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Innovative Trend Analysis of Annual Precipitation in Southeastern Anatolia Region, Turkey

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Abstract – Trend analysis of precipitation play a significant role in the efficient water resources management, especially in arid and semi-arid regions. In this study, 48 years-long (1970-2017) annual precipitation data monitored at nine selected stations (Mardin, Adıyaman, Batman, Diyarbakır, Siirt, Şırnak, Gaziantep, Kilis and Şanlıurfa) in the Southeastern Anatolia Region, Turkey were investigated by using the Innovative Şen Metod (ISM) and Mann-Kendall trend test (MK). The ISM has non-parametric basis without any restrictive assumption, moreover, its application is rather simple when compared with the other trend identification methods. Since the significance test is a crucial factor to identify the possible trends scientifically, the results were statistical tested at the 5% significance level in MK and in accordance with the proposed approach presented by Şen. The result revealed that the trend of annual precipitation was decreasing only in Mardin (Z = -2.12) with respect to both MK test. This result also approved by the ISM. Considering the other eight provinces, the ISM describe no trend at Batman, Diyarbakır and Kilis, increasing trend at Gaziantep, Adıyaman and Şırnak, and decreasing trend at Siirt and Şanlıurfa. It is concluded that the innovative method (ISM) has potential to present the monotonic and non-monotonic trends in graphical format, and a valuable method that avoids the assumptions such as independent structure of the time series, type of probability distribution function and length of the data.

Keywords – Innovative trend analysis, Mann-Kendall test, Precipitation, Southeastern Anatolia Region, Turkey

I. Introduction

In recent decades, a great concern is how to manage the water resources due to the climate change impacts, which characterized generally by increasing air temperatures and the changing pattern in precipitation. Therefore, investigations of the characteristics of variations in regional temperature and precipitation are particularly important for identifying and understanding the impacts of climate change on the hydrologic cycle [1]. To this end, trend analyses, which provide scientific information for better modeling, prediction, and control mechanism of the phenomenon concerned, are the essential efforts [2].

There are numerous trend analyses applied to hydro-climate data in the literature [3-7], however they principally base on nonparametric tests, as the Mann–Kendall (MK) analysis [8-9], the Spearman's rho test [10] and the Sen trend slope calculation methodology [11]. These objective approaches necessitate a set of assumption validity in the historical records (e.g. independent serial correlation structure, probability distribution functions, seasonality) [2], and did not specify if low or high precipitation contributed to the detected trends [12]. On the other hand, almost all the hydro-climate records have significant serial correlations at least on short memory basis [13], and efficient, effective, and optimum management of water resources requires identification of trends not only monotonically over a given time period but also whether the low, medium, and high values have separate trends [14]. For this reason, Şen [14] proposed the Innovative Şen Metod (ISM), which has found wide application in hydrology [2, 15, 16]. The ISM does not require any assumptions, and it base on the comparison of the two ascendingly ordered halves from the original time series [13].

In this study, 48 years-long (1970-2017) annual precipitation data monitored at nine selected stations (Mardin, Adıyaman, Batman, Diyarbakır, Siirt, Şırnak, Gaziantep, Kilis and Şanlıurfa) in the Southeastern Anatolia Region, Turkey were investigated by using the ISM and the results were compared with MK test results.

II. Materials and Method

Study Area and Data

In The Southeastern Anatolia Region (SAR) covers 9 provinces (Adıyaman, Batman, Diyarbakır, Gaziantep, Kilis, Mardin, Siirt, Şanlıurfa and Şırnak) located on the Euphrates-Tigris Basin and upper Mesopotamia plains.

