Regional trend detection of Turkish river flows

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Abstract This paper applies a procedure that identifies trends in hydrologic variables. The procedure utilizes the regional Mann–Kendall non-parametric test with and without both serial and cross-correlation to detect trends. The research investigates 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. A considerable difference was obtained in the assessment of results with and without consideration of serial and cross correlation which might be due to a higher number of serial and cross-correlations among the sites in the geographical regions. Therefore, a quite different interpretation of these trend analyses would have been achieved if the temporal and spatial correlation of the streamflow series within the regions had been ignored. The application of the regional trend detection technique with both considerations has also resulted in the identification of significant decreasing trends in the Marmara, Aegean, Mediterranean and Central Anatolia regions. However, almost no evidence of significant change was observed with a general downward direction in the rest of the country. Besides, there are differences in the geographical regions of significant trends in the fifteen streamflow variables considered which implies that impacts on streamflows are not spatially uniform.

Keywords Annual flows; monthly flows; regional Mann–Kendall test; trend detection; Turkey

Nomenclature

Symbols with Latin letters

$\bar{x}$	the mean of all x_i in the series
$E[S]$	the mean of S
$\bar{S}$	the regional average MK test statistic S of m independent sites
$\bar{Z}_{sc}$	the standardized regional MK statistic with temporal and spatial correlation
$\bar{Z}$	the standardized regional MK statistic without temporal and spatial correlation
$E\left[\bar{S}\right]$	the sample mean of the RAMK statistic
$\mathrm{Var}\left(\bar{S}\right)$	the sample variance of the RAMK statistic
$CL\ (r_1)$	the confidence limits for lower and upper limits on r_1
$E[S_k]$	the mean of the MK statistic of site k
m	the number of stations in a region
n^*	the effective sample size
n	sample size (year)
n^{s}	the correction factor for serial correlation
p	the number of tied groups in the data set
r_1	the lag-1 serial correlation coefficient
r_j	the sample serial correlation coefficient with lag j
$r_{k,k+l}$	the sample cross-correlation coefficient
S	the MK test statistic

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S_k	the MK test statistic S for the kth station in a region
t_i	the number of ties to extent i
$\mathrm{Var}(S)$	the variance of S
$\mathrm{Var}(S_k)$	the variance of the MK statistic of site k
$\mathrm{Var}^*(S)$	the modified variance
x_i	data series
Z^*	the modified standardized MK statistic
z	the standard normal distribution
Z	the standardized MK statistic

Symbols with Greek letters

α	significance level
ρ_1	the lag-1 serial correlation coefficient
ρ_j	the lag-j serial correlation coefficient
β	a non-parametric robust estimate of the magnitude of the slope
$\rho^c_{k,k+l}$	the cross-correlation between site k and site $k + l$

Abbreviations

AEG	Aegean region
AIMF	annual instantaneous maximum flow ($\mathrm{m}^3\ \mathrm{s}^{-1}$)
BS	Black Sea region
CA	Central Anatolia region
EA	Eastern Anatolia region
IPCC	the Intergovernmental Panel on Climate Change
MAR	Marmara region
MED	Mediterranean Sea region
MK	the rank based non-parametric Mann–Kendall test
RAMK	the regional average Mann–Kendall test
SEA	Southeastern Anatolia region

Introduction

Global climate change due to human activity and its consequences is likely to impact on the hydrological cycle at all scales from the global to the regional. Undeveloped and developing countries where semi-arid climate prevails and water resources are not properly developed will be affected most severely from climate changes (IPCC 2001). Water resources are among the most vulnerable natural systems (Salinger and Griffiths 2001) to the changes in precipitation (Sankarasubramanian *et al.* 2001), temperature (Burn and Elnur 2002), and agricultural practices and land use (Gebert and Krug 1996). Turkey is the source of the rivers that provide water for many countries in the Near East, a region of prime geopolitical and historical importance. Water is the cornerstone of agricultural viability, public health and political stability in Turkey where competition over scarce water supplies looms as a potential flashpoint for all countries sharing this resource (Touchan *et al.* 2003). As a result, the Middle East is extremely vulnerable to any, either natural or human induced, reductions in available water resources (Cullen and deMenocal 2000).

The relationship between the climatic regimes over a river basin and its hydrologic response, through its streamflow, presents different degrees of complexity due to the physical characteristics of the basin (Krepper *et al.* 2003). Chiew *et al.* (1995) have mentioned that the changes in precipitation are amplified in streamflow and that, in general, it is easier to detect a variation in discharge than directly in the basic climatic variables such as precipitation or temperature. Streamflow is a synthesis of precipitation, evapotranspiration and the rest of the hydrologic cycle components, together with possible anthropogenic influences (Krepper *et al.* 2003). Therefore, the detection of trends in streamflow time series has received a great deal of attention worldwide. They have provided insight into the direction and the significance of streamflow trends. The results of those studies vary widely depending on the study area. Pupacko (1993) analysed changes in runoff and has found an increasing winter streamflow in the northern Sierra Nevada attributed to small increase in temperature, which increase the rain-to-snow ratio at lower altitudes and cause the snowpack to melt earlier in the season at higher altitudes. Lins and Michaels (1994) identified increases in the fall and winter streamflow in the United States. Lettenmaier *et al.* (1994) found an increase in winter and spring streamflow for much of the United States. Gebert and Krug (1996) indicated that annual low flows were increasing significantly whereas annual flood peaks were decreasing in Wisconsin. Lins and Slack (1999) found upward trends prevalent in the annual minimum to medium flow quantiles while less prevalent in the annual maximum flow quantiles across the United States. Douglas *et al.* (2000) examined trends in flood and low flows in the United States together with the effect of cross-correlation in the data and found upward trends in low flows. Westmacott and Burn (1997) identified decreases in streamflow for the Canadian Prairies except for the spring mean monthly streamflow. Zhang *et al.* (2001) determined generally decreasing trends in flow volumes in Canada. However, they observed no evidence of significant trends in the flood flows. Burn and Elnur (2002) investigated the trends in annual mean, minimum and maximum, and monthly mean flow of 248 Canadian catchments. Yue and Wang (2002) evaluated annual mean, minimum and maximum daily flow series for 139, 148 and 149 stations, respectively, in ten climatic regions of Canada taking both serial and cross-correlation into consideration. Yue *et al.* (2002) implemented the Mann–Kendall and Spearman's rho test for detecting trends in annual maximum daily streamflow data of 20 pristine basins in Ontario, Canada and found a significant downward trend at four sites while only one station showed an upward trend. García and Vargas (1998) determined positive trends in the runoff in the Rio de la Plata basin. Zaidman *et al.* (2003) determined an insignificant weak correlation using Spearman Rank test for 25 annual minima events in British rivers, each having at least 30 years in length. Recently, Fu *et al.* (2004) have also reported evidence of streamflow decrease with a more significant increase in minimum temperature rather than precipitation change in the Yellow river basin in China.

