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Research Article

The Role of International Maritime Traffic on PM10 Pollutant in the Strait of Istanbul (Bosphorus)

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Abstract

As for present, over 90 percent of world trade is carried out via seas by 90,000 vessels. Like all modes of transportation that use fossil fuels, ship emissions significantly contribute to global climate change and acidification. In this aspect, the shipping industry is responsible for a significant proportion of the global climate change. According to data of International Maritime Organization (IMO), more than 3% of global carbon dioxide emissions can be attributed to ocean-going ships. Furthermore, in European coastal areas, shipping emissions contribute to 1–7% of ambient air PM10 levels, 1–14% of PM2.5, and at least 11% of PM1. Strait of Istanbul is the unique waterway between Black Sea countries and the rest of the world. As a result of intensive international maritime traffic through the strait and approaches, it is a serious emission factor for the city. Studies have shown that ship emissions cause 4500 deaths per year in the Marmara region. In this study, it is discussed whether international maritime traffic is an effective factor on PM10 emissions by comparing number of passing ships from the Strait of Istanbul and PM10 values. For this purpose, PM10 averages obtained from four different meteorological stations in the region have been compared with the monthly number of ships pass through the strait between 2014 and 2018. Obtained results have examined with descriptive statistics and exploratory data analysis.

Keywords: Ship Emissions, PM10, Strait of Istanbul, Maritime Transportation

Introduction

The Strait of İstanbul is 18 nautical miles (~33 kilometers) in length and the narrowest part of the strait is located between Aşiyan and Kandilli points with 698 meters (Özsoy, 2016). According to a study, (DNV, 2013) vessels which pass through the Strait of İstanbul have to make at least 8 major course alterations, due to geographical curves. These large angular turns are given in Figure 1. Ship traffic in the strait is monitored by three VTS sectors. These are Sector Türkeli, Sector Kandilli and Sector Kadıköy, from north to south, respectively. The area and sectors of Istanbul Vessel Traffic Services are shown in Figure 2.

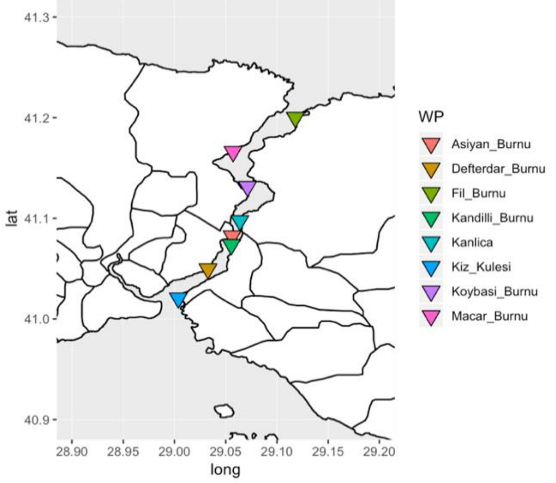

Fig. 1: Large angular turns in the Strait of İstanbul

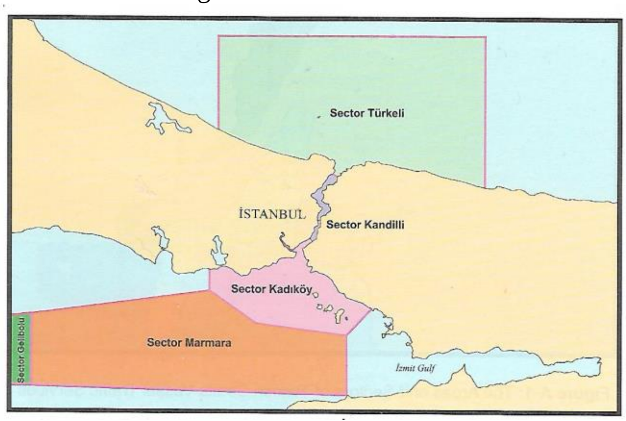

Fig. 2: The area and sectors of Istanbul Vessel Traffic Services (Turkish Straits Navigation Guide, 2015)

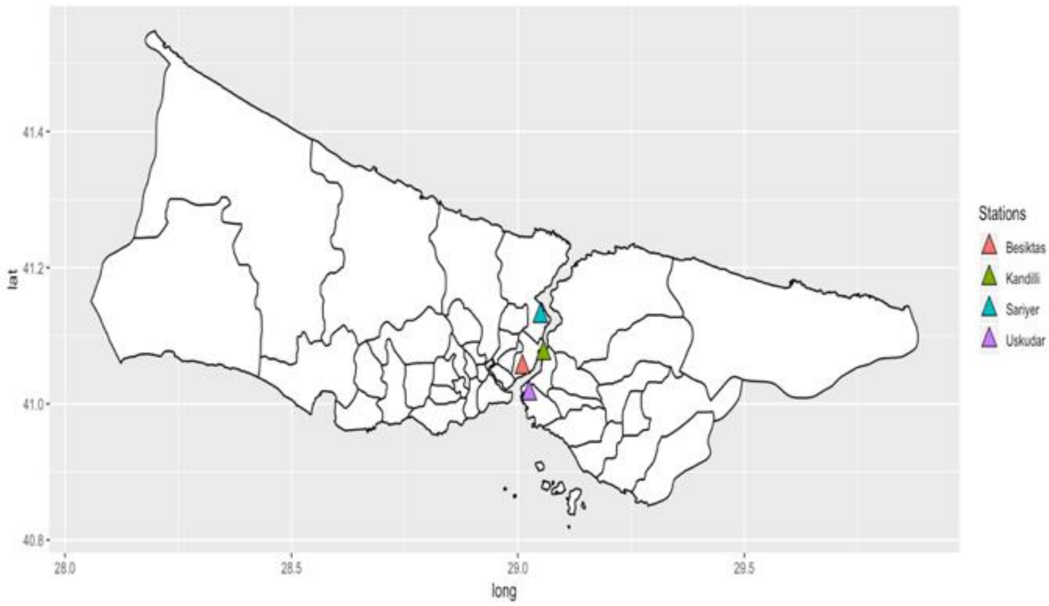

Fig. 3: Selected meteorology stations.

Due to the factor of sea currents and its curved geomorphology, each sectoral area has different dynamics in terms of ship navigation. The investigation of whether these dynamics have a statistically significant effect on ship emissions is the main motivation of this study. As can be seen in Figures 1 and 2, the most of the large angular turns in the Strait take place in the Sector Kandilli region. The load on the main engine increases during the course change, which means more emissions than the open sea. In this study, the effect of international shipping traffic in the strait and especially the sharp turns in the Sector Kandilli region on PM10 concentrations are investigated. For this purpose, PM10 measurements taken from Sarıyer, Kandilli, Üsküdar and Beşiktaş Stations were used in accordance with the route of the merchant ships passing the Strait of Istanbul. The relationship between the PM10 averages measured in the region and the number of passing ships were examined by regression analysis. Mentioned stations are shown on the Figure 3. As of 2019, the number of ships passing through the Strait of Istanbul is 41.112 (KEGM, 2020). The number of ships passing through the strait between 2014 and 2018 is shown in Table 1.

