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Trend Analysis of Monthly Total Rainfall and Monthly Mean Air Temperature Variables of Yozgat in Turkey

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Abstract

The purpose of this study is to detect possible trends in monthly total rainfall and monthly mean air temperature on the basis of Mann-Kendall (MK) and a new method recently proposed by Şen. The new method is used for trend analysis of both variables' data recorded at Yozgat province in Turkey over the period 1970-2016. For comparison purpose, the well-known MK trend test is also applied to the same data. In the first step, the historical data were divided into two time periods: 1970-1992 (276 values) and 1993-2016 (288 values). Each time part was analysed individually, and both parts were compared with each other. Consequently, there is no statistically significant trend for both variables at 95% two-tailed confidence interval in the period 1970-1992 and 1993-2016 according to the Mann-Kendall trend test. However, there is an increasing trend for monthly total rainfall at 95% one-way confidence interval in the period 1970-1992 according to the Şen trend test. Moreover, there is an increasing trend for monthly mean air temperature in the period 1993-2016 according to the Şen trend test.

Keywords: Mann-Kendall test, Rainfall, Şen's trend test, Temperature, Turkey, Yozgat

Yozgat'ın Aylık Toplam Yağış ve Aylık Ortalama Hava Sıcaklıklarının Trend Analizi

Öz

Bu çalışmanın amacı, aylık toplam yağış ve ortalama aylık hava sıcaklığında olası trendleri Mann-Kendall (MK) ve yakın zamanda Şen tarafından önerilen yeni bir yöntem ile belirlemektir. Şen metodu, 1970 ve 2016 tarihleri arasında Türkiye'de Yozgat'ta kaydedilen iki değişkenin trend analizi için kullanılmıştır. Karşılaştırma amacıyla iyi bilinen MK trend testi de aynı verilere uygulanmıştır. İlk adımda, veriler 1970-1992 ve 1993-2016 olmak üzere iki zaman aralığına ayrılmıştır. Her iki zaman aralığı ayrı ayrı analiz edilmiş ve birbiriyle karşılaştırılmıştır. Sonuç olarak, MK testine göre 1970-1992 ve 1993-2016 zaman aralıklarında her iki değişken için %95 çift yönlü güven aralığında istatistiksel olarak anlamlı bir trend bulunmamıştır. Ancak, Şen trend testine göre 1970-1992 döneminde aylık toplam yağış için %95 tek yönlü güven aralığında artan bir trendin olduğu bulunmuştur. Ayrıca, Şen trend testine göre 1993-2016 döneminde ortalama aylık hava sıcaklığı için de artan bir trendin olduğu bulunmuştur.

Anahtar Kelimeler: Mann-Kendall test, Sıcaklık, Şen's trend test, Türkiye, Yağış, Yozgat

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1. INTRODUCTION

Low, medium and high values of a variable are very important issue in hydrological, meteorological and climatological events. Moreover, these values are used to decide various design parameters based on scientific aspects and real applications everywhere in the world. According to the IPCC reports and some documents about global climate change, mean surface temperature has increased by 0.6 ± 0.2°C over the last century, and it is expected the increase in temperature could be 1.4 - 5.8 °C by 2100 [1-4]. Temperature and precipitation changes have not been uniform globally, but have varied different regions and parts around the world. As for some studies about this issue, detection trend of the precipitation variable has been investigated in many studies in different countries of the world [5-19]. For instance, Yavuz and Erdogan (2012) [20] analysed precipitation trends by using MK rank correlation test for all regions of Turkey and performed by using monthly and annual precipitation data, recorded at 120 stations during the period 1975-2009. Haktanir et al. (2013) [21] investigated on 48-year-long complete and 79-year-long incomplete maximum daily precipitation series recorded at Alexandria, Egypt, and on 61-year-long maximum daily precipitation series recorded at Antalya. Dinpashoh et al. (2014) [22] analysed trends of precipitation by using the MK trend detection test and determined the trends on monthly, seasonal, and annual time scales by using the precipitation data for the period of time 1955-2004 of the 16 stations selected from Iran. Fathian et al. (2014) [23] used three non-parametric statistical tests, the MK, Spearman rho, and Sen's T, and applied to estimate the trends in the annual and seasonal time series of temperature, precipitation, and streamflow at 95 stations in Urmia Lake basin, Iran. They found that temperature has significantly increased whereas trends in precipitation were not basin-wide. It was seen that two parameters have different trend. Addisu et al., (2015) [24] found that MK trend test gave the maximum and minimum temperature analysis resulted in a general increasing trend whereas, rainfall amount resulted in a general decreasing trend in Ethiopia. Chattopadhyay and Edwards (2016) [25] analysed the long-term trends in annual precipitation and mean annual air temperature (for the period 1950-2010) for the state of Kentucky.

