Trend Analysis of Low Flows

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ABSTRACT

Determination of trends in low flows has a great importance in water resources planning and operation. Hydrological assessment on low flows is required in water quality control problems, water supply projects, irrigation, recreation, and ecological conservation. Trends in low flows could be seen as potential evidences of climate change, and significantly affect short-, medium-, and long-term future decisions. The main objective of this study is to identify low flow trends for gauging stations in four hydrological basins, Meriç-Ergene, Gediz, Ceyhan and Seyhan, from different regions in Turkey. For the analysis, 3, 2, 2 and 5 flow gauges were selected for Meriç-Ergene, Gediz, Seyhan and Ceyhan basins, respectively. In the study, data from gauging stations with either no or minimum anthropogenic activities are considered. Therefore, record period for each gauging station has been selected such that influence by any upstream dam or water structure is excluded. Stream gauges with common period of 27 years from 1988 to 2014 are used. In the study, the *D*-day average time series are obtained by taking the overlapping *D*-day average of the daily streamflow time series. Low flows of *D* = 1, 7, 14, 30, 90 and 273-day are considered. The non-parametric Mann-Kendall test which has found an effective and general use to assess the significance of trend in hydrological time series is applied. Results on the existence and the significance of trends in low flow characteristics of hydrological basins are obtained and discussed.

Keywords: *D*-day low flow, low flow, Mann-Kendall test, trend analysis

INTRODUCTION

Low flow is the smallest average daily flow discharge in a year. Low flow analysis makes possible to provide crucial information to plan and design water resources development as well as risk assessment. Understanding and evaluating the low flow regimes in water resources management are especially significant for countries where the demand of water increases.

Various approaches and methods have been developed to examine and determine the trends of low flow. Svensson et al. (2005) found a significant increase in low-flow series in a study focused on 21 gauging stations worldwide. Stahl et al. (2008, 2010) studied trends in low flows and streamflow droughts across Europe. Assefa and Moges (2018) performed low flow trends and frequency analysis in the Blue Nile basin, Ethiopia. Nasr and Bruen (2017) investigated trends in low-flow sequences by analysing the 7-day low-flow time series generated for 33 streamflow gauging stations across various river basins in Ireland. For rivers in Turkey, there are few studies conducted related to trend analysis of low flows by Bayazit et al., (2002), Cığızoğlu et al. (2005), Başkaya Aytekin (2012) and Tosunoğlu and Kaplan (2018).

This study attempts to find out the trend of low flows using *D* = 1, 7, 14, 30, 90 and 273-day low flows of rivers in four hydrological basins from different regions of Turkey. Additionally, the study aims to pay attention both to the Mann-Kendall trend test on the streamflow data and to locate the start of trends in the regions considered.

STUDY AREA AND DATA

Turkey is divided into 25 hydrological basins (Figure 1) with different characteristics such as topographical, morphological, meteorological conditions and climate. In this study, daily streamflow data of gauging stations from Meriç-Ergene, Gediz, Seyhan and Ceyhan river basins are used. Among the hydrological basins used in the study, Meriç-Ergene basin is located in the Thrace region, the north western part of Turkey. Land in the basin is mostly used for agriculture followed by forests and semi-natural areas. The annual average precipitation in the basin is 665 mm. The basin receives a significant amount of precipitation in winter whereas precipitation decreases in summer. Gediz River Basin is located in the Aegean region. Precipitation in the basin ranges from over 1000 mm per year in the mountains to 500 mm per year near the coast. It has a hot and dry summer and a cool winter; precipitation over the basin is concentrated in the winter season. Ceyhan River Basin is located in the eastern Mediterranean region. To the west of the Ceyhan River basin is the Seyhan River basin. The lower part of both basins is dominated by the Mediterranean climate, while the middle and upper parts are influenced by the continental climate. The annual precipitation is about 700 mm in the coastal area; it increases to approximately 1000 mm at higher elevations in the north and decreases to about 400 mm at the most upstream area in further north in both basins.