The SAR provinces constitute approximately 10.7 % of Turkey's total population (80.8 million, in 2018), and covers 9.7 of country's surface area, 780.6 x 10^3 km^2 [17]. In general, the summer season in the region is very hot and under the influence of dry and warm tropical air mass while the winter is warm and rainy. The average annual rainfall varies between 400 mm and 700 mm, and the mean annual temperature is about 18 ºC, due to the high summer temperatures that approach 40 ºC in daytime. The SAR holds 20 % of the economically irrigable area of Turkey, while accounts for 28 % of total water potential. In the fertile lands, the agriculture is the main activity, so the drought has vital importance on socio-economic development.

Mann-Kendall Trend Test

The Mann-Kendall (MK) test is a non-parametric test that does not require the data to be normally distributed and has low sensitivity to outliers in the time series. The MK analysis also shows upward and downward trends with statistical significance. The strength of the trend depends on the magnitude, sample size and variations of data series. The non-parametric approach is used in many earth system studies for monotonic trend detection in a given time series data. Since the MK test is a well-known method, the detailed calculation steps are not given here, however, it can be found in several papers [18-20].

Innovative Şen Method (ISM)

In the ISM, the time series is divided into two equal parts, which are separately sorted in ascending order. Then, the first and the second half of the time series are located on the x-axis and on the y-axis, respectively, of a Cartesian coordinate system. If the data are collected on the 1:1 ideal line (45° line), there is no trend in the time series (Fig.1). If data are located on the upper triangular area of the ideal line, an increasing trend in the time series exists. If data pile up in the lower triangular area of the 1:1 line, there is a decreasing trend in the time series. It is also possible to have time series in which there are scatter of points on both sides of 1:1 line. These cases correspond to non-monotonic trends where within the same time series there are increasing and decreasing trends at different scales even hidden ones. [14]. Moreover, low, medium and high values of a parameter can be graphically evaluated with this method [21,22]. The possible trend types are given in Fig.1. Şen [13] has also proposed a statistical significant test to the method. Steps of this method are given by the following formulas Eq. (1-6).

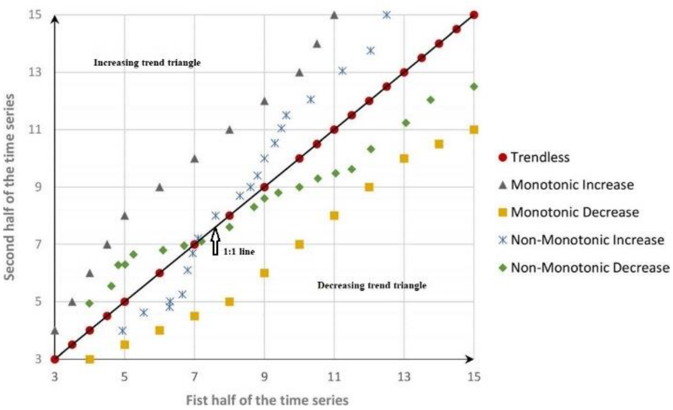


Fig.1. Illustration of trend types in the ISM [21]

$$E(s) = \frac{2}{n}[E(\bar{y}_2) - E(\bar{y}_1)] \quad (1)$$

$$\sigma_s^2 = \frac{4}{n^2}[E(\bar{y}_2{}^2) - 2E(\bar{y}_2\bar{y}_1) + E(\bar{y}_1)] \quad (2)$$

$$\rho_{\overline{y_2 y_1}} = \frac{E(\bar{y}_2\bar{y}_1) - E(\bar{y}_2)\,E(\bar{y}_1)}{\sigma(\bar{y}_2)\,\sigma(\bar{y}_1)} \quad (3)$$

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

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

$$CL_{(1-\alpha)} = 0 \pm s_{cri}\,\sigma_s \quad (6)$$

In the equations, the notations imply as below, where, $\bar{y}_1$ and $\bar{y}_2$: arithmetic averages of the first and the second halves of the data, ρ: correlation between the first and the second halves of the data, s: slope value, n: number of data, σ: standard deviation of all data, σ_s: slope standard deviation, and s_{cri}: Z critical values in one-way hypothesis at (1-α) % confidence level. Critical upper and lower limits calculated by Eq.6 are used to make for hypothesis test. If slope value, s, is outside of the lower and upper confidence limits, thus, the alternative hypothesis, ($H_{a)}$, is approved, and it can be said that there is a trend (Yes) in time series. The type of trend depend in accordance with 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 [13].

