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ANALYZING METEOROLOGICAL DATA OF STRAIT OF CANAKKALE BY USING TREND METHODS AND EVALUATING THEIR EFFECTS ON SHIP TRAFFIC

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Abstract

Strait of Canakkale is a waterway that opens to the Mediterranean for countries bordering the Black Sea and has no alternative. It proves this with the number of passes reaching up to 50,000 annually. Therefore, any negative changes that may occur in the Strait of Canakkale will cause serious damage not only to Türkiye but to many countries. One of the most parameters of navigation in maritime is meteorological conditions. If a place has a stable meteorological cycle, it brings predictable effects to its geography, and this has a positive impact on navigational safety. However, meteorological changes disrupt this order and cause a more transitional weather condition. The aim of this study was to evaluate data between 1995-2020 from 3 meteorological stations selected within the marine area of the Strait of Canakkale with trend analysis performed using Serial Correlation, Mann-Kendall test and Sen's trend slope methods for possible influences on maritime transportation. Trend analysis methods were used to predict the future situation according to datas. Before analyzing the trend methods, serial correlation was investigated to find out whether the data were serially dependent. Sen method and Mann-Kendall test were applied in this study. There was no significant trend in total precipitation amounts and average sea water temperatures. On the other hand, an increasing trend was observed in monthly average temperature values. It is estimated that it will cause navigational restrictions in the Strait of Canakkale as temperature increases will cause a decrease in water level, increased fog formation and an increase in wind strength.

Keywords: Mann Kendall test, navigation restriction, precipitation, Sen method, serial correlation, temperature

Introduction

Global climate change affects climate parameters such as precipitation and temperature at different rates all over the world. This change, which has a negative impact on the climate, causes droughts as temperatures increase, sea levels rise and precipitation patterns are disrupted. For this reason, in recent years, many different disciplines around the world have been using trend analysis to detect sudden changes and trends in climate parameters. Trend analysis tests reveal the trend by applying different formulas to data consisting of a certain time series and show the direction in which this trend is progressing, both in statistical reports and figures. The results of the study conducted with trend analysis shed light on the reliability and climate characteristics of future study data. (Ilgar, 2010). Türkiye faces with many different features of climate change. Sudden and very heavy rains, floods, drought and extreme heat are just some of these threats to the climate and environment. In order to postpone the devastating effects of climate change and combat climate change, the current situation must be handled and understood in all its aspects (Buken, 2016; Biberoglu, 2017; Dabanli, 2017). Although Çanakkale is geographically located in the Marmara Region, it mostly has the characteristics of the Mediterranean climate. Climate change directly affects the water cycle and meteorological events. When evaluated in this context, it is inevitable that the Strait of Canakkale will be seriously affected, as well as the Çanakkale province in general. In the Strait of Canakkale, which is 39 nautical miles (70 km), the width varies between 5,800 meters at the widest point and 1,300 meters at the narrowest point. The drift of surface currents in the Strait of Canakkale, whose geographical and oceanographic features are similar to the Bosporus Strait, reaches up to 6-7 knots. The Marmara Sea, which connects the Straits and is a ring of the Straits passage, is on average 225 km. Ships passing through the Turkish Straits have to cross the 325 km waterway under Türkiye's sovereignty. Visibility in the Straits region may be hampered by fog, rain and snow. The minimum natural depth in the Bosporus Strait is 19.6 meters in the north, 27 meters in the south, average of 28 meters in Strait of Canakkale. (Cerit, 2000). The Strait of Canakkale has a surface current from the Marmara Sea to the Aegean and a bottom current from the Aegean to the Black Sea. Meteorological changes such as precipitation irregularity and temperature increase pose a danger that has the potential to change the flow regime and order. This is a situation that will directly affect many sectors, from fishing to maritime transportation.

In this study, data from 3 meteorological stations located on the Strait of Canakkale were analyzed. The parameters subject to analysis are precipitation, water temperature and air temperature. Trend analysis was performed using Serial Correlation, Mann-Kendall test and Sen's trend slope method, and the possible effects of the analysis results on maritime transportation in the Strait of Canakkale were evaluated.