Table 1: Number of ships passing through the Strait of Istanbul between 2014 – 2018

Year	Passing Ship
2014	45.529
2015	43.544
2016	42.553
2017	42.978
2018	43.999

Air pollution caused by dense international maritime traffic in the Strait of İstanbul has been the subject of various studies so far due to its devastating effects. In a study, exhaust gas emissions from ships in the Sea of Marmara and the Turkish Straits were calculated by utilizing the data acquired in 2003 (Deniz and Durmuşoğlu, 2008). Main engine types, fuel types, operations types, navigation times and speeds of vessels are taken into consideration in the study. According to this study results, total emissions from ships in the study area were estimated as 5,451,224 t y− 1 for CO2, 111,039 t y− 1 for NOx, 87,168 t y− 1 for SO2, 20,281 t y− 1 for CO, 5801 t y− 1 for VOC, 4762 t y− 1 for PM. Besides, the shipping emissions in the region were corresponding to 11% of NOx 0.1% of CO and 0.12% of PM of the total emissions in Turkey. The shipping emissions in the area were 46% of NOx, 25% of PM and 1.5% of CO of road traffic emissions in Turkey. In other words, shipping emissions were higher than aircraft emissions and rail emissions. In her study (Güven, 2008) calculated exhaust gas emissions arise from oil tankers in the Turkish Straits. In another study the effect of meteorological factors and emission sources on spatial and temporal variations of PM10 concentrations in Istanbul were investigated (Unal et al., 2011). In another study GIS based high spatially and temporally resolved emission inventory for the Istanbul area were compiled (Markakis et al., 2012). Variations of air quality dependence on marine traffic in the Strait of Istanbul after the realization of Canal Istanbul project were investigated (Tuna and Elbir, 2013). In a study by Kılıç (2014), emission inventory from maritime and airline transportation was created and air pollution was modeled in the Marmara Region. In a study by Querol et al. (2015), effect of the environmental and health benefits from designating the Marmara Sea and the Turkish Straits as an emission control area (ECA) were investigated. Local marine traffic exhaust emissions in the Strait of Istanbul were evaluated (Demir, 2018). In a study by Bayırhan et al., (2019), modelling of ship originated exhaust gas emissions in the Strait of Istanbul was carried out. In his study Tokuşlu, (2019) ship-borne air emissions and their effects were examined in the Strait of Istanbul using two different emission methodologies that are Trozzi and Vaccaro Methodology and Entec Uk Limited Methodology. In a study by Mersin et al., (2019) CO2 emission and reducing methods in maritime transportation were investigated. In a study by Ekmekçioğlu et al., (2020), shipping emission factors were evaluated by using AERMOD model. In another study by Güzel and Alp, (2020), greenhouse gas emissions from the transportation sector in Istanbul by 2050 were examined by using TIMES model. In a study by Ulker et al., (2021) a comparative CO2 emissions analysis of short-sea shipping and road transport was performed in the Marmara Region and mitigation strategies were discussed. In a study by Mersin et. al, (2021) effects of CO2 emissions sourced by commercial marine fleet were examined by using energy efficiency design index. In a study by Tokuşlu et al., (2021-a) exhaust gas emissions of transit ships in the Istanbul Strait were examined and an inventory of transit ship traffic emissions was made. In another study by Tokuşlu, (2021-b) the influence of meteorological factors on shipping emissions was investigated in the Istanbul Strait.

Materials and Methods

Within the scope of this study, two separate data sets were used. The first of these was PM10 data measured from Sarıyer, Kandilli, Beşiktaş and Üsküdar meteorology stations between 2014 and 2018. These stations were chosen due to they were on the route of vessels which pass~~ing~~ through Strait of Istanbul (SoI). Second data was the number of ships passing this route in the same period. This study aims to determine the effect of international maritime traffic on PM10 pollutant in the Strait of Istanbul. For this purpose, monthly means of PM10 measurements of the mentioned stations were examined by exploratory data analysis. Obtained descriptive statistics were shown by histogram, CDF and boxplots. The relationship between monthly PM10 averages and the number of ships passing through Strait per month was examined by regression analysis. To determine level of significance LM (Linear Model) function was used. The distribution of both data were normalized using by log 10 transformation function. To see the relationship between the number of passing ship and the PM10 pollutant, monthly PM10 data was standardized climatologically and seasonal changes in the data were eliminated. Thus, the similarity of the monthly PM10 data distribution with the number of passing ships was examined when the seasonality in the data disappeared.

In this concept, a hypothesis test was created for the relationship between PM10 measurements taken from four meteorological stations and the number of ships passing through Strait. Then, a linear regression model was applied to the variables and diagnostic plots were obtained.

Ho: There is not relationship between number of the passing ship from the Strait of Istanbul and PM10 level.
Ha: There is a relationship between number of the passing ship from the Strait of Istanbul and PM10 level.

Within the scope of the hypothesis test, the number of ships passing through Strait was compared with monthly PM10 means for each station. For this purpose, primarily it was checked whether the model met the regression assumptions which normality, linearity, homoscedasticity and independence. Then, the overall p - value, the individual p - values, the diagnostic plots were respectively checked and finally the multiple R square value was evaluated. The process is given in Figure 4.

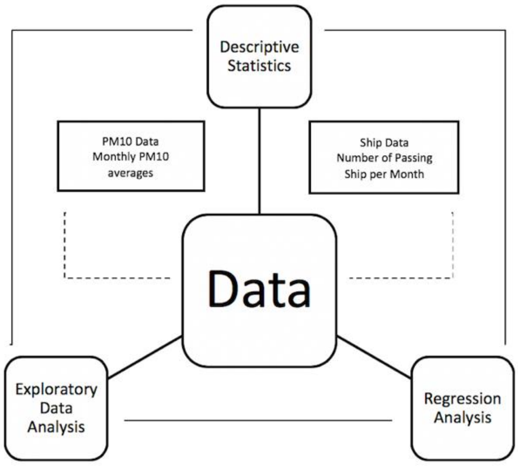

Fig. 4: Main steps of the study

Results

Descriptive Statistics

In the scope of this study threshold value for PM10 averages is accepted as 1000 mg / m^3. Monthly descriptive statistics related to meteorology stations are given in Table 2. Descriptive statistics include minimum value, first quartile, median, mean, third quartile maximum value, standard deviation and Inter Quantile Range, respectively. The selected stations are higher than 75% in terms of data integrity. Sarıyer and Beşiktaş stations have relatively more missing data with 12% and 15%.

According to air quality directive (2008/EC/50), the EU has set two limit values for particulate matter (PM10) for the protection of human health: the PM10 daily mean value may not exceed 50 µg/m^3 more than 35 times in a year and the PM10 annual mean value may not exceed 40 µg/m^3 (EEA, 2014; EC,2019). In this direction, all measurements were examined by time series plots as yearly, monthly and seasonally.

