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*Full Length Research Paper*

# Trend and change-point detection for the annual stream-flow series of the Karun River at the Ahvaz hydrometric station

**Meysam Salarijazi[1]*, Ali-Mohammad Akhond-Ali[1], Arash Adib[2] and Alireza Daneshkhah[3]**

[1]Department of Hydrology, Hydrology and Water Resources, Faculty of Water Sciences Engineering, Shahid Chamran University of Ahvaz, Khuzestan, Iran.
[2]Department of Civil Engineering, Faculty of Engineering, Shahid Chamran University of Ahvaz, Khuzestan, Iran.
[3]Department of Statistics, Faculty of Mathematical Sciences and Computer, Shahid Chamran University, Ahvaz 6135714463, Iran.

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**Karun River watershed located in southwest of Iran experiences great changes in the last decade due to hydro climatic changes, large-scale land use and land cover changes, construction of dams and agricultural and industrial development. Stream-flow series of the annual maximum, annual minimum and annual mean in Ahvaz hydrometric station as representative of the watershed have been considered. In order to determine the change points, we use the Pettitt test while the trend in the annual stream-flow series of this station is evaluated by the Mann-Kendall test. However, the Pettitt test cannot detect any change point in these series, but the Mann-Kendall test shows that there is an increasing trend. This increasing trend has no fitness with observed data in recent decade. Therefore, the potential change points were determined and consequently, these series converted to two sub-series based on the results obtained from the Pettitt test, wide variation from human activities and variation of hydro climatic conditions. We then applied the Mann-Kendall test in these two sub-series which showed significant decreasing trend in both of them. From this method, it can be concluded that the averages of the second sub-series are larger than the first one in the three annual stream-flow series. This increasing ratio is equal to 1.34, 1.16 and 1.2 for stream-flow series of annual maximum, annual minimum and annual mean respectively. These changes are similar to changes in annual rainfall time series. We can say that the sudden increase of precipitation in recent decades makes the averages of the second sub-series larger. Results showed that inspite of wide range human induced changes, stream-flow series is more affected from the watershed rainfall time series variations. In addition, significant decreasing trend in the two sub-series can be due to the following causes: the growth of population, temperature rise, construction of three dams on the Karun River, implementing the different projects for developing agricultural, and conservation from soil and water resources.**

**Key words:** Pettit test, Mann-kendall test, annual stream-flow series, Ahvaz hydrometric station.

## INTRODUCTION

We will evaluate the extreme conditions of the stream-flow series of the annual maximum in Ahvaz hydrometric station which is located in southwest of Iran. These conditions can be used to design spillways of dams and determine dimensions of culverts. It is apparent that the stream-flow series of the annual minimum could have influence on the environmental and ecological studies. For instance, when stream-flow of the Yellow River

*Corresponding author. E-mail: meysam.salarijazi@gmail.com.

decreased, it had a great impact on the economy of the delta and on the ecology of the adjacent sea (Cui, 2002).

In addition, the reduction in stream-flow reduced sediment supply and caused coastal erosion in many river systems (Yang and Saito, 2003). The various developments made by human activity and hydro climatic changes can alter the time series of a stream-flow. Determining of trends in long term stream-flow is an important tool to detect any modification in hydrological systems (Chang, 2007). The use of historical observation record is an important tool for obtaining a clearer understanding of what the future will hold (Blӧschl and Montanari, 2010). In water resources, water structures and environmental planning studies, the used hydrological time series are supposed to meet a set of ideal conditions, such as being trend-free and without change points. In many studies, the hydrological time series from many regions demonstrate significant change point or trend due to the influence of climate change and/or large-scale human activities on the water resources systems. Trend-free mean shows that there is no significant correlation between the observed time series and time. A statistically significant trend shows only if changes are strong enough and the time series is long enough (Radziejewski and Kundzewicz, 2004). Many researchers investigated the existence of trend in stream-flow time series. Walling and Fang (2003) stated that in recent decades, about 22% of the world’s rivers showed significant decrease in annual stream-flow and about 9% of them showed significant increasing trends. The reduction in the annual stream-flow is due to water consumption, diversion and reservoir construction, which led to great environmental problems as reported in the study of Yang and Saito (2003). Increase in stream-flow usually occurs in high latitude rivers (Manabe et al., 2004). For instance, the annual stream-flow in Sweden was increased by 5% over the past century (Lindström and Bergström, 2004). A number of recent studies in the USA have detected the presence of trends in stream-flow data (McCabe and Wolock, 2002). Similar studies have been conducted by Khaliq et al. (2009) to investigate the trend in low flows in Canadian rivers, and Kumar et al. (2009) assessed the trend in stream-flow in India. Mudelsee et al. (2003, 2004) studied two rivers flood time series in eastern part of Germany, and found a decrease trend in winter floods and no trends for summer floods. In Switzerland, Birsan et al. (2005) found an increasing trend in annual stream-flow. Kundzewicz et al. (2005) analyzed 70 stations over Europe and found that 11 of them showed statistically significant increasing trends and nine decreasing trends. Wang et al. (2005a, b) analyzed annual maximum discharge series for 12 rivers in Western Europe over the last century and found statistically significant increasing and decreasing trend. Pekarova et al. (2006) analyzed annual run-off series for major European rivers and did not find long-term trends. Petrow and Merz (2008) found increasing trends mostly in flood peaks in Germany and ascribed these results to climate changes. Generally, increasing trends in Germany were found by Petrow et al. (2009) as well. Moreover, seasonal analyses highlighted how these changes were larger during the winter than the summer. Schmocker-Fackel and Naef (2010) examined 83 stations in Switzerland and found that almost half of them exhibited a statistically significant trend.

Fu et al. (2007) stated that climate variability had a significant impact on stream-flow and it was sensitive to both precipitation and temperature in the Yellow River basin. Gao et al. (2009) studied annual stream-flow and sediment discharge in the Wuding River and stated that there was a significant decreasing trend. Many other studies have documented that human and economic activities might play an important role in stream-flow and sediment discharge reduction in the Yellow River basin (van den Elsen et al., 2003; Huang and Zhang, 2004; Mu et al., 2007; Gao et al., 2010, 2011). Existence of change point implies that all the collected data belong to the same statistical population. Also, many researchers investigated about the existence of change point in observed time series. Villarini et al. (2011) suggested that before evaluation of trend in hydrological time series, change point test must be applied on time series. Abrupt changes, both in mean and variance, can be associated with both climatic for example, shifts in climate regimes (Potter, 1976; Hare and Mantua, 2000; Alley et al., 2003; Swanson and Tsonis, 2009) and anthropogenic effects (for example, construction of dams and systems of reservoirs, changes in land use/land cover and agricultural practice, stream-flow gage relocation) (Potter, 1979; Villarini et al., 2009).

