7th Intercontinental Geoinformation Days

igd.mersin.edu.tr

Trend analysis of precipitation and temperature in the Western Black Sea region of Türkiye

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Keywords
Trend Analysis
Mann Kendall
Theil-Sen Slope
Temperature
Western Black Sea

Abstract

Climate change indicates alterations in climate parameters, involving both increases and decreases. Trend analysis enables the identification and direction of these changes. This study aims to conduct trend analysis in the Western Black Sea region of Türkiye. Non-parametric tests like Mann-Kendall and Theil-Sen Slope were employed to define temperature and precipitation changes in the region. In the analysis annual mean temperature (°C) and total annual precipitation (mm) data were used, collected from 15 different stations across the region. Mapping has been applied to visualize the results for better understanding of the findings. The results indicate an insignificant trend in precipitation across most of the region, while the temperature clearly demonstrates an upward trend.

1. Introduction

The detrimental impacts of climate change on both the Earth and human societies underscore the critical need for a comprehensive exploration of climate parameters. Among these investigations, trend analysis stands out as a pivotal approach, revealing the inclination of climate parameters to either rise or decline.

Mann Kendall and Theil-Sen's slope are frequently used methods in trend analysis. Mann-Kendall is a non-parametric statistical test used to detect trends in time series data. Theil-Sen's slope is a method for calculating the slope of a trend line. Kızılelma et al. (2015) conducted trend analysis of temperature and precipitation in the Central Anatolia region utilizing the Mann-Kendall and Theil Sen's slope methods. The results indicated notable temperature increases. Partal and Yavuz (2020) explored the presence of trends in drought indices within the Western Black Sea Region using trend analysis techniques. In their study, İrcan and Duman (2022) employed the Mann-Kendall and Theil Sen's slope methods to conduct trend analyses on minimum and maximum temperatures within the Van Lake Basin. Their investigation revealed an upward trend across all monitored stations.

In this research, data related to the annual average temperature (°C) and annual total precipitation (mm) were acquired from 15 meteorological measurement stations located in the Western Black Sea basin in the northern region of Türkiye. Comprehensive trend analysis was performed on this dataset utilizing the Mann-Kendall and Theil Sen's Slope methods. Subsequently, the obtained results were thoroughly interpreted and analyzed.

2. Method

2.1. Study Area and Stations

The Western Black Sea basin stands as one of Türkiye's regions with the most significant rainfall. Stretching from east to west, this area (Fig. 1), covers a rainfall territory spanning 28,855 km^2.

Monthly average temperature and monthly total precipitation data provided by the General Directorate of Meteorology were evaluated. Subsequently, 15 stations were selected that have good quality and continuity of data (Table 1). Annual average temperature and total annual precipitation data for the time period of 1990-2022 were derived from this selected dataset. Mann-Kendall Z statistics and Theil-Sen's Slope values were computed.

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Cite this study

Keskin M.Z, Abu Arra A, Akca S, & Şişman E (2023). Trend analysis of precipitation and temperature in the Western Black Sea region of Türkiye. Intercontinental Geoinformation Days (IGD), 7, 57-60, Peshawar, Pakistan

