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Temperature series analysis of the Hirfanli Dam Basin with the Mann-Kendall and Sequential Mann-Kendall tests

Utku Zeybekoglu *1

[1]*Sinop University, Construction Department, Türkiye*

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Abstract
Global warming is a result of the greenhouse effect caused by the gases released into the atmosphere; It is usually expressed as an increase in the measured average temperatures. In addition to this, extreme weather events such as droughts, floods, and severe hurricanes become more frequent, and the specified extreme events become more severe. The effects of global climate change on hydrological and meteorological variables are increasing day by day. Therefore, hydro-meteorological parameters should be examined carefully. In this study, the effects of global climate change on the Hirfanli Dam Basin temperature series were investigated using the Mann-Kendall Test and Sequential Mann–Kendall Test. The annual mean temperature series of six stations recorded between 1965 and 2017 were analyzed and evaluated. It has been determined that the annual mean temperature has increased throughout the basin and significant increases started since the 1990s. Researches analysing the effects of global climate change on hydro-meteorological parameters related to the Hirfanli Dam Basin should be increased. These studies may be the investigation of the trends of climate parameters with different methods, as well as their relations with global atmospheric indices such as the North Atlantic Oscillation and Southern Oscillation. In the Hirfanlı Dam Basin, which shows semi-arid climate characteristics, especially drought disaster should be investigated. In addition to drought detection, these studies should be conducted with an integrated disaster management perspective in order to prepare for drought disasters. With the perspective of integrated disaster management, it will be more resilience to disasters with plans in which all components in the basin are together and effective against many disasters, especially drought.

1. Introduction

Natural resources are of great importance in the rapidly developing world with the industrial revolution. The natural resources needed by industrialization started to be consumed quickly and unconsciously in this process. In addition, urbanization around the world has also accelerated by means of the industrial revolution. Subsequently, harmful gases emerged as a result of industrialization and urbanization. Considering the decreasing natural resources, this situation has caused changes in the world climate. Therefore, the causes and effects of climate change are being studied intensively by scientists.

Global climate change has become an important problem affecting civilization around the world. Global climate change manifests itself to different degrees in various geographies in Turkey. These effects were investigated using hydro-meteorological climate parameters [1–18].

Keskin et al. [19] examined the effects of global climate change on the Eastern Anatolia region by using precipitation and temperature parameters. The increasing trend in temperature series was determined at 12 stations except for Erzurum and Bitlis, increasing trends of precipitation series were determined in Kars and Ardahan. Ulke Keskin and Ozkoca [20] investigated the changes in temperature series of the Central Black Sea Region with the Mann-Kendall (MK) Trend Test and Sen's Trend Slope Test. They stated that the temperatures in the region are in an increasing trend. Köyceğiz and Buyukyildiz [21] researched the trends of annual average temperature, maximum temperature and minimum temperature data of Konya Closed Basin, stating that more than 80% of the annual temperature series has a statistically significant increasing trend.

* **Corresponding Author**
*(utkuz@sinop.edu.tr) ORCID ID 0000-0001-5307-8563

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In this study, the annual temperature series of the Hirfanli Dam Basin, which is stated to have drought climate characteristics in the literature [22–24], were investigated using MK Test and Sequential Mann-Kendall (S-MK) Test methods.

2. Material and Method

2.1. Study area and Data

The sub-basin containing the Hirfanli Dam Basin, which is located between 33.3°E and 38.7°E longitudes and 38.3°N and 40.1°N latitudes, is within the Kizilirmak River Basin, and has a surface area of approximately 26700 km^2. In the basin, the altitude varies between 799 and 3880 m (Figure 1). The east part of the basin is the hilliest region of the basin, which consists of high peaks and is bordered by mountainous areas. Plateaus, wide plains, and meadows are more common in the west part of the basin. The Hirfanli Dam, which was built on the Kizilirmak River in 1959 for flood control and hydropower purposes, has a surface area of 263 km^2 and reservoir volume of 5,980 hm^3 at normal water surface level [22–24].

Annual temperature data of stations in the basin were procured from the Turkish State Meteorological Service (TSMS). Descriptive statistics (Minimum, maximum, mean, Std. Dev., Variation, Skewness and Kurtsosis) of temperature records between 1965 and 2017 are shown in Table 1. The graphs of the temperature series for each station in the Hirfanli Dam Basin are given in Figure 2 The mean temperature is around 10.02°C and also the annual temperature decreases from the upstream to the downstream due to the increase in altitude (Figure 3) [23].

