

# Mapping of Stream Flow Trends in Porsuk Basin Using GIS Environment

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## Abstract

In this study, trends of minimum, average and maximum flows were investigated in Porsuk basin, which is a sub-basin of Sakarya basin and then changes in flows were mapped using Geographical Information Systems (GIS). In the study, in 10 flow gauging stations across the Porsuk basin, monthly average, maximum and minimum flow data is used covering the period 1961-2013 (53 years). When analyzing the distribution of observed trends in the basin, a trend has been observed in most of the river flows. A decreasing trend has been observed overall in the basin. Trends are generally decreasing over time except for a few stations. As a result, increasing trends are observed in the west part of the basin; while in the east part of the basin decreasing trends are observed. When average and maximum monthly flows are investigated, decreasing trends are observed in the stations except DSI-12182. Trend analysis of 10 flow gauging stations across the Porsuk basin is investigated by Mann-Kendall method. Trend distribution was made according to flow trends of basin by transferring Z values to GIS.

## Keywords

Flow Gauging Station (FGS), Porsuk Basin, Mann-Kendall, Trend Analysis, Geographical Information Systems (GIS)

## 1. Introduction

Since the formation of the atmosphere, global climate systems have tended to change temporally and spatially within their natural variability. This tendency of variability was directly related to the natural changes of various components in the Sun, atmosphere or in the earth/atmosphere combined system until the

middle of the 19th century. However, for the first time, human activities have also been added to the natural change components in global climate systems and they have started to become quite effective as well (Yıldız & Malkoç, 2000).

The global warming caused by the greenhouse effect, which started at the end of the 19th century, was strengthened by the greenhouse gases that continue to accumulate in the atmosphere. Then it became more evident especially after the 1980s and it has reached its highest values in the 1990s. Within the global dimension of the effects of climate change due to global warming, regional and temporal differences may occur, as in previous climate changes. This means that in the future, especially in some parts of the world, there will be an increase in the intensity and frequency of hurricanes, as well as in strong rains and meteorological disasters such as floods and overflows; while long-term, severe droughts and associated widespread desertification events may be more effective in some regions of the world. Precipitation has shown an increase in land areas in the high latitudes of the Northern Hemisphere in general, especially in the cold season, but it has shown a decreasing tendency on the subtropical and tropical zones extending from Africa to Indonesia after the 1960s. These changes have been observed as well in rivers, lake levels and soil moisture (Yıldız & Malkoç, 2000).

Nowadays, the increase in the population and the increasing industrial facilities cause the water demand to increase continuously. In order to meet the increasing water demand, measures such as transporting the water from the abundant places to lesser places and creating water storage tanks can be implemented. However, the most effective way to deal with water demand is to study the past behavior of water and then predict its future behavior based upon that. Knowing the time series of water quantities helps to use and plan the existing storage of water as well as the future storage of water more carefully. People, institutions and organizations that are investing in hydrology, hydrometeorology and water, have to know how the future stream flows in the basin will be changed. The past data of river flows which are based on year, season, month or day is required for future planning (Cığızoğlu et al., 2002).

Mean, minimum and maximum currents are important from different points of view in water resource engineering applications. Maximum and average current flow values are important for capacity calculation of dam reservoirs as well as for the design of flood structures; while the minimum flow values are important in terms of determining the amount of flow to be given to the downstream side of the river from the bottom of the dam or also for maintaining the standards of water quality. For this reason, it is of great importance for the planning of future water resources projects, to examine the past flow records and to search for a trend component in both minimum and maximum flow values. In addition, knowledge of trends in flows is of great importance in the planning and operation of water structures as well as in the planning and operation of hydroelectric power plants.

A reduction in annual average flows carries importance for determining the storage capacity as well as the realization of storage operations. An increase in maximums is important for the design of the dam-filled sluice. The river flow data used in the study were obtained from the 3<sup>rd</sup> Regional Directorate of State Hydraulic Works (1961-2013), and the final data was determined by using the Mann-Kendall test, which was used to determine whether the results of the flow data could be considered as significant trends. Statistically significant trends were evaluated at basin scale in a GIS environment and trend distribution maps were created as a result.