Statistical analysis results must be interpreted in combination with observed physical phenomena (Gedikli et al., 2010). In this paper, we will investigate the following issues:

1. Do long term stream-flow series show change points or statistically significant trends in Ahvaz hydrometric station?
2. What is the magnitude (and its significance level) of these change points or trends?
3. If there are change points in the stream-flow series, will the two sub-series (before and after the change point(s)) have an increasing or a decreasing trend?

## MATERIALS AND METHODS

### Case study

Watershed of the Karun river is located in south west of Iran (Khuzestan, Isfahan, Chaharmahal and Bakhtiari, Loristan and Kohgiluyeh and Boyer-Ahmad Provinces). The longitude of this watershed is 48 to 52° eastern and the latitude of this watershed is

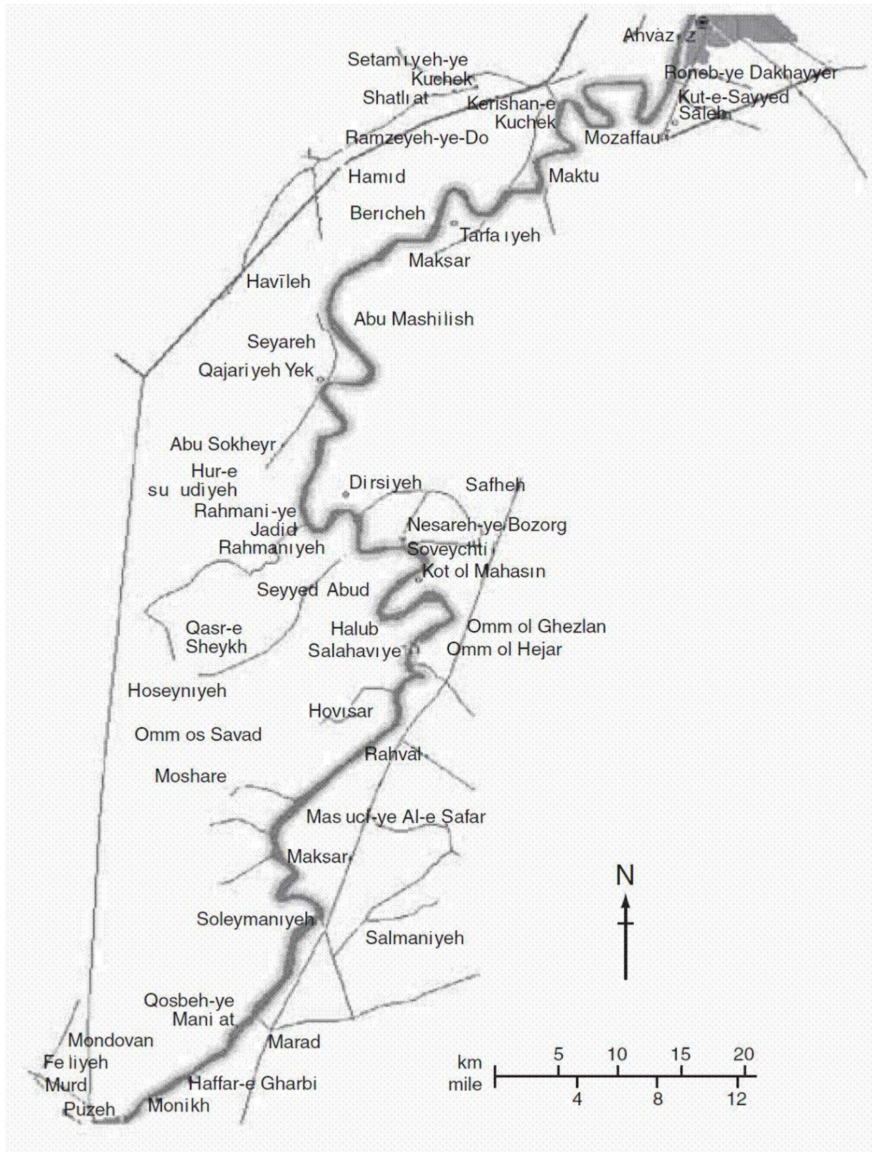


**Figure 1.** The map of watershed of the Karun River.

30 to 34° 15' northern. The area of this watershed is 67500 $km^2$ and its mean of precipitation is 550 mm. The source of the Karun river is Zard Kuh (height 4548 m) in the Zagros Mountains and this river connects to the Arvand Rood River in Khorramshar (height 12 m). The height range of the watershed of this river is very widespread. This point and special characteristics of the Zagros Mountains cause relative heterogeneous climatic conditions. The map of this watershed is shown in Figure 1.

The Ahvaz hydrometric station was constructed on the Karun river in 1950. This station is located at the south of Mola Sany hydrometric station (longitude 48° 41' eastern and latitude 31° 20' northern). The height of this station is 39 m above the sea level. Figure 2 shows stream-flow series of the annual maximum, annual minimum and annual mean while Table 1 shows maximum, minimum and mean value of these series. The data regarding these time were recorded from 1954 to 2005.