Material and Method

The study area is the Strait of Canakkale, which lies between the longitude passing through Zincirbozan Lighthouse in the north and the line connecting Mehmetçik Cape Lighthouse to Kumkale Lighthouse in the south. In this context, meteorological data from 3 meteorological stations were used. Information about meteorological stations are given at Table 1.

Table 1. Information in Meteorological Stations

Station Name	Station No	Latitude	Longitude
Çanakkale	17112	40° 08’ 27’’ N	026° 23’ 57’’ E
North Eagean Exit of Strait of Canakkale	17392	40° 02’ 54’’ N	026° 02’ 08’’ E
Lapseki/Zincirbozan Lighthouse	17425	40° 25’ 14’’ N	026° 45’ 13’’ E

Three separate parameters were examined: total precipitation amounts, monthly average temperature data and average sea water temperature data for the stations given in Table 1 between 1995 and 2020. The data used in this study were obtained from Turkish State Meteorological Service.

Serial Correlation

Serial Correlation is an important issue to be considered in the analysis of hydrological time series. Especially if there is a positive serial correlation, the trend will result in a trend that is more significant than it normally would be at a certain level of significance. (Partal, 2003). Serial correlation is calculated using the formula given in following formulae:

$$r(k) = \frac{-\sum(x(t) * x(t+k)) - \frac{1}{n-k}\sum x(t) * \sum x(t+k)}{(\sum x^2\,(t) - \frac{1}{n-k}(\sum x(t))^2)^{\frac{1}{2}}(\sum x^2\,(t+k) - \frac{1}{n-k}(\sum x(t+k))^2)^{\frac{1}{2}}}$$

If r(k), which is the number calculated in serial correlation, is less than the 10% significance level, the Mann Kendall test can be applied.

Mann-Kendall Test

Mann-Kendall test, also known as Kendall's Tau, is a non-parametric test used in the analysis of climatological and hydro-meteorological data. In this test, known as the best method for finding trends, the order of the data, not the size, is essential. (Burn and Elnur, 2002). Mann Kendall test is a non-parametric test. With this test, the null hypothesis is whether there is a trend or not; It is controlled by "H0: no trend" (Mann, 1945; Kendall, 1975; Gumus and Yenigun, 2006). In the data on which the test will be applied, pairs xi, xj are divided into two groups. If the total number of pairs with $x_i < x_j$ for $i < j$ is expressed as P and the total number of pairs with $x_i > x_j$ with M, the S relation is calculated with the relation given in the equation below.

$$S = P - M$$

Kendall correlation coefficient is calculated with the relation given in the following equation.

$$\sigma_s = \sqrt{n(n-1)(2n+5)/18}$$

The distribution of the Z statistic defined in the following equation, is the standard normal distribution.

$$Z = \begin{matrix} (S-1)/\sigma_s & S>0 \\ 0 & S=0 \\ (S+1)/\sigma_s & S<0 \end{matrix}$$

If the Z value calculated in Equation 4 is less than Zα/2 (1.645), it is concluded that there is no trend; if it is greater, there is a trend. (Mann, 1945; Kendall, 1975; Gumus and Yenigun, 2006).

Sen's Trend Slope Method

In this method, the current data series is divided into two equal halves. Both sub-series are sorted separately from smallest to largest. Then, the first sub-series (Xi) is placed on the X-axis and the second sub-series (Xj) is placed on the Y-axis, arranged on the Cartesian coordinate system. (Ceribasi, 2019). If the data to be examined lies on the 1:1 line, it is said that there is no trend. 3 fields are created as high, medium and low fields. Depending on the location of the data, if it is below the 1:1 line, there is a decreasing trend, and if it is above the 1:1 line, there is an increasing trend. If the data is in the high area, it is defined as high decreasing or increasing; if it is in the middle area, it is defined as a moderate decreasing or increasing trend; and if it is in the low area, it is defined as low decreasing or low increasing. In Figure 2, trend tendencies are shown graphically on the Cartesian coordinate system.

