Homogeneity and Trend Analysis of Long Term Temperatures in the Middle Black Sea Region

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Abstract

In this study long-term trend analysis of maximum and minimum monthly temperatures are determined in the Middle Black Sea Region of Turkey. Data is obtained from Turkish State Meteorological Service for the period of 1964 to 2015 for Amasya, Çorum, Ordu, Samsun, Sinop and Tokat stations throughout the Middle Black Sea Region. Primarily homogeneity of the data is examined with Run, Buishand and Von Neumann homogeneity methods with a 99 % confidence level. Linear trend, Mann-Kendall and Innovative Sen's trend methods are used for trend analysis with a 99 % and 95 % confidence levels. Amasya and Çorum stations are determined homogeny according to the entire homogeneity tests. Ordu is homogeny for Run test besides Samsun, Sinop and Tokat stations are homogeny for the Von Neumann test. The maximum temperatures showed an increasing significant trend, while the minimum temperatures showed increasing trends statistically insignificant. The results of Mann-Kendall and the Linear trend analysis are similar. The Sen's method was consistent with linear and Mann-Kendall tests, except for the minimum temperatures of the Amasya and Tokat stations. Since the confidence interval is very sensitive in Sen's trend method, trends in most of the stations have been determined increasing. Trends of monthly maximum and minimum temperatures are analyzed in the study. The data of 1964-2015 periods of six stations in the Middle Black Sea region were taken into consideration. Long-term trends in all trend analysis were determined that increasing significant trends are seen in maximum and minimum temperatures.

Keywords: *Trend analysis, homogeneity, temperature, Middle Black Sea Region*

1 Introduction

Temperature is one of the most important climate data that can be used to analyze the climate of any region and global warming. The fact that temperature changes cause drought, flood, productivity in agriculture and loss of biodiversity creates both negative economic and social impacts. Therefore, trend analysis of temperature is important for climate change studies and water resources management. Climate change is an increasingly violent reality and since 1950 most of the observed changes are unmatched in comparison with a thousand years ago. Air temperature analyzes since 1860 show that the average warming is 0.84 °C. (Intergovernmental Panel on Climate Change [IPCC], 2013).

According to studies conducted in recent years, the climate of the world has changed, and the main cause is excessive greenhouse gas emissions. (Anderson et al., 2010; IPCC, 2007; Mullan et al., 2008). Trend analysis with temperature data is very important in climate change studies. According to climate change studies, human-induced greenhouse gas emissions are continuing to increase, and average temperatures will continue to increase in future. To determine statistically significant variations, many trend studies were focused on the air temperature in the literature. (Begert et al., 2005; Chen et al., 2007; Zhang et al., 2008; Zhang et al., 2011; Ageena et al.,2014; Camberlin, 2017).

Parametric and non-parametric procedures are utilized to detect to trends in climatic variables. The parametric test requires that the data be normally distributed. If the time series have non-normal distribution, missing values and serial correlation, non-parametric procedures are proposed. Consequently, non-parametric procedures have been commonly used because of require of not much acceptance (Partal, 2002). The objective of this study is to investigate the applicability of Sen trend test (Innovative Sen's Trend Test) which is not dependent on any restrictive assumption as serial correlation, non-normality and sample number to maximum and minimum monthly temperatures. For this aim, temperatures data from six different locations, Sinop, Samsun, Ordu, Tokat, Çorum and Amasya in in Middle Black Sea Region of Turkey were used. This data was also analyzed by well-known Mann-Kendall trend test and Linear Regression Trend test. Finally, the results are given comparatively.

2 Study Area and Data

Study was carried out in the Middle Black Sea region which is located North of Turkey shown in Figure 1. Black Sea climate is observed in the study area. Black Sea climate is warm, semi-humid and average annual precipitation is about 700-1000 mm with an average annual temperature of 13-15°C. The Middle Black Sea region is rich in terms of water resources. Kızılırmak and Yeşilırmak rivers, which are the important water resources for Turkey, passing through the region and pour into the sea.