Exploratory Data Analysis

Yearly PM10 Distributions for Selected Stations

Within the scope of time series analysis, firstly the annual PM10 distribution for each station was examined. Figure 5 has clearly shown that stations have different distributions in terms of yearly PM10 averages. A steady decline was observed at Kandilli station from 2014 to 2018. It was seen that the PM10 distribution of Sarıyer and Beşiktaş stations located on the European side of the Strait has a similar structure. PM10 values at both stations increased from 2014 to 2015 and then declined sharply until December 2017. However, this situation changed in 2018. While PM10 values increased in Sarıyer station in 2018, it decreased dramatically in Beşiktaş Station. Üsküdar Station, which has a different profile from the other 3 stations, has shown a zigzag distribution between 2014 and 2018. The falling rate of the PM10 average, which declined sharply between 2014 and 2015, slowed down considerably between 2015 and 2016. Yearly PM10 averages, which increased from the beginning of 2017, have shown a sharp downward trend again until the end of 2018. According to the legal directive, PM10 annual mean value may not exceed 40 micrograms per cubic meter. When the selected stations were examined in terms of air quality standards, it was observed that Kandilli and Beşiktaş stations did not meet these standards until 2018. On the other hand, it was observed that the PM10 averages were calculated under 40 $\mu g / m^3$ and met the international standards since 2016 at Sarıyer station. Similarly, the annual PM10 mean recorded below 40 $\mu g / m^3$ at Üsküdar station since 2015.

Table 2: Descriptive Statistics for Meteorology Stations

Station	Min	1st Qu.	Median	Mean	3rd Qu	Max	SD	IQR	NA	NA%
Sarıyer	10.62	27.15	32.39	37.12	46.85	83.37	15.16	19.7	7	12
Kandilli	25.57	33.96	41.10	42.17	47.71	68.58	9.96	13.75	0	0
Beşiktaş	23.62	36.22	45.22	43.45	49.42	60.41	8.70	13.20	9	15
Üsküdar	22.92	30.68	36.48	39.21	46.50	65.80	10.70	15.82	0	0

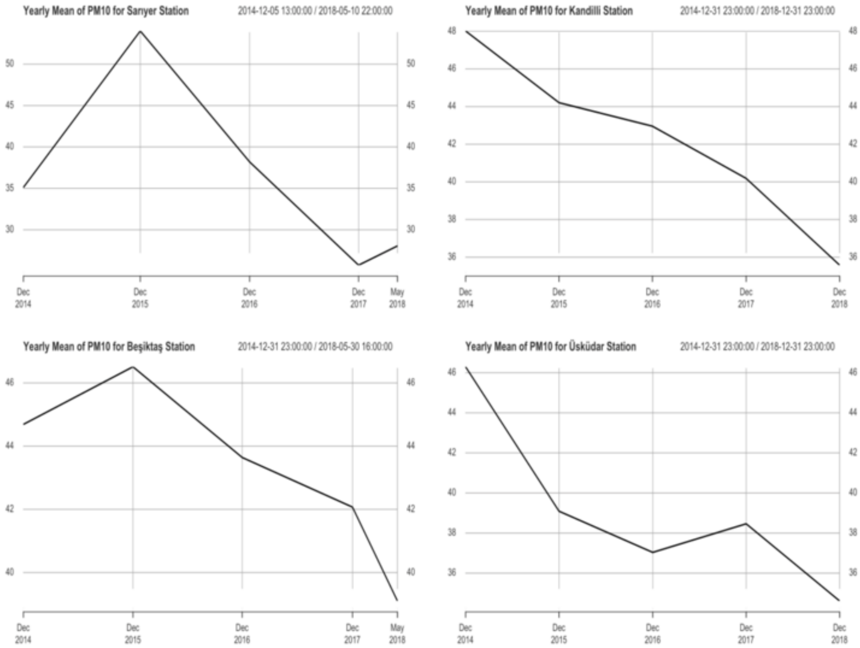

Fig. 5: Yearly PM10 distribution of the stations (MGM, 2019).

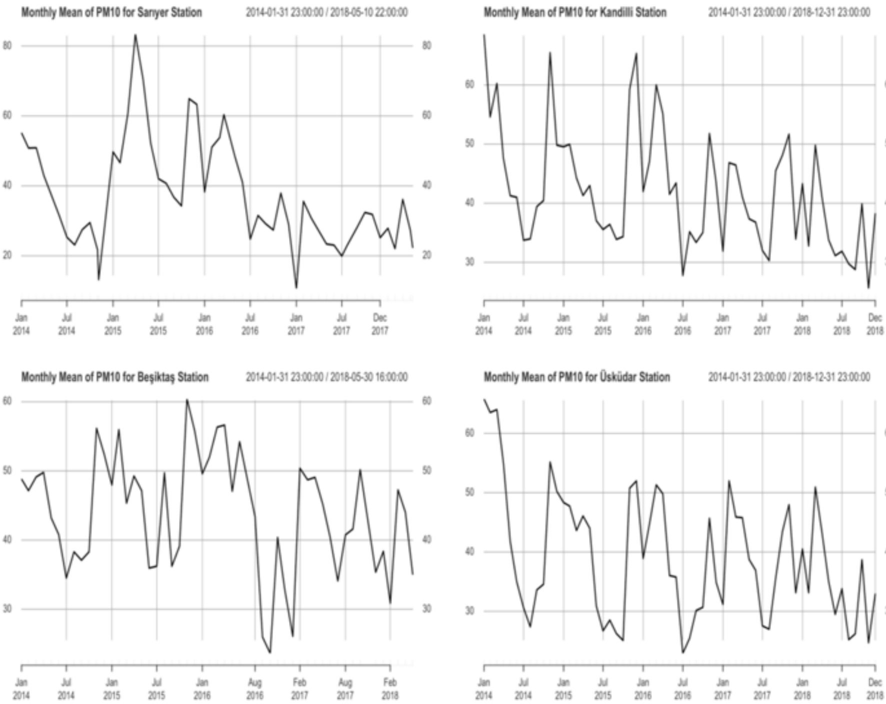

Fig. 6: Monthly PM10 distribution of the stations (MGM, 2019)

Monthly PM10 Distributions for Selected Stations

The monthly distribution of PM10 averages for each station over a 5-year period was examined.

Figure 6 has shown that monthly distribution of PM10 pollutant quite change according to stations. In Sarıyer station, the highest PM10 means was observed in March 2015. In this period, PM10 means exceeded 80 µg / m^3. Whereas, the lowest values in the mentioned station were recorded in October 2014 and in January 2017. In both periods, monthly PM10 means were below 20 µg / m^3.At Kandilli station, the highest PM10 means was recorded in January 2014 over 60 µg / m^3, while the lowest average was observed in November 2018 under 30 µg / m^3. Additionally, in October 2014 and November 2015, the PM10 means again exceeded 60 µg / m^3. At Beşiktaş Station, the highest PM10 mean occurred in November 2015, while the lowest mean of PM10 was recorded in October 2016. Similar to Sarıyer Station, the PM10 mean fell below 30 µg / m^3 in January 2017 and declined to the minimum values. The sharpest decline in the 4- year period was recorded between June and October 2016. The biggest increase was observed between January and February 2017. At Üsküdar Station, the highest PM10 mean was recorded in January 2014. Furthermore, the sharpest decline in the 4-year period was between March and August 2014. During this period, the PM10 mean dropped from about 70 µg / m^3 to about 25 µg / m^3. After March 2014, the PM10 average did not exceed 60 µg / m^3. The lowest PM10 mean between 2014 and 2018 was recorded in July 2016.