## 2. Study Area and Method

### 2.1. Study Area

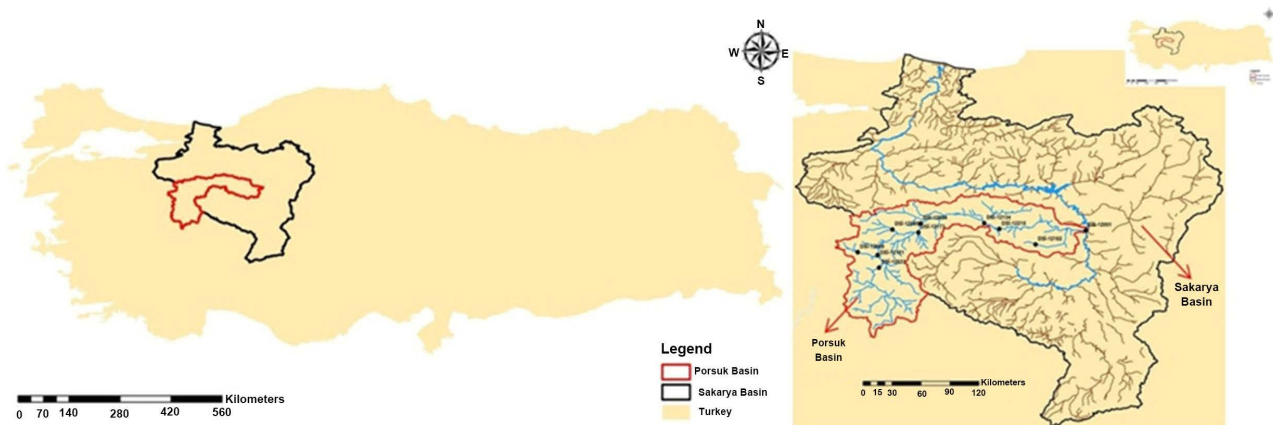
Porsuk Basin, a sub-basin of Sakarya Basin no. 12 was chosen as the test region. The data obtained from the FGs operated by the State Hydraulic Works on the selected rivers in the Porsuk basin were used. Current flow gauging stations considered in the study are given in **Table 1**, **Figure 1**.

Long-term monthly average flow values, which are dependent on many years of measurements that were measured in flow gauging stations (some of which are specified in **Table 1**), have been completed by regression analysis and then the missing flow values seen in **Figure 2** have been adjoined to create complete and unified data. For the purpose of trend analysis of these data, minimum average and maximum average flow values were extracted for each measured year of each station.

### 2.2. Method

#### 2.2.1. Mann-Kendall Tendency Test

Mann-Kendall test (Yu et al., 1993) is a special application of the test known as Kendall's Tau and it is a non-parametric test. Mann-Kendall tendency test is a non-parametric test and it is not affected by the distribution of variables (Önöz et al., 2007). This method, which is most commonly used in the analysis of