Few studies at the national scale concerning streamflow trend analysis have been done in Turkey although many studies were carried out on precipitation (Türkeş 1996; Kadıoğlu 2000; Türkeş *et al.* 2002), and temperature (Türkeş *et al.* 1995; Kadıoğlu 1997; Kömüşçü 1998; Türkeş *et al.* 2002; Türkeş and Sümer 2004). Topaloğlu *et al.* (1997) determined that annual instantaneous maximum flows (AIMF) of one streamflow station among 3 stations ($n = 20–25$ years) in Lake Van Closed basin near the Iranian border exhibited a decreasing trend for both Spearman's and Mann–Kendall tests. Topaloğlu (1999) also evaluated AIMF data from 13 stations ($n = 15–56$ years) in the Seyhan river discharging into the Mediterranean Sea and found no evidence of a significant trend. Similarly, no significant changes were also obtained for AIMF data of 9 stations ($n = 14–29$ years) in Central Anatolian Closed basin according to Spearman's correlation test (Topaloğlu *et al.* 1999). Önöz and Bayazıt (2003) compared the power of the parametric *t*-test and the non-parametric Mann–Kendall (MK) test using annual streamflows at 107 sites ($n = 25–65$ years) in various rivers of Turkey. Both tests detected a decreasing trend in 29 series. At two sites the trend was detected only by the *t*-test, and at two other sites only by the MK test. Lately, Kahya and Kalaycı (2004) found a generally downward trend for 56 stations based on the MK test using a 31 year period (1964–1994) of mean streamflow of 83 stations in Turkey.

Most trend detection studies have ignored the role of temporal (serial) correlation and/or spatial (cross) correlation among data sets (Douglas *et al.* 2000). The existence of serial and cross-correlation affects the power of statistical tests such as the Mann–Kendall test to assess the significance of trends (Yue and Wang 2002). Besides, the presence of positive serial and cross-correlation leads to a higher probability of rejecting the null hypothesis of no trend while it might be true (Douglas *et al.* 2000; Yue and Wang 2002). Therefore, both serial and cross-correlation should be considered in the detection of the regional significance of trends. An analysis of Turkish flow trends taking serial correlation and cross-correlation among sites into consideration at the national scale has not previously been undertaken. The aim of this study, therefore, is to analyse detailed observational streamflow records for Turkey in seven homogeneous geographical regions to identify the changes through time in the monthly, mean, minimum and maximum streamflows using the regional Mann–Kendall statistic with both serial and cross-correlation.

Material and data

Turkey consists of 26 river basins having a drainage area of 780 576 km^2 and is a large peninsula surrounded by the Mediterranean Sea in the south, the Aegean Sea in the west, and the Black Sea in the north. Precipitation as the main source of runoff process (Kahya and Kalaycı 2004) exhibits a considerable serial and regional variability over Turkey. Most of the precipitation falls during late autumn, winter and early spring due to the main precipitation sources of moist air masses coming from the Atlantic Ocean and the Mediterranean Sea (Türkeş 1996). Mean annual precipitation totals decrease generally from the coastal belts to the interiors. The range of mean annual precipitation totals are from 350 to 500 mm in the Central Anatolia (CA) region (Figure 1), and 600 to 800 mm in the Marmara (MAR) and Aegean (AEG) regions. Annual precipitation totals increase from the continental Southeastern Anatolia (SEA) (400 mm) to Eastern Anatolia (EA) (800 mm). Mean annual precipitation is above 800 mm in the Mediterranean Sea (MED) region where precipitation mostly occurs in winter. Mean annual precipitation totals are above 1000 mm along the western MED, and the western and eastern Black Sea (BS) coastal areas. For more details on the climatology of Turkey, readers are referred to Türkeş *et al.* (1995), Türkeş (1996, 2003) and Kadıoğlu (2000).

The data used in the study are a set of 75 streamflow station records with monthly, mean, minimum and maximum flows for a 30-year period (1968–1997). The main reasons for

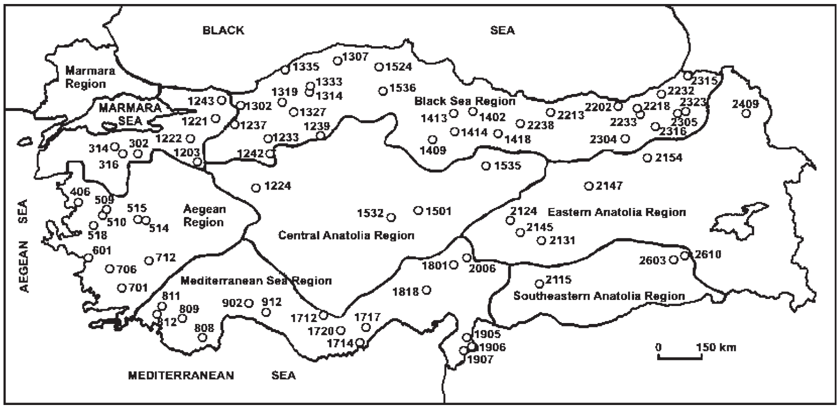

Figure 1 Spatial distribution of 75 streamflow gauging stations over Turkey

selecting these stations were the following: spatial distribution of the stations across the country; availability of the longest possible records within the period 1935–1997; and completeness of the records with no missing data points. Figure 1 shows the location of each hydrometric station and indicates the geographical region for each station. The geographical regions are as defined by Türkeş *et al.* (1995, 2002). Stations are broadly distributed, not only across the country but also across the geographical regions of Turkey; the exceptions are the CA, EA and SEA regions. This is mainly due to a greater number of missing values, shorter record lengths, and insufficient number of gauging stations in the regions. There are 3 stations in the SEA, 4 stations in the CA, 6 stations in the EA, 7 stations in the MAR, 10 stations in the AEG, 16 stations in the MED and 29 stations in the BS region. The contributing drainage areas for these stations range from 223.1 to 60 559.6 km^2 with a median of 2886.8 km^2. These 75 streamflow gauging stations distributed over 20 river basins were selected from among more than 2900 stations and from where there was no reported significant regulation and diversion in the upstream part. The data were observed and recorded by the Turkish Electrical Power Resources Survey and Development Administration (http://www.eie.gov.tr), along with many hundreds of other Turkish station records.