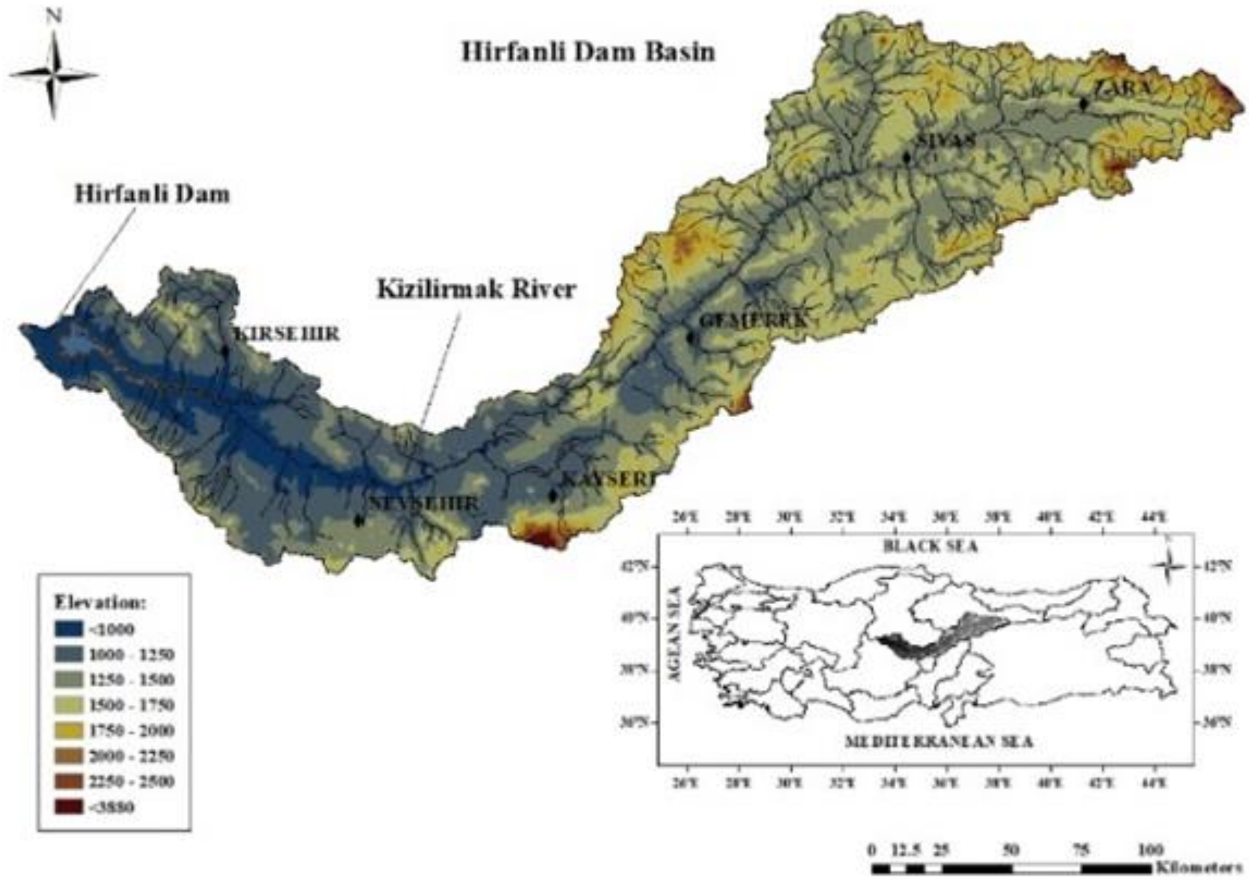

Figure 1. Geographical distributions of stations in Hirfanli Dam Basin [26]

Table 1. Descriptive statistics of temperature records of stations used in this study

°C	Gemerek	Kayseri	Kirsehir	Nevsehir	Sivas	Zara
Min.	6.94	8.41	9.43	8.49	6.64	5.94
Max.	11.77	13.23	13.78	13.64	11.99	11.27
Mean	9.63	10.52	11.46	10.69	9.17	8.63
Std. Dev.	0.96	1.03	0.84	0.98	1.04	0.96
Variation	0.92	1.06	0.71	0.97	1.07	0.92
Skewness	0.06	0.22	0.33	0.40	0.23	-0.14
Kurtosis	0.40	-0.06	0.35	0.48	0.43	0.92