III. Results

In Table 1, all the necessary calculations of the ISM and the Mann-Kendall significance test results are presented. The results of the ISM applied to the nine meteorological stations in the Southeastern Anatolia Region are given in Fig 2.

In Mardin, it is obvious that there is a distinctive decreasing trend in annual precipitations (Fig.1.) The significant decreasing trend is also approved by the MK test score (z = -2,12). It appears to be a single monotonic trend, in other words, the total precipitation in Mardin follow a decreasing trend in all clusters of low, medium and high precipitation values.

The increasing trend in Adıyaman is significant in accordance with the ISM (Table 1). However, MK test revealed that the precipitation series are trendless. In particular for the higher values than average, there is an increasing trend in recent years. In 1996 and 2012, the recorded total precipitation values are 1132 mm and 1171 mm, respectively. Additionally, for the second half of the analysed period (1994-2017) the average annual precipitation is 706 mm, that is approx. 10% higher than average of 1970-1993. That can be an explanation of the increasing trend decision in ISM. While the ISM compare the two halves of the duration, the MK test use the whole time series for trend detection. That is why there are different results between the trend tests.

Similar to Adıyaman, the same conclusion is valid also for Gaziantep, where there is a general increment in the high values of precipitation in recent years, which covers the extreme precipitation totals of 996 and 873 mm for 1996 and 2012, respectively.

In Şırnak, the precipitation time series show an increasing trend behaviour in low precipitation values; however, there is decreases in the high precipitation domain.

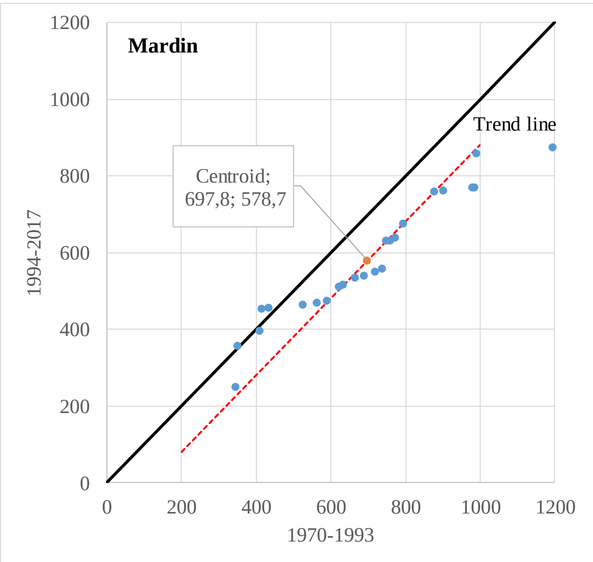
The annual precipitation records at Batman, Diyarbakır and Kilis exhibit trend-free behaviour. The decision “no trend” is accepted with both in the ISM and MK test results. In Figure 2, for the relevant provinces, it also is possible to see that most of the scatter points gather very close to 1:1 line.

For Siirt, it is possible to consider a non-monotonic decreasing trend due to the decrements in high precipitation values in addition to the increase in low precipitation totals.