Methodology

The MK test statistics of a random sample data at a site

The rank based non-parametric Mann–Kendall (MK) statistical test has been commonly used to assess the significance of trends in hydro-meteorological time series (Yue *et al.* 2002). Each data point x_i is used as a reference point and is compared with all other data points x_j such that

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} 1 & \text{for } x_j > x_i \\ 0 & \text{for } x_j = x_i \\ -1 & \text{for } x_j < x_i \end{cases} \tag{1}$$

The MK test statistic S is calculated as

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \tag{2}$$

where n is the length of the data set. The statistic S, when $n \geq 8$, is approximately normally distributed with the mean and the variance given by

$$E[S] = 0 \tag{3}$$

$$\operatorname{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i - 1)(2t_i + 5)}{18} \tag{4}$$

in which p is the number of tied groups in the data set and t_i is the number of data points in the ith tied group. The summation term in Equation (4) is only used if data values are tied in the series. The standardized MK statistic Z is computed by

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{Var}(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{S+1}{\sqrt{\operatorname{Var}(S)}} & \text{for } S < 0 \end{cases} \tag{5}$$

and follows the standard normal distribution with mean of zero and variance of one under the null hypothesis of no trend in the series. The null hypothesis is rejected if $|Z| \geq z_{1-\alpha/2}$ at the α level of significance, where $z_{1-\alpha/2}$ is the $(1-\alpha/2)$-quantile in the standard normal distribution. A positive Z value indicates an upward trend, whereas a negative value indicates a downward trend.

Yue and Wang (2002) states that modification of the variance of the MK statistic given by Equation (4) may be one reasonable way to limit the influence of serial correlation on the MK test. Then, the modified one is equalled to that with serial correlation. The modified variance Var*(S) is given by

$$\mathrm{Var}^*(S) = (n/n^*)\mathrm{Var}(S) = n^s\,\mathrm{Var}(S) \tag{6}$$

where Var(S) is calculated using Equation (4), n is the actual number of samples, n* is the effective sample size, and n^s is termed the correction factor for serial correlation. The correction factor is given by

$$n^s = \begin{cases} 1 + \frac{2}{n}\sum_{j=1}^{n-1}(n-j)\rho_j & \text{for } j > 1 \\ 1 + 2\frac{\rho_1^{n+1} - n\rho_1^2 + (n-1)\rho_1}{n(\rho_1 - 1)^2} & \text{for } j = 1 \end{cases} \tag{7}$$

where ρ_j and ρ_1 are the lag-j and lag-1 serial correlation coefficient respectively.

The modified standardized MK statistic reflecting the effect of serial correlation on the MK test statistic at a site is then given by

$$Z^* = \frac{Z}{\sqrt{n^s}}. \tag{8}$$

In practice, the population serial correlation coefficient ρ_j is always replaced by the sample serial correlation coefficient r_j as follows:

$$r_j = \frac{\frac{1}{n-j}\sum_{i=1}^{n-j}(x_i - \bar{x})(x_{i+j} - \bar{x})}{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{9}$$

where $\bar{x}$ is the mean of all x_i in the series.

A commonly used measure of time dependence in flow series is the lag-1 serial correlation coefficient (r_1) for the sample. The 95% confidence limits for lower and upper limits on r_1 are then estimated as suggested by FAO (1973):

$$CL(r_1) = [1/(n-1)] \pm [1.96((n-2)/(n-1)^{1.5})]. \tag{10}$$

If the calculated r_1 falls outside the confidence limits, the null hypothesis that r_1 is zero is rejected at the 5% level of significance using a two-tailed test.

As the existence of the trend may contaminate the serial correlation coefficient computed by Equation (9), a non-parametric robust trend estimate, β (Sen 1968) is first subtracted from a time series and then the lag-1 serial correlation coefficient r_1 is calculated (Yue and Wang 2002). β is computed by comparing each data pair to all others in a pairwise fashion. Then, the median of all possible pairwise slopes is taken as the non-parametric estimate of slope β (Helsel and Hirsch 1997)

$$\beta = \text{median}\left[\frac{(x_j - x_i)}{(j - i)}\right] \quad \text{for all } i < j. \tag{11}$$

The regional MK statistic without temporal and spatial correlation

Yue and Wang (2002) adopt the regional average MK (RAMK) statistic proposed by Douglas *et al.* (2000) to assess the field significance of trends at a regional scale rather than at individual sites and computed the regional average MK's test statistic S ($\bar{S}$) of m independent sites as follows:

$$\bar{S} = \frac{1}{m}\sum_{k=1}^{m} S_k \tag{12}$$

where S_k is the MK test statistic S for the kth station in a region.

Since the null distribution of the MK statistic at each site is approximately normally distributed, the joint distribution function of the sum of m independent normal variables is also approximately normally distributed (Yue and Wang 2002). In practice, population mean and the variance of the MK statistic of site k are replaced by the sample mean $E[S_k]$ and sample variance $\mathrm{Var}(S_k)$ respectively. The mean and the variance of the regional test statistic are given by

$$E[\bar{S}] = 0 \tag{13}$$

$$\mathrm{Var}(\bar{S}) = \frac{1}{m^2}\sum_{k=1}^{m} \mathrm{Var}(S_k) \tag{14}$$

If there are no ties in data having the same sample size n at all sites, then Equation (14) can be rewritten as

$$\mathrm{Var}(\bar{S}) = \frac{\mathrm{Var}(S)}{m} \tag{15}$$

where $\mathrm{Var}(S)$ is the variance in Equation (4) but without the correction term for ties in the data. Thus, the standardized RAMK statistic $\bar{Z}$ can be given as follows:

$$\bar{Z} = \begin{cases} \frac{\bar{S}-1}{\sqrt{\mathrm{Var}(\bar{S})}} & \text{for } \bar{S} > 0 \\ 0 & \text{for } \bar{S} = 0 \\ \frac{\bar{S}+1}{\sqrt{\mathrm{Var}(\bar{S})}} & \text{for } \bar{S} < 0 \end{cases} \tag{16}$$

Yue and Wang (2002) stated that the null distribution of the RAMK statistic they derived can be applied to a network that even has only two observation stations ($m = 2$).

