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Streamflow Trends in the Sakarya Basin

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The detection and attribution of past trends, changes, and variability in hydroclimatic variables is critical for the understanding of potential future changes resulting from anthropogenic activities. Secular trends in monthly streamflow data are evaluated for the past 31 years for 11 stations in Sakarya basin, Turkey. Several non-parametric tests, which were used successfully in water quality trend analysis, were also applied to detect trends in streamflow over Sakarya basin in this study. These tests were developed because the assumptions of classical parametric methods (i.e., normality, linearity, independence) are usually not met by typical water quality data. Moreover seasonality in data compounds the analysis problem. These data idiosyncrasies are mostly common in streamflow data as well. The non-parametric methods are more flexible and in turn can handle the foregoing difficulties. They are the Spearman's Rho test, the Mann-Kendall test, the seasonal Mann-Kendall test, Sen's T test, and the Van Belle and Hughes test. The magnitudes of linear trends were computed by using Sen's estimator. The homogeneity of trend direction at multiple stations and, in different seasons, was also tested by the Van Belle and Hughes test. The results show that all stations except one generally have downward trends according to the same conclusion from all four tests at the 95% significance level. The Van Belle and Hughes homogeneity tests for seasonal trends indicated that all monthly trends are homogeneous for the remaining ten stations. Based on the same test's procedures, a global trend did not exist for the basin.

Keywords: Streamflow, trend analysis, non-parametric tests, Sakarya basin, Turkey.

1. Introduction

The hydrologic regime of streamflow under specific geomorphic conditions represents the integrated basin response to various climatic factors. It is expected that climatic change causes changes in atmospheric temperature as well as in the phases of the hydrologic cycle, such as precipitation, evapotranspiration, runoff, groundwater storage, and so on. However changes in temperature and precipitation are mostly used climatic indicators [1]. Additionally, a basin geomorphology experiences an evolution slowly compared with possible climatic changes caused by anthropogenic increases of greenhouse gases. For this reason, changes in the hydrologic regimes of unregulated basins generally reflect changes in climatic conditions. Therefore they are a good candidate to be used as indicators in detecting climate change. It will be thus meaningful to examine trends of various hydrologic variables of unregulated river basins. Such analyses possibly result in independent corroborative evidence to verify the results of trend detection for climate variables [2].

In different parts of the world, numerous trend studies have been done generally for the climate change detection. Two major approaches, namely parametric and non-parametric tests, are used to see whether or not there are statistically significant trends in a time series. In contrast to the non-parametric tests, the parametric tests basically require the assumption of a normal distribution. At the same time, statistical tests for trends of water quality are commonly confounded by several of the following problems: missing values, censored data (i.e., values reported as less than a specified quantity) and seasonality [3]. For these reasons, several non-parametric tests, which are more flexible than parametric methods, can handle with these characteristics of time series more easily [4]. Therefore, the use of those tests have been proposed by a number of investigators [5-7].

In this study, four different non-parametric trend tests, which were successfully applied to a number of water quality records, were applied to detect a possible linear trend in streamflow in Sakarya basin. These are the Sen's T test, the Spearman's Rho test, the Mann-Kendall test

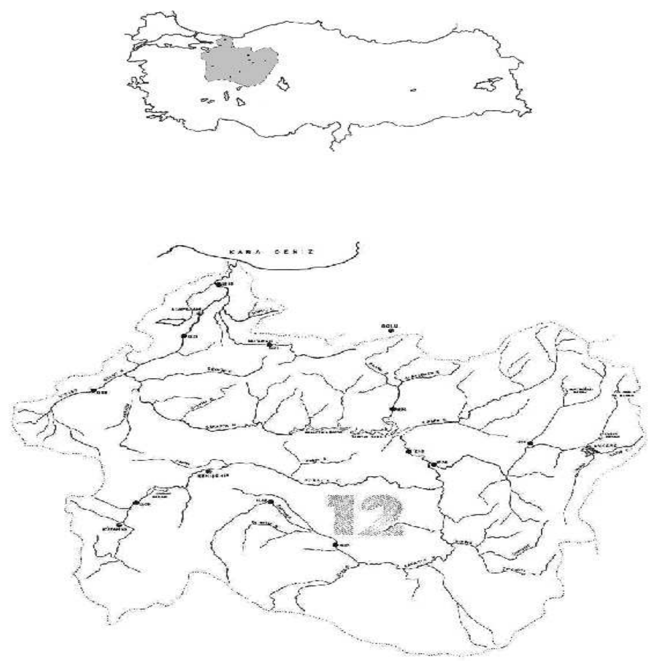

Figure 1. Sakarya basin in Turkey and stations used in this study.