Seasonally PM10 Distributions for Selected Stations

In order to see that seasonally act of the PM10 data, the measurements were examined by quarterly mean values. It was observed that PM10 averages reached the maximum level at Sarıyer Station in the first 6 months of 2015. This rate was reached its peak in June 2015. The sharpest downward trend was observed between June and September 2015 at Sarıyer Station. Since the autumn of 2016, the PM10 average has not exceeded 40 µg / m^3. In this station, distribution of PM10 data showed fluctuated trend and no seasonal relationship was observed. The seasonal distribution of measurements at Kandilli and Beşiktaş stations showed similarity annually. The means of PM10 in Kandilli station reached its maximum value in March 2014, the highest values were recorded in March 2016 at Beşiktaş station. The sharpest drop in Kandilli station occurred between March and September 2014. On the other hand, the most dramatic drop in Beşiktaş station occurred between June and October 2016.

The PM10 average, which peaked at Üsküdar Station in March 2014, showed a sharp downward trend until October. After this point, a stable seasonal movement was observed in the data. When Üsküdar Station was seasonally examined, a visible autocorrelation was observed in the mean of PM10.

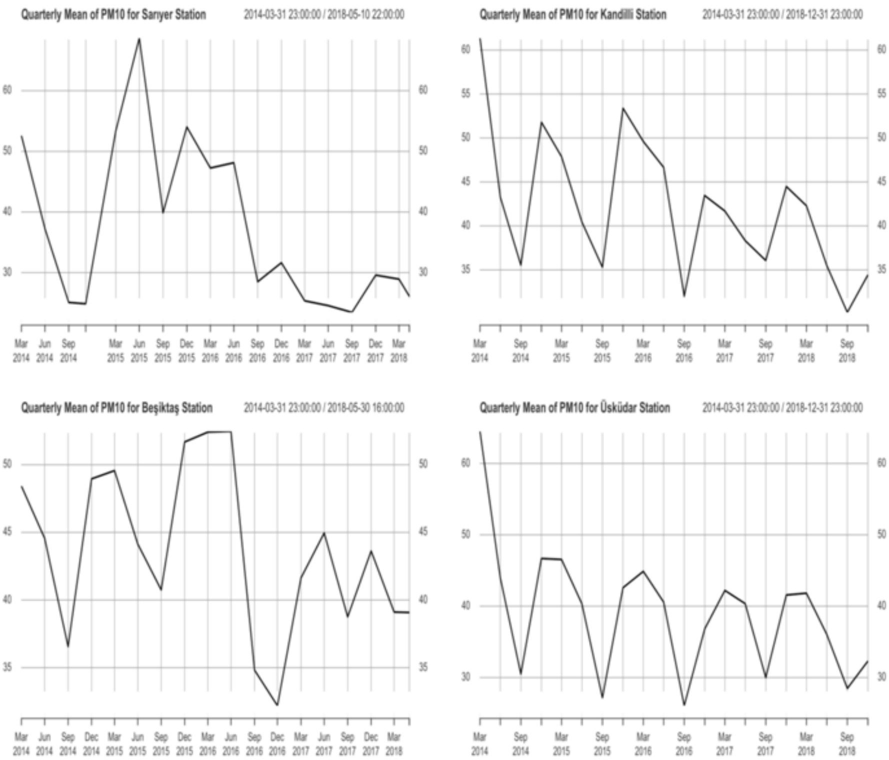

Fig. 7: Quarterly PM10 distribution of the stations (MGM, 2019).

Histogram

The histograms showed that PM10 frequency had a right skewed distribution at each station. The maximum frequency was measured between 15 and 20 µg/m^3 at Sarıyer Meteorology Station. This proportion were observed between 20 and 25 µg/m^3 in Kandilli and Üsküdar stations. On the other hand, the highest PM10 measurements was recorded in Beşiktaş between 25 and 30 µg / m^3.

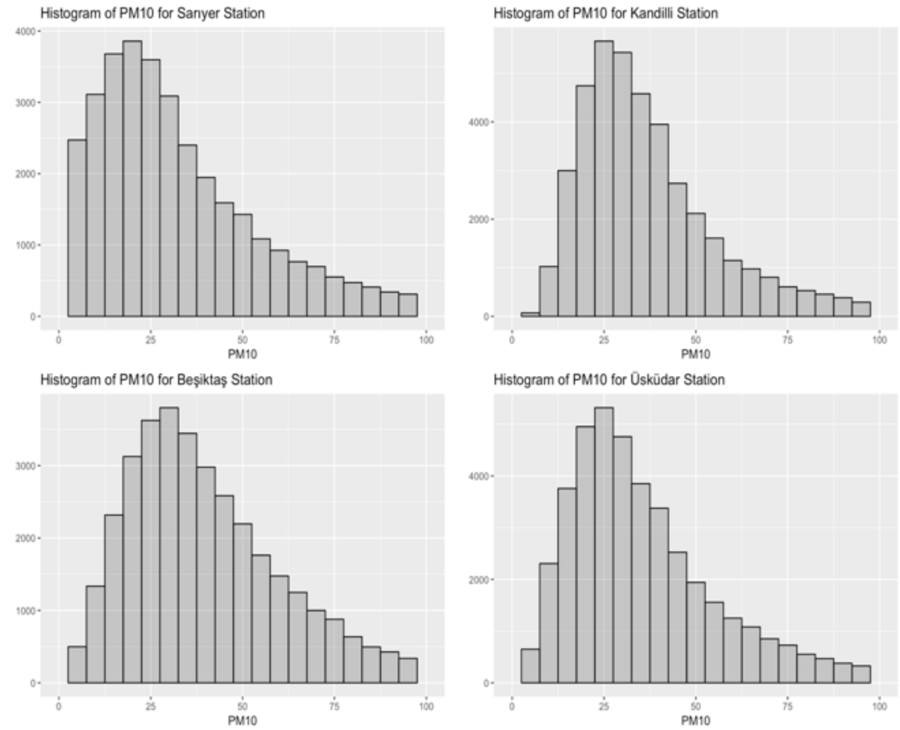

Fig. 8: Histogram of PM10 Measurements.