The regional MK statistic with both serial and cross-correlation

The modified variance of the $\bar{S}$ statistic with consideration of both serial and cross-correlation (Yue and Wang 2002) can be given as

$$\mathrm{Var}(\bar{S}) = \frac{1}{m^2}\left[\sum_{k=1}^{m} n_k^s\,\mathrm{Var}(S_k) + 2\sum_{k=1}^{m-1}\sum_{l=1}^{m-k}\sqrt{n_k^s\, n_{k+l}^s \mathrm{Var}(S_k)\mathrm{Var}(S_{k+l})}\rho_{k,k+l}^c\right] \tag{17}$$

in which $\rho_{k,k+l}^c$ is the cross-correlation between site k and site $k + l$.

In practice, the population cross-correlation coefficient $\rho_{k,k+l}^c$ is always replaced by the sample cross-correlation coefficient $r_{k,k+l}$ which can be calculated from the data at site k and site $k + l$ as follows:

$$r_{k,k+l} = \frac{\frac{1}{n}\sum_{i=1}^{n}\left(x_i^k - \bar{x}^k\right)\left(x_i^{k+l} - \bar{x}^{k+l}\right)}{\sqrt{\mathrm{Var}\left(x^k\right)\mathrm{Var}\left(x^{k+l}\right)}} \tag{18}$$

If no ties exist in data having the same sample size n at all sites, Equation (17) can be rewritten as follows:

$$\mathrm{Var}(\bar{S}) = \frac{\mathrm{Var}(S)}{m^2}\left[\sum_{k=1}^{m} n_k^s + 2\sum_{k=1}^{m-1}\sum_{l=1}^{m-k}\sqrt{n_k^s\, n_{k+l}^s}\quad \rho_{k,k+l}^c\right] \tag{19}$$

$$= \mathrm{Var}(\bar{S})n_{sc} \tag{20}$$

where

$$n_{sc} = \bar{n} + \frac{2}{m}\sum_{k=1}^{m-1}\sum_{l=1}^{m-k}\sqrt{n_k^s\, n_{k+l}^s}\quad \rho_{k,k+l}^c \tag{21}$$

and

$$\bar{n} = \frac{1}{m}\sum_{k=1}^{m} n_k^s \tag{22}$$

The standardized RAMK statistic can be computed by

$$\bar{Z}_{sc} = \frac{\bar{Z}}{\sqrt{n_{sc}}}. \tag{23}$$

Equation (20) reflects the effect of both temporal and spatial correlation on the variance of the RAMK statistic and Equation (23) indicates the modification made by the serial and cross-correlation coefficients on the RAMK statistic (Yue and Wang 2002).

Results and discussion

The regional average Mann–Kendall test developed by Yue and Wang (2002) was applied to determine the field significance of trends in fifteen streamflow variables, namely monthly means for twelve months, annual mean, annual maximum, and annual minimum streamflow series within each of seven geographical regions. The results are presented in Table 1. Table 1 shows the number of stations and significant lag-1 serial correlation coefficients along with their corresponding regional averages of lag-1 serial correlation coefficients, and the number of significant cross-correlation coefficients along with their regional averages of cross-correlation coefficients in each region respectively. Regional mean Sen's slopes (total Sen's slopes divided by the number of stations used in the region), the number of significant increasing/decreasing trends and the regional MK statistic without and with both temporal and spatial correlation for each region corresponding to streamflow variables are also given in Table 1.

The Mann–Kendall test requires the data to be identically and independently distributed. However, serial correlation nullifies this assumption. Table 1 reveals that 323 out of the data set of 1096 had a significant serial correlation value especially for the MED region (51.29%), the AEG region (48.89%) and the MAR region (40.95%). The BS and SEA regions exhibited the smallest percentage of significant serial correlations, 12.35% and 0.07%, respectively. The smallest numbers of significant serial correlation coefficients were obtained for annual maximum (8 times), mean of April (8 times), May (15 times) and December (16 times). However, a considerable amount of significant serial correlation coefficients were found for annual mean (30 times), minimum (33 times), and means of January (35 times) and February (28 times). Therefore, a nonparametric trend estimate computed by Equation (11) was first subtracted from the flow series and then r_1 was recalculated. The number of significant r_1 is also presented in Table 1 (see column 4). Removing Sen's slope from the flow series reduced the number of significant r_1 to a total of 213 out of the data set of 1096. In other words, even when the magnitude of Sen's slope was removed from the streamflow series, significant

Table 1 Trend test results for 15 streamflow variables at 75 gauging stations in seven geographical regions of Turkey