and the Seasonal Kendall test. The linear slopes (change per unit time) of trends were calculated by using the non-parametric Sen′s estimator. In addition, the homogeneity in monthly trends was tested by using a method developed by Van Belle and Hughes.

2. Data and Methodology

Sakarya river basin (located in northwestern Turkey) has an area of 58160 km^2. Monthly average streamflow records for 11 stations in this basin were obtained for the interval October 1964 - September 1994 from EIE (Electrical Power Resources Survey and Development Administration). The locations and identification numbers of 11 gauging stations are shown in Fig. 1. Because flows in the rivers of the study region are not regulated by reservoirs and/or diversions during the period of the trend analysis, the streamflow data secure the condition of homogeneity. The methods, which are used to detect linear trends in this study, are briefly described as follows.

2.1. Sen′s T Test

This procedure is distribution free and not affected by seasonal fluctuations [4]. The computational procedures are as follows: let X_{ij} represents streamflow measurement in year i and month j for i=1,...,n and j=1,...,12 at a gauging station.

(a) Compute the average for the month j, $X_{.j}$ and the average for the year i, X_{i}.

(b) Subtract the monthly average from each of the corresponding months in the n years in order to remove seasonal effects (i.e. calculating X_{ij}-$X_{.j}$)

(c) Rank all the differences from 1 to 12n to obtain R_{ij}=Rank(X_{ij}-$X_{.j}$). If t ties occur (differences are to be same) the average of the next t ranks is assigned to each of the t tied values.

(d) The ranks for each year are averaged, i.e. $R_{i.}=\sum_j R_{ij}/12$ and for each month, $R_{.j}=\sum_i R_{ij}/n$

(e) Compute the following statistic of the Sen′s T test:

$$T = \left[\frac{12m^2}{n(n+1)\sum_{i,j}(R_{ij} - R_{.j})^2} \right]^{1/2} \times$$

$$\left[\sum_{i=1}^{n}\left(i-\frac{n+1}{2}\right)\left(R_{i.}-\frac{nm+1}{2}\right)\right] \qquad (1)$$

where m shows seasonal time periods and equals to 12 in this study. The statistic test is to reject the hypothesis of no trend (the null hypothesis H_o), if the absolute value of T exceeds a particular percentile of the normal distribution ($|T|$ > z at α level of significance) and consequently the existence of a trend is accepted.

2.2. Spearman's Rho Test

A quick and simple test to determine whether correlation exists between two classifications of the same series of observations is the Spearman's rank correlations test. The formulation of the test statistic (r_s) was not presented here, since it can easily be found in a standard statistical book. For n>30, the distribution of r_s will be normal, so that the normal distribution tables can be used. In this case, the statistic test of r_s is computed as $z=r_s\sqrt{n-1}$. If $|z| > z_\alpha$ at the α significance level, then the null hypothesis of no trend (H_o), implying that values of observations are not changed with time, is rejected.

2.3. The Mann-Kendall Test

The Mann-Kendall test, which is commonly known as the Kendall's tau statistic, has been widely used to test for randomness against trend in hydrology and climatology [2]. The null hypothesis (H_o) states that the deseasonalized data (x_1,...,x_n) are a sample of n independent and identically distributed random variables [8]. The alternative hypothesis H_1 of a two-sided test is that the distribution of x_k and x_j is not identical for all k, j≤n with k≠j. The test statistic S is calculated through Eq. 2 and Eq. 3.