In this study, monthly total rainfall (mm) and average monthly air temperature (°C) data were analysed with two different trend tests. In this context, study area and data are given in Section 2; the trend tests are given in Section 3, applications are given in Section 4, and conclusion and remarks are given in Section 5.

2. STUDY AREA AND DATA

Yozgat Province is in Middle-Kizilirmak basin and is the border of the Kizilirmak River starting from Zara/Sivas province in the Central Anatolia, Bozok Plateau. The province is nearly at 34º05'-36º10' eastern longitudes and 38º40'-40º18' northern latitudes. The number of people was determined as 421041 people according to the 2016 year's survey. Generally, livelihood of the province is agriculture and livestock, and industry has medium-sized structure. About 14037 km^2 area of Yozgat is the 15^{th} largest city in Turkey in terms of geographical area. The city centre that has the rugged terrain is approximately 1298 m elevation. The annual average rainfall is about 400-600 mm and this value is smaller than annual mean rainfall (643 mm/year) of Turkey. Many irrigation, drinking water, flood protection, energy structures and dams were also constructed and there are some projects on under construction in the province [26].

Data of the monthly total rainfall and monthly mean air temperature recorded at Yozgat were used in the study, and the name of gauging station for both variables is Yozgat-17140, only station in the city centre, according to State Meteorology Works in Yozgat. Number of the data is 564, and Table 1 shows the basic statistics of monthly total rainfall and monthly mean air temperature for the period 1970-2016 (47 years, 564 values). There is no missing data in all of rainfall and temperature time series. But, there is some unrecorded rainfall data in some times (for instance: August 1977, September 1985, July 1997, July 2006, and August 2013) owing to non-existing rainfall in Yozgat.

Table 1. Basic statistics of monthly total rainfall and monthly mean air temperature of Yozgat for the time period 1970-2016 (47 years)

Parameters	Monthly total rainfall (mm)	Monthly mean air temperature (°C)
Date ranges	1970-2016	1970-2016
Number of data	564	564
Minimum value	0	-7
Maximum value	192.03	+24.4
Mean value (μ)	+49.04	+9.07
Standard deviation (σ)	38.04	7.94
Variation coefficient (C_{vx})	0.78	0.88
Skewness coefficient (C_{sx})	+0.84	-0.089

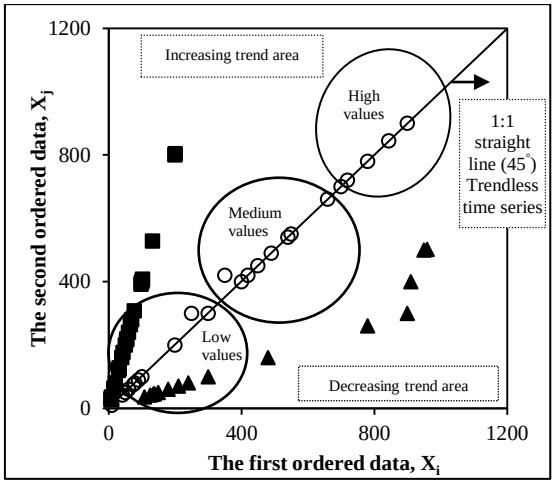

Figure 1. Illustration of decreasing, increasing and trendless areas [35]

3. TREND TESTS

3.1. Mann-Kendall (MK) Trend Test

The MK test is one of the non-parametric tests to detect trend in a time series especially for climatological, meteorological, and hydrological data. Commonly used MK trend test is not described here because it can be found in related studies [27-33].

