Volume XXIV 2021
ISSUE no.1
MBNA Publishing House Constanta 2021

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

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To cite this article: Aydin TOKUSLU, Scientific Bulletin of Naval Academy, Vol. XXIV 2021, pg.184-192.

Submitted: 27.02.2021
Revised: 15.06.2021
Accepted: 22.07.2021

Available online at www.anmb.ro

ISSN: 2392-8956; ISSN-L: 1454-864X

doi: 10.21279/1454-864X-21-I1-022

Investigation the influence of some meteorological factors on shipping air emissions dispersion in the Istanbul Strait

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Abstract. Shipping emissions are one of the most important environmental problems in Istanbul city and people living around the Bosphorus are unprotected from these effects every day. 35% of the population of Istanbul city (about 15 million people) live at a distance of approximately 4/5 km to the Bosphorus. Exhaust gas emissions (NO_X, SO_X, and PM) generated from transit ships have direct harmful effects on human health, the ecosystem, and the environment. Meteorological conditions play an important role in affecting air quality and human health due to seasonal changes and are closely related to air pollutant concentrations. In this study, the relationship of meteorological parameters (such as wind speed, temperature, relative humidity, pressure, precipitation) on the distribution of transit ship emissions was investigated using stepwise multiple regression and correlation analysis. A "good relationship" between the pollutants (NO_X, SO_X, PM) concentrations and meteorological parameters have been found.

Keywords: Meteorological Parameters, Regression Analysis, Emission, Air Pollutants

1. Introduction

International maritime trade transportation meets 90% of the world trade. As the need for energy and raw materials continues to increase in the globalizing world, maritime trade continues to maintain its importance. Ship emissions easily spread over long distances along the atmosphere between land and continents by sea, causing global, regional, and local adverse effects on sea and land air quality [1]. Approximately 80% of the merchant fleet vessels spend their time either in port or anchorage, while 55% spend their time cruising near the shore, and the exhaust gas emissions generated during these activities are concentrated along the straits, canals, gulfs, and port areas [2]. Ship-sourced emissions that have a direct impact on human health are nitrogen oxide (NO_X), sulphur oxide (SO_X), and particulate matter (PM). The effects of ship emissions on human health appear as asthma, respiratory diseases, cardiovascular disease, lung cancer, and premature death in infants [3,4,5]. In a study published by the World Health Organization, it was stated that at a global level, outdoor air pollution causes 1.3 million premature deaths each year, and 800,000 of these occur in the Asian continent [6]. In a projection made by the Organisation for Economic Co-operation and Development in 2012, it has been calculated that premature deaths in babies caused by PM will more than double until 2050 and cause 3.6 million deaths per year. China and India are predicted to be the leading countries where these deaths will be experienced the most. It is predicted that more than 500.000 people die annually due to $PM_{2.5}$ pollution in the world [5-7]. The meteorological parameters (air temperature, precipitation, relative humidity, wind, and air pressure) have a significant effect on the quality of the air we breathe (clean or dirty) and play an important role in the dispersion of pollutant concentrations in the air and transport over long distances

[8-12]. People living around the Bosphorus are exposed daily to the pollutant effects of exhaust gas emissions from transit ship traffic, and the harmful effects of NO_X, SO_X, and PM emissions on human health are felt.

Meteorological conditions play a crucial role in affecting the air quality depending on seasonal changes and it has a close relationship with air pollutant concentrations. Various scientific studies [13-21] investigated the effects of meteorological factors on air pollution. When these studies were examined; Yin et al. [13] analysed the relationship between the concentrations of $PM_{2.5}$ and PM_{10}, and the meteorological conditions for each season in Beijing from 2008 to 2014, a U-shaped relationship was found between the daily maximum wind speed and the daily PM concentration, including both $PM_{2.5}$ and PM_{10}. Zhang et al. [14] correlated analysis between air pollutants and meteorological factors. It has been observed that there is an inverse correlation between wind speed and pollutants, and a correct correlation between temperature and pollutants. Nastase et al. [15] examined the fluctuations in air pollution in Romania from the European WebDAB – EMAP database and trends in ambient concentrations of air pollutants using Romania's national air pollution monitoring network. The results indicated that Romania's annual average mass emissions decreased significantly. Bozkurt et al. [16] investigated the seasonal and spatial distributions of inorganic and organic pollutants (SO_2, NO_2, O_3, and VOCs) by using passive sampling technique. Kunt and Dursun [17] investigated the relationship between some meteorological parameters of Konya city center and sulfur dioxide and particulate matter. Sari and Esen [18] evaluated the concentration levels of PM_{10} and SO_2 by using the data of 103 measurement stations in Turkey. As a result of the mapping of pollutant concentrations and meteorological factors, it has been determined that temperature ratio and wind speed are effective in the distribution of pollutant concentrations.

