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COMPARISON OF INNOVATIVE TREND ANALYSIS METHODS FOR HYDROMETEOROLOGICAL PARAMETERS IN THE KARASU SUB-BASIN

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Highlights

- The temporal trend was investigated based on hydrometeorological data of the Karasu Sub-Basin
- The temporal trends were identified using innovative graphical and statistical trend approaches including Şen-ITA, OTT, CWTSD methods.
- Innovative trend methods were compared with the classical MK test.

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ABSTRACT: Türkiye, which has a complex climate structure, is shown among the countries that will be most affected by climate change with the effect of global warming. These effects will differ in different regions due to their topographic structure, location, and orographic characteristics. Trend analyzes are used to determine the direction and magnitude of this variability. In this study, trend analysis was carried out by using hydrometeorological data obtained from streamflow and meteorology stations located in the Karasu Sub-Basin located in the Euphrates-Tigris Basin. Three innovative trend methods, namely the Şen-Innovative Trend Analysis, Onyutha Trend Test, Combination of Wilcoxon Test and Scatter Diagram trend tests, were used together with the classical Mann-Kendall method in the monthly scale analysis of hydrometeorological data of the 1979-2020 period. Both graphical and statistical trend analysis can be done with innovative methods. The results obtained in the study, in which trend analyses were evaluated at the α=0.05 significance level, reveal significant and insignificant decreasing trends in the parameters of mean streamflow, maximum precipitation, total precipitation, mean and minimum relative humidity. Significant and insignificant increasing trends were determined in the maximum, minimum, and mean temperature, maximum relative humidity, and mean wind speed data. The trends obtained in the methods used in general are consistent with each other. The findings of this study could lead to a better knowledge of the region's hydrology and contribute sustainable water management. The trend analysis methods used in the study are thought to be quite helpful in the analysis of hydro-meteorological time series.

Keywords: *Climate Change, Hydrometeorological, Mann-Kendall, Onyutha, Şen Innovative Trend Analysis, Wilcoxon Test*

1. INTRODUCTION

Climate change as a result of global warming shows its effect on many hydrometeorological parameters. As a result of the changes in hydrometeorological parameters, there is an increase in events such as the rise of sea level due to the melting of glaciers, the occurrence of hurricanes, floods, and droughts in many parts of the world as a result of sudden temperature changes, and the increase in forest fires [1-2]. These global effects of climate change include regional differences [3-4]. Natural disasters such as floods and droughts in recent years threaten the ecosystem, water resources, and agricultural activities, especially human life [5]. Increases are observed in the incidence, impact, and duration of these natural disasters [6]. Certain regions of the world have difficulties in accessing fresh water or using water in sectors such as agriculture and industry and are faced with drought disasters. Some regions are also exposed to irregular and excessive rainfall and have to struggle with natural disasters such as floods and landslides [7-8].

It is clear that climate change will change water resources in terms of quantity and quality by changing the hydrological cycle and systems and will also directly or indirectly affect socio-economic and environmental goods and services. The significant possible impact of climate change on the water cycle (hydrological cycle) will appear as changes in water resource availability and water quality [9-10]. Examining the temporal changes of many hydrometeorological parameters with trend analysis to

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determine the possible effects of climate change is the focus of many studies [11-15]. For this purpose, statistical and graphical trend analysis methods are used. Mann-Kendall trend analysis is the most widely used statistical trend method [16-18]. The Innovative Şen Trend method, on the other hand, is a method that has been used for about ten years in the analysis of the variability of hydrometeorological parameters and offers the opportunity to evaluate trends both graphically and statistically [18-22]. In recent years, innovative graphical trend methods have been used. Some of these methods are Innovative Polygon Trend Analysis (IPTA), Trend Polygon Star Concept (TPSC), Innovative trend pivot analysis method (ITPAM), Onyutha Trend Test (OTT), Combination of Wilcoxon test and scatter diagram trend (CWTSD).

Since Türkiye is located in the east of the Mediterranean, where the effects of climate change will be felt intensely due to its geographical location, it is considered among the high-risk countries. Especially forest fires, floods, and drought in recent years reveal the effects of climate change in Türkiye. In this study, trend analysis of various hydrometeorological parameters in the Karasu Basin, which is a sub-basin of the transboundary Euphrates-Tigris Basin, one of Türkiye's arid basins, was performed using the classical Mann-Kendall method. In addition, temporal variability was investigated comprehensively and comparatively with the Onyutha Trend Test (OTT), Şen-Innovative Trend Analysis (Şen-ITA), and Combination of Wilcoxon Test and Scatter Diagram (CWTSD), which is a relatively new trend method.

2. MATERIAL AND METHOD

2.1. Study Area and Data

The Karasu Basin is a sub-basin of the Euphrates-Tigris Basin and takes its name from the Karasu River, which is one of the main tributaries of the Euphrates River (Figure 1).