3.2. Şen Trend Test

A recorded hydrological time series is divided into two equal halves from the first date to the end date, and both sub-series are separately sorted in ascending manner. The first sub-series (X_i) is located on X-axis, and the other sub-series (X_j) is located on Y-axis (Figure 1) based on the Cartesian coordinate system. If data are collected on the 1:1 (45˚) straight line, it can be said that there is no trend (a trendless time series). If data are in the below triangular area of the 1:1 straight line, it can be said that there is a decreasing trend in time series. If data are in the upper triangular area of the 1:1 straight line, it can be said that there is an increasing trend in time series [34-37]. Moreover, low, medium and high values of a parameter can be graphically evaluated with this method.

Şen (2015) [34] proposed a new statistical process to the method. Steps of this method are given by the following formulas 1-6.

$$E(s)=\frac{2}{n}\left[E(\overline{y_2})-E(\overline{y_1})\right] \quad (1)$$

$$\sigma_s^2=\frac{4}{n^2}\left[E(\overline{y_2}^2)-2E(\overline{y_2}\overline{y_1})-E(\overline{y_1}^2)\right] \quad (2)$$

$$\rho_{\overline{y_2}\overline{y_1}}=\frac{E(\overline{y_2}\overline{y_1})-E(\overline{y_2})-E(\overline{y_1})}{\sigma_{\overline{y_2}}\sigma_{\overline{y_1}}} \quad (3)$$

$$\sigma_s^2=\frac{8}{n^2}\frac{\sigma^2}{n}\left(1-\rho_{\overline{y_2}\overline{y_1}}\right) \quad (4)$$

$$\sigma_s=\frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{\left(1-\rho_{\overline{y_2}\overline{y_1}}\right)} \quad (5)$$

$$CL_{(1-\alpha)}=0\mp s_{critical}\sigma_s \quad (6)$$

In here, $\overline{y_1}$: mean of the first data, $\overline{y_2}$: mean of the second data, ρ: correlation between first and second data, s: slope value, n: number of data, σ: standard deviation of all data, σ_s: slope standard deviation, and scritical denotes Z critical values in one-way hypothesis at 95% confidence level. Critical upper and lower limits values calculated by Equation 6 are established to make limits for hypothesis test. If slope value, s, of each station is in outside the lower and upper confidence limits,

and thus, the alternative hypotheses, H_1, are approved, and it can be said that there is a trend (Yes) in time series. The type of trend is stated depending on the slope (s) sign. Slope value (s) can be positive or negative. This means that there is an increasing (+) or a decreasing (-) trend in time series [35]. This method was applied annual flow, annual total flow, annual total precipitation by Şen [35], and the long-term recorded air temperature [37]. Ay and Kisi [38] investigated rainfall variations of some provinces in Turkey. Kisi and Ay [39] determined the trend of some water quality variables. Ay and Kisi [40] applied to the precipitation data. Şen [34] applied to air temperature, streamflow and rainfall data.

4. APPLICATION

The consequences of changes in monthly total rainfall and monthly mean air temperature make it crucial for water resource designers to accurately evaluate their behaviour and impacts on related hydrologic variables. This case also brings about various problems in order to solve this issue. In this perspective, trend analysis is also one of the most important issues in any global climate change problem, and it provides a significant view for meteorological, hydrological, and climatological variables in past and future time's changes.

In this context, trend analysis of monthly total rainfall and monthly mean air temperature is individually considered in two time periods, 1970-1992 (23 years, 276 values) and 1993-2016 (24 years, 288 values). These parts are examined in following subsections.

