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Trend analysis of precipitation data using Mann Kendall and Sen's slope tests

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ABSTRACT

Changes in precipitation occur due to global or local climate changes. Studying this change is very important for human life. Rainfall is very important in meeting essential needs such as agricultural activities and clean water resources. Therefore, trend analysis in precipitation data is important. In this study, in order to examine whether there is a trend in the precipitation data of Erbaa Plain (Turkey), first homogeneity test was performed and then the standard precipitation index was calculated. The calculated data were analyzed using the Mann-Kendall test and Sen's Slope test. Monthly precipitation data for 40 years covering the years 1981-2020 were used in the study. Precipitation data were analyzed according to 90% confidence interval. Trends were detected in January and September in monthly precipitation series

1. INTRODUCTION

Change in meteorological data is a complex natural hazard that causes drought and affects ecosystems and society in many ways. In order to minimization the effects of drought as a result of meteorological variability, water resources management strategies should be developed and drought risk should be assessed (Beden et al.2020). Meteorological events on earth have unfixed feature. Therefore the size and consequences of meteorological changes cannot be easily predicted (Coskun 2019).

Various analysis methods such as time series, regression analysis and machine learning are used in the analysis of meteorological data. In this study, one of the analysis methods, time series methods were used. The precipition, known as most important meteoeological data, was selected as study topic.

Changes in precipitation in a residential area can lead to important problems affecting human life. Change has significant effects on clean water resources and agricultural activities. Efficient use and control of water is provided by the correct evaluation and analysis of the meteorological data. In order to meet the needs, the management of water resources that change depending on time and quantity parameters is very important. Thus, the meteorological data should be examined on the presence of any trend (Yüce et al. 2017). While, the continuous decrease in precipitation values, disasters can be observed such as drought and desertification, the continuous increase precipitation values, disasters such as landslides and floods are seen. Therefore, trend analysis and disaster risk maps in rainfall data have great importance (Beden et al.2020; Basara et al.2020).

In this study, precipitation analysis of the Erbaa Plain, which has a high importance in terms of agricultural activities in Tokat province, located in the Middle Black Sea Region, was performed using time series.

2. MATERIAL AND METHOD

In this study, precipitation data of Erbaa plain of Erbaa, given fig.1, district of Tokat province were used as application data. The precipitation data were taken from the NASA Langley Research Center (LaRC) POWER project. Monthly precipitation data for the 40-year period covering the years 1981-2020 were obtained from the website of the project. Standard Homogenity Test SNHT, Standard Precipitation Index (SPI), Mann-Kendall Trend Test, Sen's Slope Test were used as methods in the study.

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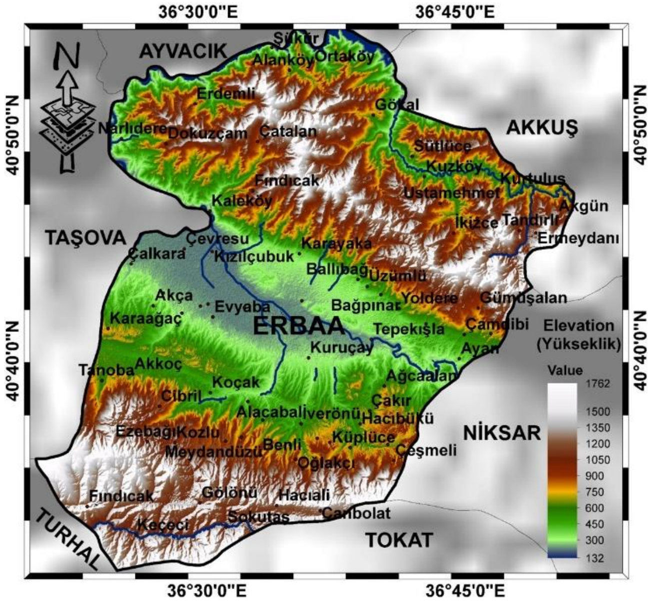