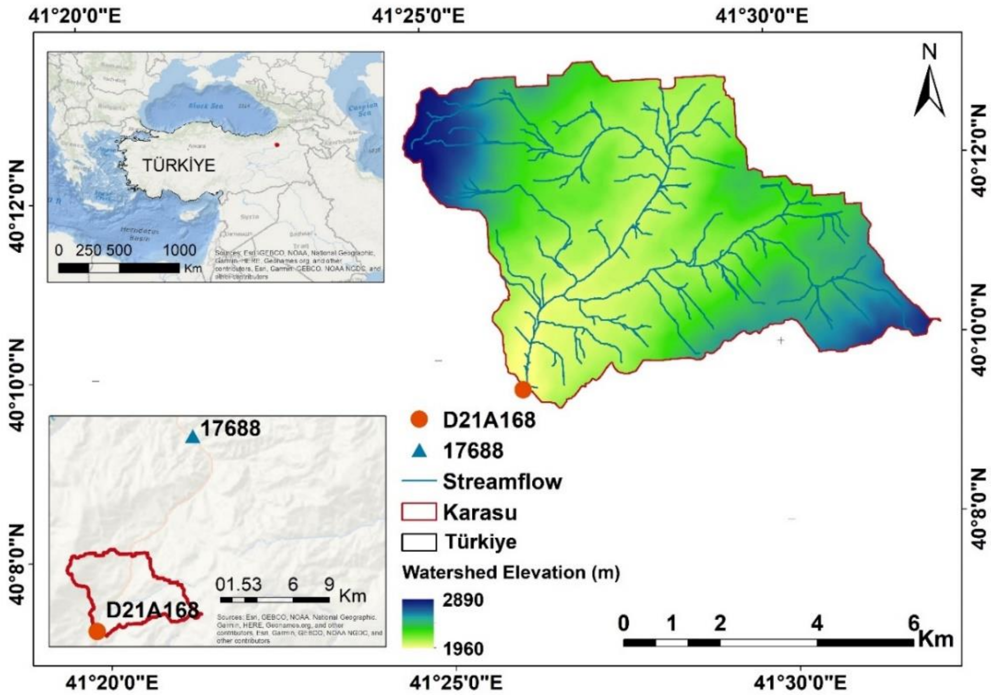

Figure 1. Karasu elevation map and locations of stations used in the study

The Karasu Basin is a high-altitude sub-basin with a continental climate. Most of the precipitation falls on the surface as snowfall. Snow cover remains on the surface for about 150 days a year. Day and night temperature differences are always high throughout the four seasons. The annual average temperature varies between 10°C and -5°C [23]. The altitude in the basin varies between 1960-2890 m. The surface area of the basin is 43.95 km² [24]. In low-altitude areas, agriculture is done partially. However, the surface cover of the majority of the basin consists of shrubs and herbaceous plants. It is a basin with heavy snowfall. It is a rich headwater basin due to its water potential and high altitude. The digital elevation model of the Karasu sub-basin used in the formation of the location map was provided by Amazon Web Services with a resolution between 3 m and 2.5 km. Streamflow data of the sub-basin are measured at D21A168 (Karagöbek-Büyük River) flow observation station. Meteorological parameters were obtained from Tortum meteorological observation station no 17688. It was chosen because it is the closest station to Karasu. In this study, the trend analyses are performed on mean streamflow (Q_{mean}), total precipitation (P_{total}), maximum precipitation (P_{max}), mean, minimum and maximum temperature (T_{mean}, T_{min} and T_{max}), mean, minimum and maximum relative humidity (RH_{mean}, RH_{min} and RH_{max}), mean wind speed (WS_{mean}). The data have a monthly temporal scale. The basic statistical values of hydrometeorological parameters for the 1979-2020 period are given in Table 1.

Table 1. Basic statistical values of hydrometeorological parameters used in the study

Parameter	**Min**	**Mean**	**Max**	**Standard Deviation (SD)**	**Skewness (C_s)**	**Kurtosis (C_k)**	**Coefficient of Variation (CV)**
Q_{mean} (m³/s)	0.02	0.76	4.86	0.81	2.17	5.03	107.58
P_{total} (mm)	0.0	36.46	170.20	26.42	1.03	1.41	72.46
P_{max} (mm)	0.0	12.30	43.00	7.79	0.91	0.89	63.30
T_{mean} (⁰C)	-10.30	8.48	23.30	8.50	-0.09	-1.24	100.22
T_{min} (⁰C)	-26.60	-4.93	11.00	9.69	-0.25	-1.06	-196.68
T_{max} (⁰C)	0.0	21.92	38.30	9.58	-0.18	-1.30	43.70
RH_{mean} (%)	34.0	59.97	76.30	7.30	-0.37	0.11	12.17
RH_{min} (%)	0.0	18.34	46.00	8.63	0.49	0.23	47.04
RH_{max} (%)	79.0	96.23	104.00	2.97	-0.89	2.78	3.09
WS_{mean} (m/s)	0.10	1.26	2.70	0.44	0.06	0.25	34.65