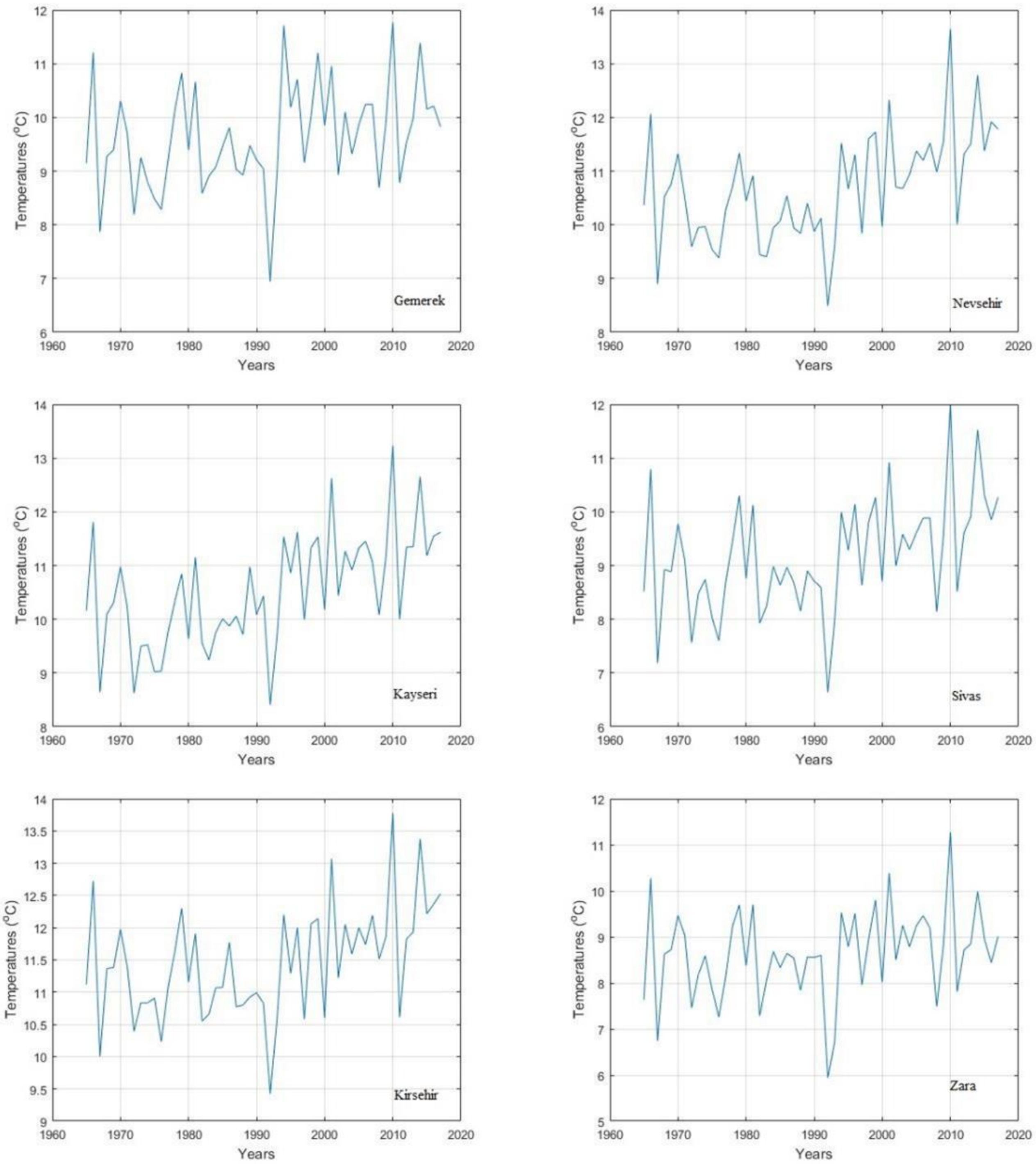

Figure 2. Temporal distribution of temperature records of station

2.2. Mann Kendall (MK)Trend Test

The MK test is independent of the distribution of variables [27–28]. Whether there is a tendency in the time series is tested by the null hypothesis (H_0: no trend) [29–31]. The pairs x_i, x_j in the series x_1, x_2, ..., x_n are divided into two groups. The test statistic (S) is expressed by Equation (1), where for i <j the number of pairs with $x_i < x_j$ is P and the number of pairs with $x_i > x_j$ is M. Kendall correlation coefficient with Equation (2); variance is calculated by Equation (3). If there are equal values in observations in the series, the variance value is calculated using Equation (4).