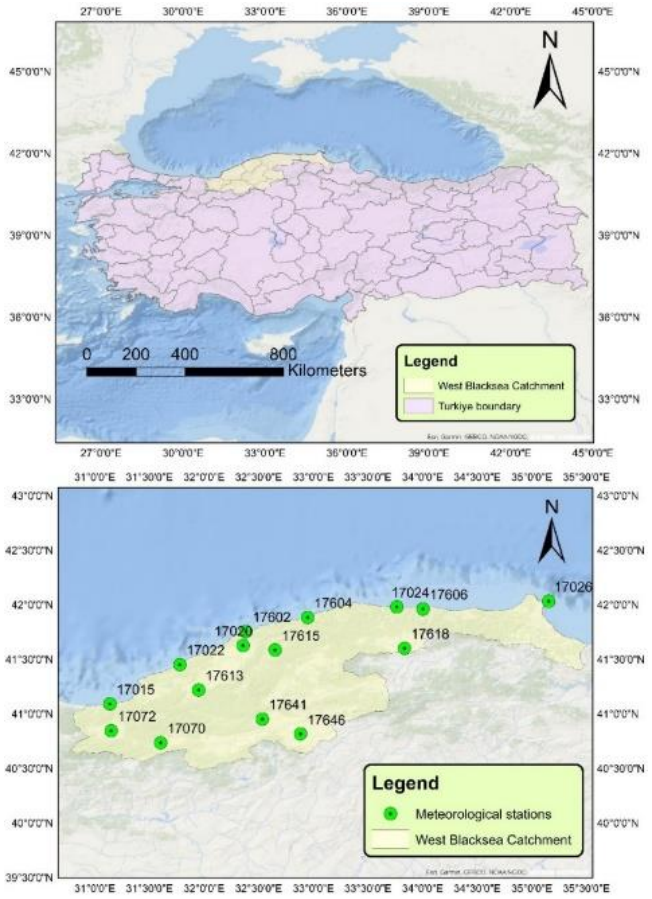

Figure 1. Study area

Table 1. Station details

Station Code	Station Name	Lat. (N)	Lon. (E)	Elev. (m)
17020	Bartın	41.62	32.36	33
17602	Amasra	41.75	32.38	73
696-17615	Ulus	41.58	32.64	162
17070	Bolu	40.73	31.60	743
17015	Akçakoca	41.09	31.14	10
17646	Çerkeş	40.82	32.88	1126
17072	Düzce	40.84	31.15	146
1397-17641	Eskipazar	40.94	32.53	757
17604	Cide	41.88	32.95	36
17618	Devrekani	41.60	33.83	1050
17024	İnebolu	41.98	33.76	64
17606	Bozkurt	41.96	34.00	167
17026	Sinop	42.03	35.15	32
962-17613	Devrek	41.23	31.97	100
17022	Zonguldak	41.45	31.78	135

The data used between 2005 and 2022 are from automatic observation stations as the stations had shifted to automatic measurement in 2005.

2.2. Trend analysis

Mann-Kendall is a statistical test that identifies trends in time series data without relying on specific parameters. It is specifically designed to detect monotonic trends, whether they are increasing or decreasing over time. S represents the number of pairs of data points with consistent trends (either both increasing or both decreasing). The sign of S denotes the direction of the trend. A notably positive S signifies an upward trend, while a significantly negative S implies a decreasing trend. S is calculated as;

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

where x_i and x_j represent data values, the function 'sgn' operates as a sign function. It yields a value of +1 when (x_j - x_i) is greater than 0, 0 when (x_j - x_i) equals 0, and -1 when (x_j - x_i) is less than 0.

In the context of the Mann-Kendall test, the Z statistics is used to assess the significance of the trend observed in a dataset. Z is estimated as;

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}; S > 0 \\ 0;\ S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}; S < 0 \end{cases}$$

The Mann-Kendall test involves two hypotheses, H_0 and H_1. H_0 suggests that there is no trend, while H_1 suggests the presence of a trend. In other words, at a chosen significance level α, if |Z| ≤ Z(α/2), then H_0 is accepted, indicating no trend. If |Z| > Z(α/2), H_1 is accepted, indicating a statistically significant trend. In this study, a confidence level of α = 0.1 was chosen, and the z value is found to be 1.645 according to the Standard Normal Distribution table. Therefore, if the calculated Z value falls within the range [-1.645, 1.645], H_0 is accepted, signifying the absence of a trend. Otherwise, H_1 is accepted, indicating the presence of a statistically significant trend.

Theil-Sen slope is a method for estimating the slope of a trend line. It is resistant to outliers and does not assume any specific distribution for the data. The Theil-Sen slope is calculated by taking the median of all slopes between pairs of points in the dataset. For each pair of data points (x_n,y_n) and (x_m,y_m) where n<m, the slope is calculated as (y_m-y_n)/(x_m-x_n).