In Table 1, the skewness (C_s) values of the investigated hydro-meteorological parameters ranged from -0.89 to 2.17. The C_s values of T_{mean}, T_{min}, T_{max}, WS_{mean}, RH_{mean}, and RH_{min} parameters are between ±0.5 and there is a very symmetrical distribution. The C_s values of the Q_{mean} and P_{total} parameters are 2.17 and 1.03, respectively, which are very skewed (>1). Other parameters have moderate skewness. The values of the parameters T_{mean}, T_{min}, T_{max}, RH_{mean}, and RH_{max} are skewed to the left, while the others are skewed to the right. Kurtosis (C_k) values of T_{mean}, T_{min}, and T_{max} parameters are negative and Platykurtic distribution is present. In the remaining parameters, C_k values are positive and there is a Leptokurtic distribution. Streamflow (Q_{mean}) data has very thick tails and many outliers with the value C_k=5.03. Table 1 also gives the coefficient of variation (CV) values representing the degree of variability of hydrometeorological parameters for the 1979-2020 period. In Table 1, coefficient of variation (CV) values for Q_{mean}, P_{total}, T_{mean}, and T_{min} are >70 and there is extremely high variability. Very high variability with CV>40 for P_{max}, T_{max}, and RH_{min}, high variability with CV>30 for WS_{mean}, and low variability with CV<20 for other parameters.

The correlation matrix is given for ten hydrometeorological parameters used in Table 2. According to Table 2, there is a negative correlation between P_{mean} and WS_{mean}, as well as between temperature and relative humidity parameters. There is a positive correlation in other parameters. While the Q_{mean} shows the highest correlation with P_{mean} and P_{max}, it has a low correlation with other parameters. P_{mean} (P_{max}) parameter has a high correlation with Q_{mean} and P_{max} (Q_{mean} and P_{mean}). Temperature parameters have a high positive correlation with each other and a high negative correlation with RH_{mean} and RH_{min}. There is also a high positive correlation between RH_{mean} and RH_{min}. RH_{max} shows the highest correlation with RH_{mean}. WS_{mean} shows the highest correlation with temperature parameters as negative.

Table 2. Correlation matrix of hydrometeorological parameters

	Q_{mean}	P_{mean}	P_{max}	T_{mean}	T_{min}	T_{max}	R_{mean}	R_{min}	R_{max}	WS_{mean}
Q_{mean}	1	0.52	0.32	0.06	0.09	0.05	0.05	0.06	0.04	0.11
P_{mean}	0.52	1	0.74	0.08	0.09	0.10	0.32	0.14	0.19	-0.11
P_{max}	0.32	0.74	1	0.08	0.07	0.11	0.24	0.12	0.19	0.01
T_{mean}	0.06	0.08	0.08	1	0.97	0.98	-0.56	-0.57	-0.13	-0.27
T_{min}	0.09	0.09	0.07	0.97	1	0.94	-0.53	-0.54	-0.12	-0.30
T_{max}	0.05	0.10	0.11	0.98	0.94	1	-0.54	-0.58	-0.10	-0.29
R_{mean}	0.05	0.32	0.24	-0.56	-0.53	-0.54	1	0.73	0.31	0.14
R_{min}	0.06	0.14	0.12	-0.57	-0.54	-0.58	0.73	1	0.08	0.19
R_{max}	0.04	0.19	0.19	-0.13	-0.12	-0.10	0.31	0.08	1	0.10
WS_{mean}	0.11	-0.11	0.01	-0.27	-0.30	-0.29	0.14	0.19	0.10	1

2.2. Trend Analysis

In this study, three innovative graphical trend methods, namely the Onyutha Trend Test (OTT), Şen-Innovative Trend Analysis (Şen-ITA) and Combination of Wilcoxon Test and Scatter Diagram (CWTSD) were used. These methods also offer the opportunity to make statistical trend interpretations. The statistical test statistics of these three methods were also compared with the results of the classical Mann-Kendall trend method. The methodology for these methods is presented below.

2.2.1 Onyutha trend test (OTT)

The OTT, which is applied by converting hydrometeorological time series to non-parametric rescaled time series, is very useful in the analysis of sub-trends [25]. It also provides the opportunity to observe climatic changes between years. Unlike many trend analysis methods in the literature, monotonic and sub-trend analysis can be done visually. Based on the rescaled series obtained, a_j and q_k graphs should be drawn to make visual analyzes. These statistics are calculated with the help of the formulas given below.

$$a_j = \sum_{i=1}^{j} e_{y,i} \text{ for } 1 \leq j \leq n \quad (1)$$

$$q_k = \sum_{i=1}^{k} a_j \text{ for } 1 \leq k \leq n \quad (2)$$

Here, a_j is a variance of time, and q_k is a statistic required for graphical analysis. The Z statistic is calculated to analyze the trend statistically. $e_{y,i}$ is the rescaled series of the hydrometeorological time series, n represents the total number of data. Confidence interval limits (CILs) (100(1−α) %) should be determined for analysis according to significance levels. If the q_k curve falls between CILs, the existence of a significant trend is denied according to the significance level considered. Within the scope of the study, a 95% significance level was considered. CILs and Z are calculated with the help of the following equations.

$$CIL_s = \pm \left| Z\alpha/_2 \right| x\sqrt{V^F(T)} \quad (3)$$

$$Z = \frac{T}{\sqrt{V(T)}} \quad (4)$$

Here, the T value is the standardized version of the Z statistic. VF(T) is expressed as the variance of the T-test statistic. VF(T) is the corrected version of V(T) to save it from permanent effects on the time series [25]. The cumulative sum of difference (CSD)-based variability analyzes tool (CSD–VAT) was used to apply the OTT. To learn more about the OTT, a useful and innovative method, and CSD-VAT refer to references [25-27].