Figure 1. Location Map

2.1. Standart Normal Homogenity Test (SNHT)

The Standard Normal Homogeneity test (SNHT) method is used in the tests of many climatic and hydrological sizes (Alexandersson 1986). A point "c" from the analyzed series is divided into two by reference and Equation 1 is calculated with the help of Equation 2 If the change occurs at a 'h' point, T (c) reaches its maximum value at the point c = h. The test statistic is as in Equation 3. If the test value exceeds the table value, it is rejected. In this case, it is decided that the data are not homogeneous.

$$T(c) = c.\bar{z}_1^{\,2} + (n-c).c.\bar{z}_2^{\,2} \quad c = 1,\dots,n \quad (1)$$

$$\bar{z}_1 = \left(\sum_{i=1}^{c}\frac{y_i-\bar{y}}{\sigma}\right)/c \text{ ve } \bar{z}_2 = \left(\sum_{i=1+c}^{n}\frac{y_i-\bar{y}}{\sigma}\right)/(n-c) \quad (2)$$

$$T_0 = max_{1\le c\le n}T(c) \quad (3)$$

2.2. Standart Precipitation Index (SPI)

The Standard Precipitation Index (SPI) was proposed in 1993 and is used to identify and monitor drought in regions with varying climate (Mckee et al. 1993). If the data is in a normal distribution, the difference of precipitation from the mean can be divided by the standard deviation to determine the abnormalities in the regions. SPI account are calculated using Equation 4. The SPI values are classified according to Table 1.

$$SPI = \frac{(x_i - x_i^{ort})}{\sigma} \quad (4)$$

Table 1. SPI Classification

SPI Value	Drought Category
≥ 2	Extremely Humid
1.5 to 1.99	Very Humid
1.0 to 1.49	Moderately Humid
0.50 to 0.99	Lightly Humid
-0.49 to 0.49	Normal
-0.99 to -0.50	Lightly Drought
-1.0 to -1.49	Moderate Drought
-1.5 to -1.99	Very Drought
≤ -2	Extreme Drought

2.3. Mann Kendall Test

The Mann-Kendall method is a non-parametric method that is processed according to the presence or absence of change in parameters in a time series (Mann 1945; Kendall 1975). It is determined whether there is a trend in the daha using Mann Kendall test (Beşel and Tanır Kayıkçı 2019). In this method, the order of the data is compared (Gilbert 1987). One of the advantages of the test is that the data does not need to any distribution.

Mann-Kendall test is calculated using Equation 5 and Equation 6. The variance calculation of the test statistic with a normal distribution is calculated using Equation 7. In order to determine the significance of the test and probability function are calculated using Equation 8-9.

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (5)$$

$$sgn(x_j - x_k) = \begin{cases} 1 \ (x_j - x_k) > 0 \\ 0 \ (x_j - x_k) = 0 \\ -1 \ (x_j - x_k) < 0 \end{cases} \quad (6)$$

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \quad (7)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \quad (8)$$

$$F(Z) = \frac{1}{2\pi} e^{\frac{-z^2}{2}} \quad (9)$$

2.4. Sen's Slope Test

The direction and size of the trend in the data are determined using the Sen's Slope test (Sen 1968). If there is a linear trend in the time series, the actual slope (change in unit time) can be determined using a nonparametric method. This method can be applied to records that are not affected by data errors or extreme values and where there are missing values (Yu et al. 1993).

The median is calculated using Equation 10 in Sen's Slope test. If the number of data (N), is an odd or even, Equation 11 and 12 are applied, respectively.

$$Q_i = \frac{(x_j - x_k)}{(j-k)} \quad (10)$$

$$Q = Q_{(N+1)/2} \quad (11)$$

$$Q = \frac{1}{2}\left[Q_{N/2} + Q_{(N+2)/2}\right] \quad (12)$$

3. RESULTS

In the first stage of the study, the Standard Homogeneity Test (SNHT) was applied to determine the suitability of the values in the data set for analysis. Then SPI values were calculated for drought classification. The Mann-Kendall test was applied to determine the direction of trends and statistical significance levels in the data series. In the last stage, Sen's Slope test was applied to determine the trend directions. This process was made for monthly and annual total precipitation series. The work flow chart of the study is given in Figure 2.

Figure 2. Flow Chart

Homogeneity testing was done using the R-Studio program. Results are given in Table 2. It was found that the data were homogeneous and suitable for analysis.