3. Results

In the scope of the study annual datasets were derived by computing the average of monthly temperature data and the cumulative sum of monthly precipitation data. Trend analysis was conducted using station data spanning from 1990 to 2022, with a significance level set at 0.1. The outcomes of this analysis are presented in Fig. 2.

Mapping was used to make it easier to evaluate the results as shown in Fig. 3.

Upon analyzing the results, a declining trend in precipitation is evident across 11 stations, with two of them displaying a notably significant decrease. Conversely, an increasing trend in precipitation is observed in 4 stations. Examination of the map in Fig. 3 reveals a tendency of decreasing precipitation, particularly along the coastal regions, which gradually changes to increasing trend as one moves inland though they are insignificant. Notably, 3 out of the 4 stations

displaying increased precipitation are located at elevations exceeding 750 meters, constituting the three highest points within the basin.

Both Mann-Kendall and Sen Slope methods consistently indicate the same direction of precipitation trends at the measurement stations. Sen Slope calculations reveal a decreasing trend in 11 stations and an increasing trend in 4 stations. The stations with an increasing or declining trend are the same in both methods. Bozkurt station exhibits the highest absolute values for both Mann-Kendall Z statistics and Sen Slope.

Regarding temperature trends, 13 stations exhibit an upward trend, while 2 stations demonstrate a declining trend according to both Mann-Kendall and Sen Slope calculations. Mann-Kendall results indicate a significant temperature increase in 12 out of the 13 stations. Correspondingly, these stations exhibit relatively high Sen Slope values. Upon inspection of the map, areas with decreasing temperatures are concentrated in the central region, whereas temperature rises are predominant, especially along the coastal areas.

		Bartin	Amasra	Ulus	Bolu	Akçakoca	Çerkeş	Düzce	Eskipazar	Cide	Devrakani	İnebolu	Bozkurt	Sinop	Devrek	Zonguldak
Total Annual Precipitation (mm)	Mean (mm)	1035.8	955.6	961.6	521.8	1117.5	407.4	804.2	435.4	1170.9	523.9	1039.3	1152.8	677.0	782.0	1201.7
	Median (mm)	1026.8	927.5	961.6	533.8	1099.3	399.0	790.2	435.4	1149.1	523.2	1058.1	1203.0	665.0	764.1	1140.6
	Std. Dev. (mm)	180.4	206.2	206.8	94.3	169.9	87.4	123.8	90.3	200.2	98.6	135.6	242.7	118.6	117.0	222.1
	MK-Z stat	→ -0.42	→ -0.82	→ -1.47	↓ -1.72	→ -1.19	→ 1.53	→ -0.67	→ 1.18	→ -1.36	→ 1.29	→ 0.08	↓ -3.21	→ -0.67	→ -0.23	→ -1.56
	Theil Sen Slope (mm/year)	-1.90	-3.19	-6.83	-2.94	-4.21	2.66	-1.48	1.83	-4.05	2.35	0.20	-12.6	-1.47	-0.60	-5.59
Annual Average Temperature (°C)	Mean (°C)	13.11	14.18	12.91	10.86	13.52	8.41	13.64	11.17	14.26	7.85	13.82	13.63	14.77	14.35	14.06
	Median (°C)	13.28	14.25	12.93	10.83	13.58	8.39	13.76	11.17	14.31	8.00	13.75	13.75	14.76	14.24	14.13
	Std. Dev. (°C)	0.80	0.80	0.56	0.82	0.98	0.93	0.93	0.65	0.77	0.84	1.07	0.79	0.93	0.64	0.84
	MK-Z stat	↑ 4.29	↑ 3.78	→ -1.44	↑ 2.49	↑ 5.07	↑ 3.01	↑ 4.23	→ 0.91	↑ 3.56	↑ 3.32	↑ 4.80	↑ 4.40	↑ 4.14	→ -1.08	↑ 4.23
	Theil Sen Slope (°C/year)	0.06	0.05	-0.02	0.04	0.09	0.05	0.07	0.01	0.05	0.05	0.08	0.05	0.07	-0.02	0.06