**Figure 1.** Position of Sakarya and Porsuk Basins in Turkey.

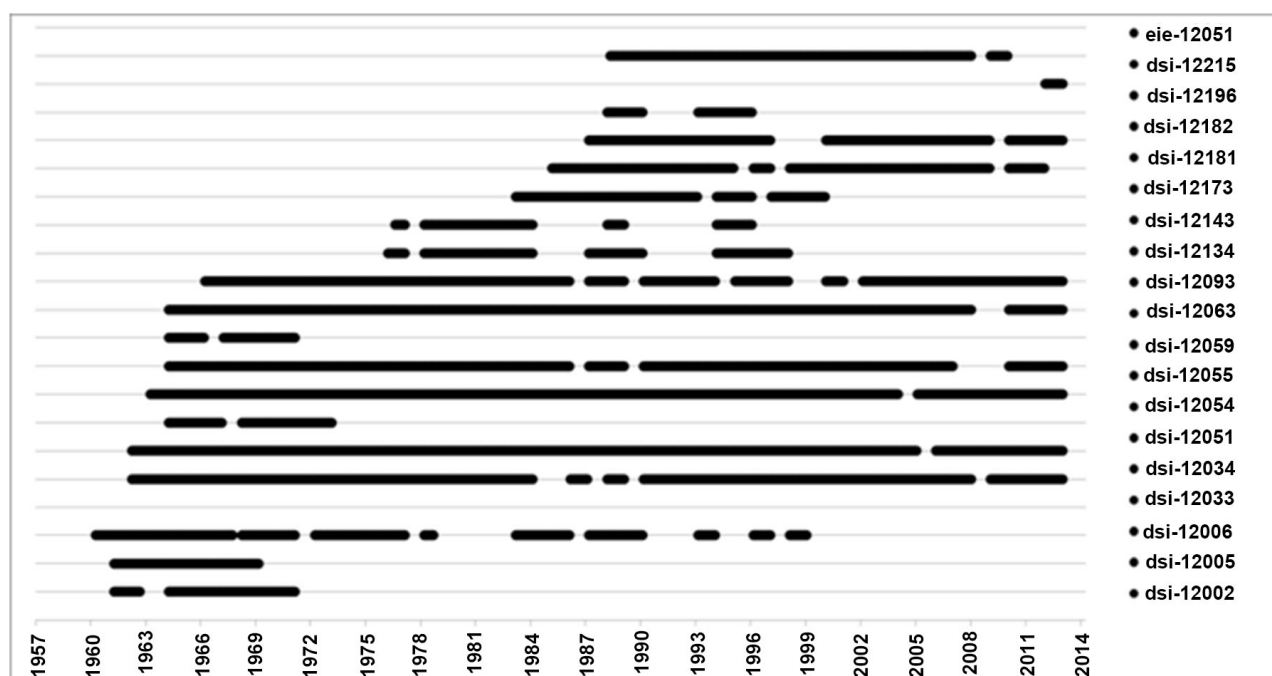


Figure 2. Measurement years of flow data.

Table 1. FGS utilized for Porsuk Basin data.

Station No	Station Name	Basin Area (km <sup>2</sup> )	Opening Date	Closing Date	Observation Period (Years)
DSİ-12002	Sazova	643	06.02.1963	31.12.1972	9
DSİ-12005	Sobran	435	15.04.1960	25.02.1970	10
DSİ-12006	Porsuk D.D.Y.Drk	320.8	13.10.1954	-	59
DSİ-12033	Porsuk Çiftliği	2432	01.12.1961	-	52
DSİ-12034	Porsuk Baraj Çıkışı	4688	20.09.1962	-	51
DSİ-12051	Genişler	152.5	14.06.1963	21.02.1974	11
DSİ-12054	Esenkara	5600	07.06.1963	-	50
DSİ-12055	Akçaköy	275.2	01.06.1963	-	50
DSİ-12059	Yoncalı	275.8	21.06.1963	31.01.1973	10
DSİ-12063	Uluçayır	290.7	22.04.1964	-	49
DSİ-12093	Eyice	153.1	20.10.1966	-	47
DSİ-12134	Yesildon	7580	03.04.1974	06.10.2003	37
DSİ-12143	Maslakbaşı-Yoncalı	441.5	07.03.1977	16.04.1997	20
DSİ-12173	Gökçekısık	5425	22.08.1983	-	30
DSİ-12181	Yeni Bosna	3810.5	01.10.1985	-	28
DSİ-12182	Memik	177.1	01.10.1985	-	28
DSİ-12196	FelentÇayı-Yoncalı	246.9	01.10.1988	16.04.1997	9
DSİ-12215	Parsibey	867.1	01.10.1994	-	19
EİE-12051	Kıranharmanı	10,655.4	01.10.1988	-	25