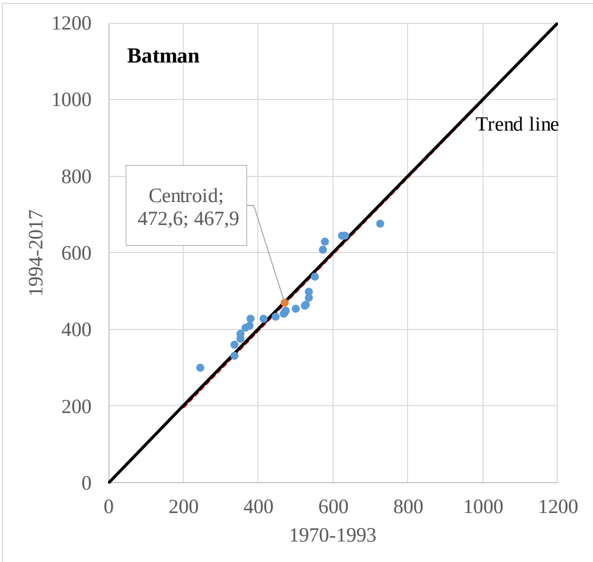
Another non-monotonic decreasing trend is seen in precipitation series of Şanlıurfa. However, here, a decreasing trend is dominant on the medium (average) values. Although the outputs of the ISM reflect a decreasing trend, due to the computed Z score (z=-1,18) in the MK test, one cannot reject the null hypothesis H_0. Moreover, it should be noted that Şanlıurfa has been experienced an extreme drought in 2017, with a total annual precipitation amount of 200 mm, which is approximately 50% less than the long-term average (420 mm).

Table 1. Results of Innovative Şen Metod and Mann-Kendall trend test

Stations	Mardin	Adıyaman	Batman	Diyarbakır	Siirt	Şırnak	Gaziantep	Kilis	Şanlıurfa
Average annual precip. (mm)	638	682	470	475	676	697	557	481	431
Slope, s	-4.96	2.03	-0.20	-0.26	-1.05	0.93	2.20	-0.24	-0.90
Standard deviation, σ	201.47	180.18	108.28	108.63	153.39	159.99	139.08	130.69	126.24
Correlation, $\rho_{\overline{y_2 y_1}}$	0.927	0.941	0.905	0.914	0.941	0.897	0.936	0.931	0.900
Slope standard deviation, σ_s	0.462	0.371	0.284	0.271	0.317	0.438	0.299	0.292	0.339
Significance level, α (One-way)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Lower CL (95%)	-0.760	-0.611	-0.467	-0.444	-0.521	-0.719	-0.492	-0.480	-0.558
Upper CL (95%)	0.760	0.611	0.467	0.444	0.521	0.719	0.492	0.480	0.558
Accepted hypothesis (ISM)	H_a	H_a	H_0	H_0	H_a	H_a	H_a	H_0	H_a
Type of trend (ISM)	Decreasing	Increasing	No trend	No trend	Decreasing	Increasing	Increasing	No trend	Decreasing
Calculated ± Z value	-2.12	0.54	0.04	0.10	0.26	0.58	0.29	-1.47	-1.18
Z critical value (α = 0.05)	± 1.96	± 1.96	± 1.96	± 1.96	± 1.96	± 1.96	± 1.96	± 1.96	± 1.96
Type of trend (MK)	Decreasing	No trend	No trend	No trend	No trend	No trend	No trend	No trend	No trend



(a)



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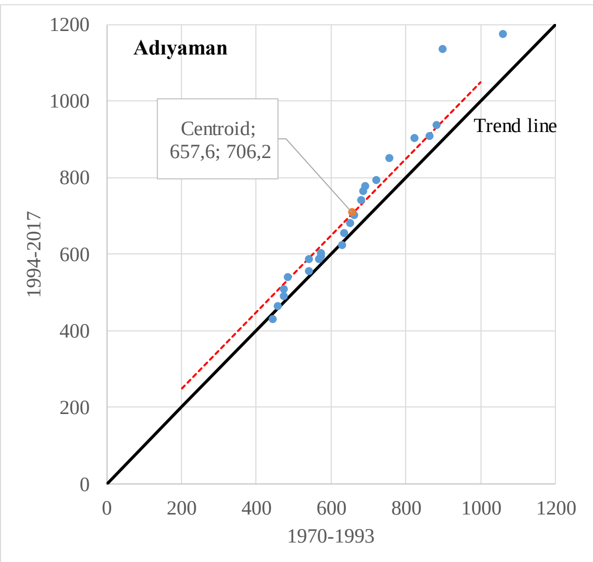