↓ Significant decrease ↑ Significant increase → Insignificant change

Figure 2. Mann Kendall and Theil-Sen slope results for total annual precipitation (mm) and annual average temperature (°C)

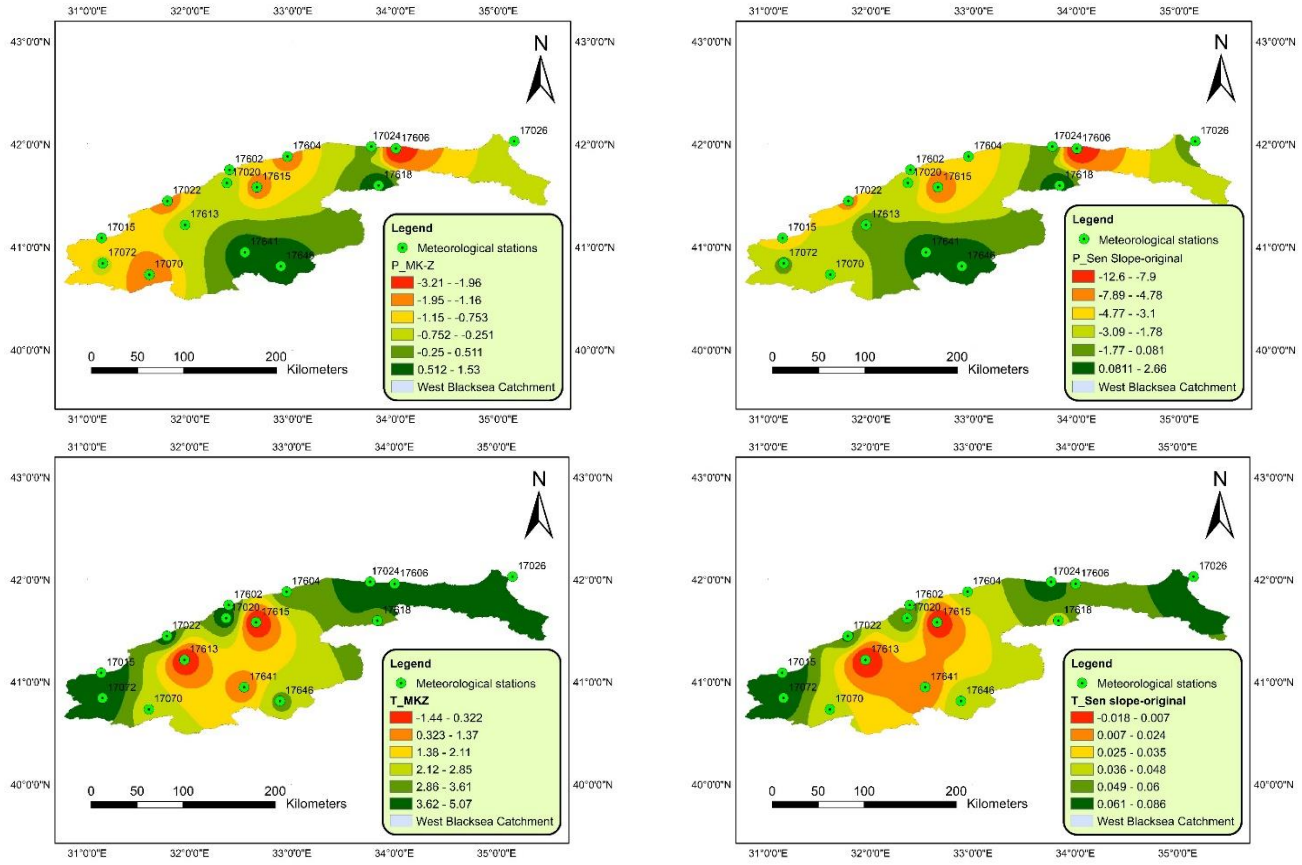

Figure 3. Mann Kendall Z statistics and Sen Slope of annual total precipitation (top left and top right respectively), Mann Kendall Z statistics and Sen Slope of annual average temperature (bottom left and bottom right respectively)