Table 2. Homogeneity Analysis Result

P-value	alpha	SNHT
0.466	0.05	Homogeneous

According to Table 2, it was decided that the data were homogeneous since P-value selected significance value (0.05). The calculation and classification of SPI values of application data are calculated using Equation 4 and Table 1. The results are given in Table 3.

Table 3. Annual SPI Classes

Year	SPI Class	Year	SPI Class
1981	Lightly Drought	2001	Normal
1982	Lightly Humid	2002	Normal
1983	Normal	2003	Normal
1984	Moderate Drought	2004	Moderately Humid
1985	Moderate Drought	2005	Lightly Humid
1986	Very Drought	2006	Moderate Drought
1987	Normal	2007	Normal
1988	Lightly Humid	2008	Normal
1989	Moderate Drought	2009	Extremely Humid
1990	Moderate Drought	2010	Lightly Humid
1991	Lightly Humid	2011	Moderately Humid
1992	Normal	2012	Very Humid
1993	Moderate Drought	2013	Very Drought
1994	Normal	2014	Normal
1995	Normal	2015	Lightly Drought
1996	Lightly Humid	2016	Moderately Humid
1997	Normal	2017	Lightly Drought
1998	Lightly Humid	2018	Normal
1999	Moderately Humid	2019	Lightly Drought
2000	Lightly Humid	2020	Very Drought

From the Table 3, Extremely Humid in 1 year, Very Humid in 1 year, Moderately Humid in 4 years, Lightly Humid in 8 years, Normal in 13 years, Lightly Drought in 4 years, Moderate Drought in 6 years, Very Humid in 3 years rainfall was observed. There was no rainfall in the Extreme Drought class.

Mann-Kendall Test results of the monthly total precipitation data set are given in Table 4.

Table 4. Monthly Mann Kendall Trend Analysis Results

Months	MK-z Tau	MK-P Value	MK Hypo-thesis
January	0.297	0.007	Refuse
February	-0.108	0.328	Accept
March	0.162	0.142	Accept
Aprıl	-0.136	0.217	Accept
May	0.151	0.169	Accept
June	0.181	0.100	Accept
July	0.001	0.991	Accept
August	0.003	0.981	Accept
September	0.196	0.075	Refuse
October	-0.090	0.415	Accept
November	-0.110	0.316	Accept
December	0.074	0.499	Accept

Sen's Slope Test results for the monthly total precipition data set are given in Table 5.

Table 5. Monthly Sen's Slope Trend Analysis Results

Months	Sen's Slope	Sen's Type of Trend
January	0.033	Increase
February	-0.007	No Trend
March	0.018	Increase
Aprıl	-0.016	Decrease
May	0.013	Increase
June	0.017	Increase
July	0.000	No Trend
August	0.000	No Trend
September	0.018	Increase
October	-0.010	Decrease
November	-0.018	Decrease
December	0.007	No Trend

Trend charts obtained as a result of the analysis are given in Figure 3-5.

4. DISCUSSION AND CONCLUSION

In this study, monthly precipitation data of Erbaa Plain in mm were used. SNHT was applied to monthly precipitation data and H_0 hypothesis was accepted since P = 0.466 value was higher than significance level 0.05 value. It was seen that the data were suitable for analysis.

The SPI values were analyzed with Mann-Kendall trend test, which is one of the non-parametric tests, as monthly. The analysis was made according to 10% significance level. According to the trend analysis, an increasing trend was determined in January and September. Although not statistically significant, an increasing trend was observed in March, May and June. A downward trend was observed in February, April, October and November.