hydro-climatological data, is an excellent method for finding trends, and it is based on the order of the data rather than the size of the data (Partal, 2003). Mann-Kendall rank correlation is a method independent of distribution to find the relationship between the two variables (Kosif, 1999). The Mann-Kendall test is particularly suitable for non-normally distributed data with extreme and non-linear tendencies (Helsel & Hirsch, 1992; Birsan et al., 2005). This technique is very useful for data that does not need to comply with low and normal distribution (Yu et al., 1993). In this test, time-based observations show that the time-independent and similar distributed random variables according to the  $H_0$  hypothesis and that the  $H_1$  hypothesis shows that the values of these distributions are not similar, i.e. there is no linear trend in the sequence. Thus, the said test to be applied in this research is given in Equality (1).

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

In the equation,  $x_j$  and  $x_k$  show the flow rates in years  $j$  and  $k$ , respectively. If  $j > k$ , then the sign function is written as in Equation (2).

$$\text{sgn}(x_j - x_k) = \begin{cases} +1 & (x_j - x_k) > 0 \\ 0 & (x_j - x_k) = 0 \\ -1 & (x_j - x_k) < 0 \end{cases} \tag{2}$$

The theoretical distribution of S statistics is normal in long data. Accordingly, the mean and variance were calculated by Equation (3).

$$\begin{aligned} \mu_s &= 0 \\ \text{ve} \\ \text{Var}(S) &= \left[ n(n-1)(2n+5) - \sum_{i=1}^m t_i(i-1)(2i+5) \right] / 18 \end{aligned} \tag{3}$$

Standard normal variable was calculated by Equation (4).

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & S < 0 \end{cases} \tag{4}$$

Compared with the standard normal variable significance level ( $\alpha: 0.05$ ), if  $|Z| < z_{\alpha}/2$ , then the  $H_0$  hypothesis is accepted, and if it is not, then the hypothesis is rejected. If the calculated Z value is positive, it is stated that there is an increasing tendency and if it is negative, it has a decreasing tendency. The calculated Z value ranges from (-1.96) to (+1.96) when there is no trend. If Z value is greater than (+1.96), it shows that there is a statistically increasing tendency and if it is less than (-1.96) then it shows a decreasing trend (Aksoy, 2002).

**2.2.2. Inverse Distance Weighted-IDW Method**

In this study, Z trend values obtained by Mann-Kendall analysis were trans-

ferred to GIS environment by applying IDW method and trend distribution maps were created on Porsuk basin. **Figure 3** shows the selected FGSs for trend analysis in Porsuk basin.

Weighting by inverse distance is an estimation method that assigns a higher weight value to nearby points than distant points and which also takes into account all possible sample points. Each sample point has an inverse weight value based on its distance from the point to be estimated. The estimated value at point  $x_0$  is calculated as shown in Equation (3).

$$W_i = \frac{1}{d_i^p(x_i)} \quad (5)$$

$$\sum_{i=1}^n \frac{1}{d_i^p(x_i)}$$

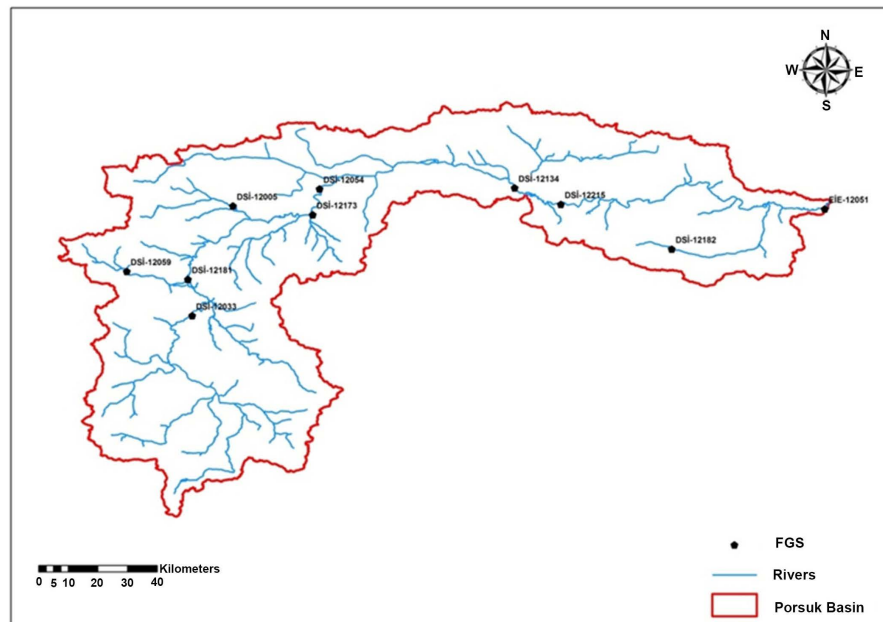
$$Z^*(x_0) = \sum W_i \cdot Z(x_i) \quad (6)$$