4.1. Trend Analysis of the Period 1970-1992 (23 Years) for Monthly Total Rainfall and Monthly Mean Air Temperature

First part of the study is for monthly total rainfall and monthly mean air temperature in the period 1970-1992. Assumptions such as pre-whitening process [41] were not applied to the data in this study. Original recorded data were taken into consideration in order not to lose originality of the time series in the trend methods [14, 42, 43, and 44]. Moreover, H_0 hypothesis refers to "There is no statistically significant trend in the time series". Opposite hypothesis, H_1, refers to "There is a statistically significant trend in the time series".

Table 2 shows the results of MK trend test of monthly total rainfall and monthly mean air temperature for the period 1970-1992. Z value of each variable was calculated and compared with normal distribution critical Z values at 95% two-tailed confidence intervals. It can be seen that the calculated Z values (+1.09 and -0.082) are smaller than the critical Z value (±1.96). Thus, monthly total rainfall and monthly mean air temperature have no trend (trendless time series) according to the MK trend test; and there is no statistically significant trend. Therefore, H_0 hypothesis (the null hypothesis) is accepted for both variables.

Table 2. Results of the Mann-Kendall trend test for Yozgat over the period 1970-1992 (23 years)

Parameters	Monthly total rainfall (mm)	Monthly mean air temperature (°C)
Data ranges	1970-1992	1970-1992
Number of data	276	276
Test statistic (S)	1665	-126
Calculated ± Z value	+1.09	-0.082
Z critical value (α=0.05, Two-tailed)	±1.96	±1.96
Trend	No (Trendless time series)	No (Trendless time series)
H_0, null hypothesis	Accepted	Accepted

Results of the Şen trend test are also given in Figures 2, 3 and Table 3. Low, medium and high values of the monthly total rainfall and monthly mean air temperature can be clearly seen in these graphics. Moreover, some statistical features and type of trend can be seen in Table 3 (in the last row). For instance, an increasing trend in medium and high values is clearly seen for monthly total rainfall in Figure 2 (b); moreover, monthly total

rainfall has the increasing time series as seen in Table 3; therefore, H_1 hypothesis is accepted. Slope value (+0.04), as seen in Table 3, is out of critical limits (-0.00244<s<+0.00244) for 95% confidence interval. Moreover, it can be seen the linear increasing trend from the Figure 2(a).

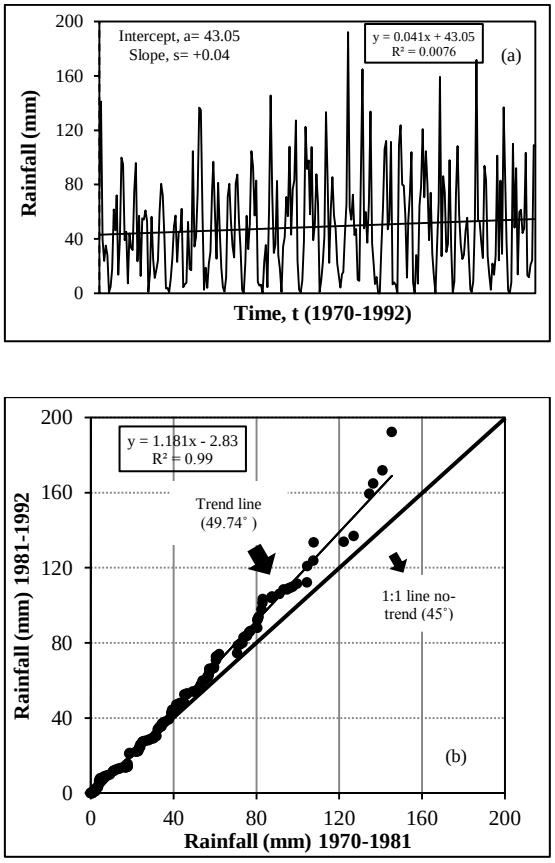

Figure 2. Results of Şen [34] trend of monthly total rainfall and (a) time series and (b) scatter diagrams for the period 1970-1992