Streamflow variables	Region	Number of sites	No. of signif. r_1	Regional mean r_1	No. of signif. cross-corre. $r_{k,k+l}$	Regional mean cross-corre.	No. of negative trend and (Z/Z^*)	No. of positive trend and (Z/Z^*)	Regional mean Sen's slope (m^3/s)	$\bar{Z}$	$\bar{Z}_{sc}$
1	2	3	4	5	6	7	8	9	10	11	12
Minimum	MAR	7	4/3	0.266	9	0.398	7 (4/3)	0	−0.283	−6.291*	−2.553*
	AEG	6	4/4	0.320	9	0.420	6 (6/4)	0	−0.288	−9.403*	−3.480*
	MED	13	11/10	0.451	48	0.391	13 (11/6)	0	−0.149	−10.208*	−2.504*
	SEA	3	1/0	0.116	3	0.499	2 (2/1)	1 (0/0)	−0.109	−2.946*	−1.822
	CA	4	1/0	0.098	3	0.301	4 (1/1)	0	−0.076	−3.497*	−2.314*
	BS	26	8/5	0.147	96	0.214	20 (4/4)	6 (1/1)	−0.028	−3.990*	−1.299
	EA	6	4/3	0.285	8	0.426	4 (3/1)	1 (0/0)	−0.053	−3.197*	−1.286
Mean	MAR	7	3/3	0.218	21	0.700	7 (6/5)	0	−1.287	−7.701*	−2.602*
	AEG	10	7/5	0.332	45	0.793	10 (10/8)	0	−0.693	−10.387*	−2.421*
	MED	16	13/10	0.414	112	0.642	16 (9/4)	0	−0.505	−8.532*	−1.614
	SEA	3	0	0.129	3	0.771	1 (0/0)	2 (0/0)	−0.051	−0.021	−0.011
	CA	4	1/1	0.110	3	0.629	3 (1/1)	1 (0/0)	−0.153	−2.819*	−1.512
	BS	29	4/3	0.103	219	0.402	13 (3/2)	14 (0/0)	−0.021	−1.811	−0.455
	EA	6	2/1	0.222	15	0.674	6 (0/0)	0	−0.074	−2.323*	−0.866
Maximum	MAR	7	1/0	0.014	17	0.484	7 (1/1)	0	−7.088	−3.837*	−1.861
	AEG	10	3/1	0.101	32	0.480	10 (8/7)	0	−6.236	−9.506*	−3.686*
	MED	16	3/3	0.009	41	0.271	15 (6/6)	1 (0/0)	−3.493	−6.008*	−2.551*
	SEA	3	0	−0.169	1	0.328	2 (0/0)	1 (0/0)	−0.161	−0.144	−0.132
	CA	4	0	0.057	1	0.230	4 (1/1)	0	−2.049	−2.926*	−2.141*
	BS	29	1/0	−0.050	110	0.197	14 (4/5)	14 (1/0)	−0.761	−2.401*	−0.951
	EA	6	0	−0.023	7	0.378	5 (0/0)	0	−0.772	−1.814	−1.090
	MAR	7	5/4	0.342	21	0.715	7 (5/1)	0	−1.735	−5.921*	−1.790

Table 1 – *continued*

Streamflow variables	Region	Number of sites	No. of signif. r_1	Regional mean r_1	No. of signif. cross-corre. $r_{k,k+l}$	Regional mean cross-corre.	No. of negative trend and (Z/Z^*)	No. of positive trend and (Z/Z^*)	Regional mean Sen's slope (m^3/s)	$\bar{Z}$	$\bar{Z}_{sc}$
January	AEG	10	8/6	0.464	45	0.814	10 (7/2)	0	− 1.189	− 7.808*	− 1.588
	MED	16	14/13	0.442	109	0.634	13 (4/2)	3 (0/0)	− 0.853	− 5.196*	− 0.986
	SEA	3	2/1	0.329	3	0.759	0	3 (0/0)	0.253	1.432	0.648
	CA	4	1/1	0.189	6	0.721	1 (1/1)	3 (0/0)	0.231	− 0.437	− 0.202
	BS	29	2/1	0.065	251	0.414	11 (2/0)	18 (1/2)	− 0.025	0.893	0.227
	EA	6	3/3	0.303	7	0.322	3 (0/0)	2 (0/0)	− 0.001	− 0.299	− 0.122
	MAR	7	4/2	0.147	19	0.667	7 (7/7)	0	− 2.744	− 7.937*	− 2.952*
February	AEG	10	3/2	0.039	45	0.703	10 (10/10)	0	− 1.446	− 10.951*	− 3.736*
	MED	16	8/8	0.310	104	0.573	14 (9/3)	2 (0/0)	− 0.964	− 7.078*	− 1.622
	SEA	3	0	0.080	3	0.671	0	3 (0/0)	0.170	0.474	0.286
	CA	4	3/2	0.303	5	0.685	2 (1/1)	2 (0/0)	− 0.085	− 2.203*	− 0.928
	BS	29	7/6	0.171	254	0.417	20 (6/4)	8 (0/0)	− 0.326	− 4.638*	− 1.050
	EA	6	3/3	0.285	6	0.285	3 (0/0)	2 (0/0)	− 0.021	− 0.284	− 0.124
	MAR	7	3/2	0.133	19	0.612	7 (5/3)	0	− 2.593	− 7.000*	− 2.658*
March	AEG	10	2/2	0.012	45	0.743	10 (10/9)	0	− 1.346	− 9.811*	− 3.352*
	MED	16	7/4	0.201	102	0.566	16 (9/8)	0	− 1.174	− 9.094*	− 2.381*
	SEA	3	0	0.189	3	0.732	2 (0/0)	1 (0/0)	− 0.388	− 0.515	− 0.272
	CA	4	1/0	0.251	6	0.780	4 (1/1)	0	− 0.983	− 4.255*	− 1.819
	BS	29	5/3	0.132	200	0.351	24 (7/5)	5 (0/0)	− 0.452	− 6.362*	− 1.653
	EA	6	3/3	0.204	7	0.437	5 (0/0)	1 (0/0)	− 0.135	− 2.520*	− 1.119
	MAR	7	1/1	0.090	20	0.664	6 (1/0)	1 (0/0)	− 1.001	− 2.043*	− 0.828
April	AEG	10	2/0	0.004	45	0.741	10 (5/6)	0	− 0.644	− 6.319*	− 2.250*
	MED	16	4/2	0.125	96	0.563	14 (4/1)	1 (0/0)	− 0.685	− 5.401*	− 1.528
	SEA	3	0	− 0.054	3	0.680	1 (0/0)	2 (0/0)	0.185	0.227	0.156
	CA	4	0	− 0.040	3	0.570	3 (1/1)	1 (0/0)	− 0.275	− 1.971*	− 1.269

