-parametric τ (Mann–Kendall) test.[16] They found that the existence of a trend was more common in mean and low flows when compared with maximum flows.

Characteristic	Value
Mean annual streamflow: m^3/s	995·08
Volume of annual streamflow: m^3	$31{\cdot}38 \times 10^9$
Depth of annual discharge: mm	259·52
Mean annual efficiency: l/s per km^2	8·23
Ratio of discharge in the Euphrates basin to total discharge in Turkey: %	16·75

Table 1. General characteristics of the Euphrates basin

As seen from the preceding literature review, trend studies covering Turkey have usually focused on all the basins of Turkey and give general results. No specific basin has been studied in detail except the Sakarya basin. The objective of the current study is to carry out comprehensive trend analysis of streamflow of the Euphrates basin, the biggest basin in Turkey. In this study, more stations have been analysed than in previous works carried out for the Euphrates basin.[12,16] The current study is more comprehensive according to results and uses a different technique, which is the Mann–Kendall rank correlation test, for determining the trend-starting year. Non-parametric trend tests such as Mann–Kendall and Spearman's rho are applied to annual average, minimum and maximum streamflow of 22 selected stations in the Euphrates basin.

2. MATERIAL AND METHOD

2.1. Study field and data

Turkey is located in the Mediterranean macroclimate region, but the geographical factors create some changes in climatic conditions.[17] The hydrological characteristics of the country represent high spatial and temporal variability.[18] The Euphrates basin is located in the southeastern Anatolia region of Turkey. It is the largest of 26 basins in the country and has the biggest mean annual streamflow in Turkey. It is part of the Southeast Anatolian Project, which is a multi-sector and integrated regional development effort approached in the context of sustainable development. The Euphrates river, formed from the Karasu and Murat tributary rivers, is the main river of the basin, has a length of 2800 km and crosses Iraq to join the Tigris, where it flows into the Persian Gulf. Its average discharge upstream and at the border of Syria is 650 m^3/s and 950 m^3/s, respectively. In the basin, 32 large dams have been designed to exploit the energy and irrigation potential of the basin.[19] The region of the Euphrates basin has a continental subtropical climate, with extremes of heat in summer and cold in winter, as well as great diurnal variations. The regime of the Euphrates basin depends most heavily on winter rains and spring snowmelt in the mountains located in the region of East Anatolia. The total precipitation area of the Euphrates basin is 120 917 km^2 and its average elevation is 1009·87 m. The general characteristics of the Euphrates basin are given in Table 1.[20] Fig. 1 shows the location of the Euphrates basin in a map of Turkey's basins. The Euphrates basin is divided into three parts, as shown in Fig. 1.

The streamflow gauging stations are operated by the General Directorate of the Electrical Power Resources Survey and Development Administration (Turkish initials 'EİEİ') and General Directorate of State Hydraulic Works (Turkish initials 'DSİ'). In the present study, 22 stations were selected from the 83 stations operated by EİEİ. The selection of the stations is based on the length of records, the reliability of data and the continuous nature of the data. The rivers that have streamflow gauging stations are not regulated by large storage reservoirs and are not affected by urbanisation. The rivers included in this study have relatively natural flow. Table 2 gives the details of the selected streamflow gauging stations and their observation period and precipitation area. As seen in Table 2, all selected stations have adequate record length for the statistical validity of trend results. All the streamflow records are over a period of at least 24 years, with time periods in the range 24–44 years.

The parts of the Euphrates basin and the location of the selected 22 hydrometric stations in the current study are shown in Fig. 2, where the selected stations cover the basin almost uniformly.

2.2. Trend detection tests

In statistical terms, the purpose of trend analysis is to determine if a series of observations of a random variable is generally increasing or decreasing with time, or whether the probability distribution has changed with time. Several tests are available for the detection and/or quantification of trends such as non-parametric, mixed and parametric.[21] Non-parametric tests are widely used in trend analysis of climatic and hydrological data, which are robust with respect to missing and tied values,