**Change point test**

A number of methods can be applied to determine change points of a time series (Buishand, 1982; Chen and Gupta, 2000; Radziejewski et al., 2000). In this study, the non-parametric Pettitt change point test is used to detect occurrence of the abrupt change (Pettitt, 1979). It is a rank-based and distribution-free test for detecting a significant change in the mean of a time series and it is particularly useful when no hypothesis required to be made about the location of the change point. The Pettitt test has been widely applied to detect changes in the observed climatic as well as observed hydrological time series (Verstraeten et al., 2006; Mu et al., 2007; Zhang and Lu, 2009; Gao et al., 2011). The Pettitt test is also applicable for testing an unknown change point by considering a sequence of random variables X1, $X_2$,., $X_T$, which have a change point at $\tau$ . As a result, $(X_1, X_2,..., X_\tau)$ have a common distribution

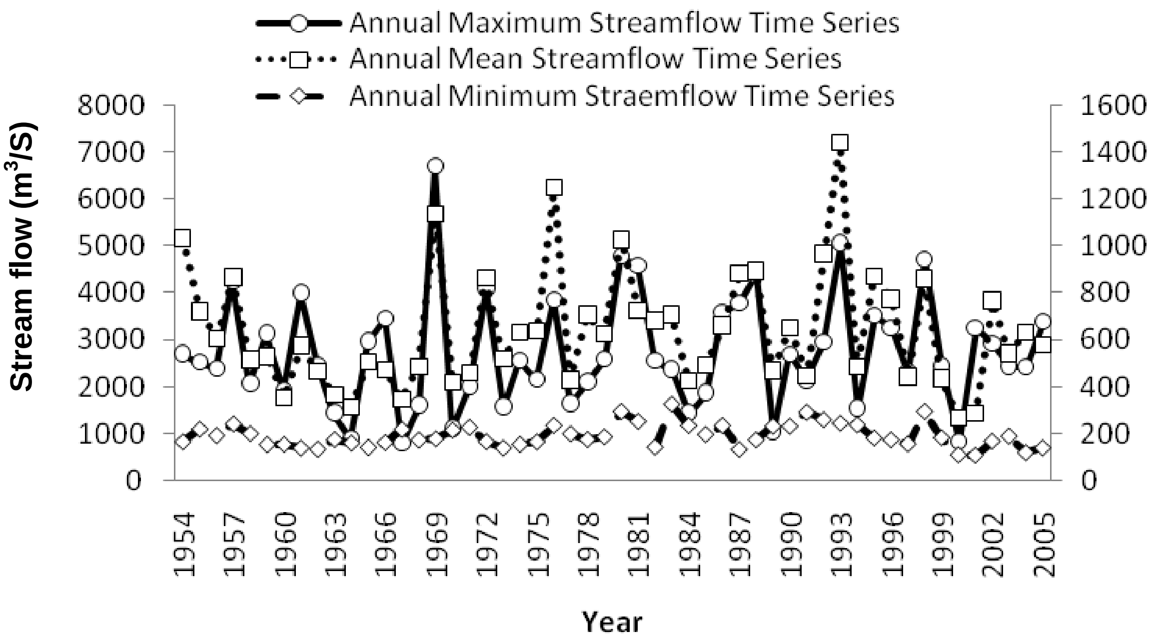


**Figure 2.** Stream-flow series of the annual maximum, annual minimum and annual mean.

**Table 1.** The maximum, minimum and mean value of stream-flow series of the annual maximum, annual minimum and annual mean.

| Stream-flow series | Maximum value (CMS) | Minimum value (CMS) | Mean value (CMS) |
|---|---|---|---|
| Stream-flow series of the annual maximum | 6704 | 800 | 2756 |
| Stream-flow series of the annual minimum | 328 | 107 | 192 |
| Stream-flow series of the annual mean | 1442 | 269 | 641 |

function $F_1$ (.), but ($X_{\tau+1}$, $X_{\tau+2}$,..., $X_T$) are identically distributed as $F_2$ (.), where $F_1$ (.) ≠ $F_2$ (.). The null hypothesis $H_0$: no change (or τ=T); is tested against the alternative hypothesis $H_1$: change (or 1≤ τ <T); using the non-parametric statistic $K_T = \max|U_{t,T}| = \max\ (K_{T+}\ ,\ K_{T-})$ where:

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \text{sgn}(X_t - X_j) \quad (1)$$

$$\text{sgn}(\theta) = \begin{Bmatrix} 1 & \theta > 0 \\ 0 \quad if & \theta = 0 \\ -1 & \theta < 0 \end{Bmatrix} \quad (2)$$

$K_{T+}$=max $U_{t,T}$ for downward shift and $K_{T-}$=-min $U_{t,T}$ for upward shift (Kahya and Kalayci, 2004).The confidence level associated with $K_{T+}$ or $K_{T-}$ is determined approximately by:

$$\rho = \exp\left(\frac{-6K_T^{\,2}}{T^3+T^2}\right) \quad (3)$$

When p is smaller than the specific confidence level, for example, 0.95 in this study, the null hypothesis is rejected. The approximate significance probability for a change-point is defined as:

P=1−ρ.

It is obvious that where a significant change point exists, the series is segmented at the location of the change point into two sub-series.

The main aim of this study is to investigate the existence of the change points in the stream-flow characteristics time series. We present some tests to detect and the possible change points. When a significant change point exists, a ratio of the mean values for the segments after and before the change point will be used to assess the magnitude of the change point. In time series showing a significant change point, the trend test will be applied on the sub-series, and if the change point is not significant, the trend test will be applied on whole time series.

**Trend test**

In order to investigate about the trend in a given time series, one can use the Mann-Kendall test. Mann (1945) originally used this test and Kendall (1975) subsequently derived the test statistic distribution. This test is distribution-free and we are not required to assume any special form of the distribution function of the data, including censored and missing data (Yue et al., 2002). This test has been recommended widely by the World Meteorological Organization for public application (Mitchell et al., 1996). Furthermore, Hirsch et al. (1982), Burn and Elnur (2002), Yue and Pilon (2004), Kahya and Kalayci (2004) and Yue et al. (2003) have used this test for evaluating the trend of water resources data. Thus, the Mann–Kendall (MK) test has been found to be an excellent tool for trend detection by other scholars in similar applications. It should be noticed further that the MK test considers only the relative values of all terms in the series, $X = \{x_1, x_2, ..., x_n\}$ to be analyzed. The MK test statistic is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i) \quad (4)$$

Where xi and xj are the sequential data values, n is the number of the recorded data.