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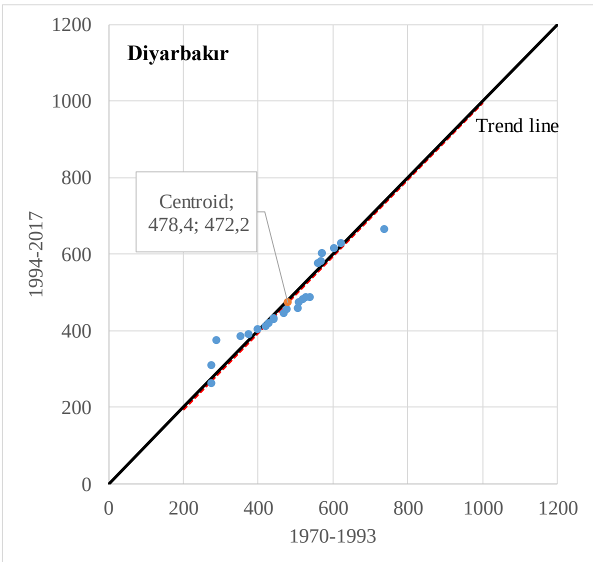

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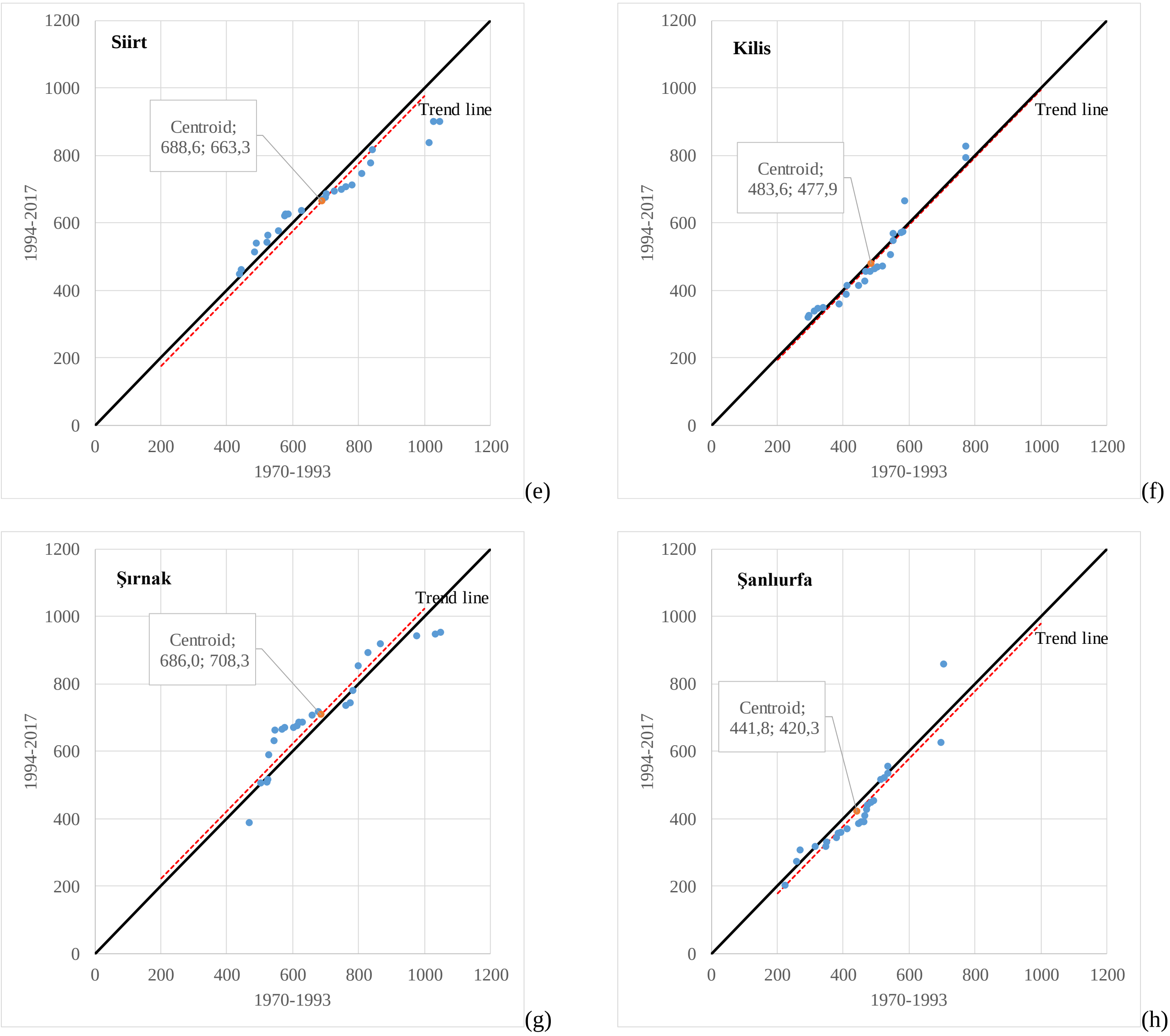