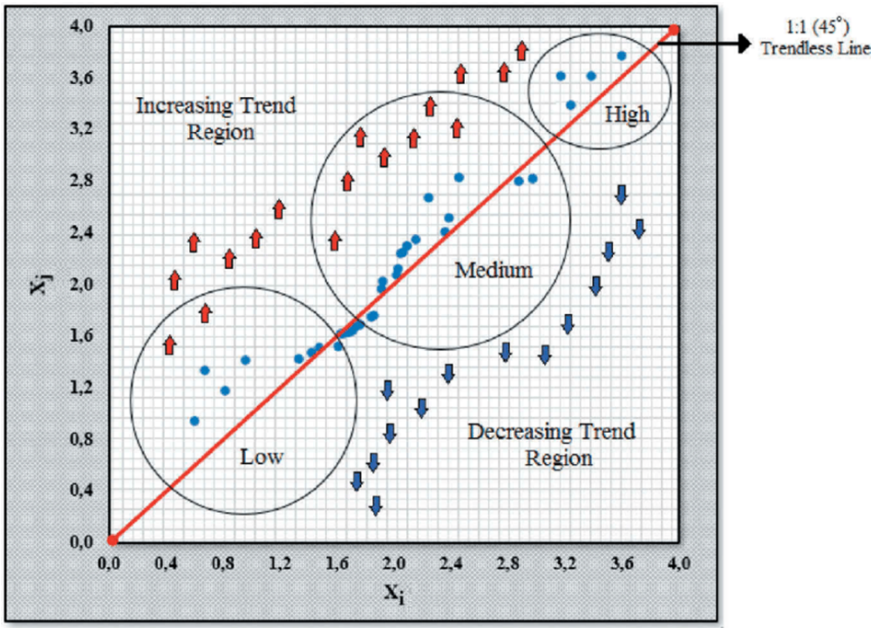

Figure 2. Sen Method (Ceribasi & Caliskan, 2006)

Results and Discussion

Meteorological observation stations from which data is received operate integrated into the buoy on the sea. This situation caused some malfunctions to occur due to the effect of the sea and the failure to intervene immediately to repair these malfunctions. Therefore, some data could not be accessed and the missing data were completed with the interpolation method. For the Çanakkale meteorological observation station, 3 separate parameters and 14 missing data were interpolated and put into relevant tests. Since there was too much missing data at the North Aegean Exit of Strait of Canakkale meteorological observation station, data completion could not be performed by interpolation. For this reason, complete data was collected on 1 parameter and 2 parameters were missing. Due to the lack of data on the total precipitation parameter at the Lapseki/Zincirbozan Lighthouse meteorological observation station, data could be collected on 2 parameters. In these 2 parameters, 21 missing data were completed by entelpolation.

Data on total precipitation amount, monthly average precipitation and average sea water temperature were subjected to serial correlation. As a result of this process, no serial correlation was found within the 10% confidence interval, as can be seen in Table 2. For this reason, data without internal dependence were subjected to Mann-Kendall and Sen's Trend Slope Test, as can be seen in Table 3.

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Table 2. Serial Correlation Analysis of Strait of Canakkale Meteorological Data