2.2.2 Combination of Wilcoxon test and scatter diagram (CWTSD)

This method was proposed by Saplıoğlu and Güçlü [28] and offers graphical and statistical trend analysis. In the graphical application of the method, first of all, the time series at hand is divided into two equal parts. In the two sub-series obtained, without any order, the first sub-series is represented on the horizontal axis and the second sub-series on the vertical axis, and the data are mutually marked in the Cartesian coordinate system. The triangular area above (below) the 1:1 straight line represents the ascending (descending) trend region. Depending on which triangle region the marked points are located in, the increasing or decreasing trend evaluation is made visually. If the points are equally distributed in both triangle regions, there is no trend, it is interpreted. According to this method, statistical trend evaluation is made to the Wilcoxon test. The calculation procedure of the Wilcoxon test is available in various studies in the literature and is not included here [20, 23]. To the $Z_{Wilcoxon}$ value obtained as a result of the application, the trend evaluation is made by comparing the Z_{critic} value at the α significance level obtained from the standard normal distribution table [20, 23].

2.2.3 Şen innovative trend analysis (Şen-ITA)

With the non-parametric Şen-ITA method, independent of the distribution suggested by Şen [21], trend interpretation can be made both graphically and statistically. To make a trend analysis visually, the time series is divided into two equal parts as in the CWTSD method. The two sub-series obtained are ordered from smallest to largest (or from largest to smallest). Then, the values in both sub-series are marked mutually, with the first sub-series on the horizontal axis and the second sub-series on the vertical axis. Considering the distribution of the marked points according to the 1:1 straight line, five different trend evaluations can be made monotonic increasing trend, monotonic decreasing trend, non-monotonic increasing trend, non-monotonic decreasing trend, and no trend. See references for details of the method [20-21]. Şen-ITA trend indicator ($D_{Sen\text{-}ITA}$) is calculated by Equation 5.

$$D_{Şen-ITA} = \frac{1}{n}\sum_{i=1}^{n} 10\,\frac{(y_i - x_i)}{\bar{x}} \tag{5}$$

Here, n, x_i, y_i, and $\bar{x}$ represent the number of data in each subseries, the data value at the time i in the first ordered subseries, the data value at the time i in the second ordered subseries, and the mean of the first subseries. The negative (positive) value of $D_{Sen\text{-}ITA}$ shows a decreasing (increasing) trend [18, 20, 29].

2.2.4 Mann-Kendall (MK) trend test

The MK method [30-31], which is a non-parametric and distribution-independent method, is one of the most widely used methods in trend analysis studies. The test statistic of the MK method is calculated by Equation 6.

$$z_{MK} = \begin{Bmatrix} \dfrac{S-1}{\sqrt{Var(S)}} & if \quad S>0 \\ 0 & if \quad S=0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & if \quad S<0 \end{Bmatrix} \tag{6}$$

S value is calculated by Equation 7 and Equation 8 and n is data length. X_i and X_j represent data values at i and j times, respectively. sgn is the sign function.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_i) \tag{7}$$

$$\text{sgn}(x_j - x_i) = \begin{cases} +1 & \text{if} \quad (x_j - x_i) > 0 \\ 0 & \text{if} \quad (x_j - x_i) = 0 \\ -1 & \text{if} \quad (x_j - x_i) < 0 \end{cases} \tag{8}$$

Var(S) is calculated by equation 9. In Equation 9, k represents the number of connected groups, and t_i represents the number of data values in the i^{th} cluster. If the sign of the MK test statistic (Z_{MK}) and S values calculated with Equation 6 and Equation 7 is negative (positive), there is a decreasing (increasing) trend in the time series. The significance of the trends is determined by the selected α significance level. In this study, α=0.05 significance level (Z_{critic}=1.96) was used. If $|Z_{MK}| < Z_{1-\alpha/2}$, the null hypothesis ($H_o$) is accepted and the alternative hypothesis (H_1) is rejected. The H1 hypothesis shows that there is a significant trend at the selected α significance level in the examined time series [16, 18].

$$\text{Var}(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{k} t_i(t_i - 1)(2t_i + 5)}{18} \tag{9}$$

Before applying the MK test, it should be checked whether there is a serial correlation in the examined time series. In the serial correlation control, first of all, the autocorrelation value (r_1) for lag-1 is calculated with the following equation.

$$r_1 = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}(x_i - \bar{x})(x_{i+1} - \bar{x})}{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{10}$$

Here, n, x_i and $\bar{x}$ represent the number of samples, the serial value at the time i, and the sample mean, respectively. If the calculated r1 value is between the limit values given by Equation 11 (for α=0.05), there is no serial correlation in the time series, otherwise, there is a serial correlation.

$$\frac{-1-1.96\sqrt{(n-2)}}{n-1} \leq r_1 \leq \frac{-1+1.96\sqrt{(n-2)}}{n-1} \tag{11}$$

In this study, in the case of serial correlation, the pre-whitening procedure suggested by Von Storch and Navarra [32] was applied to the time series (Equation 12).

$$y_i = x_{i+1} - r_1 x_i \tag{12}$$

The MK method should be applied to the pre-whitened time series obtained by Equation 12.