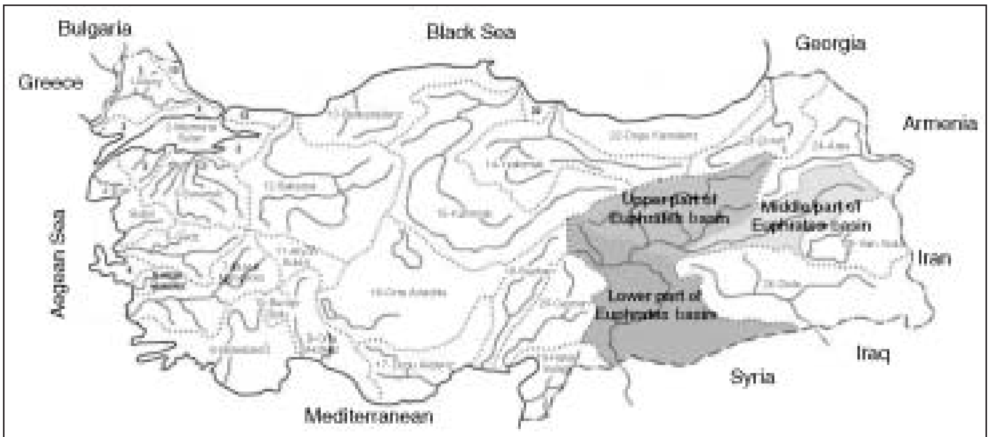

Fig. 1. The location of the Euphrates basin on the map of Turkey's basins

Station identification number (SID)	Part of basin	Name of station	Precipitation area: km^2	Observation period
2102	Middle	Murat Nehri-Palu	25 515·6	1968–2000
2115	Lower	Göksu Nehri-Malpınar	3998·8	1968–2000
2119	Upper	Firat Nehrı-Kemah Boğazı	10 356·0	1954–1987
2122	Middle	Murat Nehri-Tutak	5882·4	1962–2000
2123	Lower	Çağçağ Suyu-Çinarköy	863·6	1961–1993
2124	Lower	Tohma Suyu-Yazıköy	1336·4	1963–2000
2131	Lower	Beyderesi-Kılayık	277·6	1957–2000
2132	Lower	Culp Suyu-incirli	464·5	1963–1999
2135	Lower	Bulam Çayı-Fatopaşa	166·4	1961–2000
2141	Upper	Persisuyu-Korudibi	3604·4	1964–1991
2145	Lower	Tohma Suyu-Hisarcık	5822·0	1963–2000
2149	Upper	Munzur Suyu-Miskidağ	1669·0	1963–1998
2151	Upper	Fırat Nehri-Demirkapı	8185·6	1964–2000
2154	Upper	Karasu-Aşaği Kağdariç	2886·0	1969–2000
2156	Upper	Firat Nehri-Bağıştaş	15 562·0	1969–2000
2157	Middle	Karasu-Karaköprü	2098·4	1969–2000
2158	Middle	Bingöl Çayı-A.Paşa Köp.	1577·6	1969–2000
2164	Middle	Göynük Çayi-Çayağzı	2232·0	1969–2000
2165	Lower	Zerkan Suyu-Hocaköy	490·0	1969–1998
2166	Upper	Peri Suyu-Loğmar	5385·8	1970–1998
2167	Upper	Çaltı Suyu-Dazlak	4288·0	1968–1991
2168	Upper	Dumlu Suyu-Yeşildere	52·0	1973–1997

Table 2. The selected streamflow gauging stations, their observation periods and their precipitation area

seasonality, non-normality, non-linearity and serial dependency. In the present study, the non-parametric Mann–Kendall and Spearman's rho tests are used in trend detection of streamflow in the Euphrates basin. The Mann–Kendall rank correlation test is used to determine the starting year of a trend. The linear slopes of trends are calculated by using Sen's estimator of slope technique. The methods used in the analysis are briefly described as follows.

2.2.1. Mann–Kendall test. The Mann–Kendall method[22,23] is one of the widely used non-parametric tests for detecting trends in climatological and hydrological time series. It has been used and suggested by the World Meteorological Organisation (WMO) to assess trends in environmental data time series.[24] The method is simple, robust and handles missing values as well as values below a detection limit.[1,12,25–27] The Mann–Kendall test statistic S is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sign}(x_j - x_i) \tag{1}$$

where n is the number of data, x is the data point at times i and j $(j > i)$ and the sign function is given as

$$\operatorname{sign}(x_j - x_i) = \begin{cases} +1 & x_j > x_i \\ 0 & x_j = x_i \\ -1 & x_j < x_i \end{cases} \tag{2}$$

The variance of S is computed by

$$\operatorname{var}(S) = \left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i i(i-1)(2i+5) \right] / 18 \tag{3}$$

where t_i is the number of ties of extent i and m is the number of tied rank groups. For n larger than 10, the standard normal Z test statistic is computed as the Mann–Kendall test statistic as follows

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{\operatorname{var}(S)}} & S > 0 \\ 0 & S = 0 \\ \dfrac{S+1}{\sqrt{\operatorname{var}(S)}} & S < 0 \end{cases} \tag{4}$$

The presence of a statistically significant trend is evaluated using the Z value. In a two-sided test for trend, the null hypothesis H_o should be accepted if $|Z| \leqslant Z_{a/2}$ at the level of significance. A positive S value indicates an 'upward trend' and a negative value indicates a 'downward trend'.

The presence of serial correlation may lead to an erroneous rejection of the null hypothesis. The effect of a serial correlation problem should therefore be taken account in the Mann–Kendall test. The most common approach for removing the serial correlation from a data set is pre-whitening.[1,9,28] The pre-whitening approach involves calculating the serial correlation and removing correlation if the calculated serial correlation is significant at the 5% level. Pre-whitening is accomplished through

$$x_i^* = x_i - r x_{i-1} \tag{5}$$

where x_i^* is the pre-whitened series value for time interval i, x_i is the original time series value for time interval i and r is the lag-1 serial correlation coefficient estimated after de-trending the original series x.[1,6,25,28] In the current study, the pre-whitening procedure was applied to the data set before executing the tests.

2.2.2. Spearman's rho test. Rank-based non-parametric statistical Spearman's rho can also be used to detect monotonic trend in a time series.[5] The Spearman's rank correlations test is a quick and simple test to determine whether any significant