For monthly mean air temperature, a trendless time series in high, medium and low values is seen in Figure 3(b); moreover, monthly mean air temperature has a trendless time series as seen in Table 3; therefore, H_0 hypothesis is accepted for this variable. Slope value (-0.0001) of this variable in Table 3 is in critical limits (-0.000415<s<+0.000415) for 95% confidence interval. Moreover, it can be seen the results of linear trend method from the Figure 3(a).

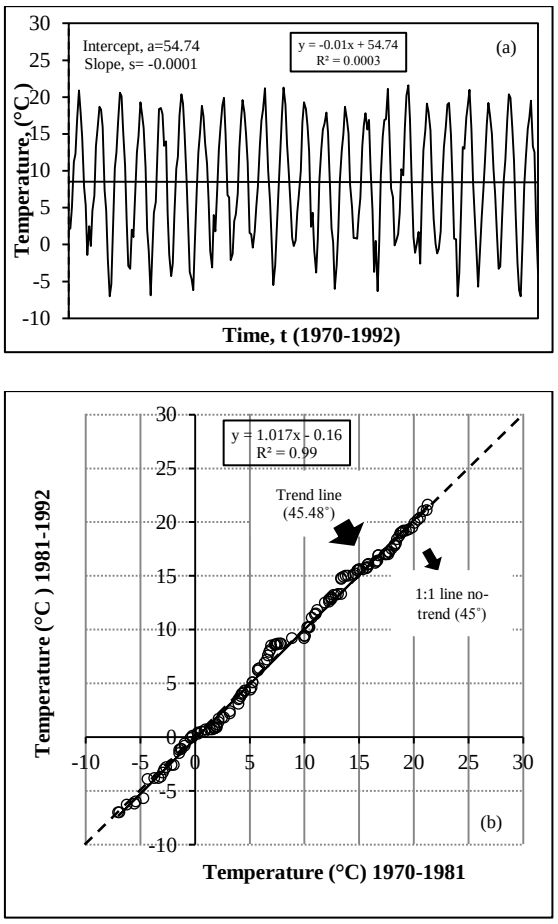

Figure 3. Results of Şen [34] trend of monthly mean air temperature and (a) time series and (b) scatter diagrams for the period 1970-1992

It can be seen the linear function (y=0.041x+43.05) in Figure 2(a). This trend line can refer to increasing way; and slope of the function is positive way. This result is also similar with Şen's trend test (see Table 3) but Mann-Kendall trend test (see Table 2). In Figure 3(a), the linear function is y=-0.01x+54.74. Slope of the function is slightly negative way, and linear trend is too close to the zero value. This result is also similar with Şen's trend test (see Table 3) and Mann-Kendall trend test (see Table 2).

Table 3. Results of Şen [34] trend test for the period 1970-1992 (23 years)

Parameters	Monthly total rainfall	Monthly mean air temperature
Unit	mm	°C
Number of data, n	276	276
Slope, s (+ or -)	+0.04	-0.0001
Intercept, a	43.05	54.74
Standard deviation, σ_n	38.44	7.88
Mean value, $\overline{X}_n$	48.85	8.49
Correlation coefficient (r), $\overline{\rho_{y_1}}, \overline{\rho_{y_2}}$	+0.9961	+0.9973
Slope standard deviation, σ_s	0.00148	0.00025
Significance level, α=0.05 (One-way)	0.05	0.05
Z critical value (α=0.05)(One-way)	±1.645	±1.645
Lower CL (confidence limit) (95%)	-0.00244	-0.000415
Upper CL (confidence limit) (95%)	+0.00244	+0.000415
Hypothesis (H_0 or H_1)	H_1	H_0
Decision (Yes or No)	Yes	No
Type of trend (increasing, decreasing or no trend)	Increasing trend	Trendless time series

4.2. Trend Analysis in the Period 1993-2016 (24 Years) for Monthly Total Rainfall and Monthly Mean Air Temperature

Data were divided into two sets because it provides both sufficient data for each time period and to see how trend changes for two time periods (for 23 years and 24 years). As we know, climate change effects around the world and our region are very important. It is thought that it may be seen these effects especially in the second time period, 1993-2016.