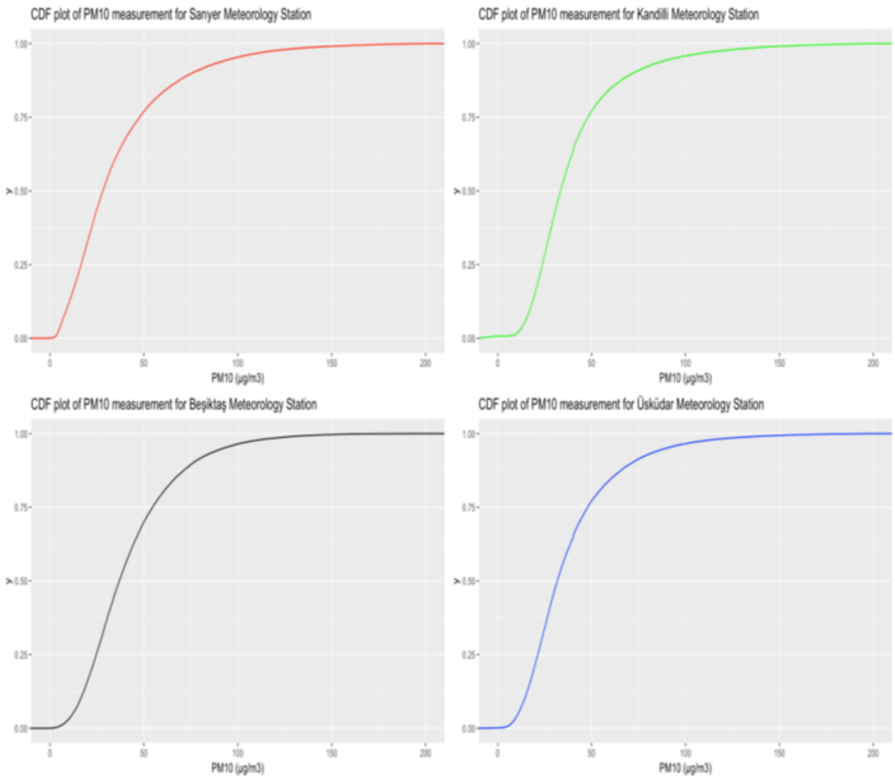

Fig. 9: CDF Plots of PM10 Measurements

In Figure 8 the stations were analyzed by histograms. In Figure 9 the stations were examined by CDF plots in order to see detail quantitative features of the data.

Cumulative Distribution Function (CDF Plots)

Cumulative distribution function shows that empirical cumulative distribution of the data. CDF plots advantageous for comparing the distribution of different sets of data. In this section, different meteorology stations were compared by CDF plots.

The CDF graphs has shown that approximately 95% of PM10 measurements are below 100 µg / m^3 for each station. Furthermore, almost 75% of PM10 measurements is less than 50 µg / m^3 for all station. Finally, nearly half of PM10 measurements is less than 25 µg / m^3 in the all stations.

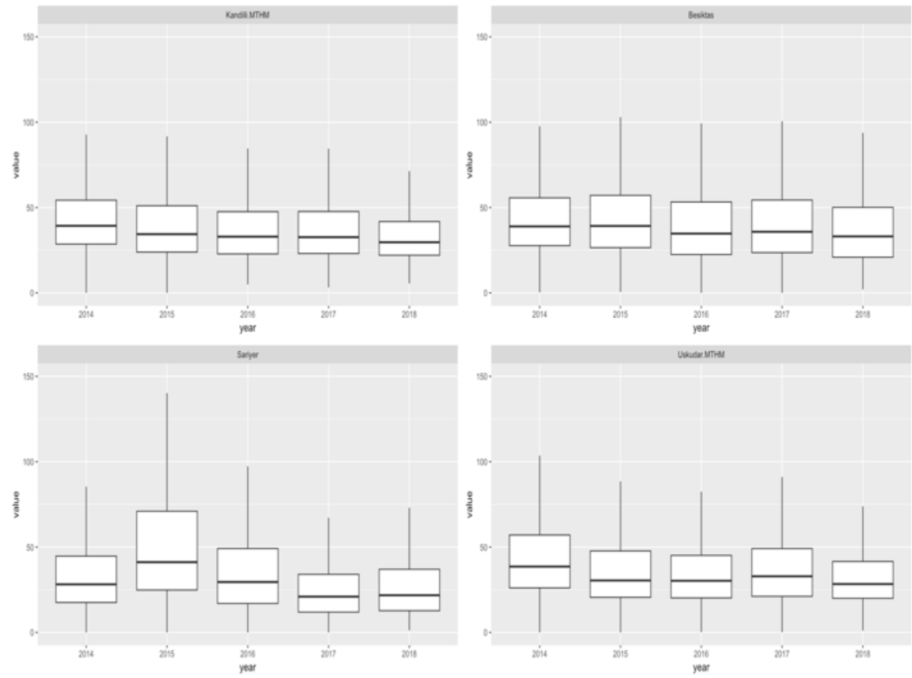

Fig. 10: Yearly boxplots plots of PM10 Measurements

Yearly Boxplot of PM10 Distribution for Selected Stations

In this section, yearly PM10 averages are examined by boxplots. Obtained results are given in Figure 10. The box plots showed that all stations had similar PM10 distribution annually. According to Figure 10, medians of PM10 were between 25 and 50 μg/m^3 at all stations over 5 years. Measured PM10 values rarely exceeded 100 μg / m^3 for each station and increased to around 150 μg / m^3 at only Sarıyer Station.

Monthly Boxplot of PM10 Distribution for Selected Stations

Monthly box plots were created to observe the monthly change and seasonal characteristics of PM10. Obtained results were given by Figure 11.

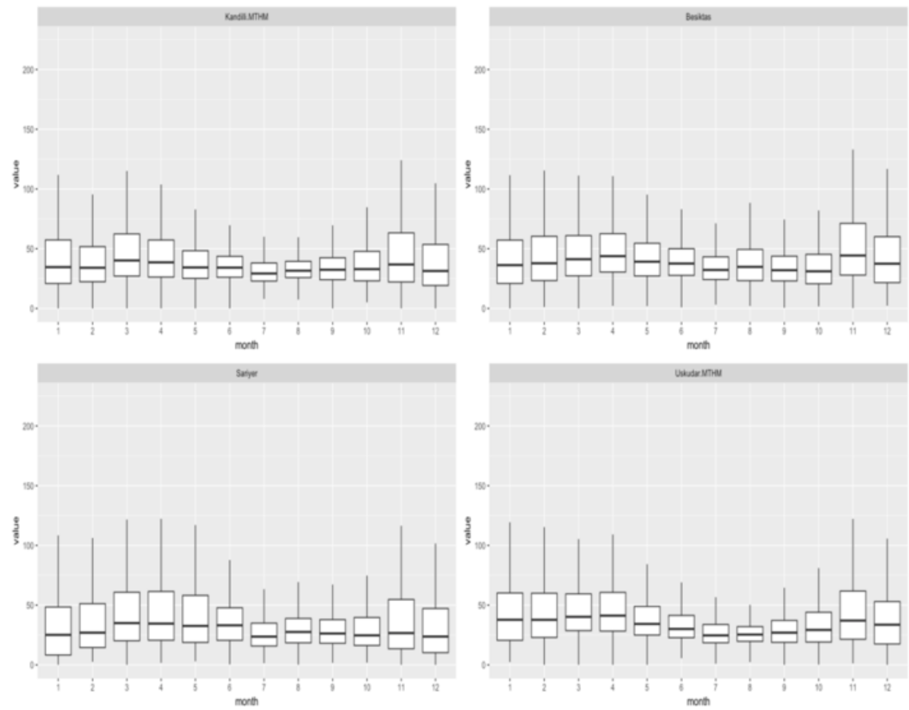

Fig. 11: Monthly boxplots plots of PM10 measurements

Figure 11 has shown that median values of PM 10 are in similar range for all stations. In other words, the distribution of monthly PM10 averages has similar properties in all stations. Compared to yearly averages, monthly means have been observed to exceed 100 **µ**g / m^3 more frequently at each station. Furthermore, it has observed that the PM10 means of the summer months have measured at lower rate than the other months at all stations.