About 15 million people (35% of the population of Istanbul city) live at a distance of approximately 4/5 km to the Bosphorus. Exhaust gas emissions (NO_X, SO_X, and PM) generated from transit ships have direct harmful effects on human health, the ecosystem, and the environment. People living around the Bosphorus are unprotected from these effects every day. The study of the year 2015, together with the available data, indicates that the cases of respiratory diseases and asthma diseases increased in Istanbul in 2015 compared to other years [22]. In this study, the relationship between transit ship emissions and meteorological parameters (such as wind speed, temperature, relative humidity, pressure, precipitation) was investigated using stepwise multiple regression and correlation analysis. In this study, it will be examined whether ship traffic emissions are distributed in the city depending on meteorological factors. This study will help us to understand the relationship between ship emissions and meteorological parameters for the Istanbul Strait.

2. Materials and methods

2.1. Transit Traffic in the Istanbul Strait

Transit ships crossing the Bosphorus have been increasing rapidly for years. In 1938, the number of ships crossing was 4,500, as of 2019, this increased by 41,112 ships [23]. As nearly 150 transit and non-transit ships pass through each day, approximately 23 of them constitute dangerous cargo vessels. In the event of a possible accident, damage to Istanbul and its surroundings will be very significant. The size and tonnage of transit ships are increasing day by day. Figure 1 summarizes the number of transit ships passing through the Istanbul Strait for years.

As shown in Figure 1, due to the increasing energy demand in the world, the number of ships crossing the Bosphorus and their cargo size increased at the same rate till 2007. The size of the ships increased at the same rate and large tonnage ships have passed through the Straits after 2007. With the increase in tonnage along with the number of ships, air pollution caused by these ships has increased in parallel. The tonnage of ships in ship-borne air pollution is an important criterion. Large tonnage ships have to have larger engines to move, and these engines consume more fuel and cause more air pollution.

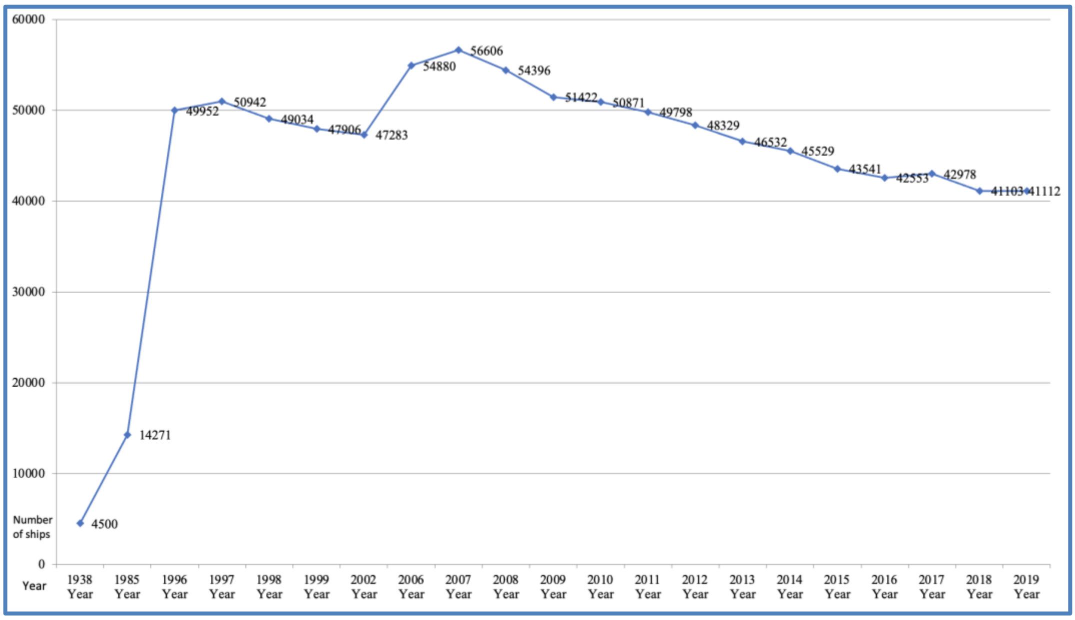

Fig. 1. The number of transit ships passing through the Istanbul Strait for years [23]

When the passing ship's cargo alternatives and divided by percentage were examined; general cargo with 45% ratio, solid bulk has 21% ratio, liquid bulk with 20% ratio, the container with 6% ratio, and rest of the ships with 8% ratio (passenger, passenger-ro-ro-cargo, military ships, sails/motorboats, tugs, and service boats. The monthly ship passes for 2019 were presented in Figure 2 and the busiest months in order by passing ships were October, December, March, and July respectively.