Station Name	Parameter	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Çanakkale	Total Precipitation	+1,00032	+1,00021	-1,00046	+1,00053	+1,00048	-1,00034	-1,00029	+1,00098	+1,00125	+1,00098	-1,00087	+1,00568
	Monthly Average Temperature	-1,00548	+1,00787	+1.00088	+1,00100	-1,00388	+1,00372	-1,00267	+1,00210	-1,00145	+1,00251	-1,00131	+1,00090
	Average Sea Water Temperature	+1,00168	+1,00043	+1,00214	-1,00523	-1,00424	+1,00436	-1,00383	+1,00282	-1,00256	+1,00146	-1,00352	+1,00765
North Agean Exit of Strait of Canakkale	Monthly Average Temperature	+1,00900	-1,00696	-1,00028	+1,00427	+1,00501	-1,00126	+1,00068	-1,00012	+1,00877	+1,00120	-1,00231	+1,00647
Lapseki / Zincirbozan Lighthouse	Monthly Average Temperature	+1,00412	+1,00742	+1,00581	-1,00200	+1,00307	-1,00543	+1,00904	-1,00155	+1,00764	+1,00422	-1,00124	+1,00087
	Average Sea Water Temperature	+1,00527	-1,00456	+1,00090	+1,00353	+1,00167	-1,00196	+1,00427	-1,00122	+1,00354	+1,00024	-1,00367	+1,00122

Table 3. Trend Analysis of Strait of Canakkale Meteorological Data

Station Name	Parameter		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Çanakkale	Total Precipitation	Mann-Kendall (Z)	0,18	-0,54	0,00	0,00	0,89	0,36	-0,36	-0,19	0,00	1,61	-1,07	-0,36
		Sen's trend slope method	0,005	-0,08	0,001	0,001	0,08	0,07	-0,003	0,000	0,001	0,09	-0,09	-0,003
		Trend	….	….	….	….	….	….	….	….	….	….	….	….
	Monthly Average Temperature	Mann-Kendall (Z)	2,86	2,78	0,63	0,54	2,07	0,72	3,22	2,78	2,68	3,22	2,86	2,33
		Sen's trend slope method	0,838	0,314	0,129	0,163	0,200	0,067	0,250	0,360	0,200	0,600	0,267	0,275
		Trend	↑	↑	….	….	↑	….	↑	↑	↑	↑	↑	↑
	Average Sea Water Temperature	Mann-Kendall (Z)	1,80	1,25	0,99	0,18	-0,09	0,27	2,42	0,18	0,00	-0,09	-0,36	1,71
		Sen's trend slope method	0,500	0,300	0,167	0,029	-0,060	0,043	0,214	0,100	0,000	0,000	-0,043	0,250
		Trend	….	….	….	….	….	….	↑	….	….	….	….	….
North Agean Exit of Strait of Canakkale	Monthly Average Temperature	Mann-Kendall (Z)	1,86	2,54	0,41	0,79	2,38	0,68	2,84	2,68	2,68	3,11	2,71	2,14
		Sen's trend slope method	0,550	0,234	0,019	0,106	0,225	0,089	0,265	0,241	0,241	0,586	0,253	0,212
		Trend	….	↑	….	….	↑	….	↑	↑	↑	↑	↑	↑
Lapseki / Zincirbozan Lighthouse	Monthly Average Temperature	Mann-Kendall (Z)	1,84	2,45	0,49	0,85	2,26	0,88	2,94	2,16	2,25	3,31	2,23	1,89
		Sen's trend slope method	0,546	0,229	0,02	0,113	0,218	0,116	0,281	0,198	0,206	0,600	0,231	0,53
		Trend	….	↑	….	….	↑	….	↑	↑	↑	↑	↑	….
	Average Sea Water Temperature	Mann-Kendall (Z)	1,75	1,09	0,90	0,14	-0,1	0,24	2,22	0,23	0,01	-0,19	-0,23	1,82
		Sen's trend slope method	0,485	0,219	0,150	0,021	-0,07	0,039	0,200	0,04	0,009	-0,04	-0,031	0,503
		Trend	….	….	….	….	….	….	↑	….	….	….	….	….