Ship data contains number of ships passing through the Strait of Istanbul between 2014 and 2018. These vessels are merchant ships that pass through the region non - stop over. Strait of Istanbul, which separates the continents of Asia and Europe, is the only waterway linking the Black Sea countries to the rest of the world and it serves as a bridge between the world's major economies. The strait, which is the second busiest waterway in the world after the Malacca Strait, has four times more traffic than the Panama Canal and three times the Suez Canal (Maritime Local Traffic Guide of Harbor Master of Istanbul, 2011). The number of ships passing through the strait between 2014 and 2018 is given below.

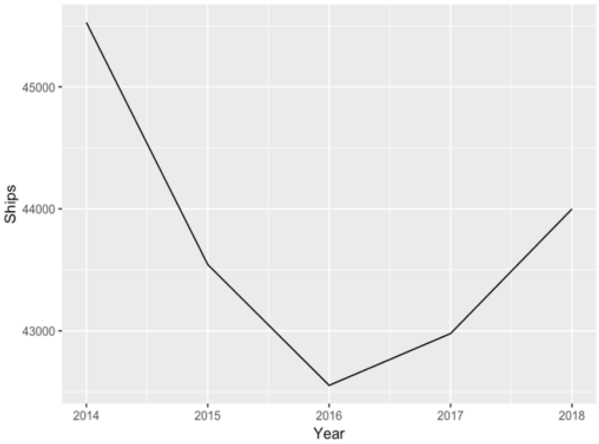

Fig. 12: Annual change in the number of ships pass through the Strait of Istanbul (2014-2018)

According to Figure 12, merchant ship traffic experienced a sharp decline from 2014 to 2016 and increased after 2016. This upward trend gained momentum between 2017 and 2018.

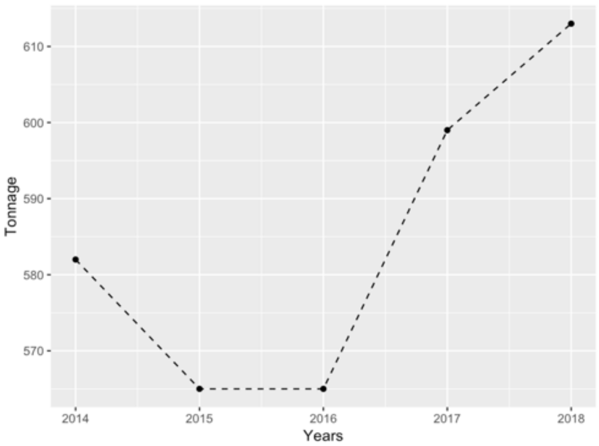

Fig.: Annual change of the passing ship GRT in SoI (2014 - 2018)

There was a sharp decrease in the number of ships passing through the strait between 2014 and 2016. Nevertheless, it started to rise again in 2016 and carried on increase by gaining momentum since 2017. In addition, the tonnage capacity of ships passing through the strait shown an increasing trend. The tonnage factor affects the amount of emissions by affecting the maneuvering performance of the ship.

The monthly change in the number of ships passing through the strait was examined below for each year, respectively. The common feature of the 5 graphs showing the monthly profile of ship transits is the sharp increase from February to March. The reason for this is that all companies engaged in international maritime trade, due to the freight agreements made at the beginning of the year, rapidly include their ships in the transportation service. This situation has reflected in the graphics as sharp rises in the first three months of the year. However, the world merchant fleet consists of a limited number of ships. Therefore, the number of ships that will carry cargo after March cannot meet the increasing demand and it is expected that the ship will discharge its current cargo and take a load again in order to take the next load. This process causes the monthly profile to form a zig-zag structure that shows periodic increases and decreases.

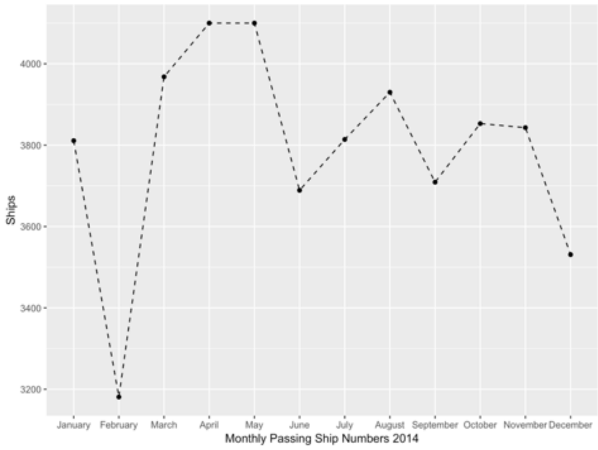

Fig. 14: Monthly change in the number of ships pass through the Strait of Istanbul (2014)

According to Figure 14, the movement of international maritime traffic tends to fluctuate monthly. Within this framework, the least ship traffic was observed in February and the sharpest increase occurred in March. On the other hand, in April and May, the number of ships passing through the strait reached its highest value within the year.

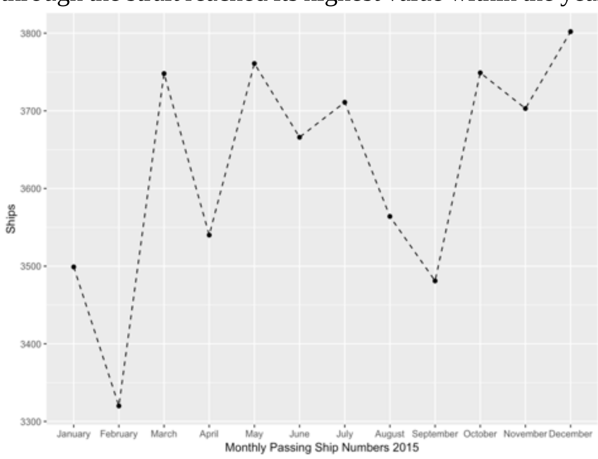

Fig. 15: Monthly change in the number of ships pass through the Strait of Istanbul (2015)

Similar to 2014, at least international maritime traffic in 2015 was observed in February and biggest increase was recorded in March. The number of ships that reached their maximum in December did not show a stable trend during the year.

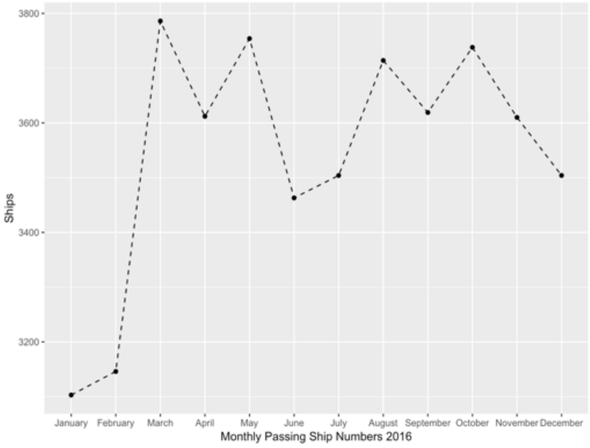

Fig. 16: Monthly change in the number of ships pass through the Strait of Istanbul (2016)

In 2016, no regular movement was observed monthly in terms of international maritime traffic. Similar to previous years, minimum ship movement was observed in the first moths of the years and the biggest leap was again in March.