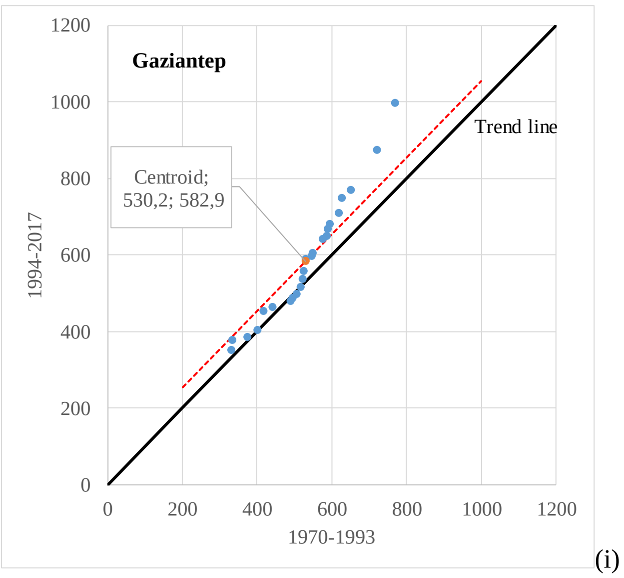

Fig. 2. Results of ISM for annual precipitation during 1970–2017

IV. Conclusion

In this study, the innovative Şen method (ISM) and the classical Mann-Kendall trend test were applied to the annual precipitation series of nine provinces located in the Souteastern Anatolia Region of Turkey. The trend analyses revealed different results for five of nine provinces in the region, and the same results were obtained for the other four provinces. Mardin was determined as the most vulnerable province in the region, due to the significant decreasing trend in precipitation series. In accordance with the results of the ISM, it is striking that there has been an increasing trend in precipitation in Gaziantep and Adıyaman. Both methods indicate that Batman, Diyarbakır and Kilis have trendless series in annual total precipitation.

Trend analysis is one of the most significant elements in any climate change study and provides a foresight for meteorological, hydrological, and climatological variables from past observations to future changes. The well-known trend test, Mann-Kendal (MK) trend test, which is misleading in the presence of data autocorrelation, requires few basic assumptions, which may not be valid in natural hydro-climatological time series. However, the ISM does not require assumption, and it is based on the comparison of the two ascendingly ordered halves from the original time series. It also make it possible to identify significant sub-trends of low, medium and high values. Moreover, due to its simplicity, it may be considered as a first step in the detailed climate change researches, for getting a general idea about the study area.

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