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn(x_j-x_k) \qquad (2)$$

$$sgn(x_j-x_k)=\left\{\begin{array}{ll} +1 & \text{if } (x_j-x_k)>0 \\ 0 & \text{if } (x_j-x_k)=0 \\ -1 & \text{if } (x_j-x_k)<0 \end{array}\right\} \qquad (3)$$

It has mean equal to zero and variance: Var (S)=[n(n-1)(2n+5)-$\sum_t$t(t-1)(2t+5)]/18 and is asymptotically normal [6], where t is the extent of any given tie and $\sum_t$ denotes the summation over all ties. For n larger than 10, the standard normal variate z is computed by using the following equation [9].

$$\left\{\begin{array}{ll} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S>0 \\ 0 & \text{if } S=0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{if } S<0 \end{array}\right\} \qquad (4)$$

Thus, in a two-sided test for trend, the H_o should be accepted if $|z| \leq z_{\alpha/2}$ at the significance level of α. A positive value of S indicates an upward trend and a negative value indicates a downward trend.

2.4. The Seasonal Kendall test

This test can be used for time series with seasonal variation and does not require normality of the time series [5, 8]. This test is intended to assess the randomness of a data set X=(X_1,...,X_{12}) and X_i=(x_{i1},...,x_{in}), where X is a matrix of the entire monthly data over n years for a single constituent at a sampling station. The test statistic is a sum of the Mann-Kendall statistic computed for each season (i.e., month). The interpretation of the results is similar to Mann-Kendall test. Its relevant mathematical relations are not presented here due to scarcity.

2.5. Sen's Estimator of Slope

If a linear trend exists in a time series, the true slope (that is to say, change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen [8]. The computational procedures are as follows. First, the slope estimates of N pairs of data are computed by Q_i=(x_j-x_k)/(j-k) for i=1,...,N, where x_j and x_k are data values at times j and k, respectively with j>k. 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_{median}= $Q_{(N+1)/2}$ and if N is even, then Sen's estimator is computed by Q_{median}=[$Q_{(N)/2}$+$Q_{(N+2)/2}$]/2. The detected value of Q_{median} is tested by a two-sided test at the 100(1-α) % confidence interval and true slope may be obtained by the non-parametric test.

2.6. Van Belle and Hughes Test for Homogeneity of Trends

All the tests discussed so far implicitly presume that the trend is homogeneous among seasons. If the trend is heterogeneous among sea-

Table 1
A summary of results of trend analysis for stations in Sakarya basin.

Station	Mann-Kendall Test	Seasonal Kendall Test	Spearman's Rho Test	Sen's T Test	Sen's Estimator of Slope	Significance Level α=0.05	TREND
1203	−10.96	−13.89	9.79	11.15	−0.01795	1.96	*Downward* ↓
1216	−8.78	−10.17	7.45	10.05	−0.00556	1.96	*Downward* ↓
1221	−9.89	−10.15	7.89	10.57	−0.23425	1.96	*Downward* ↓
1222	−6.12	−6.89	3.56	5.92	−0.01814	1.96	*Downward* ↓
1223	−9.04	−10.92	8.83	9.49	−0.00335	1.96	*Downward* ↓
1224	−11.47	−11.99	8.46	11.66	−0.01310	1.96	*Downward* ↓
1226	0.28	3.61	−1.38	1.76	0.00471	1.96	*No detected*
1233	−3.84	−5.22	2.54	4.12	−0.00478	1.96	*Downward* ↓
1237	−4.30	−5.65	3.22	4.26	−0.00471	1.96	*Downward* ↓
1242	−9.82	−9.87	6.20	10.70	−0.06300	1.96	*Downward* ↓
1243	−7.25	−7.35	5.37	8.08	−0.21788	1.96	*Downward* ↓

sons, namely there is a downward trend in one season and an upward trend in another, then an overall test of trend direction and slope estimator could be misleading. Therefore a test regarding homogeneity of trend directions is said to be necessary before any trend test can be applied [8].