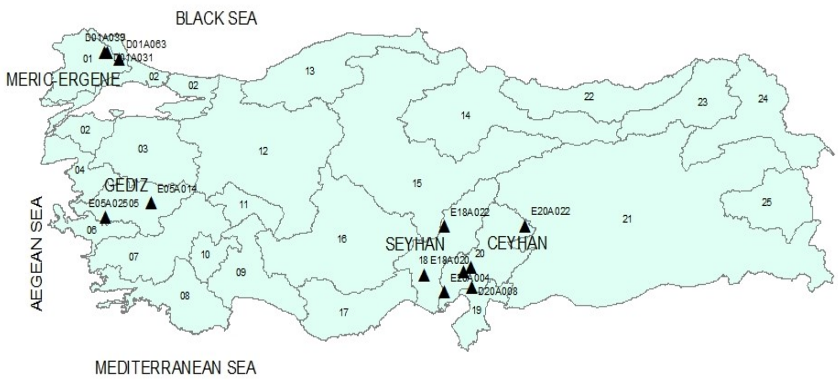

Figure 1. Location of the basins and gauging stations

Daily streamflow data were obtained from the State Hydraulic Works of Turkey (DSI with its Turkish acronym). In total, there are 99 gauging stations available in the basins but a common period at all stations was considered for the trend analysis. Therefore, 3, 2, 2 and 5 streamflow gauges in Meriç-Ergene, Gediz, Seyhan and Ceyhan river basins, respectively, with uninterrupted time series of a record length of 27 years from the common period of 1988-2014 were used. Besides, in the study, data from gauging stations with either no or minimum anthropogenic activities are considered. Therefore, record period for each gauging station has been selected such that influence by any upstream dam or water structure is excluded. Table 1 shows the statistical characteristics of the data used in this study. The following characteristics were calculated from the observed daily streamflow time series: mean, minimum, maximum and standard deviation.

Table 1. Statistical Characteristics of Daily Streamflow Data

						Flow (m^3/s)			
Basin	**Station no**	**Station Name**	**River**	**Drainage Area (km^2)**	**Altitude (m)**	**Mean**	**Min**	**Max**	**St. Dev.**
Meriç-Ergene	D01A031	Soğucak	Soğucak	71.3	271	0.06	0.00	0.47	0.06
	D01A039	Poyralı	Poyralı	96.4	249	0.01	0.00	0.59	0.05
	D01A063	Ayvacık	Ayvacık	25.8	183	0.01	0.00	0.33	0.04
Gediz	E05A014	Dereköy	Selendi Çayı	689.6	345	0.07	0.00	1.26	0.17
	E05A025	Yiğitler	Yiğitler Deresi	64.0	158	0.03	0.00	0.45	0.07
Seyhan	E18A020	Hacılıköprü	Körkün Suyu	1440.8	167	3.41	0.59	13.95	1.99
	E18A022	Fraktin Köp.	Zamantı Nehri	6334.8	1270	7.04	0.81	17.59	3.45
Ceyhan	E20A008	Kadirli	Savrun	480.0	70	1.27	0.17	7.55	1.13
	E20A022	Hanköy	Söğütlü	400.0	1347	0.46	0.03	3.27	0.39
	D20A046	Sarıdanışmanlı	Keşiş	420.0	200	0.22	0.22	9.81	9.81
	D20A008	Osmaniye	Karaçay	131.1	255	0.26	0.00	2.93	0.43
	E20A004	Misis	Ceyhan	20466.0	15	75.46	13.70	190.11	35.73

METHOD

D-day low flow

The annual minimum flow has been traditionally the variable of interest in frequency analysis and the method is usually referred to as low flow analysis. It encompasses time series of annual minimum flow averaged over a range of data, the annual minimum *D*-day average streamflow. In literature, 1, 3, 7, 10, 15, 30, 60, 90, 120, 150, 180 or 273 days were used commonly (Tallaksen, 2000). The *D*-day low flow time series is obtained by taking the overlapping *D*-day average of the daily streamflow time series (Eris et al., 2019). The *D*-day low flow sequence at any year is composed of the minimum value of the calculated low flows in each year. The number of *D*-day low flows is $365 - (D - 1)$. In this study, minimum of D = 1, 7, 14, 30, 90 and 273-day average flows were used in Meriç-Ergene, Gediz, Seyhan and Ceyhan river basins.