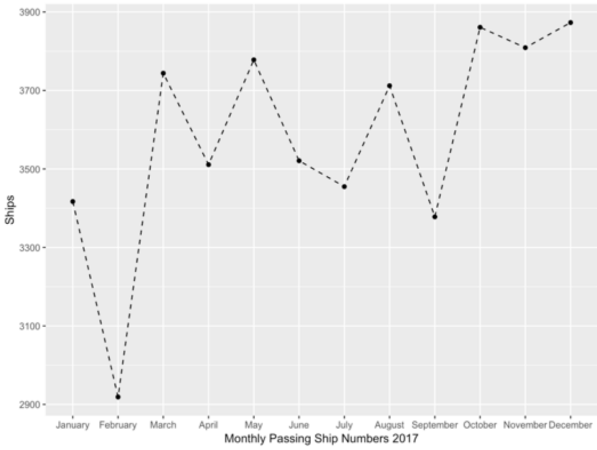

Fig. 17: Monthly change in the number of ships pass through the Strait of Istanbul (2017)

Figure 17 showed that number of monthly ships passing through Strait of Istanbul in 2017. In 2015 and 2016, the least ship movement was observed in February and the most dramatic upward trend in March. The number of ships, which did not show a regular increase or decrease tendency throughout the year, reached their maximum value in December.

Similar to other years, the month with the lowest international ship traffic in 2018 is February. On the other hand, the highest number of ships passing through the Strait was recorded in October. The sharpest increase in the number of ships passing through the strait, which did not show a steady movement as monthly, has been observed again between February and March.

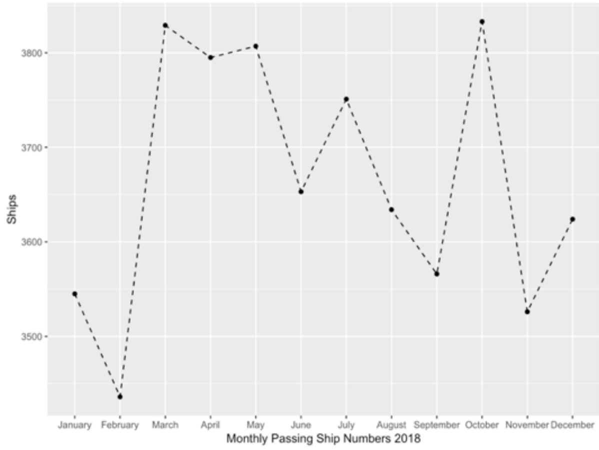

Fig. 18: Monthly change in the number of ships pass through the Strait of Istanbul (2018)

Regression Analysis

The results of the exploratory data analysis showed that the number of ships passing through the Strait of Istanbul may have an explanatory power over the PM10 averages in the region.

Kandilli PM10 & Passing Ship

Kandilli is the narrowest part of the Strait, so this point requires large angular maneuvering for the ships. These sharp turns increase the emission amount by increasing the performance of the main engine. Monthly PM10 means of Kandilli Meteorology Station were compared with the number of monthly ships passing through the strait and the following results were obtained.

Table 3: Monthly PM10 means and number of passing ships - log transformed ANOVA Table for Kandilli Station

```
Residuals:
      Min        1Q    Median        3Q       Max
-0.145754 -0.068328  0.008434  0.058475  0.176004

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.172e+00  1.865e-01   6.286 4.59e-08 ***
Ships       1.191e-04  5.226e-05   2.280   0.0263 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.08363 on 58 degrees of freedom
Multiple R-squared:  0.08223,	Adjusted R-squared:  0.06641
F-statistic: 5.197 on 1 and 58 DF,  p-value: 0.02632
```

Analysis results have shown that overall p-value is 0.02, individual p-value is 0.02 and intercept is 4.59e-08. These values are less than the significance level of 0.05. In other words, there is a relationship between the sharp turns in the Sector Kandilli region and the PM10 concentration. The diagnostic plots of the analysis are examined below.

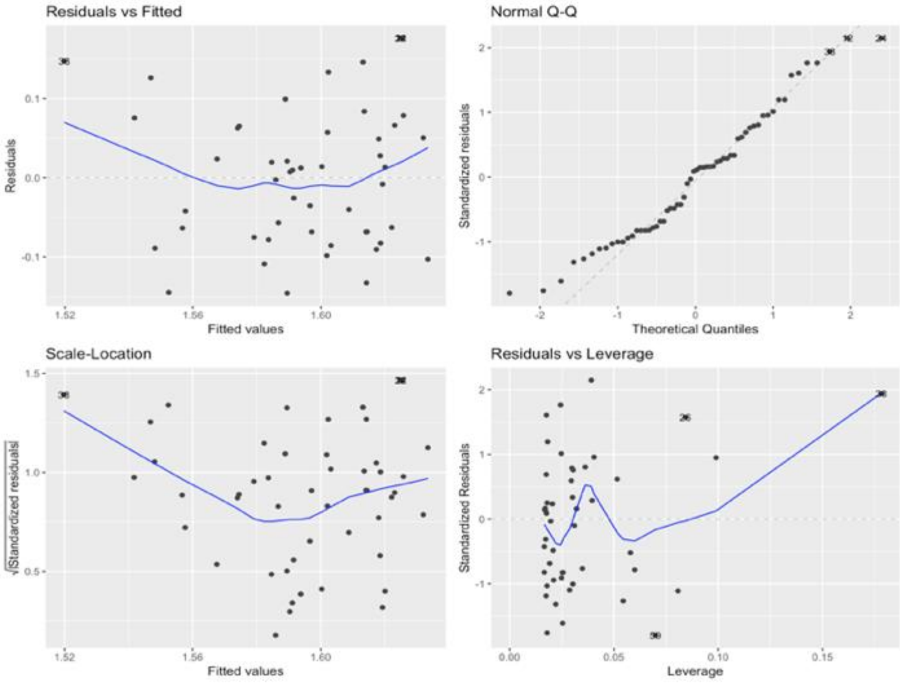

Figure 19: Diagnostic plots for Kandilli Station.