Under the null hypothesis of no trend, and this facet that the data are independent and identically distributed with zero mean and the following variance of S denoted by $\sigma^2$ is computed as:

$$\sigma^2 = \frac{n(n-1)(2n+5)}{18} \quad (5)$$

The standard normal variant is then used for hypothesis testing, and is designated here as the trend test statistic illustrated by Z, as follows:

$$Z = \begin{cases} \frac{S-1}{\sigma} & S > 0 \\ 0 \quad if & S = 0 \\ \frac{S+1}{\sigma} & S < 0 \end{cases} \quad (6)$$

Thus, in a two-tailed test for the trend, the null hypothesis presented as: $H_0$: there is no trend in the data set, will then be rejected if the calculated Z statistics is greater than the critical value of this statistics obtained from the standard normal distribution table corresponding to the pre-specified significance level. The positive value of Z shows increasing trend and the negative value shows decreasing trend.

### Sen's slope estimator

The trend magnitude is estimated using a non-parametric median based slope estimator proposed by Sen (1968) and extended by Hirsch et al. (1982). The slope estimation is given by:

$$\beta = Median\left[\frac{x_j - x_k}{j-k}\right] \quad for \quad all\ k < j \quad (7)$$

Where $1 < k < j < n$, and β is considered as median of all possible combinations of pairs for the whole data set.

## RESULTS

Figure 3 shows occurrence of the change point in stream-flow series of the annual maximum, annual minimum and annual mean, respectively. The Pettitt change point test, explained earlier is used for this purpose. Using this test, we cannot find any statistically significant change point at 1 and 5% significance level.

In order to determine the direction and evaluate the trend of the stream-flow series in Ahvaz hydrometric station as explained in the previously, we use the non-parametric Mann-Kendall test. These series illustrate positive trend but their trend are not significant (at 1 and 5% significance level). In addition, the slope estimation presented in Equation 7 was calculated for the variations of this stream-flow. Table 2 shows results of the Mann-Kendall test and the Sen's slope estimator. Karun River's watershed experienced varied changes in hydro climatic variables and human activity. Investigation of annual rainfall showed some of the series have significant change points and some of them have non-significant change points which showed that the average of second sub-series is more than the first one. The occurrences of these change points were between 1970 and 1980 and the observed trends in most of the sub-series were decreasing (Ameriun et al., 2011). Results of change point and trend test on annual rainfall series at Ahvaz and Shahrekord stations was illustrated in Figures 4 and 5. These results showed that watershed experienced drought period before 1980. Watershed population has increasing trend and many soils and water conservation project is performed in the last decades. Average annual temperature also has an increasing trend (Salarijazi et al., 2011). Stream-flow series have decreasing trend in recent decade.

Considering interaction of the mentioned component, increasing trend in stream-flow series is not reliable. Observed data perception is essential in statistical results analysis. Considering different mentioned component, stream-flow time series was divided into two sub-series with respect to Pettitt test statistic values. The values of Pettitt test statistic were maximum between 1970 and 1980. Mann-Kendall test and Sen's slope estimator was applied on produced sub-series. Table.2 shows results. Results demonstrated that in spite of the increasing trend in stream-flow series, all of the sub-series have a decreasing trend and two sub-series have significant decreasing trend. In one hand, the average of the second parts of the sub-series is more than the first part. The ratio of the average of the sub-series after the change point relative to the average prior to the change point was calculated as magnitude of change point. Magnitude of change points were 1.34, 1.16 and 1.2 for annual maximum, annual minimum and annual mean series respectively. Variations of mean of values and slope of variations of stream-flow per time are shown for sub-series in Figures 6, 7 and 8.