Mann-Kendall Trend Test

Mann-Kendall (Mann, 1945; Kendall, 1975) trend test evaluates and indicates the presence of a monotonic increasing/decreasing trend in the time series. The Mann-Kendall test is a non-parametric test. The method was widely used to test the randomness against trend in hydro-climatological time series data (Assefa and Moges, 2018). The test does not depend on the statistical distribution of the data and its results are appropriate as long as $10 \leq n$ (where n is the number of data). The test also can check up with the null hypotheses (H_0: not trend) in the time series (Bayazıt,1996). The data is ranked from the smallest to the largest. The test is based on the calculation of the special statistical values such as S. Comparing each of the couples x_i, x_j of the random value X, $x_i < x_j$ for $i < j$ is shown by P and another couple $x_i > x_j$ is shown by M. S is defined as (Bayazıt and Önöz, 2008):

$$S = P - M \qquad (1)$$

The Mann-Kendall statistic Z follows the standard normal distribution and is calculated by

$$Z = (S-1)/\,{\sigma_s}^{1/2} \quad if \quad S > 0$$
$$Z = 0 \quad if \quad S = 0 \qquad (2)$$
$$Z = (S+1)/\,{\sigma_s}^{1/2} \quad if \quad S < 0$$

In equation (2), σ_s is defined as

$$\sigma_s = \sqrt{\frac{[n(n-1)(2n+5) - \sum_i t_i(t_i-1)(2t_i-5)}{18}} \qquad (3)$$

where t_i is the number of tied values. The test statistic Z is also used as a measure of trend. If Z is greater than $Z_{\alpha/2}$, where α represents the chosen significance level, H_0 should be rejected; for example; at 5% significance level with $Z_{0.025} = 1.96$, H_0 is rejected when $Z > 1.96$. This means there is trend. A positive value of Z indicates an increasing trend; likewise, a negative value of Z indicates decreasing trend.

On the other hand, as the Mann-Kendall trend test is a non-parametric test, it is especially useful because data do not have to obey a specific distribution (Yue and Whittemore, 1993). Also, the test statistic Z gives more information about increasing or decreasing of the trend, but not its magnitude exactly (Onoz and Bayazıt, 2003; Santos et al., 2007).

RESULTS

D = 1, 7, 14, 30, 90 and 273-day low flows were calculated by using the above method on the daily streamflow time series of each gauging stations described in Table 1, for each year of the common period from 1988 to 2014. Each *D*-day low flow sequence has the same length of each particular time series; i.e. selected streamflow gauging stations have 27-year record. The Mann-Kendall trend test was applied on the *D*-day low flow for the selected stations. Results of the non-parametric Mann-Kendall trend test at the 5% significance level were presented in Table 2. Also, Table 2 summarizes significant decreasing and increasing trends during the study period 1988-2014. The 1, 7, 14, 30,90 and 273-day low flow series of some gauging stations in Meriç-Ergene, Gediz and Ceyhan basins have zero values while non-zero low flows were observed in the streamflow gauging stations in Seyhan river basin. In other words, except for the Seyhan river basin, other basins have zero-low flows, this indicates that they are prone to get dry.