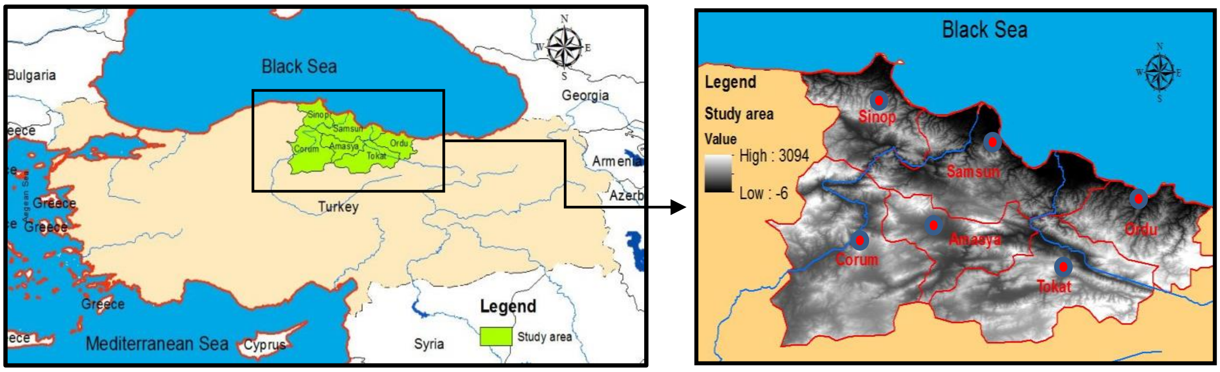

Figure 1. Location of Middle Black Sea Region

Monthly average temperature data sets used in the study, and data obtained from Turkish State Meteorological Service. As shown in Table 1, there is six stations chosen for the study (Amasya, Çorum, Ordu, Samsun, Sinop and Tokat) for the period of 1964 to 2015. All stations have 51-year continuous observations for the 1964-2015 period. Monthly average temperatures have used to calculate the average annual temperatures that used in the study.

In many climate studies, fully homogeneous data sets cannot be used because of human effects i.e. changing the positions of stations, incorrect calibrations of measuring instruments etc. Firstly, for the analysis of the statistical homogeneity of the data, Run (Swed-Eisenhard) test, Von Neumann rate test, and Buishand rank test were applied at the 1 % significance level.

Table 1. Information about meteorological stations

Climatic Zone	Station Name	Climatic Zone	Period	Latitude (ºN)	Longitude (ºE)	Altitude (m)
Black Sea	Amasya	Blacksea	1964-2015	40.39	35.50	412
	Çorum	Blacksea	1964-2015	40.33	33.58	837
	Ordu	Blacksea	1964-2015	40.59	37.54	4
	Samsun	Blacksea	1964-2015	41.17	36.18	4
	Sinop	Blacksea	1964-2015	42.02	35.10	32
	Tokat	Blacksea	1964-2015	40.18	36.34	608

3 Methodology

3.1 Mann-Kendall Trend Test

Objective of this study to determinate changes in temperature in Middle Black Sea Region during the observation period. Statistical variations in temperatures have been subjected to the non-parametric Mann-Kendall (MK) test method. The Mann-Kendall test is a non-parametric method commonly used in hydrology and meteorology to find trends over period. Steps of this method are given in Equation 1-4 (Mann, 1945; Kendall, 1975).

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

$$sgn(x_j - x_i) = \begin{cases} 1; & \dot{I}f \; x_j > x_i \\ 0; & \dot{I}f \; x_j = x_i \\ -1; & \dot{I}f \; x_j < x_i \end{cases} \tag{2}$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{P} t_i(t_i - 1)(2t_i + 5)}{18} \tag{3}$$

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}; & \dot{I}f \; S > 0 \\ 0; & \dot{I}f \; S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}; & \dot{I}f \; S < 0 \end{cases} \tag{4}$$

In the Equations, n is the number of data, x_i and x_j are the data values in time series j and k, respectively and in sgn ($x_k - x_j$) is the sgn function as; Var(S), variance value; P indicates the number of tied groups; t_i shows the number of ties of extent i; Z is the comparison value of Mann-Kendall. The standard normal distribution and the Z value are compared according to the confidence intervals. (α =5 %, α =1 %). If the computed Z value is greater than $|Z| < |Z_{1-\alpha/2}|$, null hypothesis (H_0) is accepted and thus H_1 hypothesis is rejected. On the contrary case hypothesis H_1 agreeable and besides there is a statistically significant trend.