For homogeneity in seasonal trends at the station, the following statistic is calculated.

$$\chi^2_{homogeneous} = \chi^2_{total} - \chi^2_{trend} = \sum_{i=1}^{m}(Z_i)^2 - m(\bar{Z})^2. \qquad (5)$$

The values of (Z_i) and ($\bar{Z}$) are calculated by

$$Z_i = \frac{S_i}{\sqrt{Var(S_i)}} \; and \; \bar{Z} = \frac{1}{m}\sum_{i=1}^{m} Z_i \qquad (6)$$
$$(m = 12 \; for \; monthly \; data)$$

where S_i is the Mann-Kendall statistic and calculated for each individual month. Because the analysis procedure was presented in detail elsewhere (see [4, 6, 8], a brief summary for the analysis procedures is presented as follows:

- If $\chi^2_{homogeneous}$ exceeds the α level critical value for the chi-square distribution with (m-1) degrees of freedom (d.o.f.), the null hypothesis of homogeneous seasonal trends over time (trends in the same direction) must be rejected.

- If $\chi^2_{homogeneous}$ does not exceed, then the calculated value for χ^2_{trend} is referred to the chi-square distribution with (1) d.o.f. to test for a common trend in all seasons.

The chi-square statistics can be computed from the equations shown in Table 2 of Van Belle and Hughes [4] (not presented here). The acceptance or rejection of the hypothesis can then be determined by comparing the computed values of $\chi^2_{station}$, χ^2_{season} and $\chi^2_{station-season}$ with the α level critical values in the standard chi-square table with (k-1), (m-1) and (k-1).(m-1) d.o.f., respectively.

3. Results

The results obtained from the non-parametric trend tests are shown in Table 1. A station's record is assumed to have a trend when at least three out of the four tests reveal a similar conclusion. For all tests, the significance level was taken as α=0.05, thus if the absolute value of a test statistic appears larger than 1.96 (z value at α level of significance), then it is decided the existence of trend. Otherwise, it is statistically insignificant inferring that no trend could be detected. Table 1 presents the results of the Mann-Kendall, the Seasonal Mann-Kendall, the Spearman's Rho and the Sen's T tests and indicates that all stations, except Station 1226, have a trend based on the same conclusion from three tests at the α=0.05 level of significance. However, the results of Seasonal Mann-Kendall test indicate a significant trend in all stations. Because the absolute values of test statistic of the three tests for Station 1226 are less than 1.96, no trend was detected in this station. The negative numerical values associated with the Mann-Kendall, the

Table 2
The results of homogeneity test in the seasonal trends.

Van Belle and Hughes Homogeneity Test				
Station	$\chi^2_{homogeneous}$	$\chi^2_{critical}$ α=0.05 (m-1)	χ^2_{trend}	$\chi^2_{critical}$ α=0.05 (1)
1203	4.32	19.68	193.02*	3.84
1216	18.28	19.68	103.27*	3.84
1221	2.03	19.68	103.05*	3.84
1222	4.72	19.68	47.50*	3.84
1223	18.56	19.68	118.36*	3.84
1224	6.68	19.68	143.74*	3.84
1226	71.22+	19.68	13.05	3.84
1233	8.17	19.68	27.33*	3.84
1237	9.23	19.68	32.04*	3.84
1242	7.90	19.68	97.48*	3.84
1243	4.61	19.68	54.10*	3.84

+: Non-homogeneous monthly trends (different trend directions in each month)
*: Homogeneous monthly trends (same trend directions in each month)

Seasonal Mann-Kendall and the Sen′s estimator of slope tests, of course, imply a downward trend. This is shown in Table 1 in a manner that the direction of detected trend is represented by an arrow pointing downward for a negative trend or vice versa.

Moreover Table 1 indicates that Stations 1203, 1216, 1221, 1222, 1223, 1224, 1233, 1237, 1242, and 1243 exhibit a downward trend with a decreasing rate about 0.0033 or larger unit per year. The Sen′s slopes for streamflow vary widely from -0.00335 to -0.23425 unit per year. In contrast, Station 1226 shows a positive Sen′s slope value (Table 1), which is, however, not statistically significant. In fact there may be no trend in the study period, one specific point at the beginning or the end of the period may possibly cause a misleading a slope [10].

The results of homogeneity test developed by Van Belle and Hughes [4] in the seasonal trends for each station are shown in Table 2. Because $\chi^2_{homogeneous}$ value of Station 1226, equal to 71.22, exceeds the critical value for the chi-square distribution with 11 d.o.f., only this station shows that monthly trends are non-homogeneous, that is to say, trend in each month is in different direction. In all other stations, $\chi^2_{homogeneous}$ values do not exceed the χ^2 critical values. The calculated value for χ^2_{trend} is referred to the chi-square distribution with 1 d.o.f. to test for a common trend in all months. χ^2_{trend} values of these stations exceed the critical value indicating that all monthly trends are homogeneous or trend in each month is in the same direction (Table 2).