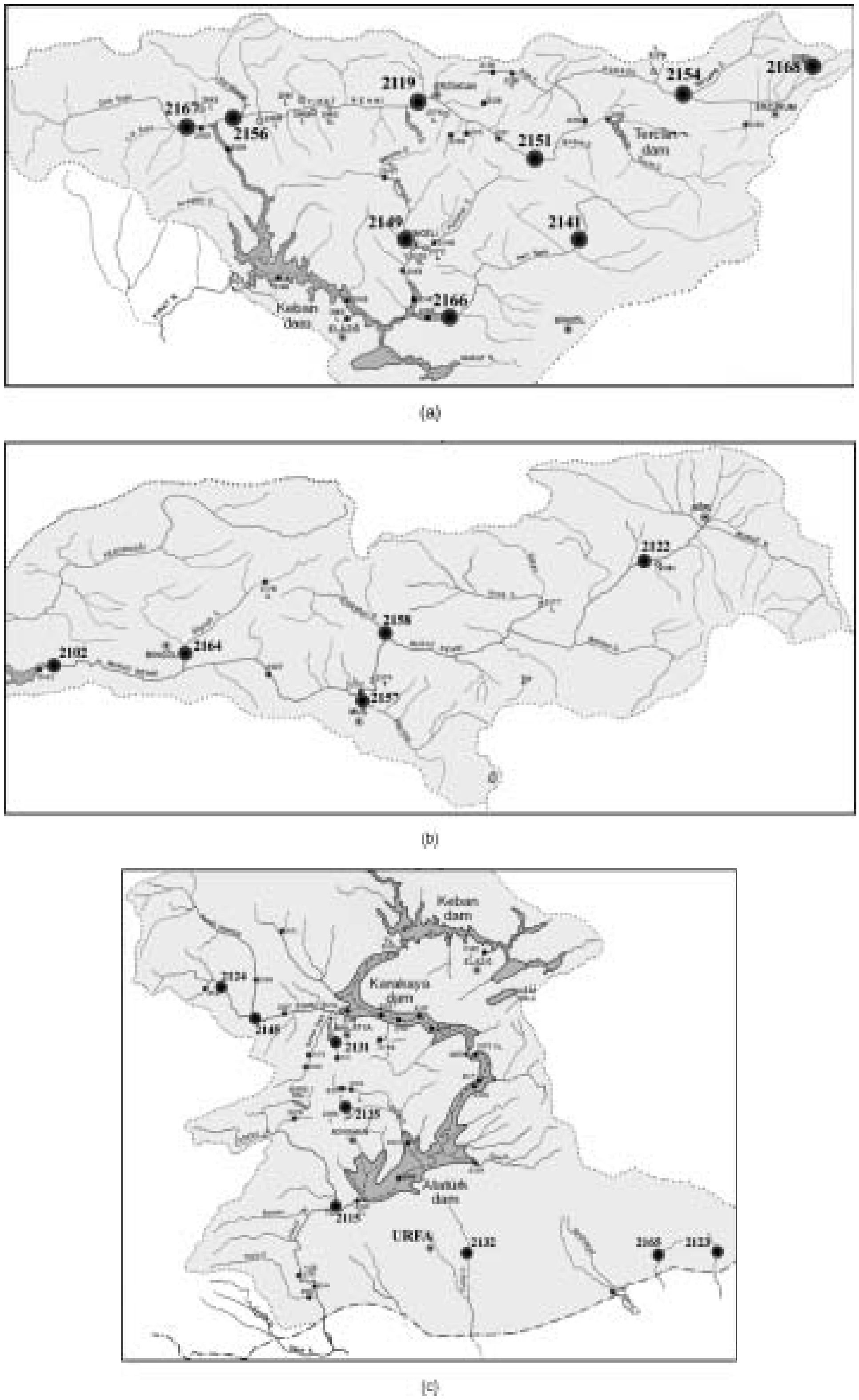

Fig. 2. The parts of the Euphrates basin: (a) upper; (b) middle; and (c) lower, also showing the location of the selected 22 stations

correlation may exist between two classifications of the same series. In this test, there is a significant trend only if the correlation between time steps and streamflow observations is found to be significant.

Given a sample data set $\{x_i, i = 1, 2, \ldots, n\}$, the null hypothesis H_o of the Spearman's rho test against trend tests is that all values of x_i are independent and identically distributed, whereas the alternative hypothesis is that x_i increases or decreases with i (i.e. there is a trend). The test statistic is given by Sneyers[29]

$$r_s = 1 - \frac{6\left[\sum_{i=1}^{n} (R(x_i) - i)^2\right]}{(n^3 - n)} \quad (6)$$

where $R(x_i)$ is the rank of the ith observation x_i in the sample of size n. The standard normal distribution is used, the test statistic of

SID	Part of basin	P-value of Mann–Kendall test			P-value of Spearman's rho test		
		Mean streamflow	Minimum streamflow	Maximum streamflow	Mean streamflow	Minimum streamflow	Maximum streamflow
2102	Middle	0·4165	**0·0230** ⇓	0·4548	0·4052	**0·0250** ⇓	0·4562
2115	Lower	0·3790	0·0791	0·0892	0·3745	0·1292	0·0708
2119	Upper	0·1971	0·3492	0·0892	0·2483	0·3936	0·3336
2122	Middle	0·2105	**0·0074** ⇓	0·4060	0·2420	**0·0071** ⇓	0·3745
2123	Lower	0·2635	**0·0094** ⇓	0·1119	0·1685	**0·0089** ⇓	0·1335
2124	Lower	0·2635	0·1976	0·0848	0·2578	0·1685	0·0708
2131	Lower	0·0327	**0·0085** ⇓	0·0491	0·0475	**0·0069** ⇓	0·0537
2132	Lower	**0·0099** ⇓	0·3200	0·4837	**0·0104** ⇓	0·3372	0·4286
2135	Lower	0·2568	0·1329	0·0616	0·0446	0·0446	0·0694
2141	Upper	0·4174	0·1963	0·3232	0·3632	0·2005	0·2709
2145	Lower	0·1447	0·0387	0·0598	0·1038	0·0344	0·0537
2149	Upper	0·2477	0·5000	0·4827	0·2709	0·4681	0·4880
2151	Upper	0·3364	0·2108	0·1180	0·2981	0·2090	0·1190
2154	Upper	0·4459	0·1460	0·3542	0·4247	0·1075	0·3632
2156	Upper	0·0479	**0·0136** ⇑	0·4192	0·0485	**0·0122** ⇑	0·3409
2157	Middle	0·4459	0·1105	0·2933	0·4522	0·0446	0·2546
2158	Middle	0·3852	0·2592	0·0767	0·4602	0·2119	0·0694
2164	Middle	0·4548	0·0767	0·1884	0·3936	0·0505	0·2061
2165	Lower	0·2489	0·4356	0·1694	0·2266	0·3085	0·1922
2166	Upper	0·2969	0·4858	0·3473	0·2843	0·4325	0·3121
2167	Upper	0·2806	0·4163	0·2461	0·2676	0·4681	0·2206
2168	Upper	0·2797	**0·0092** ⇓	0·1431	0·2843	**0·0078** ⇓	0·1401