## Conclusion

Because of the different water resources, soil and water

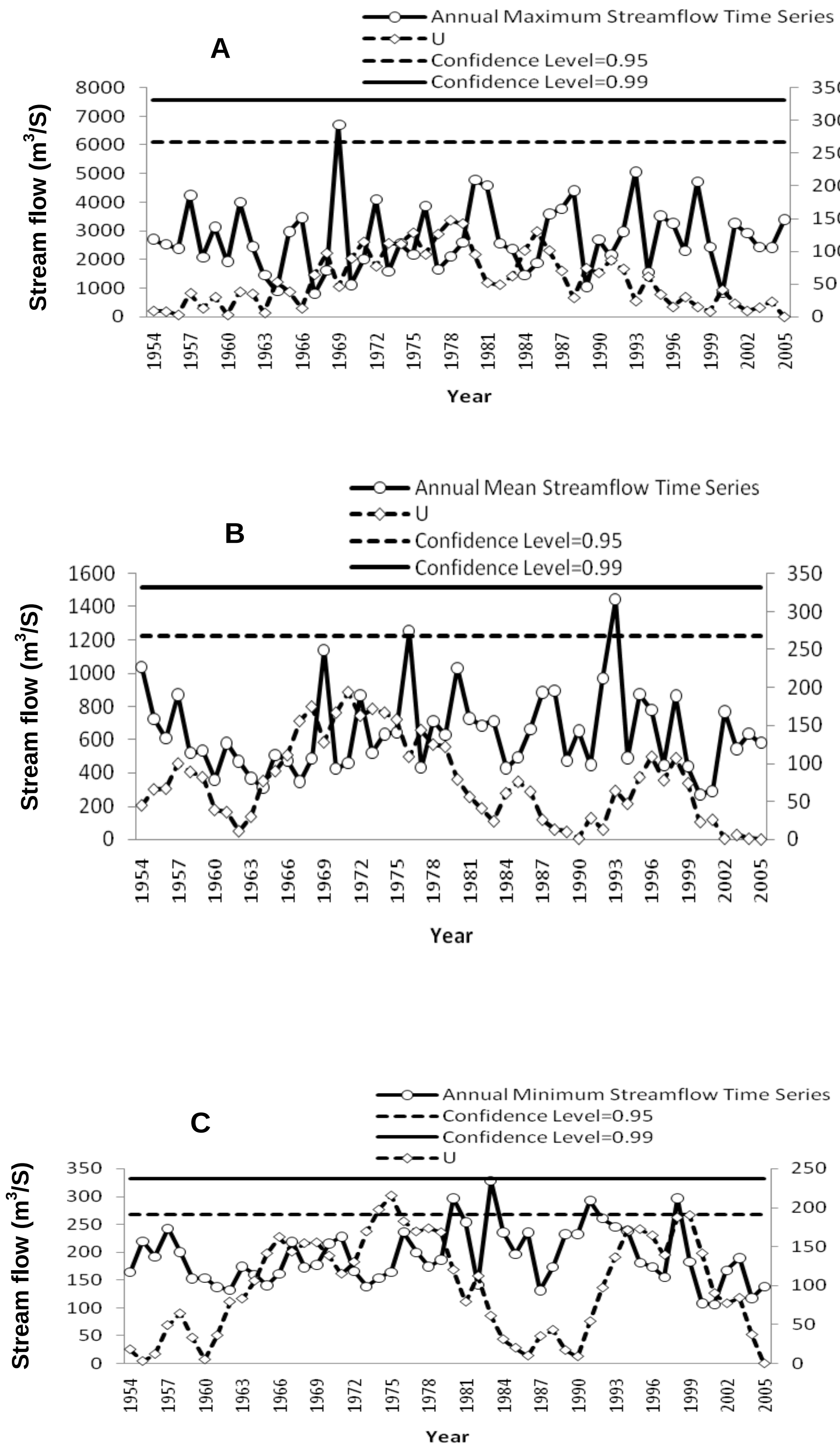


**Figure 3.** The results of applied Pettitt change point test to stream-flow series at Ahvaz hydrometric station.

**Table 2.** Results of applied Mann-Kendall test and Sen's slope estimator to stream-flow series and sub-series.

| Time series | Slope of variation of stream-flow per time (CMS/year) | The Mann-Kendall test statistics (significance level 5%) | Mean of stream-flow (CMS) |
|---|---|---|---|
| Stream-flow series of the annual maximum | 8.77 | 0.73 | 2756 |
| First sub-series of stream-flow series of the annual maximum | -22.45 | -0.67 | 2577 |
| Second sub-series stream-flow series of the annual maximum | -7.67 | -0.45 | 2922 |
| Stream-flow series of the annual minimum | 0.31 | 0.56 | 192 |
| First sub-series of stream-flow series of the annual minimum | -0.5 | -0.39 | 176 |
| Second sub-series stream-flow series of the annual minimum | -2.76 | -2.24 | 204 |
| Stream-flow series of the annual mean | 0.91 | 0.43 | 641 |
| First sub-series of stream-flow series of the annual mean | -16.52 | -2.19 | 566 |
| Second sub-series of stream-flow series of the annual mean | -3.99 | -1.15 | 680 |

conservation, agricultural and environmental projects, Karun River watershed is one of the most important watersheds in Iran. It is important to investigate the effect of different projects on stream-flow series. The Ahvaz hydrometric station was located at distance 200 km from Persian Gulf. Because of the location of Ahvaz hydrometric station, tidal surges affect hydrometric stations that are located in the downstream of Ahvaz hydrometric station. Tidal effects cause the measurement of stream-flow to be impossible in these stations. Investigation of changes of stream-flow series is essential for planning in different stations that are located in the downstream of Ahvaz. Therefore, occurrence of the change point and existence of the trend in stream-flow series and its sub-series of Ahvaz hydrometric station can be used for the hydrometric stations that are located in its downstream. Human activities and the changes of hydro climatic conditions would extremely vary in the characteristics of the watershed of the Karun River in recent decades. The Dez dam and the Karun 1 (Shahid Abbaspour) dam were constructed on the Karun River in 1961 and 1975, respectively. These dams were located in the upstream of Ahvaz hydrometric station.

In addition, the growth of population of this watershed is very high in the recent decades. On the other hand, there have been several great projects which were implemented for conservation and exploitation from water and soil resources in this watershed such as, agricultural projects and preservative projects against water and wind erosion. The observed data showed that the mean annual temperature has an increasing trend (Salarijazi et al., 2011) while stream-flow of the annual maximum, annual minimum and annual mean have decreasing trend in the recent decades. This finding is in contrast with the results obtained based on using the Mann-Kendall test. Therefore, we recommend the use of the Pettitt test in this situation. The stream-flow series reach maximum value of the Pettitt test statistics in the interim 1970 to1980. The stream-flow series was divided into two sub-series in the point that value of the Pettitt test statistics was maximum. Although, the Mann-Kendall test shows increasing trend for the three time series (stream-flow of the annual maximum, annual minimum and annual mean series) but this test illustrated that six sub-series have decreasing trend. Furthermore, this test indicates a significant trend for the two sub-series. Ameriun et al. (2011)