$$S = P - M \tag{1}$$

$$\tau = \frac{S}{\left[{n(n-1)}/{2} \right]} \tag{2}$$

$$\sigma_s = \sqrt{\frac{n(n-1)(2n+5)}{18}} \tag{3}$$

$$\sigma_s = \sqrt{\frac{n(n-1)(2n+5) - \sum t_i(t_i-1)(2t_i+5)}{18}} \tag{4}$$

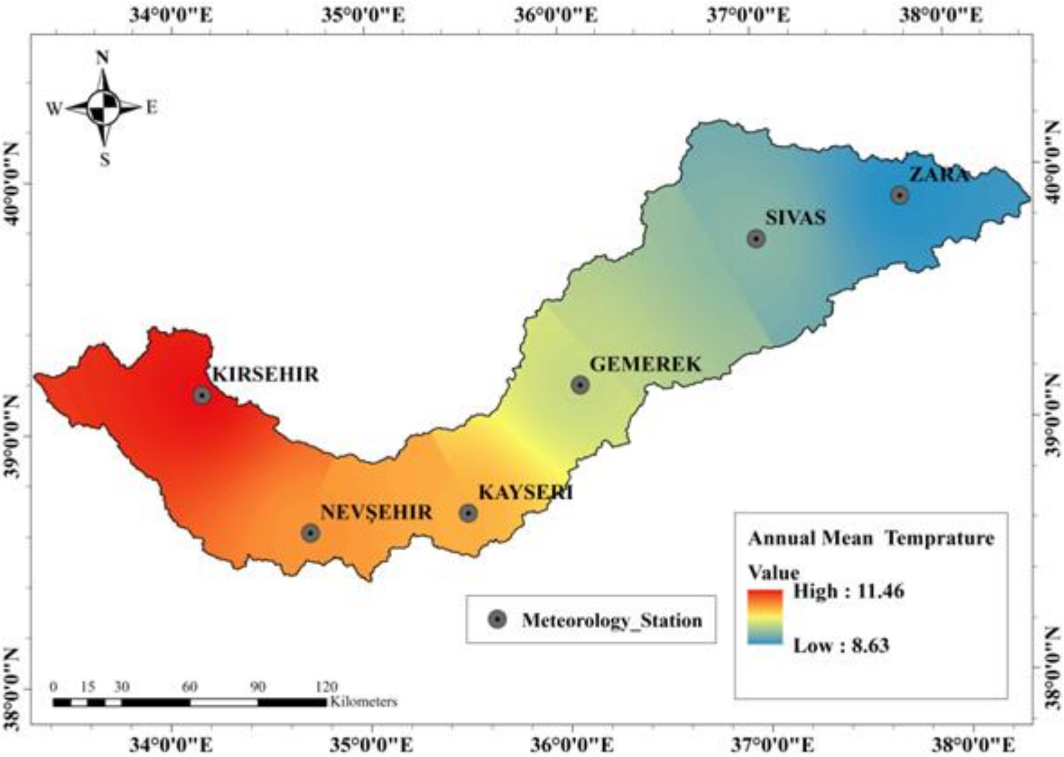

Figure 3. Spatial distribution of annual temperature series

Standardized MK test statistics are calculated by Equation (5).

$$\begin{matrix} \frac{(S-1)}{\sigma_s} & ; & S>0 \\ 0 & ; & S=0 \\ \frac{(S+1)}{\sigma_s} & ; & S<0 \end{matrix} \qquad (5)$$

If the absolute Z obtained by Equation (5) is less than the critical Z of the normal distribution corresponding to the selected α significance level, the H_0 is accepted; otherwise, the existence of the trend is determined. Positive values indicate the presence of an increasing trend, while negative values indicate a decreasing tendency [32].

2.3. Sequential Mann Kendall (S-MK) Test

The S-MK Test is used to find out whether the series increases or decreases over time. While the test presents the results graphically, it can also determine the starting point of the trend [33].

The t value, which is the test statistic, is calculated by summing the n_i values obtained by counting the smaller ones from the previous ranks for each rank. Mean value of t's is calculated by Equation (7); variance Var(t) is calculated by Equation (8) and Test statistic u(t) is calculated by Equation (9). The backward test statistic u'(t) is calculated similarly to u(t) [34-35].