4. TREND ANALYSIS RESULTS

4.1. OTT Results

The time series of the different parameters of the Karasu sub-basin within the borders of the Euphrates-Tigris basin and the a_j and q_k series obtained by applying the OTT is given in Figure 2.

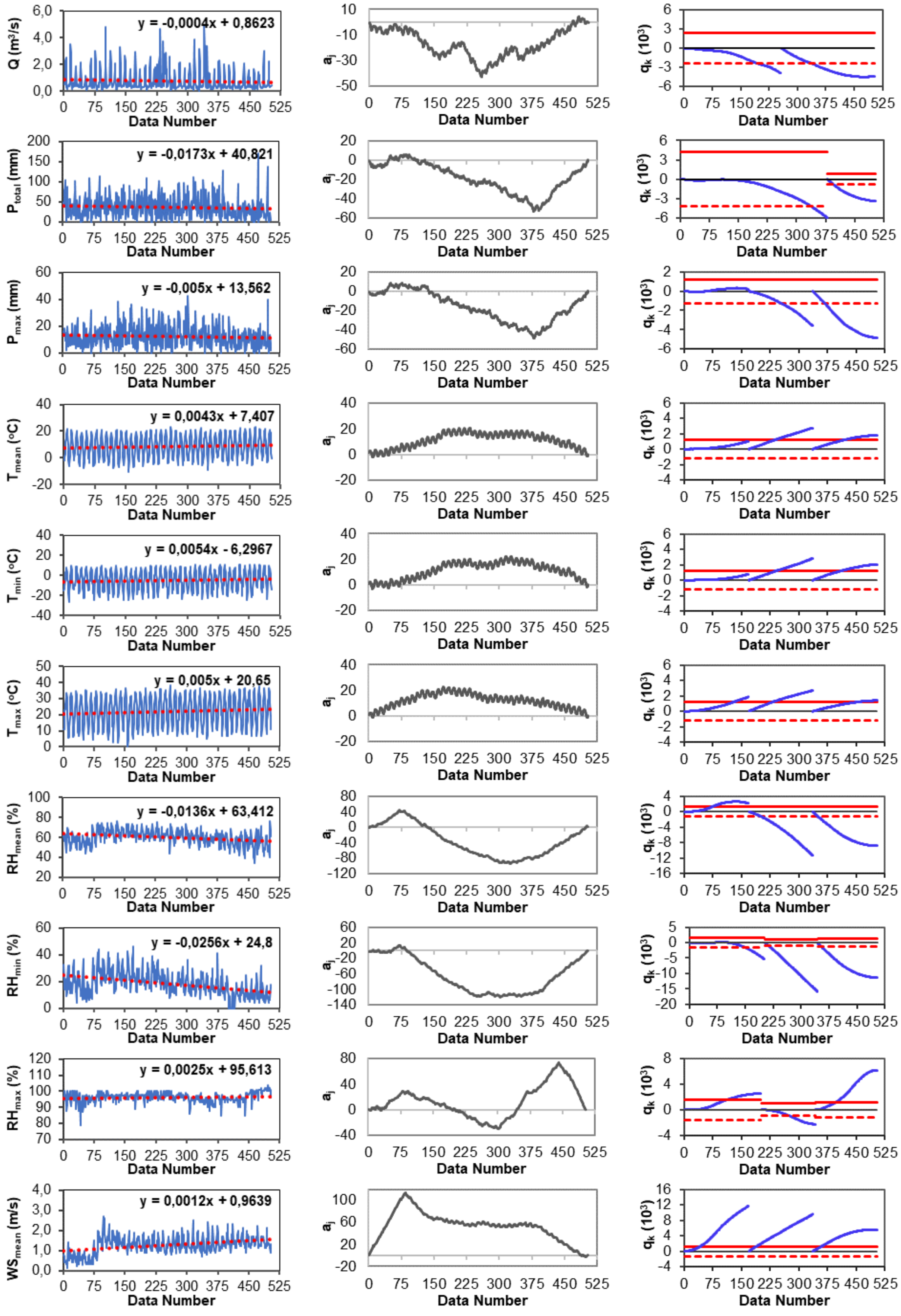

Figure 2. a) Time series, **b)** a_j series, and **c)** q_k series for the hydrometeorological parameters

Changes that cannot be detected from time series can be observed with the help of a_j series, which is a variance of time. The sub-periods determined from the a_j series are examined in the q_k time series to their significance levels. According to Figure 2, the temperature parameters (T_{min}, $T_{max,}$ and T_{mean}) increase throughout the study period. However, it is noteworthy that the trend magnitude of these parameters differs in the sub-periods. Especially in the middle of the study period, they have a strong increasing trend. When the streamflow time series is examined, it is determined from the linear slope that the general behavior is in the decreasing direction. The a_j series of the flow indicates a break in the middle of the study period (about 1999). There is a significant decreasing trend for the two determined sub-periods. Although a slightly increasing trend, which was not significant until 1990, was observed in two parameters of precipitation (P_{total} and P_{max}), the strong decreasing trend dominated the ongoing process. When three different parameters of relative humidity (RH_{mean}, $RH_{max,}$ and RH_{min}) are examined, there is a decrease for RH_{min} in the first sub-period and an increase for other parameters. Significant decreasing trend behavior was observed for all three parameters in the second sub-period, which coincided with the middle of the study period. In the last sub-period, RH_{max} has a significant increase, while other parameters have a significantly decreasing trend. There is a strong increasing trend in all three sub-periods determined for mean wind speed (WS_{mean}). There is a very high increasing trend at a 95% significance level. The break at the beginning of the study period is quite remarkable. Breaks were observed in many parameters between 1985-1990. It is thought that there were important hydrometeorological changes between these years.