Table 3. The results of Mann–Kendall and Spearman's rho tests (⇑ indicates upward trend, ⇓ indicates downward trend)

r_s, z is computed by

$$z = r_s\sqrt{n-1} \quad (7)$$

If $|z| > z_a$ at a significance level of a, then the null hypothesis of no trend (in other words, values of observations are identically distributed) is rejected.

2.2.3. Mann–Kendall rank correlation test. The Mann–Kendall rank correlation test gives the beginning point in time of a developed trend. This test does not take differences in magnitude of the values into account, it only counts the number of consecutive values where the value increases or decreases compared with the value before. The test procedure is given below.[29,30]

SID	Part of basin	The beginning year			Sen's slope: m^3/s per year		
		Mean streamflow	Minimum streamflow	Maximum streamflow	Mean streamflow	Minimum streamflow	Maximum streamflow
2102	Middle		1982		−1·0592	**−0·5623**	−9·3611
2115	Lower				−0·4501	−0·2707	−7·2287
2119	Upper				0·1928	−0·0461	1·9500
2122	Middle		1985		−0·0892	**−0·0922**	−3·8750
2123	Lower		1983		−0·0607	**−0·0641**	0·2366
2124	Lower				−0·0135	−0·0271	−0·5400
2131	Lower		1972		−0·0142	**−0·0073**	−0·3046
2132	Lower	1972			**−0·0147**	0·0000	−0·0295
2135	Lower				−0·0093	−0·0126	−0·3400
2141	Upper				0·0000	−0·1171	5·2166
2145	Lower				−0·1461	−0·1363	−1·2166
2149	Upper				0·0350	−0·0653	0·4000
2151	Upper				−0·1961	−0·0943	−2·8249
2154	Upper				−0·0489	−0·0155	−0·0801
2156	Upper		1994		0·7611	**0·4294**	−0·8333
2157	Middle				−0·0208	0·0079	0·2798
2158	Middle				−0·0133	−0·0080	2·0000
2164	Middle				0·0348	−0·0503	−4·0277
2165	Lower				−0·0091	−0·0017	−0·7333
2166	Upper				0·3300	0·0100	−0·9285
2167	Upper				−0·2530	−0·0245	−4·5634
2168	Upper		1990		−0·0007	**−0·0028**	−0·0768

Table 4. The beginning year of observed trends according to the Mann−Kendall rank correlation test and the values of Sen's slope

In the test, for each element x_i the number of n_i elements x_j preceding it ($i > j$) is calculated so that $x_i > x_j$. The test statistic t is then given by

$$t = \sum_{i=1}^{n} n_i \tag{8}$$

t is distributed very nearly as a Gaussian normal distribution with expected value and variance as