3.2 Linear Regression Trend Test

Regression analysis is based on the solution of the graph obtained by writing two different variables on separate axes. It is necessary to select a line that best expresses the obtained graph and determine the curve of this line.

$$Y = \beta_0 + \beta_1 X \tag{5}$$

In Equation 5, β_0 is a constant value and β_1 is the slope. If this equation used in the determination of Middle Blacksea Region temperatures trend analysis, β_1 is expressed the amount of decrease or increase on trend (Davidson and MacKinnon, 2003).

Whether the temperature data show a statistically significant trend is determined by the t test. t value of the β_1 value (inclination) calculated with the help of Equation 5 is calculated. "t_{cal}" is compared with a selected significance level (eg 5%). If it exceeds the confidence interval (critical level), there is increase and decreases according to the sign. If it does not exceed ($-t_{cri} < t_{cal} < t_{cri}$) the trend is called no.

3.3 Innovative Sen's Trend Test

The Sen (2012) method is independent of assumptions such as sample size and serial correlation, within the data can be distributed as normally and non-normally also. Steps of this method are given in Equation 6-11.

$$E(s) = \frac{2}{n}\left[E(\overline{y_2}) - E(\overline{y_1})\right] \tag{6}$$

$$\sigma_s^2 = \frac{4}{n^2}\left[E(\overline{y_2}^2) - 2E(\overline{y_2}\,\overline{y_1}) - E(\overline{y_1}^2)\right] \tag{7}$$

$$\rho_{\overline{y_2}\,\overline{y_1}} = \frac{E(\overline{y_2}\,\overline{y_1}) - E(\overline{y_2}) - E(\overline{y_1})}{\sigma_{\overline{y_2}}\,\sigma_{\overline{y_1}}} \tag{8}$$

$$\sigma_s^2 = \frac{8}{n^2}\frac{\sigma^2}{n}(1-\rho_{\overline{y_2}\,\overline{y_1}}) \tag{9}$$

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}}\sigma\sqrt{(1-\rho_{\overline{y_2}\,\overline{y_1}})} \tag{10}$$

$$CL_{(1-\alpha)} = 0 \pm S_{critical}\sigma_s \tag{11}$$

Where $\overline{y}_1$, 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; Z critical values in one-way hypothesis at 95 % (for example) confidence level.

Critical upper and lower values established for hypothesis test limits (Equation 11). It can be said that, if each station's slope value, s, is outside the lower and upper confidence limits, and alternative hypotheses, H_1, are verified, there is a trend (Yes) in time series. The type of trend is stated depending on the slope value (s) sign. Slope (s) can be positive or negative. That means there is a decreasing (-) or an increasing (+) trend in time series (Sen, 2015).

3.4 Run (Swed-Eisenhart) Test

The test procedure depends on the truncation of the time series concerned at the median level, giving rise to data values greater or smaller than the median. Any uninterrupted sequence of greater (smaller) values preceded and succeeded by at least one smaller (greater) value is referred to as a run. A succession of greater (smaller) values constitute a positive (negative) run. Generally, the number of positive runs is equal to negative runs plus or minus 1. For the time series concerned to be homogeneous, the number of positive (negative) runs should be confined within the upper and lower confidence limits at a given significance level (usually 5 or 10 per cent) (Swed and Eisenharth, 1943; Kadıoglu, 1997). The calculation of confidence limits assumes of a normal distribution.

According to results, if data are independent of each other and from the same society, that series called simple random series. The assumptions made for the homogeneity of the data are (Oliver, 1981);
H_0: The data are homogeneous.
H_1: The data are not homogeneous.

$$z = \frac{\left(r - \dfrac{2N_e N_p}{(N_e + N_p)} \right)}{\sqrt{\dfrac{2N_e N_p (2N_e N_p - N)}{N^2 (N-1)}}} \tag{12}$$

In equation 12; result z, number of data N, run number r, number of values that bigger then median, N_p, number of values that smaller then median N_e. The H_0 hypothesis is rejected at values greater than ±1.96 for z, corresponding to a 95% confidence measure according to the test results.