Table 1 – *continued*

Streamflow variables	Region	Number of sites	No. of signif. r_1	Regional mean r_1	No. of signif. cross-corre. $r_{k,k+l}$	Regional mean cross-corre.	No. of negative trend and (Z/Z^*)	No. of positive trend and (Z/Z^*)	Regional mean Sen's slope (m^3/s)	$\bar{Z}$	$\bar{Z}_{sc}$
May	BS	29	1/1	−0.053	224	0.375	10 (1/0)	17 (0/0)	0.125	0.463	0.139
	EA	6	0	0.051	15	0.575	5 (0/0)	1 (0/0)	−0.220	−1.930	−0.917
	MAR	7	1/0	−0.038	20	0.658	7 (4/4)	0	−1.367	−5.165*	−2.397*
	AEG	10	6/2	0.198	42	0.646	10 (6/6)	0	−0.441	−7.797*	−2.435*
	MED	16	5/3	0.141	110	0.630	15 (5/3)	1 (0/0)	−0.499	−6.307*	−1.656
	SEA	3	0	−0.004	3	0.839	1 (0/0)	2 (0/0)	−0.069	−0.144	−0.088
	CA	4	1/1	−0.264	3	0.583	3 (1/1)	1 (0/0)	−0.273	−2.310*	−1.827
June	BS	29	2/1	−0.163	202	0.381	18 (2/2)	11 (0/1)	0.054	−0.902	−0.305
	EA	6	0	−0.004	15	0.737	4 (0/0)	2 (0/0)	−0.061	−0.845	−0.385
	MAR	7	4/0	0.035	18	0.559	7 (4/4)	0	−1.270	−7.397*	−3.340*
	AEG	10	7/6	0.288	32	0.517	10 (10/8)	0	−0.389	−11.329*	−3.198*
	MED	16	7/5	0.257	94	0.557	16 (10/6)	0	−0.330	−8.082*	−1.933
	SEA	3	0	0.080	3	0.778	1 (0/0)	2 (0/0)	−0.143	−0.227	−0.131
	CA	4	0	−0.139	3	0.561	4 (1/1)	0	−0.239	−2.935*	−2.060*
July	BS	29	2/1	0.010	211	0.392	12 (1/1)	15 (0/0)	0.022	−1.726	−0.488
	EA	6	0	0.014	13	0.589	5 (1/0)	1 (0/0)	−0.136	−2.571*	−1.253
	MAR	7	3/1	0.157	17	0.475	7 (4/3)	0	−0.659	−6.318*	−2.679*
	AEG	8	4/3	0.302	8	0.276	6 (5/4)	2 (0/0)	−0.076	−5.034*	−2.073*
	MED	15	9/6	0.277	95	0.621	13 (9/8)	1 (0/0)	−0.198	−10.015*	−2.346*
	SEA	3	0	0.033	3	0.699	2 (0/0)	1 (0/0)	−0.114	−0.814	−0.505
	CA	4	1/0	−0.091	3	0.519	4 (1/1)	0	−0.073	−2.382*	−1.663
	BS	29	2/1	−0.037	205	0.389	13 (2/2)	16 (1/1)	0.065	−0.743	−0.219
	EA	6	1/1	0.072	11	0.543	6 (0/0)	0	−0.095	−2.666*	−1.237
	MAR	7	4/1	0.148	13	0.401	7 (5/4)	0	−0.600	−6.797*	−3.087*

Table 1 – *continued*

Streamflow variables	Region	Number of sites	No. of signif. r_1	Regional mean r_1	No. of signif. cross-corre. $r_{k,k+l}$	Regional mean cross-corre.	No. of negative trend and (Z/Z^*)	No. of positive trend and (Z/Z^*)	Regional mean Sen's slope (m^3/s)	$\bar{Z}$	$\bar{Z}_{sc}$
August	AEG	7	5/3	0.331	10	0.311	7 (6/4)	0	−0.244	−7.944*	−3.273*
	MED	14	9/5	0.220	77	0.538	14 (10/8)	0	−0.170	−9.694*	−2.622*
	SEA	3	0	0.089	3	0.683	3 (1/1)	0	−0.131	−2.184*	−1.303
	CA	4	1/0	−0.038	4	0.548	4 (1/1)	0	−0.125	−4.264*	−2.746*
	BS	28	5/4	0.071	141	0.282	24 (2/2)	4 (1/1)	−0.024	−3.571*	−1.111
	EA	6	2/0	0.082	14	0.619	6 (3/2)	0	−0.095	−3.722*	−1.657
	MAR	7	4/1	0.140	15	0.437	7 (7/5)	0	−0.810	−7.937*	−3.533*
September	AEG	8	4/4	0.265	11	0.269	8 (7/6)	0	−0.570	−9.745*	−3.807*
	MED	15	11/7	0.300	73	0.464	14 (9/7)	1 (0/0)	−0.185	−10.010*	−2.596*
	SEA	3	0	0.083	3	0.737	1 (1/1)	2 (0/0)	−0.086	−0.577	−0.338
	CA	4	1/0	−0.115	3	0.449	4 (1/1)	0	−0.116	−4.121*	−3.051*
	BS	28	4/2	0.022	120	0.261	22 (4/3)	6 (1/1)	0.004	−4.602*	−1.534
	EA	6	0	−0.003	8	0.456	5 (4/3)	1 (0/0)	−0.068	−4.523*	−2.373*
	MAR	7	2/1	0.060	7	0.324	7 (6/6)	0	−0.752	−7.593*	−4.111*
October	AEG	8	5/2	0.101	10	0.312	8 (8/8)	0	−0.505	−11.209*	−5.129*
	MED	15	10/6	0.226	74	0.457	15 (10/8)	0	−0.283	−10.927*	−3.064*
	SEA	3	0	−0.071	3	0.743	1 (0/0)	2 (0/0)	−0.085	−0.185	−0.126
	CA	4	1/0	0.053	3	0.297	4 (1/1)	0	−0.082	−2.890*	−2.045*
	BS	28	3/3	0.064	143	0.293	17 (3/1)	11 (1/1)	−0.039	−2.243*	−0.688
	EA	6	1/1	0.189	15	0.609	5 (0/0)	1 (0/0)	−0.054	−3.503*	−1.424
	MAR	7	1/1	−0.007	10	0.377	7 (3/3)	0	−0.702	−4.767*	−2.497*
November	AEG	8	3/2	0.170	10	0.348	8 (4/3)	0	−0.490	−6.636*	−2.651*
	MED	16	5/3	0.167	96	0.517	8 (5/5)	7 (0/0)	−0.041	−3.693*	−1.048
	SEA	3	0	−0.022	1	0.483	0	3 (0/0)	0.140	1.215	0.885
	CA	4	1/1	0.003	6	0.658	1 (1/1)	3 (0/1)	0.210	1.070	0.622