4.2. CWTSD and Şen-ITA Results

To apply the CWTSD and Şen-ITA method to the monthly scale values of the meteorological parameters belonging to the meteorological observation station no 17688 and runoff data belonging to the flow observation station D21A168 for the period 1979-2020 (42 years), firstly, the data of each parameter was divided into two sub-series. The first sub-series covers the period 1979-1999, and the second sub-series covers the period 2000-2020. CWTSD graphs were obtained by marking the first (second) sub-series on the horizontal (vertical) axis without any ordering in the two sub-series obtained for each parameter (Non-Ordered ITA=NO-ITA). Şen-ITA graphs were drawn with the mutual marking of the data obtained by ordering the data of the two sub-series from the smallest to the largest on the same graph. The obtained NO-ITA and Şen-ITA graphs are presented in Figure 3. As seen in Figure 3, for the parameters Q_{mean}, P_{max}, $RH_{mean,}$ and RH_{min}, according to both NO-ITA and Şen-ITA methods, most of the points are in the region below the 1:1 line and there is a decreasing trend. For T_{mean}, T_{min}, $T_{max,}$ and WS parameters, according to both methods, most of the points are in the region above the 1:1 line and there is an increasing trend. As a result of visual inspection for P_{total} and RH_{max}, it is seen that the distribution of points in both triangular regions for the NO-ITA method is approximately equal. This makes it difficult to interpret a decreasing or increasing trend according to NO-ITA. According to the Şen-ITA method, while there is a decreasing trend in the P_{total} parameter, it can be said that there is no trend in the RH_{max} parameter.

4.3 Statistical Evaluation of MK, OTT, CWTSD and Şen-ITA Trend Analysis Methods

The hydrometeorological parameters, whose temporal variability in the 1979-2020 period was examined graphically using OTT, Şen-ITA, and CWTSD methods, were also statistically evaluated for the same methods and compared with the classical Mann-Kendall (MK) method. Statistical evaluation of the graphics of the CWTSD method was performed with the Wilcoxon test, and statistical trend evaluation for Şen-ITA was performed with the D indicator.

The results obtained are given in Table 3. Before applying the MK method, it was checked whether there is a serial correlation in the time series of hydrometeorological parameters. For this purpose, the correlation coefficients (r_1) calculated with Equation 10 for lag-1 of each parameter are given in Table 3. The r_1 values for all parameters are positive. The highest (lowest) serial correlation was obtained for temperature (precipitation) parameters. Since the calculated r_1 values are outside the limit values of -0.089 and 0.085 determined by Equation 11, there is a serial correlation in the time series of each parameter. The serial correlation was removed from the time series with pre-whitening (Equation 12), and then the MK test was applied.