Here;  $Z^*(x_0)$  means the value of the prediction at point  $x_0$ ,  $Z(x_i)$ : the value of the sample point at point  $x_i$ ,  $W_i$ : the weight of the inverse distance relative to the point  $x_0$  of the sample,  $d$ : the distance between the sample point and the point to be estimated,

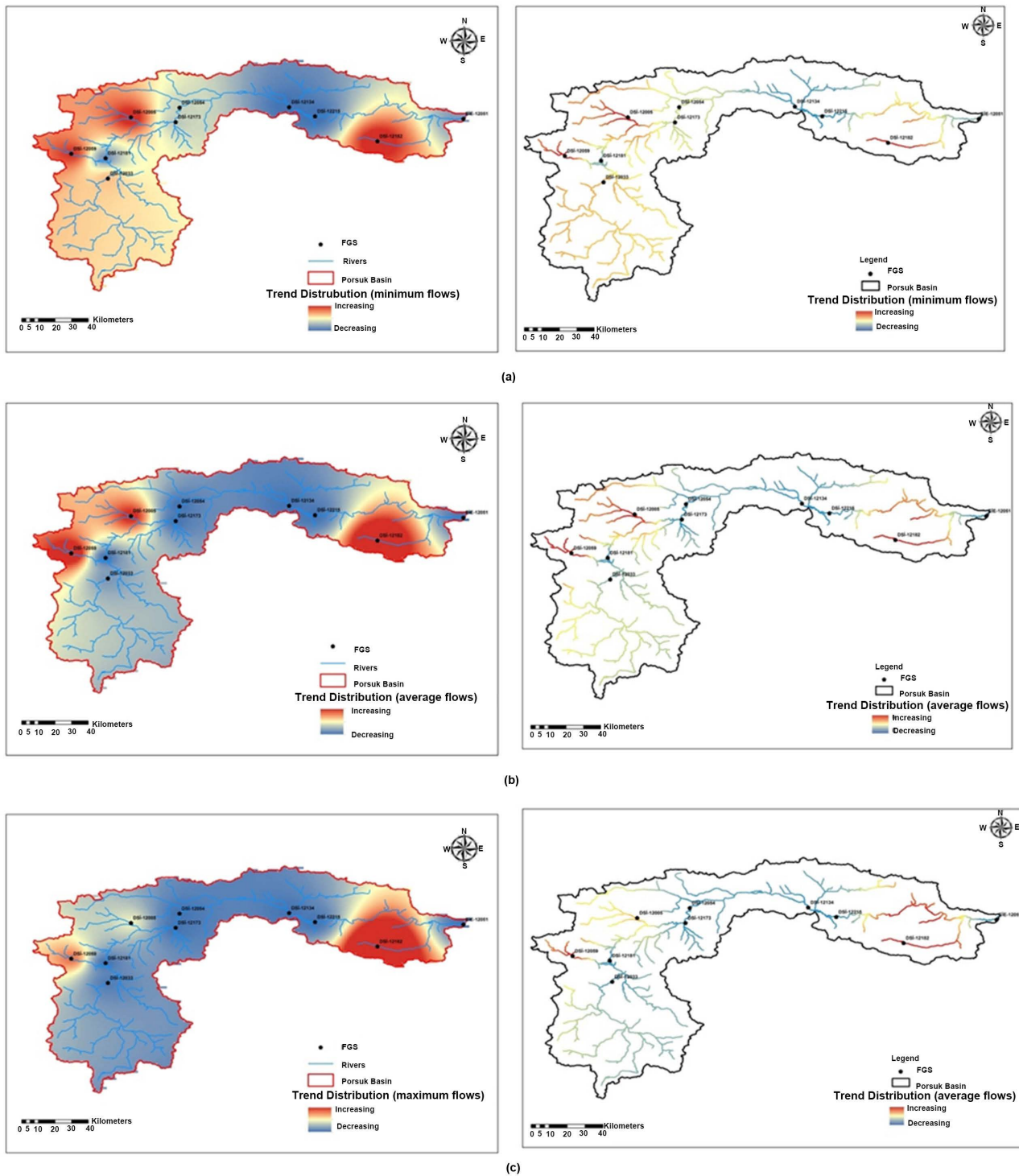
$p$ : the exponential value,  $n$ : the number of sample points.