Second part of the study includes the other time period 1993-2016. Table 4 shows the results of the MK trend test for monthly total rainfall and monthly mean air temperature. Z value of each variable was calculated and compared with normal distribution critical Z values at 95% two-tailed confidence intervals. It can be seen that the calculated Z values (-0.64 and +0.78) are smaller than the critical Z value. Thus, monthly total rainfall and monthly mean air temperature have no trend (trendless time series) according to the MK trend test; and there is no statistically significant trend. Therefore, H_0 hypothesis (the null hypothesis) is accepted for monthly total rainfall and monthly mean air temperature of Yozgat.

Table 4. Results of the Mann-Kendall trend test for Yozgat over the period 1993-2016 (24 years)

Parameters	Monthly total rainfall (mm)	Monthly mean air temperature (°C)
Data ranges	1993-2016	1993-2016
Number of data	288	288
Test statistic (S)	-1043	1270
Calculated ± Z value	-0.64	+0.78
Z critical value (α=0.05, Two-tailed)	±1.96	±1.96
Trend	No (Trendless time series)	No (Trendless time series)
H_0, null hypothesis	Accepted	Accepted

Results of the Şen [34] trend test are also given in Figures 4, 5 and Table 5. Low, medium and high values of the monthly total rainfall and monthly mean air temperature can be clearly seen in these graphics over the period 1993-2016. In the same way, some statistical features and type of trend can be seen in Table 5 (in the last row). For instance, a trendless time series in high, medium, and low values is seen for monthly total rainfall in Figure 4(b); moreover, monthly total rainfall has a trendless time series as seen in Table 5; therefore, H_0 hypothesis is accepted. Slope value (+0.0018) of this variable in Table 5 is in critical limits (-0.0030<s<+-0.0030) for 95% confidence interval. Moreover, it can be seen the results of linear trend method from the Figure 4(a).

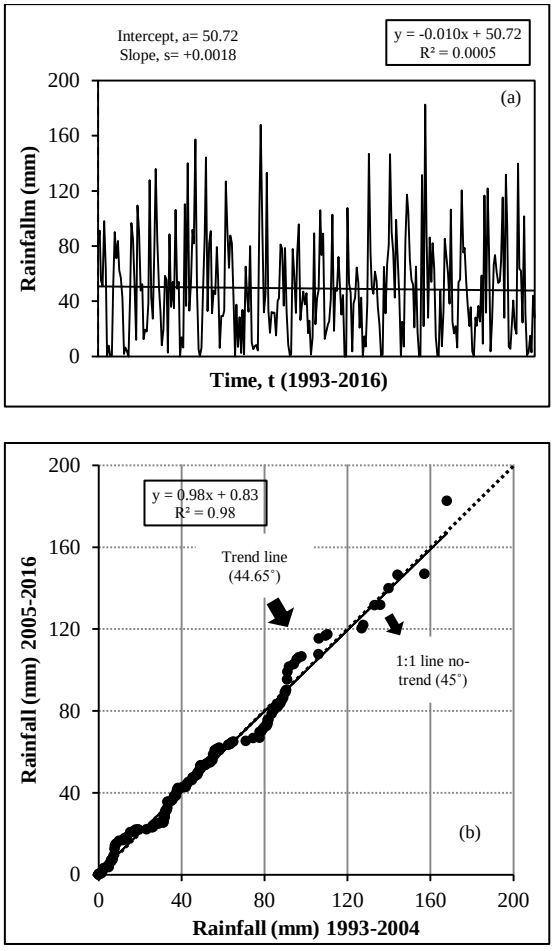

Figure 4. Results of Şen [34] trend of monthly total rainfall and (a) time series and (b) scatter diagrams for the period for the period 1993-2016