In all tests, the α significance level was taken as 0.05. In this context, if the value obtained is greater than z=1.96, it indicates an increasing trend; if it is less than z=-1.96, it indicates a decreasing trend. There was no trend in the total amount of precipitation by month at the Çanakkale station. There was an increasing trend in monthly average temperature values in 9 out of 12 months. There was an increasing trend in average sea water temperature in July, but there is no trend in other months. When monthly average temperature values at the North Aegean Exit of Strait of Canakkale station were examined, it was determined that an increasing trend occurred in 8 months out of 12 months. An increasing trend was observed in the average sea water temperature parameter at Lapseki/Zincirbozan Lighthouse station only in July, but no trend formation was observed in other months. Considering the monthly average temperature values, an increasing trend was observed in 7 months, and no trend was detected in the remaining 5 months.

An average of 50,000 ships pass through the Strait of Canakkale annually. (Ilgar, 2015). Considering the potential effects of climate change on maritime transportation, together with the fact that every parameter change poses a huge risk and there are not many precautions that can be taken against these risks, it becomes clear that there is a situation that requires urgent intervention.

Table 4. Potential Impacts of Climate Change on Maritime Transport (UNECE, 2013)

Factors	Effects
Temperature Change	
Rising Average Temperature	• Damage to infrastructure, materials and cargo • High energy consumption for cold transport cargo • Low water levels and navigation restrictions in inland waters • Reduced ice breaking costs • New and shorter routes • Longer transportation season
Changes in Precipitation Regime	
Changes in Pricipitation Frequency and Intensity	• Flooding of land structures • Damage to equipment and cargo • Restrictions in inland waterways due to draught
Wind and Storm	
Changes in Wind Frequency and Intensity	• Difficulties in navigation and docking
Increasing Destructive Impact of the Storm	• Port infrastructure reinforcement costs • Sedimentation formation in ports and channels • Increase in insurance costs
Water Level and Wave	
Changes in average water level	• Damage to cargo and equipment due to waves and floods

The effects of the parameter changes in Table 4 on maritime transportation are limited to the effects occurring at sea. The decrease in trade and the decrease in the number of passages and total tonnage, especially in waterways with intense ship passage such as the Strait of Canakkale, will also create serious problems. One of the reasons for the numerical decrease in possible passages and tonnages will be the emergence of draft restrictions as water levels decrease in inland waters and thus ships will be loaded with less cargo. Another reason is the mandatory use of the Strait of Canakkale in the import routes of major grain producers such as Ukraine and Russia. It is seen that the grain trade, which was blocked with the war between Russia and Ukraine, which started on February 24, 2022, caused a numerical decrease. In addition, it is thought that there will be a decrease in the number of ship passages as climate change directly affects grain production.

Conclusion

In this study, trend analysis was conducted by examining data between 1995 and 2020 from 3 automatic meteorological observation stations located in the Strait of Canakkale. According to the analysis results, since the acceptance of trend existence was made based on the 95% confidence interval, a significant increasing trend was found only in monthly average temperature values. An increase in the monthly temperature values of three separate stations has been accepted. This indicates that the temperature in the specified region slope to increase over the years. The effect of temperature increase on maritime transportation is shown in Figure 1. In the case of the Strait of Canakkale, an increase in temperature will cause a decrease in water level due to increased evaporation. Although there is no significant navigation restriction throughout the strait due to its depth, it will reveal the possibility of facing this restriction in the future. This will cause the ships using the strait to reduce tonnage. As the amount of evaporated water increases, the water vapor absorbed by the air condenses and forms fog. In addition, temperature increases and temperature changes during the day also increase wind strength. Strong winds can cause a meteorological phenomenon called upwelling. Upwelling is the movement of cold sea water upwards under the influence of wind and rising to the surface. This situation causes the water temperature to drop suddenly, triggering fog formation. In both cases, the fog formed will negatively effect on maritime traffic.

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Ethical approval

No ethical approval needed for this study since no living organisms were used.

Informed consent

Not available

Data availability statement

The authors declare that data can be provided by corresponding author upon reasonable request.

Conflicts of interest

There are no conflict of interests for publishing this study.

Funding organizations

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Contribution of authors

The author contributed to conceptualization, data curation, formal analysis, writing the original draft, investigation, methodology, resources, validation, visualization, and finalizing the paper.

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