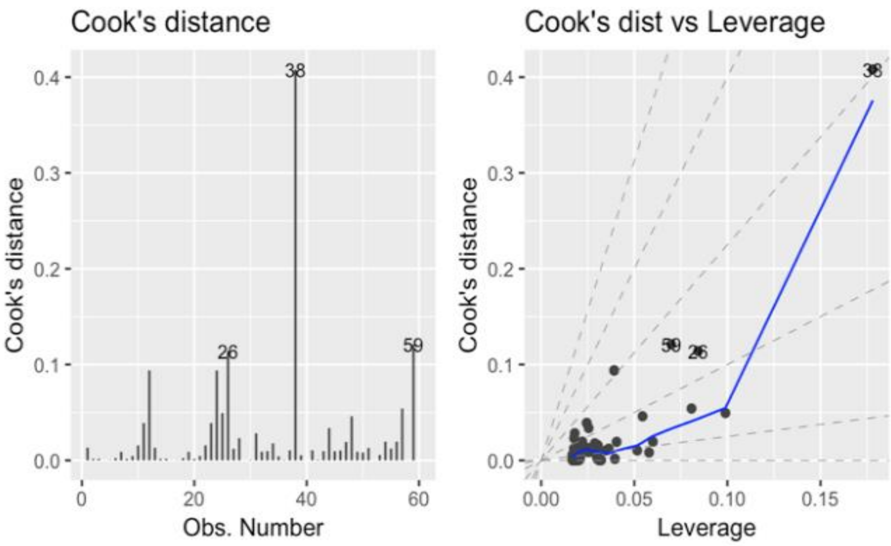

Figure 20: Cook's plots for Kandilli Station

Figure 19 shows that the data distribution is very close to the theoretical normal distribution line and the error terms are randomly distributed in a range much close to zero. Figure 20 shows possible outliers on Cook's plots. According to Cook's plot of the data, possible outliers are in lines 26, 38 and 59.

Sarıyer PM10 & Passing Ship

Monthly PM10 averages of Sarıyer Meteorology Station were compared with the number of monthly ships passing through the region. The obtained results shows that the overall and individual p-values are greater than the significance level of 0.05. Therefore, Ho hypothesis is accepted as true. Namely, there is no statistically significant relationship between Sarıyer Station monthly PM10 averages and the number of ships passing through the Strait of İstanbul. Diagnostic plots drawn with raw data shows that the error terms are distributed in the range of - 25 and 50. This range is quite far from zero and is not meet the regression assumption. Cook's plot shows that the possible outliers for the raw data are in lines 16, 17 and 24. When log transformation is applied to the data, p - value of intercept is calculated less than 0.05, but overall p - value and individual p - value are still greater than 0.05. Therefore, Null hypothesis is accepted as true. Namely, there is no relationship between monthly PM10 means of Sarıyer Station and monthly passing ship number in the Strait. Cook's plots demonstrate that the log transformed data distribution is closer to the theoretical normal distribution line and the error terms are randomly distributed at a much closer range to zero. However, regression assumptions are not met.

Beşiktaş PM10 & Passing Ship

Monthly PM10 averages of Beşiktaş Meteorology Station were compared with the number of monthly ships passing through the region. According to obtained results, both overall p - value and individual p - values are greater than 0.05. Diagnostic plots drawn with raw data have indicated that error terms scatter randomly and data distribution close to line of the theoretical normal distribution. Additionally, possible outliers for raw data are in lines 25, 26 and 38. However, error terms far from zero and they are spread over a wide range. For this reason, log transformation is applied to the data. Obtained results shown that intercept p - value less than 0.05, but both overall p - value and individual p – value are still greater than 0.05. Log transformed data distribution is closer to the theoretical normal distribution line and the error terms are randomly distributed at a much closer range to zero. However, regression assumptions are not met. As a result, it was concluded that there is no statistically significant relationship between the monthly PM10 means of Beşiktaş meteorology station and the number of monthly ships passing through the region. In other words, the Ho hypothesis is accepted as true.

Üsküdar PM10 & Passing Ship

Monthly PM10 averages of Üsküdar Meteorology Station were compared with the number of monthly ships passing through the Strait. Similar to Sarıyer and Beşiktaş stations, both overall p - value and individual p - values are greater than 0.05. Diagnostic plots drawn with raw data shown that error terms are quite far from zero, although error terms scatter randomly and data distribution close to line of the theoretical normal distribution. Since the results obtained from the raw data are not efficient, the data was re-modeled by applying log 10 transformation. When Log 10 transformation is applied to the data, intercept p - value is calculated less than 0.05. However, both overall p - value and individual p – value are still greater than 0.05. Cook's plot demonstrates that the log transformed data distribution is closer to the theoretical normal distribution line and the error terms are randomly distributed at a much closer range to zero. However, regression assumptions do not meet.

Discussion and Conclusion

The Strait of İstanbul is one of the main arteries of the international maritime trade, as it is the only waterway connecting the Black Sea countries and rest of the world. Therefore, it has an intense international maritime traffic. The number of ships passing through the strait is increasing day by day. Although this heavy traffic offers various advantages in terms of maritime trade, it creates disadvantages for the city of Istanbul in terms of environmental impacts. The deterioration of air quality is one of the most important of these effects. Information obtained as a result of the literature review showed that ship emissions are responsible for 4500 deaths in a year in the Turkish Straits System (Kılıç, 2014). According to the legal directive, PM10 annual mean value may not exceed 40 micrograms per cubic meter.

When the selected stations were examined in terms of air quality standards, it was observed that Kandilli and Beşiktaş stations did not meet these standards until 2018. On the other hand, it has observed that the PM10 averages measured under 40 μg / m^3 and met the international standards since 2016 at Sarıyer station. Similarly, the annual PM10 mean has recorded below 40 μg / m^3 at Üsküdar station since 2015.

In this study, the effect of the number of the ships passing through the Strait on the air quality in the region was investigated. In this context, the 5-year PM10 means taken from four different meteorological stations in the region were compared monthly with the number of ships passing through the Strait. For this purpose, the profile of PM10 data and ship traffic data firstly examined by exploratory data analysis. The annual results showed that PM10 means tended to decrease at four stations after 2015, and the sharpest decrease realized at Kandilli Station. When the data is analyzed on a monthly basis, it is observed that there is less pollution in the summer compared to the winter months. At this point, the downward trend in the summer shows the effect of residential heating on PM10 means in the region. When data analyzed seasonally, it is observed that there is visible autocorrelation at Üsküdar Station. Exploratory data analysis shown that the number of the ships passing through the strait tend to increase after 2016 and it reached the peak in the first months of the year. Exploratory data analysis showed that the ship traffic in the strait may have an explanatory power over the PM10 averages. To answer this question, a hypothesis test was created and a linear regression model was established to observe the relationship between the variables. In this context, the relationship between number of ships passing through the region and PM10 means examined by regression analysis separately for each station. In the first stage, raw data, in the second stage, log transformed data were subjected to analysis. As a result of the analyses, both positive and negative outputs were obtained to explain the relationship between the variables.

Regression analysis results showed that no significant correlation between PM10 averages and international ship traffic for Sarıyer, Beşiktaş and Üsküdar stations. The results obtained for the Kandilli station shown that international maritime traffic in the Strait of Istanbul has explanatory power over PM10 averages in the region. As a result of the analysis normalized by Log 10 transformation, both overall and individual p values were calculated less than 0.05. At the same time, diagnostic plots showed that error terms were randomly distributed in a range close to zero, and the distribution obtained was quite close to the theoretical normal distribution line. In line with these results, regression assumptions were met, but multiple R squared value is 0.08. Namely, the number of ships passing through the Strait of Istanbul has explanatory power over the PM10 means at Kandilli Station. However, the regression model explains this relationship only at 0.08 percent. This is because monthly data are used in the analysis. If daily data were used, the correlation between the variables could be explained with a higher rate. Since daily data on ship traffic in the strait is not available, daily analysis could not be performed. For future research after this study, a regression analysis with AIS data will provide high resolution results.

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