Table 1 – *continued*

Streamflow variables	Region	Number of sites	No. of signif. r_1	Regional mean r_1	No. of signif. cross-corre. $r_{k,k+l}$	Regional mean cross-corre.	No. of negative trend and (Z/Z^*)	No. of positive trend and (Z/Z^*)	Regional mean Sen's slope (m^3/s)	$\bar{Z}$	$\bar{Z}_{sc}$
December	BS	29	4/2	−0.027	265	0.466	7 (2/1)	22 (4/4)	0.059	2.990*	0.793
	EA	6	3/3	0.261	11	0.504	4 (0/0)	2 (0/0)	−0.013	−0.940	−0.364
	MAR	7	3/1	0.107	15	0.548	7 (4/4)	0	−1.260	−6.318*	−2.734*
	AEG	10	3/2	0.180	45	0.803	10 (5/5)	0	−0.647	−7.312*	−2.090*
	MED	16	3/0	−0.014	104	0.647	12 (5/5)	4 (0/0)	−0.385	−4.830*	−1.499
	SEA	3	0	0.083	3	0.823	1 (0/0)	2 (0/0)	0.001	0.000	0.000
	CA	4	1/0	0.226	6	0.693	1 (1/1)	3 (0/0)	0.147	−1.053	−0.481
	BS	29	3/2	0.038	228	0.385	10 (3/0)	18 (1/1)	−0.032	0.342	0.092
	EA	6	3/3	0.247	9	0.412	3 (0/0)	3 (0/0)	−0.004	−0.015	−0.006

Column 4 shows the number of significant r_1 before/after Sen's slope elimination

Column 6 shows the number of significant cross-correlations computed by Equation (18) based on 5% significance level and 30 years' data

Column 8 shows the number of negative trend and (the number of significant negative trend according to Z/Z^* computed by Equations (5) and (8), respectively, based on 5% significance level)

Column 9 shows the number of positive trend and (the number of significant positive trend according to Z/Z^* computed by Equations (5) and (8), respectively, based on 5% significance level)

Column 11 and 12 show the regional MK statistic with and without both serial and cross-correlation computed by Equations (16) and (23), respectively, based on 5% significance level. Therefore, $\bar{Z}$ and $\bar{Z}_{sc}$ are significant (*) if $-1.96 \geq \bar{Z}$ or $\bar{Z}_{sc} \geq +1.96$

serial correlations in the flow series were apparent. Douglas *et al.* (2000) reached a similar conclusion in low flow series using a pre-whitening technique.

The cross-correlation coefficients among the sites in the regions is generally higher than 0.358, based on the 95% confidence limits and 30 years of data (Salas *et al.* 1980), implying the presence of a significant cross-correlation among the sites (see column 6 of Table 1). However, the lowest percentages of significant cross-correlations were found for annual maximum flow (33.93%, or 209 times out of 616), annual minimum flow (38.01%, or 176 times out of 463) and means of September and October flow series (41.91% and 45.86%, respectively). The mean cross-correlation coefficients of the sites in the regions (see column 7 of Table 1) were generally determined to be lower for annual maximum flow (4 out of 7 regions) and means of October flow series (4 regions) which also showed very weak regional mean serial correlations for all regions. A similar result was also obtained by Yue and Wang (2002) for the results of annual maximum flows showing serial correlation coefficients almost near to zero and weaker cross-correlation coefficients than those in the other fourteen streamflow variables. In contrast, the months of May and December flows showing the smallest number of significant serial correlations (7 and 8 times over 75, respectively, see column 4) gave higher regional mean cross-correlations for all geographical regions.

Large number of decreasing trends in Turkish river flows were observed for March (68 times), August (65 times) and September (61 times) months (see column 8 in Table 1). However, flows of November (35 times), December (44 times) and January (45 times) showed the least decrease among the other streamflow variables. Moreover, the decreasing trends were determined to be generally significant according to Z and Z^* computed by Equations (5) and (8) at the significance level of 5% (presented in parentheses in column 8 of Table 1). The highest percentages of negative trends were observed in the MAR (99.05%) followed by the AEG (98.52%) and MED (89.66%) regions. In addition, the BS region was determined to be the only region exhibiting a significant increase in streamflow variables (see column 9 in Table 1). Besides, almost no stations were observed with positive trends in the MAR and AEG regions. Additionally, important differences were obtained between Z and Z^* for stations with decreasing trends (see column 8 in Table 1). However, Z and Z^* (see column 9 in Table 1) gave similar results for regions with stations exhibiting increasing trends.

The magnitude of the slope was determined using Equation (11) which is provided in column 10 of Table 1. Among the 105 regional mean Sen's slopes, only 14 demonstrated an upward trend. Flows in the BS region were found to be increasing starting from April to July. However, none of the regions of MAR, AEG, MED and EA showed increasing mean slope. The percentage of regions displaying a downward trend is 87.7%, showing that the Turkish river flows are mostly decreasing. This downward trend occurred much more severe for all streamflow variables in the MAR and AEG regions than that of the others. Monthly mean streamflows for most months have decreased with the strongest decrease in winter and spring months. Zhang *et al.* (2001) stated that monthly mean streamflow in Canada for most months decreased as well. However, they obtained the strongest decrease in the summer and autumn months.

The MK statistics with and without consideration of serial and cross-correlation computed by Equations (16) and (23) are also presented in column 11 and 12 of Table 1, respectively. By comparing these two tests using the two-tailed test at the significance level of 5%, it is clear that the assessment of results with and without consideration of serial and spatial correlation are very different (at least in 3 regions of the 7 regions) for annual mean, minimum and the means of January, February, March, April and August flows whereas the results are not much different for the rest of the streamflow variables (at most in 2 regions of the 7 regions).