The point where u(t)-u'(t) intersect shows where the trend starts [33].

$$t = \sum_{i=1}^{n} n_i \qquad (6)$$

$$E(t) = \frac{n(n-1)}{4} \qquad (7)$$

$$Var(t) = \frac{n(n-1)(2n+5)}{72} \qquad (8)$$

$$u(t) = \frac{\left(t - E(t)\right)}{\sqrt{Var(t)}} \qquad (9)$$

3. Results and Discussion

The MK Trend Test was applied to identify the tendency in the Hirfanli Dam Basin stations recorded by TSMS in the period of 1965-2017. The results of the analyzes performed at 95% confidence levels are shown in the Table 2.

An upward trend has been determined in all stations in the basin except Zara. Upward trends in Gemerek, Kayseri, Kirsehir, Nevsehir and Sivas stations are statistically significant ($Z>Z_{Cr}$).

In order to determine the starting time of the tendency, S-MK Test was applied to the temperature time series obtained from Gemerek, Kayseri, Kirsehir, Nevsehir and Sivas stations which statistically significant trends were determined. The graphical results of the station are given in Figure 4.

It is seen that there was a fluctuation in the trend change in the first half of the 90s in Gemerek. In the u(t)-u'(t) graph, the curves intersect at two points, in 1992 and 1995. The temperature series started to decrease in 1992 and to increase in 1995. This increasing trend continues throughout the observation period after 1995.

Table 2. Results of MK Trend Test

	Z_{cr}	Z	Trend
Gemerek	±1.96	2.43	Significant upward
Kayseri	±1.96	4.48	Significant upward
Kirsehir	±1.96	3.18	Significant upward
Nevsehir	±1.96	3.82	Significant upward
Sivas	±1.96	3.32	Significant upward
Zara	±1.96	1.90	No trend