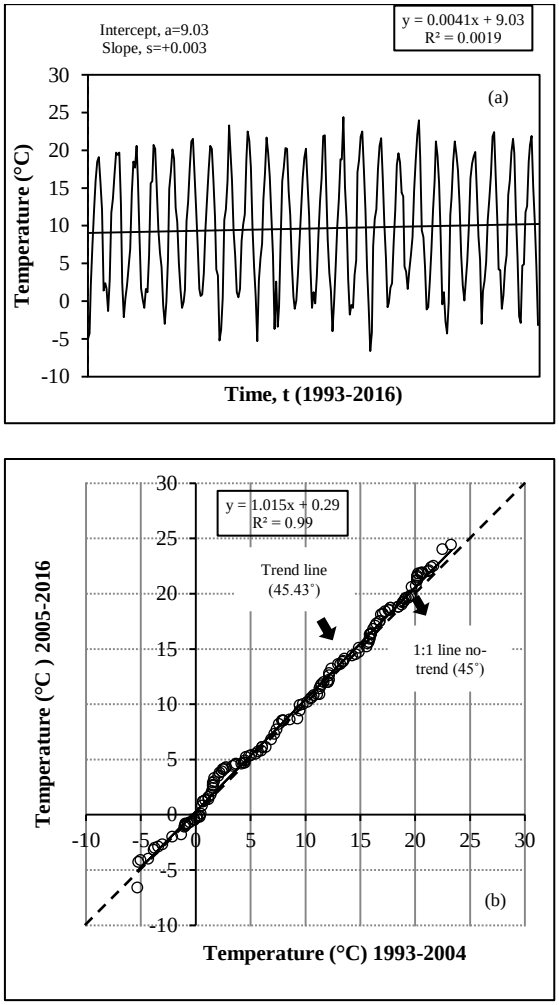

Figure 5. Results of Şen [34] trend of monthly mean air temperature and (a) time series and (b) scatter diagrams for the period 1993-2016

It is clearly understood that low, medium and high values of the monthly mean air temperature for the period 1993-2016 are seen in Figure 5(b). Type of trend is seen in Table 5 (in the last row). A slightly increasing time series in high values is seen for monthly mean air temperature in Figure 5(b); moreover, monthly mean air temperature has an increasing trend as seen in Table 5; therefore, H_1 hypothesis is accepted. Slope value (+0.003) of this variable in Table 5 is out of critical limits ($-0.00036<s<+0.00036$) for 95% confidence interval. Moreover, it can be seen the results of linear trend method from the Figure 5(a).

It can be seen the linear function is y=-0.01x+50.72 in Figure 4(a). Slope of the function is negative way, and linear trend is almost to zero value. This result is also different from Şen's trend test (see Table 4) and Mann-Kendall trend test (see Table 5). In Figure 5(a), trend line can refer to slightly increasing trend. The linear function is y=0.0041x+9.03. Slope of the function is positive way. This result is also similar with Şen's trend test (see Table 5) and Mann-Kendall trend test (see Table 4).

Table 5. Results of Şen [34] trend test for the period 1993-2016 (24 years)

Parameters	Monthly total rainfall	Monthly mean air temperature
Unit	mm	°C
Number of data, n	288	288
Slope, s (+ or -)	+0.0018	+0.003
Intercept, a	50.72	9.03
Standard deviation, σ_n	37.78	7.99
Mean value, $\overline{X}_n$	49.22	9.63
Correlation coefficient (r), $\overline{\rho_{y_1}}, \overline{\rho_{y_2}}$	+0.9930	+0.9977
Slope standard deviation, σ_s	0.001829	0.000221
Significance level, α=0.05 (One-way)	0.05	0.05
Z critical value (α=0.05)(One-way)	±1.645	±1.645
Lower CL (confidence limit) (95%)	-0.0030	-0.00036
Upper CL (confidence limit) (95%)	+0.0030	+0.00036
Hypothesis (H_0 or H_1)	H_0	H_1
Decision (Yes or No)	No	Yes
Type of trend (increasing, decreasing or no trend)	Trendless time series	Increasing trend