Table 2 Summary of the regional MK test results with temporal and spatial correlation according to geographical regions of Turkey

Streamflow variables	MAR	AEG	MED	SEA	CA	BS	EA
Minimum	Downward	Downward	Downward	Downward	Downward	No ↓	No ↓
Mean	Downward	Downward	No ↓	No ↓	No ↓	No ↓	No ↓
Maximum	Downward	Downward	Downward	No ↓	Downward	No ↓	No ↓
January	Downward	No ↓	No ↓	No ↑	No ↓	No ↑	No ↓
February	Downward	Downward	No ↓	No ↑	No ↓	No ↓	No ↓
March	Downward	Downward	Downward	No ↓	Downward	Downward	No ↓
April	No ↓	Downward	No ↓	No ↑	No ↓	No ↑	No ↓
May	Downward	Downward	Downward	No ↓	Downward	No ↓	No ↓
June	Downward	Downward	Downward	No ↓	Downward	No ↓	No ↓
July	Downward	Downward	Downward	No ↓	Downward	No ↓	No ↓
August	Downward	Downward	Downward	No ↓	Downward	No ↓	Downward
September	Downward	Downward	Downward	No ↓	Downward	No ↓	Downward
October	Downward	Downward	Downward	No ↓	Downward	No ↓	No ↓
November	Downward	Downward	No ↓	No ↑	No ↑	No ↑	No ↓
December	Downward	Downward	No ↓	No ↔	No ↓	No ↑	No ↓

Arrows show the flow direction: ↓, refers to downward trend; ↑, refers to upward trend and ↔, refers to no trend

Table 2 shows the assessment of results by the MK test with consideration of serial and cross-correlation. There are differences in the geographical regions of significant trends in the fifteen streamflow variables considered, implying that impacts are not spatially uniform. Only significant downward (50 times) or no (55 times) trends rather than an upward (0 time) trend were obtained nationally for the different streamflow variables and regions. The directions of streamflows exhibiting no trend are also presented in Table 2. An upward direction was obtained 9 times in 55 no trends.

A significant downward tendency was generally determined for the MAR, AEG, MED and the CA regions. However, no significant change in most streamflow variables was experienced in the SEA, BS and the EA regions. Kahya and Kalaycı (2004) have also mentioned that basins in the central and eastern Turkey, in general, showed no trends.

Annual minimum flow decreased significantly across Turkey in the MAR, AEG, MED, SEA and CA regions except in the BS and the EA regions where no significant trend was detected. Lins and Slack (1999) indicated that decreasing pattern in annual minimum flow suggests increasing drought.

Annual mean and means of November, December, January and February showed a similar tendency, downward for the MAR and AEG regions, and no trend for the rest of the geographical regions. Zhang *et al.* (2001), in their study, explained this decreasing trend in annual mean streamflow by increasing trends in temperature combined with almost no change in precipitation. Türkeş (1996) has also pointed out that slightly insignificant decreases in annual rainfall series were generally observed over Turkey, particularly in the BS and the MED regions. However, it was determined that no streamflow trend with downward direction was observed for the winter months in the MED although significant decreasing trends were obtained in the winter precipitation series (Türkeş 2003).

Annual maximum and means of May, June, July and October were determined to have no trends in the SEA, BS and EA regions whereas they decreased significantly in the MAR, AEG, MED and CA regions. The mean flow of April was only found to be significantly decreasing for the AEG region. The monthly mean of March showed no trend for the SEA and EA regions whereas August and September were found to have no trend in the SEA and BS regions. These trends, negative for May to October and no trend in April in the MAR, AEG, MED and CA regions may be due to an earlier snowmelt caused by a possible increase in temperature that resulted in less water remaining in the basin later in the year, which caused a trend toward lower streamflow in summer and autumn. Kadıoğlu (2000) also stated that these regions except for the CA region receive most of their precipitation totals in winter rather than spring. However, a general no trend in SEA, BS and EA regions are attributable to no significant change in precipitation and temperature.

Conclusions and discussions

Regional trends in annual mean, minimum, maximum and monthly means were evaluated using the regional Mann–Kendall test statistic with and without both serial and cross-correlation. A considerable difference was obtained in the assessment of the results of both considerations which might be due to a higher number of serial and cross-correlations among the sites in the regions. Therefore, a quite different interpretation of these trend analyses would have been achieved if the temporal and spatial correlation of the streamflow series within the regions had been ignored.

The application of regional trend detection technique to seven geographical regions of Turkey has resulted in the identification of significant decreasing trends appearing in the MAR, AEG, MED and CA regions. However, almost no evidence of statistically significant trends was observed in the rest of the country. Although the specific causes of these variations in streamflows are not simply and immediately explained, their wide spatial consistency is quite sufficient to suggest some systematic cause or causes. Türkeş (2003) indicated that the SEA and CA could be arid lands that are affected by desertification processes, due to the climatic factors that may lead to desertification. Our study results are also in agreement with this conclusion although any downward trend was not determined for all streamflow variables except for the annual minimum streamflow in the SEA region. The annual minimum streamflow reflects the baseflow and is a measure of hydrologic drought (Lins and Slack 1999). A decreasing minimum flow in the SEA region indicates that baseflows are also decreasing, suggesting increased drought. Besides, Türkeş (2003) concluded that the MED region could also be considered as an area that may be more vulnerable to desertification processes in the future. In the light of the study, the MAR and AEG regions may also be considered as regions vulnerable to desertification processes with respect to a decrease in streamflow. Global and regional projections of climate change could further decrease the streamflow in countries around the Mediterranean (IPCC 2001) and lead to increased water shortages.

Among recent regional streamflow trend studies, Lettenmaier *et al.* (1994) stressed that the trend in streamflow are not fully parallel to the changes in precipitation and temperature due to a combination of climate and water management effects. However, Sankarasubramanian *et al.* (2001) found that there is a high regional sensitivity of streamflow to changes in precipitation. Burn and Elnur (2002) also indicated that trends in hydrologic variables are related to trends in meteorological variables due to similarities in trends and patterns in the hydrologic variables and in meteorological variables at selected locations. Recently, Fu *et al.* (2004) reported that land use/land cover change, including agricultural activities, deforestation/forestation, urbanization and road building with effects that may outweigh any climatic trends are one of the major factors resulting in the observed runoff reduction. Changnon and Demissie (1996) showed that human-induced changes mask the effects of climatic variability. It is evident that the results of these studies have varied widely, depending on the hydrological behaviour of the study area. It should also be remembered in evaluating trends in hydrologic time series that the multidecadal variability could appear as a trend in 30-year samples. Therefore, it would be inappropriate to express that the observed trends in Turkish streamflow patterns have occurred primarily as a consequence of climate change. Moreover, the trend attribution and the relation between the observed streamflow trends and climate change should be addressed in future studies with the inclusion of the influences of climate variables (Kahya and Kalaycı 2004).

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