$$E(t) = \frac{n(n-1)}{4} \tag{9}$$

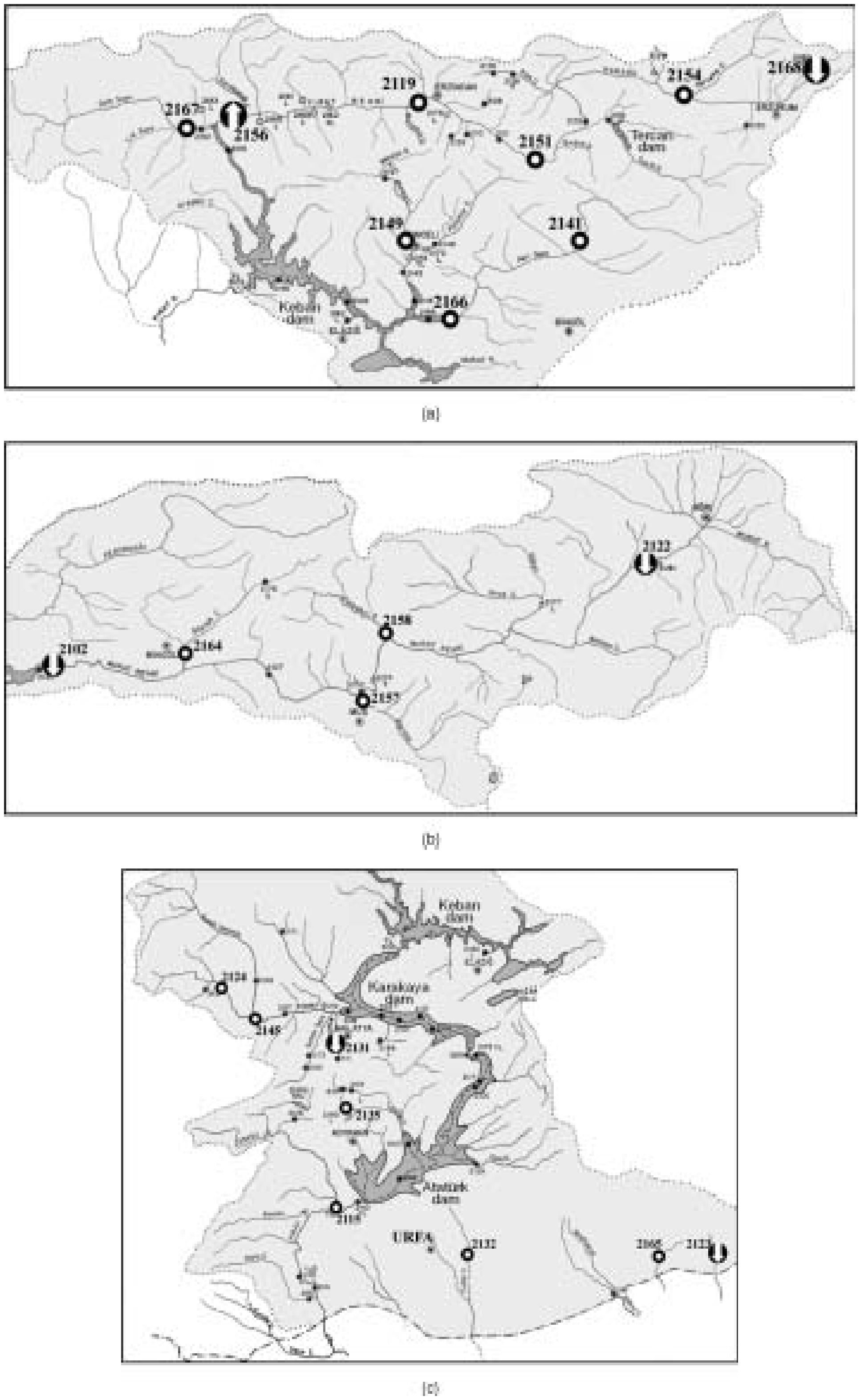

Fig. 3. The stations of the observed trends in annual minimum streamflow of the Euphrates basin: (a) upper; (b) middle; and (c) lower (downward arrow indicates downward trend, upward arrow indicates upward trend and circle symbol indicates no trend)

and

$$\mathrm{var}(t) = \frac{n(n-1)(2n+5)}{72} \tag{10}$$

respectively. A trend can be seen for high values of $u(t)$ with

$$u(t) = \frac{[t - E(t)]}{\sqrt{\mathrm{var}\, t}} \tag{11}$$

This procedure can be usefully extended to the backward series and $u'(t)$ can be obtained. The intersection of $u(t)$ and $u'(t)$ curves denotes approximately the beginning of the trend.

2.2.4. Sen's estimator of slope. If a linear trend is present, the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen.[31] The test procedure is given below in detail.[12]

The slope estimates of N pairs of data are first computed by

$$Q_i = (x_j - x_k)/(j - k)(i = 1, \ldots, N) \tag{12}$$

where x_j and x_k are data values at times j and k $(j > k)$ respectively. The median of these N values of Q_i is Sen's estimator of slope. If there is only one datum in each time period, then $N = n(n-1)/2$ where n is the number of time periods. If N is odd, then Sen's estimator is computed by

$$Q_{\mathrm{median}} = Q_{(N+1)/2} \tag{13}$$

If N is even, then Sen's estimator becomes

$$Q_{\mathrm{median}} = \frac{\lfloor Q_{(N)/2} + Q_{(N+2)/2} \rfloor}{2} \tag{14}$$

The detected value of Q_{median} is tested by a two-sided test at the $100(1-\alpha)$ % confidence interval and true slope may be obtained by the non-parametric test.

In the present study, a computer program called TAFW was used to analyse the trend in streamflow.[32] The TAFW was developed by using Borland Delphi programming language.

3. RESULTS AND DISCUSSION

The application of the binomial distribution to evaluate the field significance of trends can be used.[5,33] The binomial probability distribution for assessing the field significance of a trend was therefore adopted in this study. The probability of five or more sites showing a downward trend by chance at a significance level of 0·05 is 0·8% by the binominal distribution. Thus, it was assumed that the detected trends in the region may not be owing to chance alone. The cross-correlation did not therefore influence the test results.

The results of Mann–Kendall and Spearman's rho test applications to annual minimum, maximum and mean streamflow of the selected stations are summarised in Table 3, which indicates that Mann–Kendall and Spearman's rho tests consistently yield the same result. The upward sign indicates an increasing trend and the downward sign signifies a decreasing trend. Significant trends were more common in minimum streamflow than annual mean streamflow. In annual mean streamflow, a significant decreasing trend is detected only at 2132 station (one of the 22 stations). While Kahya and Kalayci[12] detected negative trends in monthly mean streamflow at 2124, 2131, 2132, 2145 and 2151 stations (five of the seven stations), Cigizoglu *et al.*[16] found a downward trend in annual mean flow at 2123 station (one of the 16 stations).