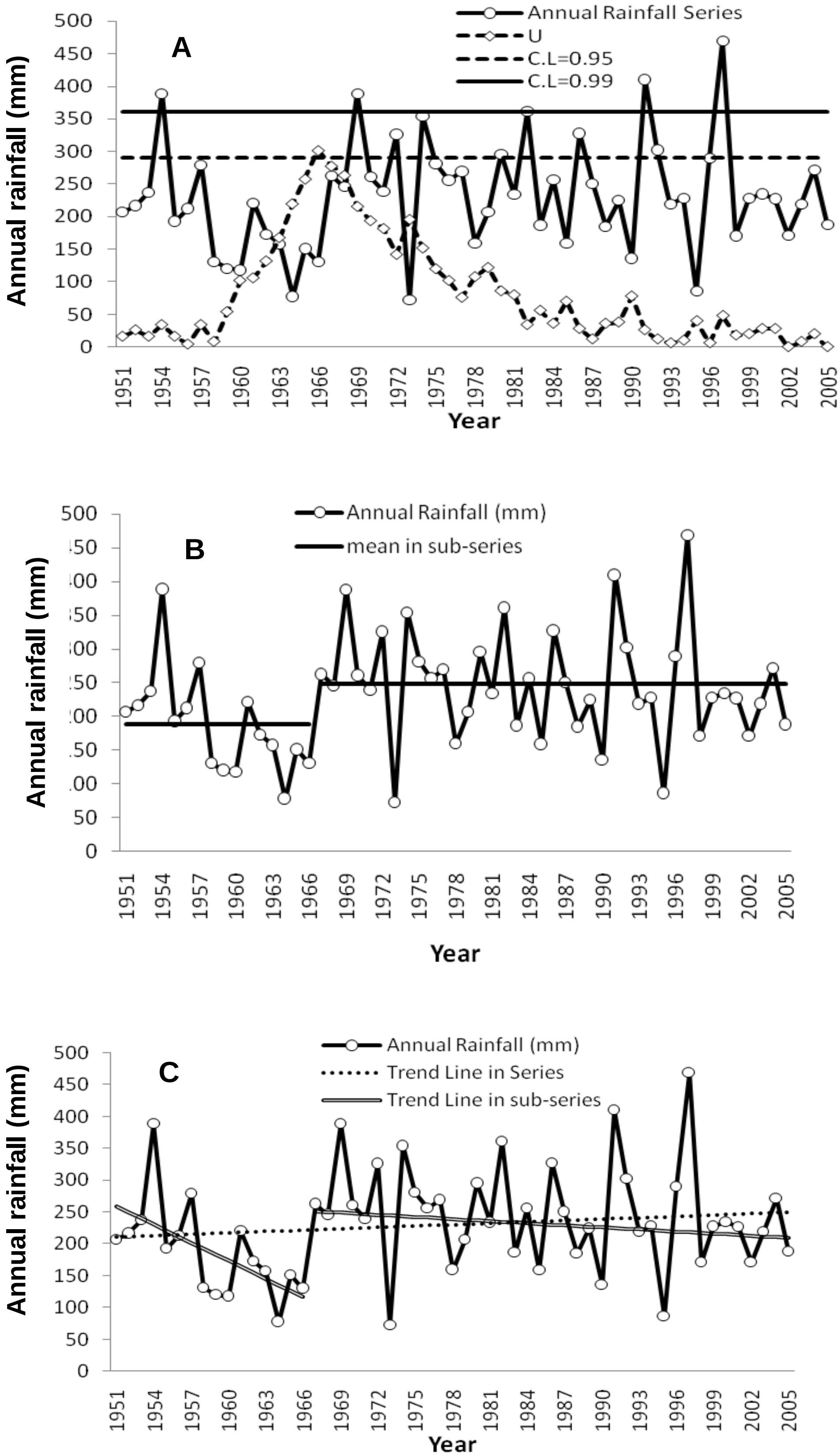


**Figure 4.** The variations of annual rainfall at Ahvaz station.

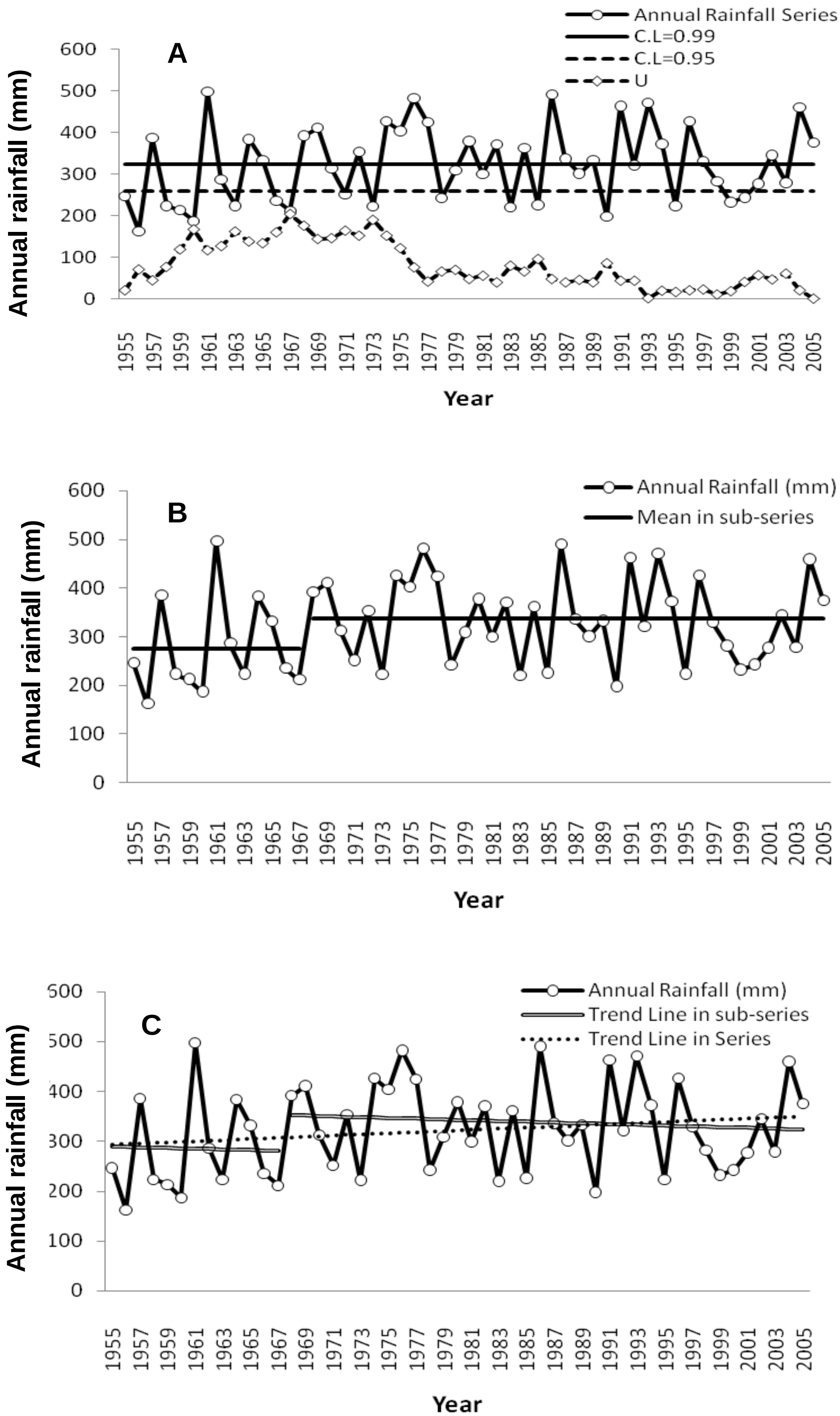


**Figure 5.** The variations of annual rainfall at Shahrekord station.

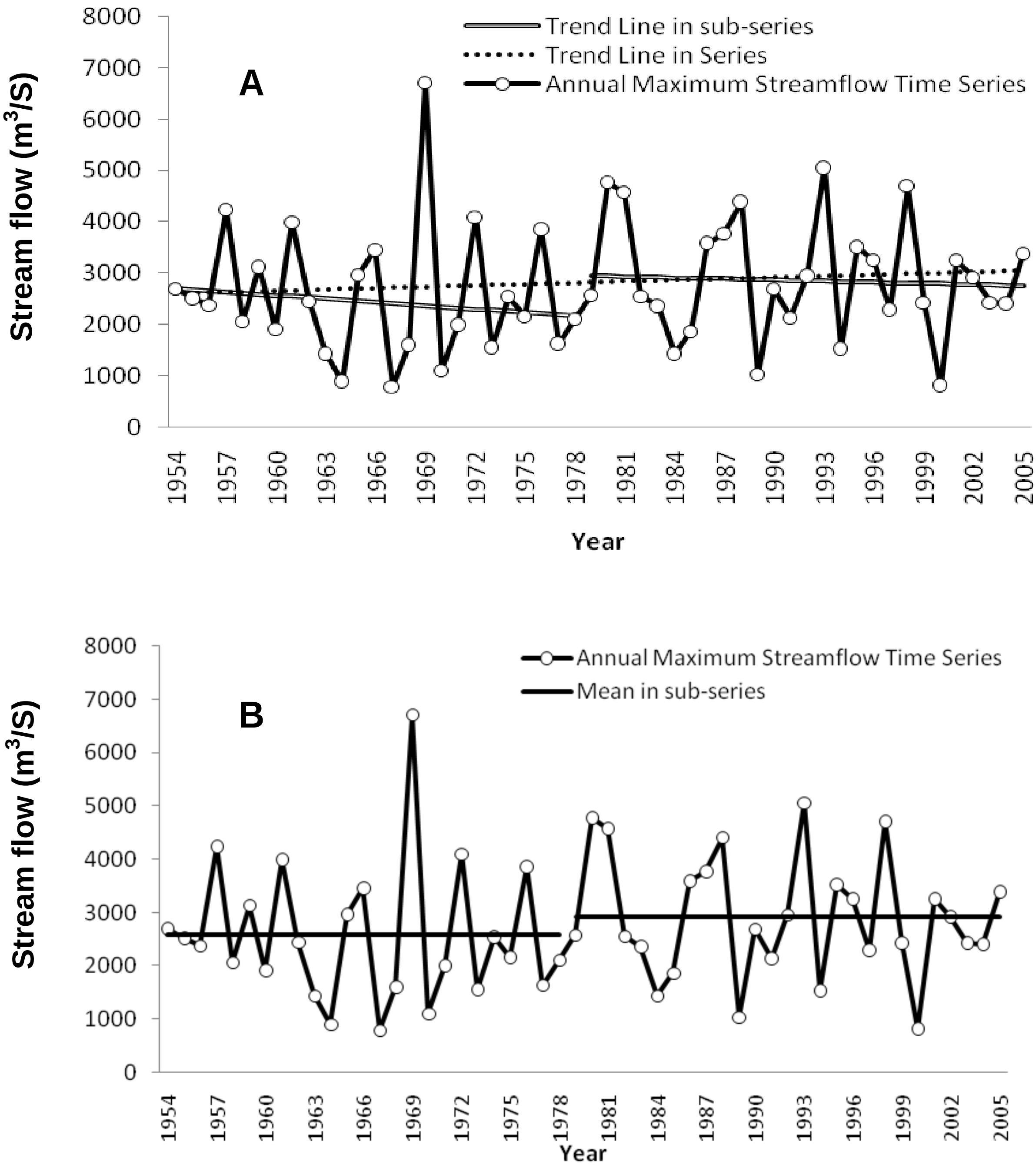


**Figure 6.** The variations of mean values and slope over time regarding the two sub-series of stream-flow series of the annual maximum.

reported significant and non-significant change points in annual rainfall between 1970 and 1980 in the watershed. The results of this research showed decreasing trend in most sub-series. Also, it was revealed that the magnitude of change points were positive. The pattern of trend in sub-series and the occurrences of change points in stream-flow series and annual rainfall are relatively similar. Thus, we can conclude that the effects of hydro climatic conditions are more important than the effects of human activities such as construction of dams, performance of great projects for conservation and exploitation from water and soil resources. Despite the rainfall effect, decreasing trend in sub-series can also be due to human induced activity.