3.5 Buishand Rank Test

This test is defined as corrected partial sums as seen in equation;

$$S_0^* = 0 \tag{13}$$

$$S_k^* = \sum_{i=1}^{k} (Y_i - \overline{Y}) \tag{14}$$

When the data series are homogeneous, S_k value will be “0” because there is no systematic deviation of Y_i. The ratio of the difference between the maximum and minimum S_k to the standard deviation gives the R correction rate, which is also the standard deviation equation (Wijngaard et al., 2003). R correction rate is calculated as in Equation 6. If the result of the homogeneity test is less than the critical value, that data set is called homogeneous.

$$R = \frac{(\max_{0 \le k \le n} S_k^* - \min_{0 \le k \le n} S_k^*)}{s} \tag{15}$$

3.6 Von Neumann Test

The Von Neuman rate is defined as the ratio of the variance value of the sum of the mean to the mean of N years (Von Neuman, 1941). If the result of the homogeneity test is greater than the critical value, then the data set is called homogeneous.

$$N = \frac{\sum_{i=1}^{n-1} (Y_i - Y_{i+1})^2}{\sum_{i=1}^{n} (Y_i - \overline{Y})^2} \tag{16}$$

4 Application and Results

The aim of this study is to analyze the behavior of temperature for the Middle Black Sea Region. Data is obtained from Turkish State Meteorological Service for the period of 1964 to 2015 for Amasya, Çorum, Ordu, Samsun, Sinop and Tokat stations. Observation data from gauge stations were applied to the non-parametric Mann-Kendall (MK) test, as a parametric method linear trend test and the innovative trend analysis (Sen Trend) approach to investigate the temperature trends. Run, Von Neumann and Buishand test methods were applied to the data for homogeneity.

4.1 Results of Homogeneity

Run test, Buishand rank test, and Von Neumann rate test were applied at the 5 % significance level for the analysis of the statistical homogeneity of the data. Critical values for homogeneity test are shown in Table 2.

Table 2. Critical values for homogeneity tests

Critical Values (5% Significance Level)		
Run	Buishand	Von Neumann
2.576	1.76	1.34

Amasya and Çorum stations are determined homogeny according to the entire homogeneity tests. Ordu is homogeny for Run test besides Samsun, Sinop and Tokat stations are homogeny for the Von Neumann test as shown in Table 3. After homogeneity analysis temperature series are subjected to trend analysis. It is expected that the trends will be strong in non-homogeneous stations.

Table 3. Homogeneity test results

	Run		**Buishand**		**Von Neumann**	
Station	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**	**Min.**
Amasya	-0.138	0.993	1.708	0.766	1.683	2.190
Çorum	0.993	1.559	0.812	0.941	2.497	2.445
Ordu	-1.836	1.559	**2.406**	0.977	**0.868**	2.129
Samsun	-1.252	**2.691**	**1.973**	0.716	1.565	2.090
Sinop	-1.252	**3.257**	**2.033**	0.854	1.375	2.303
Tokat	-0.684	2.125	**1.887**	0.784	1.431	2.197

4.2 Results of Trend Analysis

According to the Mann-Kendall test results, at the levels of significance of 1 % and 5 %, it has been determined that the maximum temperatures tend to increase in all stations except Çorum station. At minimum temperatures it is not statistically significant since the trend direction is positive (increasing). In addition, the maximum increase in temperatures are seen at the Ordu station. Mann-Kendall test results shown in Table 4.

Table 4. Mann-Kendall test results for temperatures

	Station	**Parameter**	**MK Z**	**%95 ±Zcri**	**Hypothesis**	**%99 ±Zcri**	**Hypothesis**
Middle Blacksea Region	**Amasya**	**Max.**	**3.395**	1.96	**Ha**	2.58	**Ha**
		Min.	1.015	1.96	Ho	2.58	Ho
	Çorum	**Max.**	1.901	1.96	Ho	2.58	Ho
		Min.	1.559	1.96	Ho	2.58	Ho
	Ordu	**Max.**	**5.247**	1.96	**Ha**	2.58	**Ha**
		Min.	1.714	1.96	Ho	2.58	Ho
	Samsun	**Max.**	**3.046**	1.96	**Ha**	2.58	**Ha**
		Min.	1.316	1.96	Ho	2.58	Ho
	Sinop	**Max.**	**4.094**	1.96	**Ha**	2.58	**Ha**
		Min.	1.543	1.96	Ho	2.58	Ho
	Tokat	**Max.**	**3.574**	1.96	**Ha**	2.58	**Ha**
		Min.	1.113	1.96	Ho	2.58	Ho

Mann-Kendall and Linear trend results are very consistent and supports each other. According to the Linear trend analysis in 5 % and 1% significance level, the maximum temperatures of all stations except Çorum station tend to increase similarly to the Mann-Kendall method results. Linear trend test results shown in Table 5.