Significant decreasing trends are also found in minimum streamflow at 2102, 2122, 2123, 2131 and 2168 stations (five of the 22 stations). Cigizoglu *et al.*[16] found a downward trend in 1- and 7-day annual minimum flows only at 2102, 2123, 2124 and 2164 stations (four of the 16 stations). In the current study, no significant trend was detected for 2124 and 2164 stations contrary to the study by Cigizoglu *et al.*[16] The decrease in minimum streamflows may indicate the presence of the dry periods within a year in these rivers. Only 2156 station shows an upward trend in minimum streamflow. Cigizoglu *et al.*[16] did not find any significant trend for 2156 station, but Kahya and Kalayci[12] did not include the 2156 station in their study. Although some results are parallel to the results obtained from the studies by Kahya and Kalayci[12] and Cigizoglu *et al.*,[16] the discrepancy between results obtained in the present study and previous studies may be owing to handling different periods of data set and different evaluation of the data series. For annual maximum streamflow, none of the stations shows a significant trend. Cigizoglu *et al.*[16] also did not detect any significant trend for stations handled in their study. The decrease in low flows is especially important for the location of the water treatment facility, the quantity of irrigation and drinking water. The changes in low-flow statistics also affect the minimum water quantity released by dams downstream for sustainable protection of ecological cycles.[16]

The beginning years of observed trends are calculated by using the Mann–Kendall rank correlation test and the results are given in Table 4. The range of the beginning trend years detected is between 1971 and 1994. There are 35 dams used for irrigation and energy production in the Euphrates basin. The greatest dams among these are Keban, Karakaya and Ataturk dams.[34] Although the rivers included in this study have relatively natural flow, it is

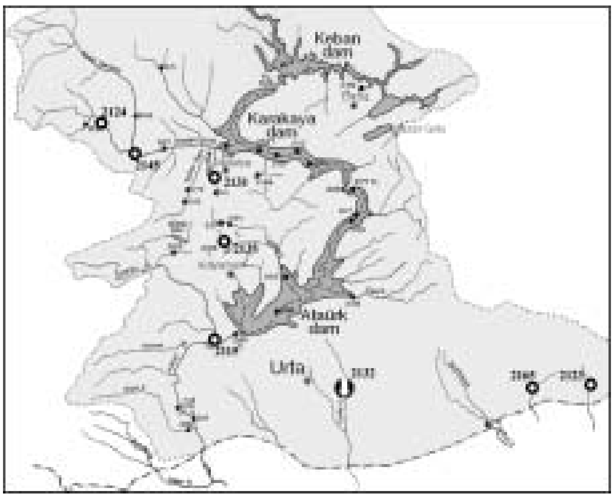

Fig. 4. The station of the observed trends in annual mean streamflow in the lower part of the Euphrates basin (downward arrow indicates downward trend, upward arrow indicates upward trend and circle symbol indicates no trend)

interesting that the starting years for operation of these dams (1975, 1987 and 1992) are in the period of the beginning years of observed trends (1971–1994). This may be attributed to other factors such as climatological variables including precipitation, temperature and the contentious subject of global warming. Partal and Kahya[35] found a noticeable decrease in the annual mean precipitation in southern Turkey and in some parts of eastern Turkey where the present study was focused. The trends found in streamflow of the Euphrates basin are in general parallel to those detected in precipitation data by the same authors. So, the presence of trends in Turkish streamflow patterns were generally attributed to the decreases in rainfall.[12,16]

The Sen's slopes of all trends in streamflow are also presented in Table 4. The statistically significant slopes are set in bold. The signs of the slopes are consistent with the results of Mann–Kendall and Spearman's rho tests (Table 3). In Figs 3 and 4, the detected trends in annual minimum and mean streamflow are shown on the Euphrates basin map for each part respectively. It can be seen that downward trends are observed in both annual mean and minimum streamflow for the stations of the lower part of the Euphrates basin, which is near the Syrian border. An upward trend is detected in annual minimum streamflow for only one station of the upper Euphrates basin part. Fig. 5 shows the variation of annual minimum streamflow for stations that have significant trends with their long-term mean and their linear trends. The variation of annual mean streamflow for station 2132 is given in Fig. 6. Figs 5 and 6 display the evidence of this trend in the data.