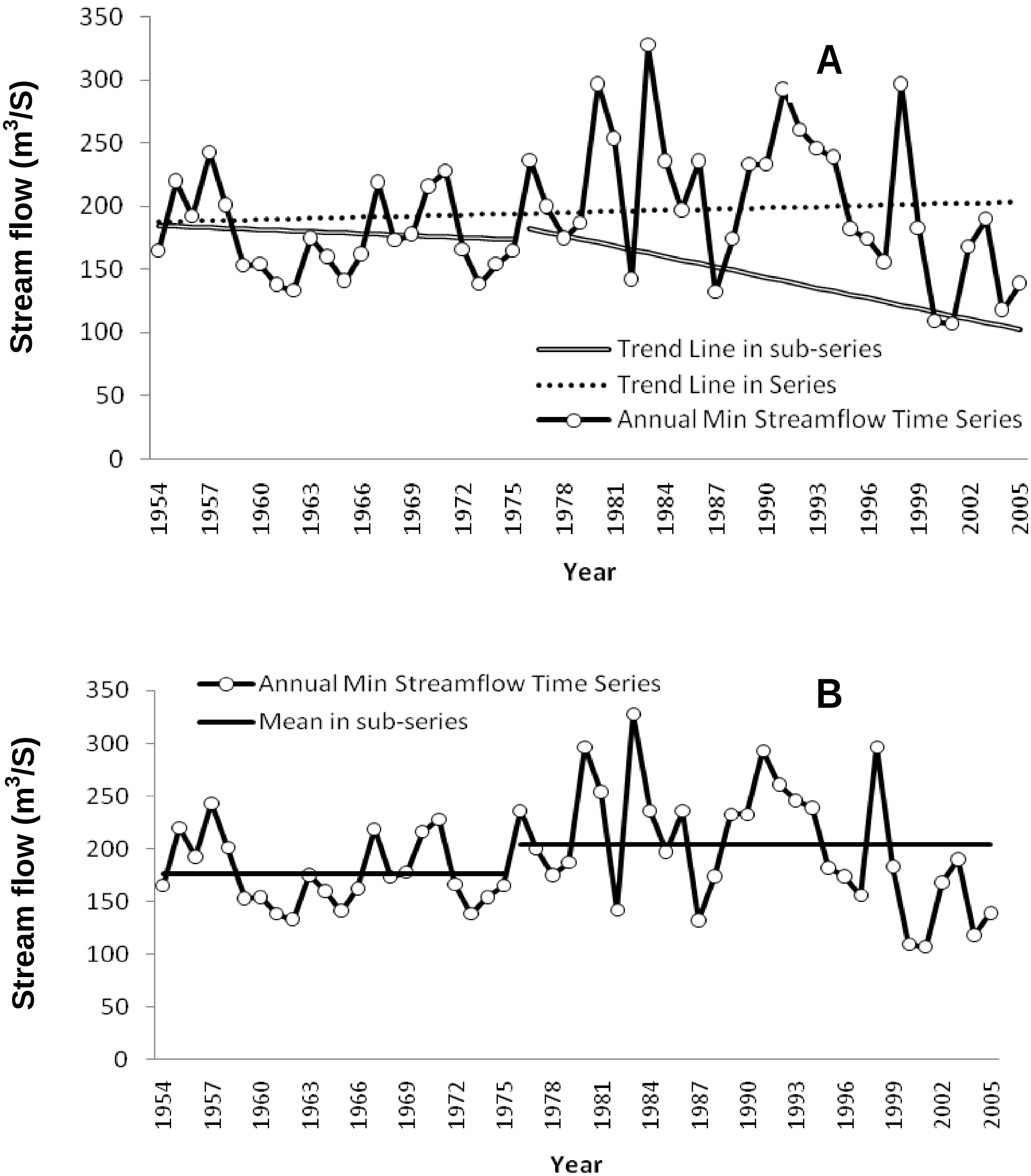


**Figure 7.** The variations of mean values and slope over time regarding the two sub-series of stream-flow series of the annual minimum.

Especially, dam construction can affect annual maximum series decreasing trend. With respect to for instance, long distance between dams and hydrometric station, these results can reliable. The results of this research is consistent with the report of Fu et al. (2007) and can be utilized for ecological and environmental planning, design of agricultural projects and hydraulic structures and risk analysis.

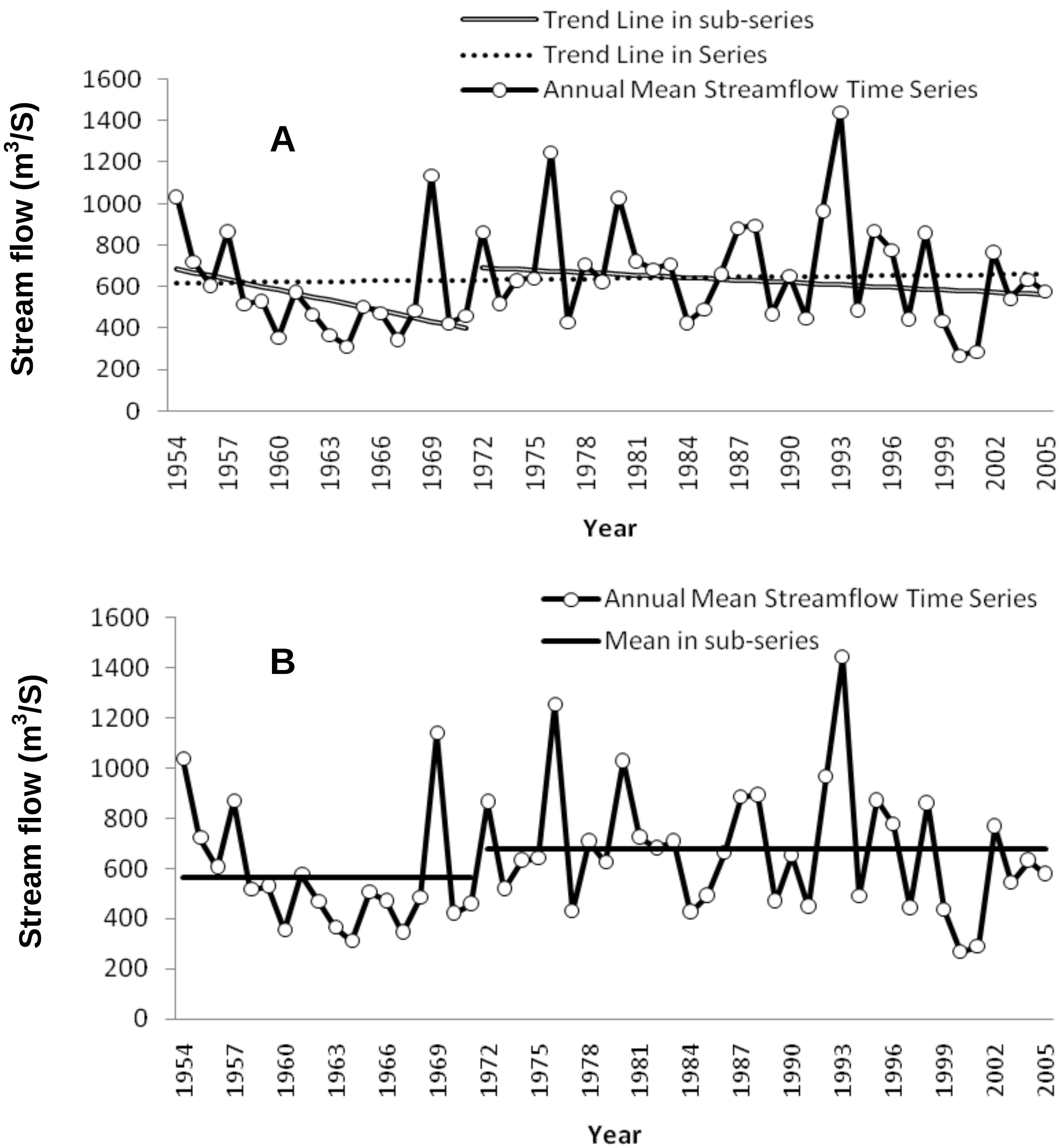


**Figure 8.** The variations of mean values and slope over time regarding the two sub-series of stream-flow series of the annual mean.

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