	Bartın	Amasra	Ulus	Bolu	Akçakoca	Çerkeş	Düzce	Eskipazar	Cide	Devrakani	İnebolu	Bozkurt	Sinop	Devrek	Zonguldak
Total Prec. change (mm)	-62.8	-105.3	-225.2	-96.9	-139.1	87.9	-48.8	60.3	-133.6	77.6	6.6	-417.3	-48.6	-19.9	-184.6
Total Temp. change (°C)	2.1	1.8	-0.5	1.2	2.8	1.5	2.2	0.3	1.5	1.5	2.6	1.8	2.3	-0.6	2.1

Figure 4. Changes in total precipitation (mm) and temperature (°C) based on Sen Slope calculations over the course of 33 years

4. Discussion

Several trend analysis studies conducted in the region provide valuable insights and contribute to the assessment of this study.

In his doctoral thesis, Çeribaşı (2015) applied the Mann-Kendall test at a 95% significance level to analyze precipitation data collected from the West Black Sea region between years from 1979 to 2012. Similar to this study's findings, Çeribaşı's research indicated that most stations exhibited no significant trends. However, this study identifies a decreasing trend in the Devrekani station, which was deemed insignificant in Çeribaşı's research. Interestingly, this study also identifies decreasing trends in the Bolu and Bozkurt stations, contrary to the absence of trends reported in the relevant study. It's important to note that this study extends the analysis beyond 2012, the endpoint of the previous study, suggesting that the observed decreasing trends in these two stations might have originated from the years after 2012.

In their research, Tokgöz and Partal (2020) employed the Mann-Kendall test at a 95% confidence level to analyze annual precipitation and temperature data from stations in the Black Sea region of Turkey. Their findings indicated that Bartın, Zonguldak, Bolu, and Düzce stations showed no trends, whereas Sinop exhibited an increasing trend. However, in our study, while Bartın, Zonguldak, and Düzce exhibited no trends, Bolu displayed a decreasing trend, and Sinop's trend was found insignificant. Moreover, in the previous study, Bartın, Sinop, and Bolu stations exhibited significant increasing trends in mean annual temperature, whereas Zonguldak and Düzce had insignificant trends. In our study, all five stations exhibited significant increasing trends in temperature analysis.

It is reasonable to assert that prior research in the region predominantly aligns with the findings of this study, particularly within the context of trend analysis.

5. Conclusion

As the results indicate in this study, precipitation and temperature trend analysis show concerning results.

Temperature in the region tends to increase especially in recent years.

As depicted in Fig. 4, the temperature in the region underwent significant changes over the 33-year period, reaching up to 2.8°C in some places based on Sen Slope calculations. Coastal stations like Akçakoca, İnebolu, and Sinop experienced the highest temperature changes (2.8°C, 2.6°C, and 2.3°C respectively). Given these observations, it is crucial to conduct a thorough assessment to determine if the observed rising trends in coastal areas are connected to increased sea water temperatures.

While precipitation trends are mostly insignificant, a negative trend is noticeable in most stations. The few stations that display insignificant increasing trends are located at the region's highest elevations. Over the 33-year span, certain stations experienced a decline in precipitation depth exceeding 20 centimeters (Fig 4). For instance, Sen Slope calculations indicate a loss of over 40 centimeters in Bozkurt station and above 20 centimeters in Ulus station, emphasizing the substantial decrease in precipitation levels. Overall, these trend results suggest the potential for more substantial changes in the region in the years ahead.

Acknowledgement

The authors express their gratitude to the General Directorate of Meteorology for providing the data.

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