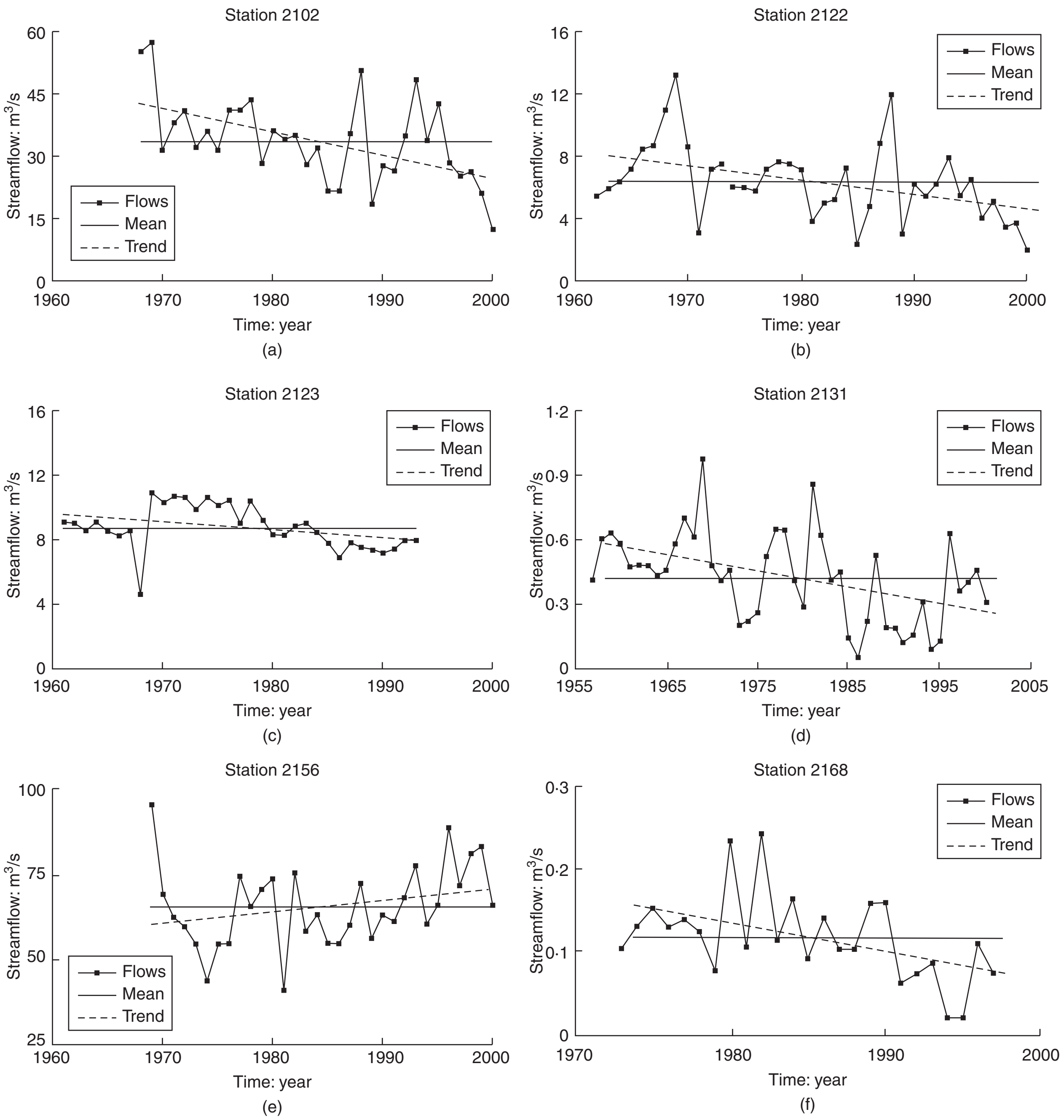

Fig. 5. Variation of annual minimum streamflow for stations (a) 2102, (b) 2122, (c) 2123, (d) 2131, (e) 2156 and (f) 2168 with their long-term mean and linear trends

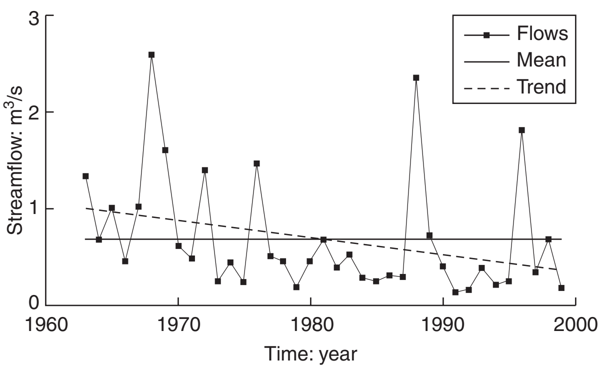

Fig. 6. Variation of annual mean streamflow for station 2132, with its long-term mean and linear trend

4. CONCLUSIONS

The trends in annual mean, minimum and maximum streamflow of the Euphrates basin, Turkey, have been evaluated by using non-parametric trend tests using at least 24 years' worth of measured data. All non-parametric trend tests applied to hydrological variables in this study yield similar results. Using a 5% significance level, a significant trend is detected in seven stations. While 25% of the stations show a decreasing trend in annual minimum streamflow, no significant trends are found in annual maximum streamflow for any station selected for analysis. An upward trend is found in annual minimum streamflow for only one station, whereas decreasing trends are found in annual mean streamflow for only one station. The results are expected to assist water resources managers and policy makers in making better planning decisions in the Euphrates basin.

The trends observed in the streamflow regime in the Euphrates basin need to be analysed in terms of climatic and anthropological effects in order to be better understood. These factors are therefore expected to be the focus of future work.