The results of homogeneity test for a global trend in the basin are shown in Table 3. The $\chi^2_{station}$, χ^2_{season} and $\chi^2_{station-season}$ values were computed and compared with the corresponding level critical values in the respective standard chi-square table with (k-1), (m-1) and (k-1).(m-1) d.o.f. where k and m are the number of stations and the number of months (seasons). According to Table 3, it seems that both $\chi^2_{station}$ and $\chi^2 season$ are significant (non-homogeneity in both station and seasonal trends). So the χ^2 trend test should not be done [8]. As a result, a global trend did not exist for the basin based on the same test′s procedures.

4. Discussion and Conclusions

Temporal changes in the trend form of monthly streamflow data for 11 stations in Sakarya river basin have been examined. The results show that all stations except one have downward trends at the α=0.05 level of significance. The largest of these decreases occurs in Station 1221 and does the lowest in Station 1223 (Table 1). The amount of decrease per year for the period 1964-1994 is estimated as -0.23425 m^3/s in Station 1221. In other words, overall linear trend in this station is -7.26175 m^3/s for the study period.

The decreases in monthly mean streamflows within Sakarya basin could, to some extent, be re-

Table 3
The results of homogeneity test for the global trend.

Van Belle and Hughes Homogeneity Test		Degree of Freedom	$\chi^2_{critical}$ α=0.05
χ^2_{total}	1088.67	$k.m = 132$	124.30
$\chi^2_{homogeneous}$	377.10	$k.m - 1 = 131$	124.30
χ^2_{season}	38.56	$m - 1 = 11$	19.68
$\chi^2_{station}$	221.37	$k - 1 = 10$	18.31
$\chi^2_{station-season}$	117.17	$(k-1)(m-1) = 110$	124.30
χ^2_{trend}	711.57	$1 = 1$	3.84
Homogenity of Seasons		$\chi^2_{season} \cdots \chi^2_{critical}$	>
Homogenity of Stations		$\chi^2_{station} \cdots \chi^2_{critical}$	>
Interaction		$\chi^2_{station-season} \cdots \chi^2_{critical}$	<
Explanation			χ^2 trend test should not be done
Global Trend		$\chi^2_{trend} \cdots \chi^2_{critical}$	
TREND			

lated to the previously implied increases in mean temperature over Turkey, which, in turn, cause increased losses in evapotranspiration processes in the region. It should appropriate to remind that, this comment, of course, could be made safely with the assurance of negligible man-made basin-wide influences in the past. Meanwhile a study concerning the analysis of trend in precipitation patterns of Turkey is under way by the authors. A large body of analyses aiming the long-term precipitation changes by many researchers exists for global and regional purposes [11]. For example, the sensitivity of streamflow to changes in precipitation and other climate parameters was well documented by [9] hence it was informative to investigate whether streamflow records exhibited evidence of increasing trends which might be linked to climate change. They pointed out that statistically significant rate of mean global temperature increase between 0.4 and 0.6 °C per century. For Turkey, [10] indicated that overall mean seasonal (except autumn) and annual minimum temperatures for the period 1938-1989 had increasing trends in Turkey. [11] reported that statistically significant decreasing trends have been identifiable in annual rainfalls at 15 stations, of which 7 were in the Mediterranean rainfall region. He concluded that many of these significant downward trends appear to have occurred as a result of abrupt decreases during the last 20-25 years of the study period.

Generally speaking, physical interpretations for the essence of trend in a surface hydroclimatologic variable are best to relate to greenhouse effect, urban heat islands, and aerosol or to a controversial issue of global warming. It is always wise not to rule out the possibility that this type of inconclusive (due to several inherent reasons) changes in a time series of such climatic variables is due to natural variability. In conclusion, the presence of trends in streamflows of Sakarya basin may be attributed to the observed increases in temperature [10] and decreases in rainfall [11].

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