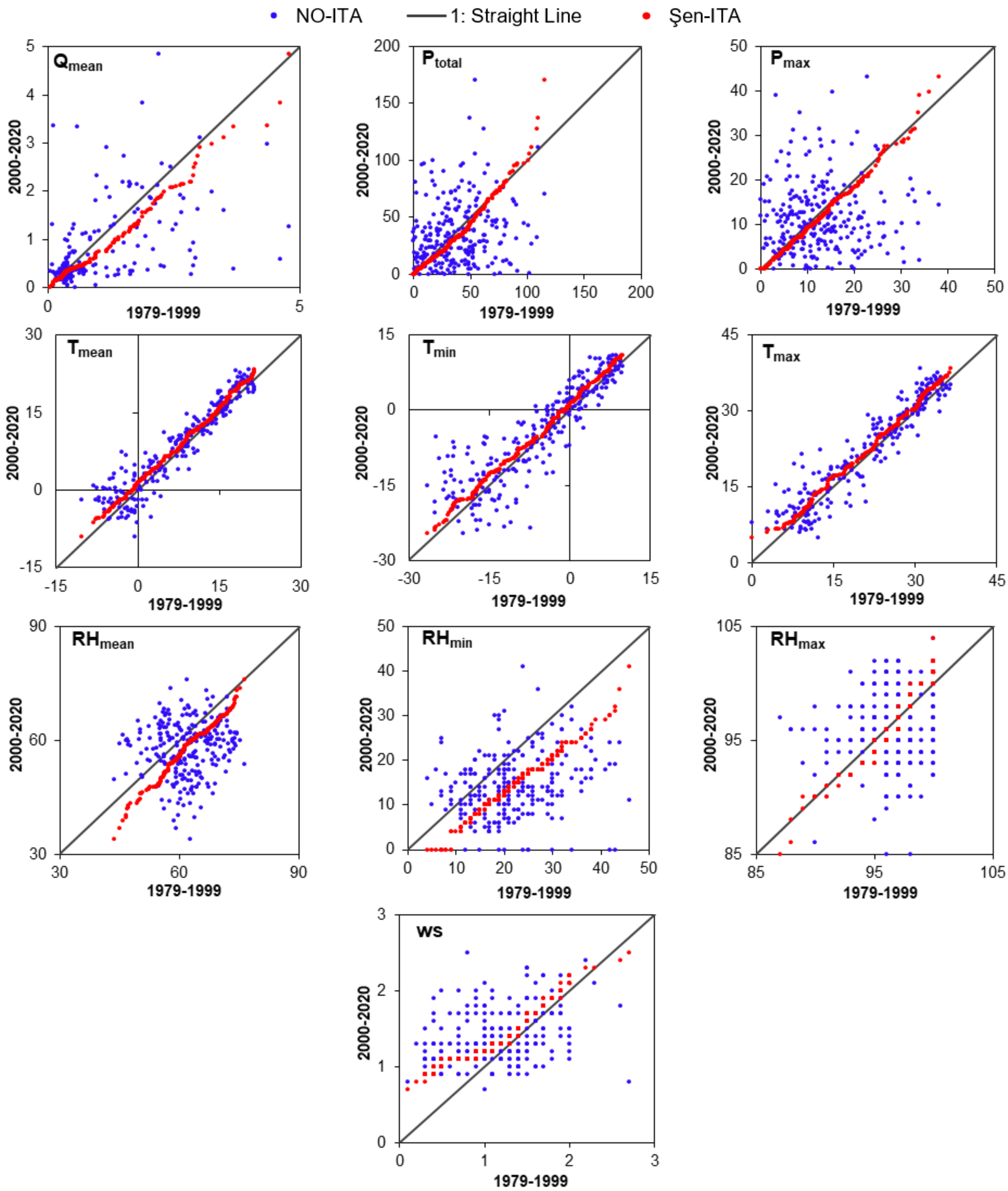

Figure 3. Şen-ITA and NO-ITA graphs

Negative values in Table 3 represent a decreasing trend and positive values represent an increasing trend. Significant trends were determined according to α=0.05 significance level ($Z_{critical}$ = ±1.96). According to the results in Table 3, the trend direction for each parameter (except RH_{max}) is generally consistent with each other in all methods. In Q_{mean}, P_{total}, P_{max}, RH_{mean}, and RH_{min} parameters, there is a decreasing trend in all methods, and in other parameters, there is an increasing trend in all methods. Only a slight decrease trend (insignificant) was determined in Şen-ITA method and an increasing trend (insignificant) was determined in other methods in the RH_{max}. In the RH_{min} and WS_{mean} parameters, the test statistics values of each method show significant decreasing and significantly increasing trends, respectively. In the Q_{mean} parameter, MK and OTT test statistics show an insignificant decreasing trend, and Wilcoxon test statistics show a significant decreasing trend. In this parameter, the condition $|D| > Z_{critical}$ was provided and the decreasing trend was determined according to the Şen-ITA method. In P_{total}, Z_{MK} and Z_{OTT} values are outside the values of ±1.96 and there is a significant decreasing trend due to negative values, while there is an insignificant decreasing trend compared to the other two methods. While there is a decreasing trend for P_{max} to all methods, there is a significant trend with Z_{MK}=-2.14 value only to the MK method. In the study conducted by Buyukyildiz [20], the trend analysis results for the annual total precipitation in the entire Euphrates-Tigris Basin in the 1965-2020 period also showed a decreasing trend in the precipitation data in the entire basin.

Table 3. Statistical trend analysis results

		Q_{mean}	P_{total}	P_{max}	T_{mean}	T_{min}	T_{max}	RH_{mean}	RH_{min}	RH_{max}	WS_{mean}
MK	r_1	0.487	0.192	0.140	0.835	0.791	0.829	0.613	0.667	0.487	0.700
	Z_{MK}	-1.38	**-2.40***	**-2.14***	0.22	0.61	0.16	**-3.47***	**-3.99***	0.73	**4.46***
OTT	Z_{OTT}	-1.84	**-2.15***	-1.65	**4.40***	**3.73***	**5.14***	-1.22	**-2.24***	0.47	**2.77***
CWTSD	$Z_{Wilcoxon}$	**-4.30***	-1.77	-1.58	**5.60***	**4.13***	**5.50***	**-6.66***	**-10.43***	0.99	**6.87***
Şen-ITA	$D_{Şen\text{-}ITA}$	**-1.97**	-0.85	-0.82	1.21	**2.11**	0.51	-0.70	**-3.50**	-0.02	**1.98**

*Significant trend at the α=0.05 confidence level

According to Table 3, Z_{OTT} and $Z_{Wilcoxon}$ test statistics in T_{mean} and T_{max} parameters are greater than the critical value of 1.96 and there is a significant increase, while in other methods there is an increasing trend, and it is not significant. An increasing trend was determined for T_{min} in all methods. However, there is an insignificant increase trend with Z_{MK}=0.61. Z_{OTT} and $Z_{Wilcoxon}$ values also show an increasing trend in this parameter with the values of 3.73 and 4.13, respectively. In addition, it is seen that $D_{Şen\text{-}ITA}$=2.11>$Z_{critical}$ has occurred. There is a significant decreasing trend in the RH_{mean} parameter according to the Z_{MK} and $Z_{Wilcoxon}$ values, and an insignificant decreasing trend according to the other two methods. In the RH_{max} parameter, none of the trends determined are significant. The trend evaluations obtained by Şen-ITA and NO-ITA graphs given in Figure 3 and the statistical trend results given for these methods in Table 3 are largely consistent.