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REFERENCES

1. Burn D. H. and Elnur M. A. H. Detection of hydrologic trends and variability. *Journal of Hydrology*, 2002, **255**, No. 4, 107–122.
2. Whitfield P. H. and Cannon A. J. Recent variations in climate and hydrology in Canada. *Canadian Water Resources Journal*, 2000, **25**, No. 1, 19–65.
3. Douglas E. M., Vogel R. M. and Kroll C. N. Trends in floods and low flows in the United States: impact of spatial correlation. *Journal of Hydrology*, 2000, **240**, No. 1–2, 90–105.
4. Lins H. F. and Slack J. R. Streamflow trends in the United States. *Geophysical Research Letters*, 1999, **26**, No. 2, 227–230.
5. Yue S., Pilon P. and Cavadias G. Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology*, 2002, **259**, No. 1–4, 254–271.
6. Birsan M. V., Molnar P., Burlando P. and Pfaundler M. Streamflow trends in Switzerland. *Journal of Hydrology*, 2005, **314**, No. 1–4, 312–329.
7. Zhang X., Harvey K. D., Hogg W. D. and Yuzyk T. R. Trends in Canadian streamflow. *Water Resources Research*, 2001, **37**, No. 4, 987–998.
8. Marengo J. A., Tomasella J. and Uvo C. R. Trends in streamflow and rainfall in tropical South America: Amazonia, Eastern Brazil and Northwestern Peru. *Journal of Geophysical Research*, 1998, **103-D2**, 1775–1784.
9. Burn D. H., Cunderlik J. M. and Pietroniro A. Hydrological trends and variability in the Liard River basin. *Hydrological Sciences Journal*, 2004, **49**, No. 1, 53–68.
10. Burn D. H., Aziz O. I. A. and Pietroniro A. A comparison of trends in hydrological variables for two watersheds in the Mackenzie River Basin. *Canadian Water Resources Journal*, 2004, **29**, No. 4, 283–298.
11. Zhang Q., Liu C., Xu C., Xu Y. and Jiang T. Observed trends of annual maximum water level and streamflow during past 130 years in the Yangtze River basin, China. *Journal of Hydrology*, 2006, **324**, No. 1–4, 255–265.
12. Kahya E. and Kalayci S. Trend analysis of streamflow in Turkey. *Journal of Hydrology*, 2004, **289**, No. 1–4, 128–144.
13. Kalayci S. and Kahya E. Streamflow trends in Sakarya Basin. *ARI, Bulletin of the Istanbul Technical University*, 2003, **54**, No. 1, 79–80.
14. Topaloğlu F. Regional trend detection of Turkish river flows. *Nordic Hydrology*, 2006, **37**, No. 2, 165–182.
15. Bayazit M., Ciğizoğlu H. K. and Onoz B. Trend analysis in Turkish river flows (in Turkish). *Turkish Engineering News*, 2002, **420–421–422**, 8–10.
16. Ciğizoğlu H. K., Bayazit M. and Onoz B. Trends in the maximum, mean and low flows of Turkish rivers. *Journal of Hydrometeorology*, 2005, **6**, No. 3, 280–290.
17. Ikiel C. Rainfall regime regions in Turkey (a statistical climate study). *Proceedings of International Conference on Forest Impact on Hydrological Processes and Soil Erosion.* University of Forestry, Yundola, Bulgaria, 2005, pp. 108–116.
18. Kahya E., Demirel M. C. and Piechota T. C. Spatial grouping of annual streamflow patterns in Turkey. *Proceedings of 27th AGU Hydrology Days, Fort Collins, Colorado*, 2007, 169–176.
19. Tosun H., Zorluer I., Orhan A., Seyrek E., Savas H. and Turkoz M. Seismic hazard and total risk analyses for large dams in Euphrates basin, Turkey. *Engineering Geology*, 2007, **89**, No. 1–2, 155–170.
20. EİE. *Monthly Average Streamflow (1935–2000)* (in Turkish). General Directorate of Electrical Power Resources Survey and Development Administration, 2003.
21. Helsel D. R. and Hirsch R. M. *Statistical Methods in Water Resources*. Elsevier, Amsterdam, 1992.
22. Mann H. B. Non-parametric test against trend. *Econometrika*, 1945, **13**, 245–259.
23. Kendall M. G. *Rank Correlation Methods*. Charles Griffin, London, 1975.
24. World Meteorological Organization. *Analyzing Long Time Series of Hydrological Data with Respect to Climate Variability*. WMO, Geneva, Switzerland, 1988, WCAP-3, WMO/TD- No: 224, pp. 1–12.
25. Hamed K. H. and Rao A. R. A modified Mann–Kendall trend test for auto correlated data. *Journal of Hydrology,* 1998, **204**, No. 1–4, 182–196.

26. XU Z. X., TAKEUCHI K. and ISHIDAIRA H. Monotonic trend and step changes in Japanese precipitation. *Journal of Hydrology*, 2003, **279**, No. 1–4, 144–150.
27. SILVA V. P. R. On climate variability in Northeast of Brazil. *Journal of Arid Environments*, 2004, **58**, No. 4, 575–596.
28. YUE S., PILON P. J. and PHINNEY B. Canadian streamflow trend detection: Impacts of serial and cross correlation. *Journal of Hydrological Science*, 2003, **48**, No. 1, 51–64.
29. SNEYERS R. *On the Statistical Analysis of Series of Observations*. World Meteorological Organization, Geneva, Switzerland, 1990, Technical Note no. 143, WMO-no. 415.
30. KARACA M., TAYANÇ M. and TOROS H. Effects of urbanization on climate of İstanbul and Ankara. *Atmospheric Environment*, 1995, **29**, No. 23, 3411–3421.
31. SEN P. K. Estimates of the regression coefficient based on Kendall's tau. *Journal of American Statistical Association,* 1968, **63**, No. 324, 1379–1389.
32. GÜMÜŞ V. *Evaluation of Euphrates basin's Streamflow with Trend Analysis* (in Turkish). MSc thesis, Graduate School of Natural and Applied Sciences, Department of Civil Engineering, Harran University, Turkey, 2006.
33. LIVEZY R. E. and CHEN W. Y. Statistical field significance and its determination by Monte Carlo techniques. *Monthly Weather Review*, 1983, **111**, 46–59.
34. DSI. General Directorate of Turkish Hydraulic State Works, Search for Dam 2007. See http://www.dsi.gov.tr/baraj/baraj.cfm for further details (accessed 26/06/2008).
35. PARTAL T. and KAHYA E. Trend analysis in Turkish precipitation data. *Hydrological* Processes, 2006, **20**, No. 9, 2011–2026.