While applying the Mann-Kendall trend test, zero values were considered with a particular care. Trend analysis was not applied in any case when number of zero values is higher than 30% of the total length of the *D*-day low flow sequence; 8 years with zero *D*-day low flow prevented testing the trend in this study. As presented in Table 2, the selected 12 stations indicate trends of low flow. For some *D*-day low flow sequences of three gauging stations, the trend test was not applied due to the high number of zero values exceeding 30% of the total length. It is seen that as the *D*-day low flow increases, the likelihood of no trend increases. Unlike the other stations, station D01A031 has also indicated an increasing trend. Almost in none of the low flows in Gediz river basin was observed a trend. In general, trend in Seyhan and Ceyhan river basins has almost a similar character as in both basins, a decreasing trend is observed at D = 1, 7, 14- and 30-day low flow. On the other hand, in none of the gauging stations, the D = 273-day low flow indicates a trend except for one gauging station.

The general behaviour of the low flow in the four basins has indicated different characteristics. It is important to notice that any low flow sequence with zero-low flow of 30% of the total length or more cannot be processed through the trend test. One more point worth to mention is that no zero *D*–day low flow was observed in the Seyhan basin at the common period.

Table 2. Trends in the *D*-day low flow sequences for the selected stations in the Meriç-Ergene, Gediz, Seyhan and Ceyhan river basins.

Basin	Station No	Station name	1		7		14		30		90		273	
MERIÇ-ERGENE	D01A031	Soğucak	1.18	-	1.50	-	1.71	-	2.31	↑	4.00	↑	2.42	↑
	D01A039	Poyralı											0.08	-
	D01A063	Ayvacık									0.54	-	0.75	-
GEDIZ	E05A014	Dereköy	-1.83	-	-1.75	-	-1.86	-	-2.00	↓	-1.29	-	1.21	-
	E05A025	Yiğitler					1.41	-	1.63	-	1.42	-	0.88	-
SEYHAN	E18A020	Hacılıköprü	-2.78	↓	-2.71	↓	-2.86	↓	-2.77	↓	-1.88	-	-1.63	-
	E18A022	Fraktin Köprüsü	-1.54	-	-1.29	-	-1.17	-	-0.92	-	-0.63	-	-1.54	-
CEYHAN	E20A008	Kadirli	-4.09	↓	-3.79	↓	-3.71	↓	-3.79	↓	-3.79	↓	-0.63	-
	E20A022	Hanköy	-0.40	-	-0.50	-	-0.75	-	-0.33	-	-0.17	-	-1.92	-
	D20A046	Sarıdanışmanlı	-2.86	↓	-2.46	↓	-2.54	↓	-1.79	-	-1.04	-	-0.33	-
	D20A008	Osmaniye									-1.29	-	-0.54	-
	E20A004	Misis	-0.81	-	-0.63	-	-0.50	-	-0.75	-	0.04	-	0.13	-

-	No trend	$1.96<z<1.96$
↑	Increasing trend	$z>1.96$
↓	Decreasing trend	$-1.96>z$

CONCLUSION

Low flow trend analysis is a commonly used technical tool to evaluate low flow characteristic. In this study, different *D*-day low flows are considered for streamflow gauging stations located in different hydrological regions in Turkey. Trend analysis of D = 1, 7, 14, 30, 90 and 273-day low flows at 12 stations in Meriç-Ergene, Gediz, Seyhan and Ceyhan river basins was carried out using the daily minimum low flow series. Results in this study show different trend characteristics in low flow sequences for the selected stations. This indicates that different trends are located in different basins at the same common observation period. This is based on the basin dynamics, especially the land use and land cover changes, anthropogenic activities and climate change over the basins. Using the trend analysis and the relation between the *D*-day low flow with basin characteristics could help to predict the low flows in the water resources management practice. However, one-point worth to mention is that result of the trend analysis given in this study are limited in terms of the number of gauging station and the length of the observation period and they are therefore not sufficient to indicate a climate change over the basins. Further studies should thus be performed to evaluate the relation between any change and the observed trends.

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