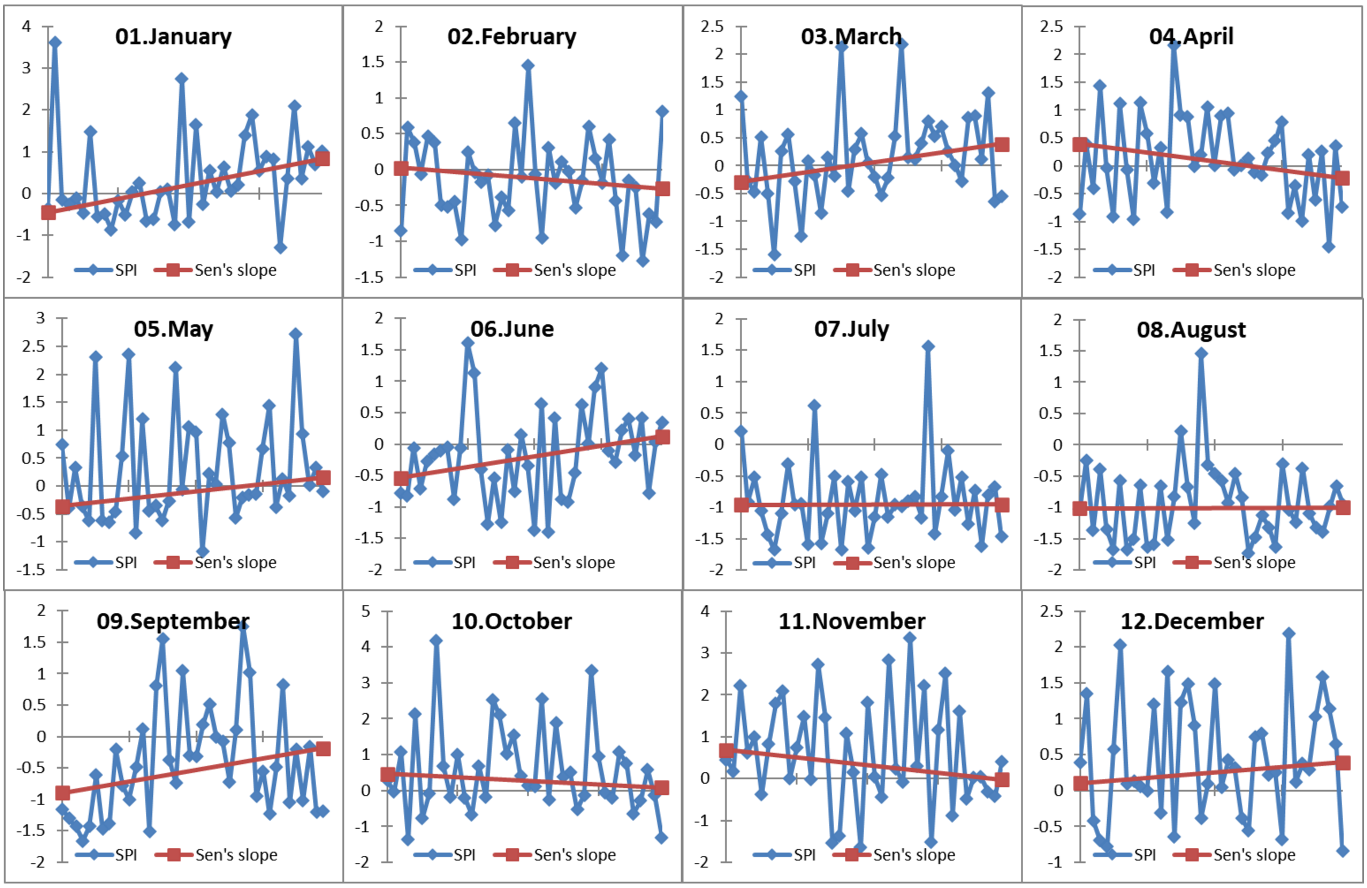

Figure 3. Monthly Trend Graphs

The SPI values were analyzed with the Sen's Slope trend test, which is one of the non-parametric tests, for monthly with 10% signifidance level. According to the analysis results, Mann Kendall z values and Sen's Slope values show parallelism.

While there is generally increasing precipitation in the Erbaa Plain, droughts have been observed in recent years (2016-2020). It has been observed that the decreasing tends was in the autumn months, when the region receives the most precipitation. Also, an increasing trend was observed in the summer months, when the lowest rainfall was observed throughout the year. The plans should be made in order to reduce the damages that may occur due to the negative effects of climate change. Similar studies done for other regions of Turkey and hydrological and climatological elements. In this way, the formation and effects of climate changes can be observed on a wider scale and contribute to the planning to be made.

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