5. DISCUSSION AND CONCLUSIONS

All methods used in this study are nonparametric methods. Therefore, they do not require criteria such as linearity, normal distribution and independence required in time series for parametric methods to be applied. MK and Şen-ITA methods are frequently used trend analysis methods in the literature. OTT and CWTSD, which are innovative trend analysis methods that are quite new compared to the Şen-ITA method, are increasingly preferred in different fields with their advantages. Both statistical and innovative trend approaches offer holistic trend detection. However, in addition to holistic trend detection, innovative trend methods have the advantages of observing sub-trends, graphically displaying the results, and visually evaluating the trend, unlike statistical methods such as MK. For example, Şen-ITA and CWTSD methods allow more detailed comments on the detection of the trend of "low", "medium" and "high" values of the analyzed climate parameter. In addition to the overall trends in the whole time series, OTT also allows the determination of temporal sub-trends unlike Şen-ITA and CWTSD methods. Sub-trends cannot be detected by traditional trend methods (such as MK, Spearman's Rho, Sen's T). Among the innovative methods, Şen-ITA and CWTSD methods have the additional advantages of being easy to apply and having low computational cost compared to OTT method. The OTT method has a more complex calculation and visualization procedure. In the visual analysis provided by Şen-ITA, the data set needs to be ordered. This leads to the loss of information about the natural distribution of the data set. This disadvantage is not present in the other two innovative methods.

The results show that there is an increasing trend in temperature (mean, min, max), maximum relative humidity and mean wind speed, and a decreasing trend in other parameters. This indicates that climate change is strongly observed in Karasu basin. In the innovative methods (OTT and CWTSD), it is observed that the direction of trends produces results consistent with the MK. This shows that the strong climatic change detected by the MK is confirmed by innovative methods. However, there are differences in the significance of some parameters compared to the MK. This indicates that the methods may have different sensitivity in trend analysis of different data sets.

MK is a non-parametric method recommended by the World Meteorological Organization, which is often preferred in trend analysis. Since its introduction to the literature, its robustness has been comparatively evaluated in many studies [33]. However, it is still sensitive to serial correlation. Therefore, preprocessing is recommended before applying the MK. The serial correlation control and pre-whitening processes used in this study are examples. In innovative methods, this weakness is eliminated within the method. In addition, visual trend analysis, which is not available in MK, is one of the important differences in innovative methods. The MK test statistic is robust when dealing with non-normally distributed data, censored data, and time series with missing values since it is determined by the rankings and sequences of time series rather than the original values [34]. This is one of the strengths of the MK method.

In this study, the effects of climate change on hydrometeorological parameters in the Karasu Sub-basin, one of the sub-basins of the Euphrates-Tigris Basin in Türkiye, were investigated. Trend analyses of ten hydrometeorological parameters (Q_{mean}, P_{total}, P_{max}, T_{mean}, T_{min}, T_{max}, RH_{mean}, RH_{min}, RH_{max}, and WS_{mean}) were carried out with four different methods using monthly scale data for the period 1970-2020. The results obtained by MK, OTT, CWTSD, and Şen-ITA methods were consistent with each other in terms of the direction of the trend. According to the results obtained, a decreasing trend was obtained in Q_{mean}, P_{total}, P_{max}, RH_{mean}, and RH_{min} parameters compared to all methods, and an increasing trend was obtained in other parameters compared to all methods (RH_{max} also decreased compared to Şen-ITA). However, approximately 55% of the trends obtained were significant at the α=0.05 significance level, while the rest gave the result of an insignificant trend. The results show that climate change causes a decrease in precipitation with the increase in temperature in the basin and a decrease in river flow. In a study investigating the sensitivity of streamflow to the effects of climate change in the Euphrates-Tigris basin, a general decrease in precipitation and streamflow data, while an increasing trend in temperature and potential evapotranspiration data was determined [35]. According to projection studies on the relative humidity in Turkey, significant decreases are expected in relative humidity averages, especially in the periods after 2040 [36]. The decrease in relative humidity also has a negative effect on precipitation and causes a decrease in precipitation. This situation also poses a threat to the basin in terms of drought. It is also seen in the trend results obtained. Along with the increase in temperature, the trend of decreasing relative humidity, precipitation, and river flow poses a risk in terms of water resources in the Karasu sub-basin and the transboundary Euphrates-Tigris Basin. Such studies will shed light on decision-makers to eliminate the negative effects of climate change on the management and sustainability of water resources both for Türkiye, which constitutes the upstream part of the basin and for other riparian neighboring countries. Therefore, it is of great importance to carry out such studies on a larger scale.

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Declaration of Ethical Standards

Not applicable.

Credit Authorship Contribution Statement

The authors contributed equally to the study conception and design.

Declaration of Competing Interest

The authors declare that they have no known competing interest.

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Data Availability

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