The trend variations of the monthly total rainfall and monthly mean air temperature of Yozgat are also summarized in Table 6 and Table 7 in terms of low, medium and high values. In this table; Şen and MK test results are particularly evaluated for both variables. It is clearly seen from this table that although there is no trend in both variables according to the MK trend test, the increasing trend is seen with respect to Şen's test for the monthly mean air temperature. It can be said that it may be an expected result for increasing trend in temperature variable. Moreover, the other expected case is the decreasing way (from increasing trend to no trend for monthly total rainfall) in rainfall variable when comparing the other studies [1-4, 11, 17, 18, 20, 21, 38, 40, 45 and 46]. It can be also said that Şen's test is more precision than the MK method, and shows all ranges (low, medium and high) of data, and data can be graphically furnished on the Cartesian coordinate system. Moreover, Şen's test has a statistical solution.

Table 6. Comparison results of the Mann-Kendall and Şen's trend tests for 1970-1992 (23 years) in Yozgat

Variable	MK test result	Şen's trend test		
		Low values	Medium values	High values
Monthly total rainfall (mm)	No	No	Yes (+)	Yes (+)
Monthly mean air temperature (°C)	No	No	No	No

Table 7. Comparison results of the Mann-Kendall and Şen's trend tests for 1993-2016 (24 years) in Yozgat

Variable	MK test result	Şen's trend test		
		Low values	Medium values	High values
Monthly total rainfall (mm)	No	No	No	No
Monthly mean air temperature (°C)	No	No	No	Yes (+)

5. CONCLUSION AND REMARKS

In this study, we took into consideration two time periods (1970-1992, 23 years and 1993-2016, 24 years) for the trend analysis of monthly total rainfall and monthly mean air temperature. Each time part was analysed individually, and both parts were compared with each other, and it was tried to tell some thoughts for trends of the variables and differences between two trend tests. As a result, general and specific findings derived from the study can be:

1) According to the Mann-Kendall trend test, there is no statistically significant trend for both variables at 95% two-tailed confidence interval for the two time periods: 1970-1992 and 1993-2016. But, there is insignificant increasing trend for monthly total rainfall (mm) in the period 1970-1992 (see Table 2). Z value of this variable is +1.09. This value is close to +1.96 (critical Z). This result is similar to result of Şen's trend test (see Table 3).

2) According to Şen's trend test, one of the most important results is that whereas monthly mean air temperature has no trend in the first time period 1970-1992, it changes as an increasing trend in the second time period 1993-2016. The other result of this study, monthly total rainfall has an increasing trend in the first time period 1970-1992, but this variable changes as trendless time series for the second time period. Thus, it can be said that amount of monthly total rainfall has a decreasing way; amount of monthly mean air temperature has an increasing way in Yozgat. However, if it is looked over the graphics, equations, tables, and statistical features of the variables, it can be said that situation of increasing and decreasing trend (from increasing trend to no trend for monthly total rainfall and from no trend to increasing trend for monthly mean air temperature in second time period, 1993-2016) is slightly degree.

3) The MK and Şen trend tests giving different trends for both variables provide to us relevant aspects and complexity of the trend phenomenon for significantly interpreting with other studies.

4) The study also implies that benefit of Şen's method is that all ranges of data can be graphically furnished on the Cartesian coordinate system. Thus, it helps to identify trends in low, medium and high records. This may also be a step towards the development of statistical methods to estimate water variables having short or long term records.

5) We hope that the results of this study can present vital information and the priori view to engineers and practitioners for the province.

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