Table 5. Linear trend test results for temperatures

	Station	Parameter	LT t	%95 ±tcri	Hypothesis	%99 ±tcri	Hypothesis
Middle Blacksea Region	**Amasya**	**Max.**	**3.300**	2.01	**Ha**	2.67	**Ha**
		Min.	0.457	2.01	Ho	2.67	Ho
	Çorum	**Max.**	0.474	2.01	Ho	2.67	Ho
		Min.	1.281	2.01	Ho	2.67	Ho
	Ordu	**Max.**	**6.879**	2.01	**Ha**	2.67	**Ha**
		Min.	1.751	2.01	Ho	2.67	Ho
	Samsun	**Max.**	**3.204**	2.01	**Ha**	2.67	**Ha**
		Min.	1.609	2.01	Ho	2.67	Ho
	Sinop	**Max.**	**4.573**	2.01	**Ha**	2.67	**Ha**
		Min.	1.379	2.01	Ho	2.67	Ho
	Tokat	**Max.**	**3.025**	2.01	**Ha**	2.67	**Ha**
		Min.	0.772	2.01	Ho	2.67	Ho

The results obtained using Innovative Sen trend method are given in Table 6. Although similar results are obtained with the other two methods, it has been determined that minimum temperatures tend to decrease in Amasya and, Tokat stations. Statistically significant trends were observed at all stations except Tokat station at 5 % significance level. Çorum, Ordu, Samsun and, Sinop stations showed statistically significant trends in the significance level of 1 %.

Table 6. Innovative Sen trend test results for temperatures

	Station	Parameter	ST slope	Lower Upper CL %95	Hypothesis	Lower Upper ±CL %99	Hypothesis
Middle Blacksea Region	**Amasya**	**Max.**	0.049	0.008	**Ha**	0.011	**Ha**
		Min.	-0.013	0.010	**Ha**	0.013	Ho
	Çorum	**Max.**	0.019	0.021	Ho	0.028	Ho
		Min.	0.028	0.014	**Ha**	0.019	**Ha**
	Ordu	**Max.**	0.057	0.004	**Ha**	0.005	**Ha**
		Min.	0.020	0.006	**Ha**	0.008	**Ha**
	Samsun	**Max.**	0.043	0.003	**Ha**	0.004	**Ha**
		Min.	0.025	0.006	**Ha**	0.008	**Ha**
	Sinop	**Max.**	0.054	0.002	**Ha**	0.003	**Ha**
		Min.	0.027	0.005	**Ha**	0.007	**Ha**
	Tokat	**Max.**	0.054	0.005	**Ha**	0.007	**Ha**
		Min.	-0.008	0.015	Ho	0.019	Ho

5 Conclusion

In the present study, long-term trend and homogeneity trends for maximum and minimum monthly temperature series was analyzed at the levels of significance of 1 % and 5 %. Data is obtained from Turkish State Meteorological Service for the period of 1964 to 2015 for Amasya, Çorum, Ordu, Samsun, Sinop and Tokat stations throughout the Middle Black Sea Region. Monthly average temperatures have used to calculate the average annual temperatures that used in the study.

According to the homogeneity tests, except Amasya and Çorum stations the data belonging to the Ordu, Samsun, Sinop and Tokat stations are found mis-trustfully non-homogeneous. Temperature series belonging to 6 stations are subjected to Mann-Kendall trend, Linear trend and Innovative Sen trend analysis after these homogeneity analyses.

The maximum temperatures showed an increasing significant trend, while the minimum temperatures showed increasing trends statistically insignificant. The results of Mann-Kendall and the Linear trend analysis are similar. According to the Mann-Kendall test results, at the levels of significance of 1 % and 5 %, it has been determined that the maximum temperatures tend to increase in all stations except Çorum station. According to the Linear trend analysis in 1 % and 5 % significance level, the maximum temperatures of all stations except Çorum station tend to increase similarly to the Mann-Kendall method results.

Innovative Sen trend method was consistent with Linear and Mann-Kendall trend tests, except for the minimum temperatures of the Amasya and Tokat stations, it has been determined that minimum temperatures tend to decrease in these stations. Since the confidence interval is very sensitive in Innovative Sen trend method, trends in most of the stations have been determined increasing. It is very clear that the trends are stronger at the non-homogeneous stations. As a result, temperatures in the middle black sea region tend to increase in all three methods.4

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