### 3. Research Findings

In this study, long term monthly current data of 19 current monitoring stations were examined and trends of mean, minimum and maximum current data were examined. Of the examined stations, 9 stations did not show a specific trend, whereas 10 stations showed a trend. The trends of these stations were analyzed by spatial estimation in GIS software according to IDW method. The map of the



**Figure 3.** Current observation stations in Porsuk Basin.



**Figure 4.** Trend distribution maps of (a) minimum, (b) average and (c) maximum flows for Porsuk Basin.

trend distributions of the Porsuk basin average, minimum and maximum flows is given in **Figure 4**.

According to Mann-Kendall test results, 57.34% of the basin did not show trend distribution, while 22.43% of it showed a decreasing trend and 20.23% showed an increasing trend. According to the average flows, 24.99% of the basin

**Table 2.** Mann-Kendall test results.

Station No	Trend Tendency		
	Minimum	Average	Maximum
DSİ-12005	4.98	2.74	-2.58
DSİ-12033	0.97	-4.16	-5.08
DSİ-12054	-1.89	-5.28	-5.28
DSİ-12059	4.24	4.15	-0.16
DSİ-12134	-5.28	-5.26	-5.28
DSİ-12173	-2.17	-5.21	-4.97
DSİ-12181	-3.99	-5.02	-5.1
DSİ-12182	5.28	4.96	5.21
DSİ-12215	-5.28	-5.28	-5.08
EİE-12051	-3.74	-5.15	-5.19

did not show any trend distribution, while 63.32% decreased and 11.69% showed increasing trends. According to maximum flows, 6.65% of the basin did not show trend distribution, while 76.77% of it decreased, and 16.58% of the basin showed increasing trend distribution. In the basin, DSİ-12182 flow gauging station showed an increasing trend in all flows. In general, it can be said that the basin is in a trend of decreasing flow.

#### 4. Conclusion

In this study, monthly average, minimum and maximum flow data of 19 flow gauging stations of Porsuk Basin, which is one of the important sub-basins of Sakarya Basin, were determined by the application of the Mann-Kendall test. In the analyses, the data of the current observation stations covering the flow data of the years 1961-2013 in the basin were examined and 10 stations with significant trend values were found. The trends of these stations are recorded in the GIS database and distributed in the GIS environment according to the IDW method, which is a spatial estimation method. As a result of the study, trends of the flows along the basin were determined according to the mean, minimum and maximum values of the flows (Table 2).

According to the results, no change in trends was observed in more than half of the basin at minimum flows. On average and maximum flows, a declining trend was observed in most of the basin. These results can be accepted as an indicator of future water shortages in the basin. For this reason, the water resources in the basin should be evaluated well and necessary precautions should be taken.

#### Acknowledgements

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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