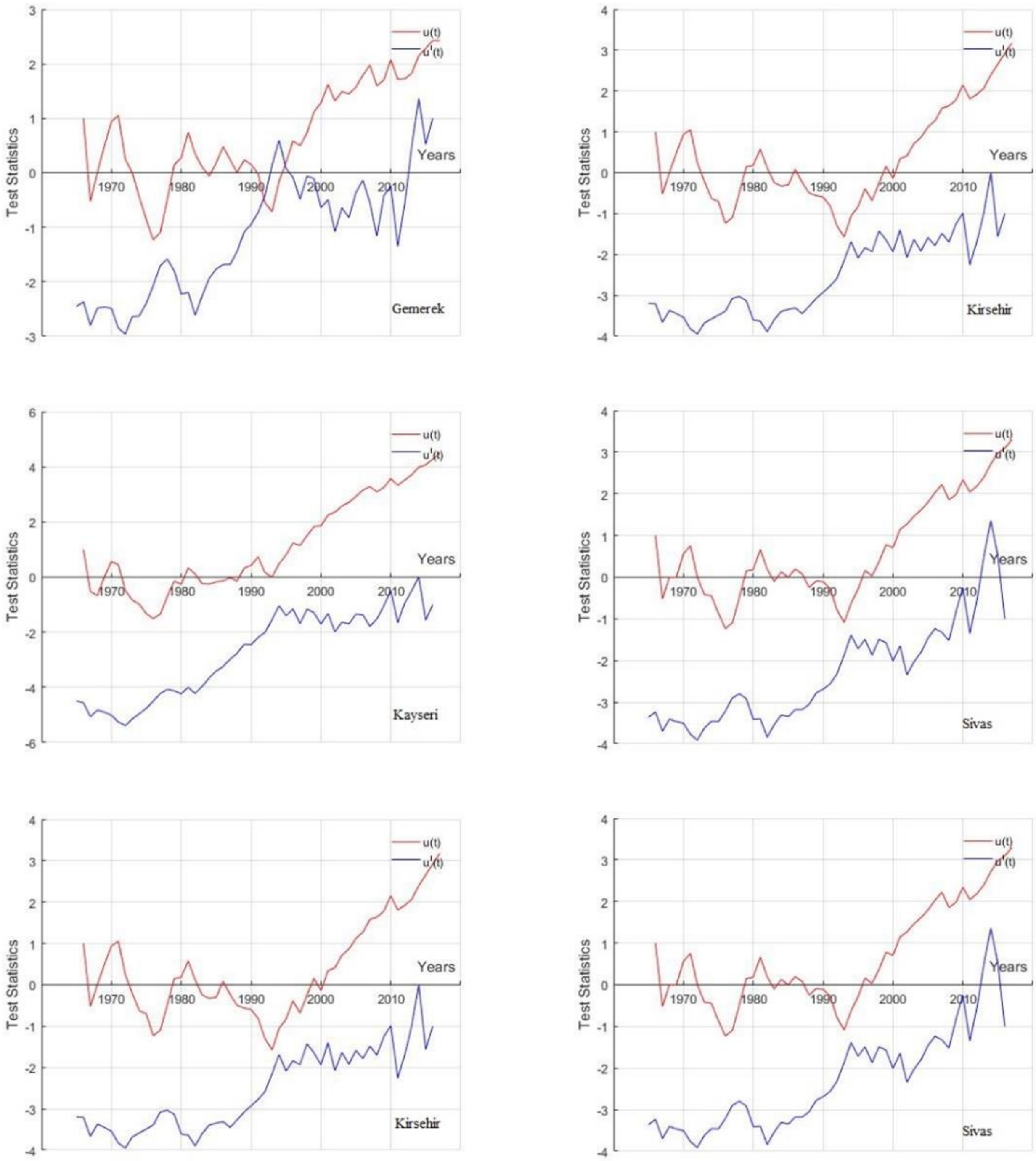

Figure 4. S-MK results of stations

From the u(t)-u'(t) graphs of Kayseri, Kirsehir, Nevsehir and Sivas stations, the curves do not intersect. Therefore, the starting date of the trend could not be determined. Despite this situation, it is thought that the increasing tendencies became evident in Kırşehir and Nevşehir after 1993; it becomes prominent in Kayseri and Sivas after 1994.

As can be seen in the literature, the effects of global climate change on various hydro-meteorological parameters are being investigated. It is known that the temperature series in the world show an increasing trend [35–36]. In previous studies involving this study area, increasing trends were determined in annual and seasonal temperature series for Turkey [1, 38–44].

The existence of an increasing trend in annual temperature records has been ascertained by various trend analysis methods in the Central Anatolia region and the Kizilirmak River basin [21, 25, 39, 43–48].

In addition, Doğan et al. [40] stated that 1992 was a turning point for increasing trends. Terzi and Ilker [44] determined increasing trends in Kayseri, Kirşehir, Nevşehir and Sivas as a result of the temperature records for 1980-2017. Another study was carried out by Ercan and Yüce [43] who stated that there are increasing trends for Gemerek, Kayseri, Kirşehir, Nevşehir and Sivas for the 1975-2015. As a result of this study, the increase trends determined throughout the basin, except Zara, support each other with the studies in the literature and similar study areas. The determination of increasing trends in the first half of the 90s shows parallelism with the results of the study of Doğan et al. [40].

4. Conclusion

In this study, the effect of global climate change on the temperature series in the Hirfanli Dam Basin was investigated. Hirfanli Dam basin, which is located in the semi-arid climate region where climate change can be seen due to its location. The annual mean temperature values measured by TSMS in the period 1965-2017 were used. The trend in the basin was determined using the MK test. And the S-MK test was used to determine the starting date of the tendency. An increasing trend has been determined in the temperature values throughout the basin except Zara. Statistically significant increasing trends were found in Gemerek, Kayseri, Kırşehir, Nevşehir and Sivas stations. According to the S-MK Test, the temperatures in this drought-threatened basin increased significantly, especially since the first half of the 1990s.

As a result of global climate change, drought in the basin is expected to increase even more in the future. Therefore, the following measures and activities can be carried out:

- Plans involving the community should be made against disasters caused by hydro-meteorological climate parameters [49].
- A drought-monitoring center for the basin can be established to monitor the temperature time series.
- A drought action plan should be prepared by evaluating all hydro-meteorological parameters in the basin.
- Activities related to the efficient use of water resources should be carried out.
- Information, prevention and sustention activities should be carried out against possible negative effects in agricultural activities.
- Existing urban green spaces should be protected and afforestation activities should be increased.

In the Hirfanli Dam basin, which has a semi-arid feature, it is peradventure that drought actions will be seen as a result of the temperature increase caused by global climate change. It is thought that future drought events may be severe and long-lasting. For this reason, it is of great importance to put to good use in the basin in terms of hydro-meteorological climate parameters, drought, water resources, agriculture, industry, and also civilization.

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Conflicts of interest

The authors declare no conflicts of interest.

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