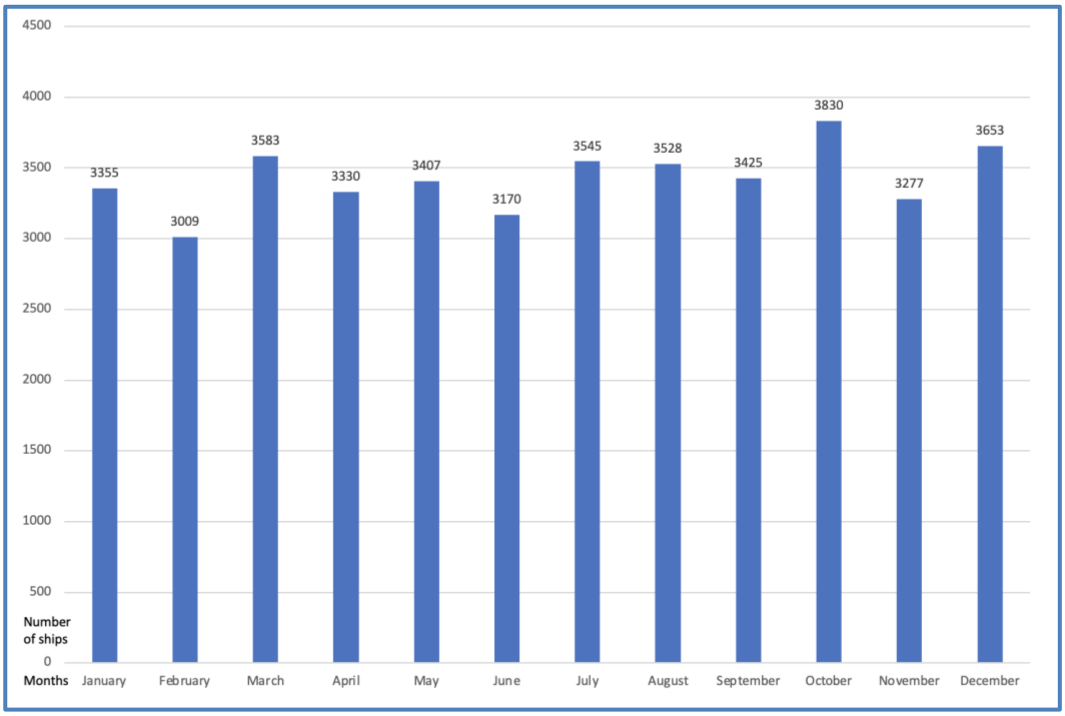

Fig. 2. Monthly Transit Ships Passes [23]

The monthly average of transit vessels passing through the Bosphorus was 3,426 vessels. It was evaluated that monthly air pollution concentrations increased or decreased in parallel with the number of transit ships. Exhaust gas emissions generated by transit ships passing through the Istanbul Strait were 937,017 tons of CO_2, 18,324 tons of NO_X, 5,294 tons of SO_X, 2,138 tons of CO, 693 tons of VOC, and 692 tons of PM, a total of 964,158 tons [22]. The types of ships that cause the most air pollution were general cargo ships, tanker ships, bulk cargo ships, container ships, and other types of ships. The monthly emission results obtained according to the transit ships passing in were shown in Table 1 [22].

Table 1. Monthly Emission Results [22]

Months	NOx	SOx	PM
January	1451	410	53
February	1392	412	54
March	1564	471	62
April	1498	440	58
May	1598	472	62
June	1565	460	60
July	1571	456	60
August	1470	403	52
September	1454	410	53
October	1556	437	57
November	1596	452	59
December	1609	471	62

The monthly meteorological statistics (precipitation, air pressure, relative humidity, wind speed, temperature) of the Istanbul Bosphorus region provided from the Turkish State Meteorological Service are presented in Table 2. According to our data, the month with the highest precipitation was February (123.6 mm) and the month with the lowest precipitation was July (26.4 mm). Air pressure is the highest in December (1026.1 hPa) and the lowest is in August (1009.9 hPa). Over 1013 hPa is considered high air pressure, and the months of high pressure are January, March, April, October, November, and December. The month with the highest relative humidity is February (83.6%) and the lowest is in April (72.7%). The wind speed is the highest in February (3.6 knots) and the lowest is in May (2.2 knots). The highest temperature is in August (26.1 ºC) and the lowest is in January (6.9 ºC). Monthly meteorological parameters were included in the analysis as independent variables in regression and correlation analysis.

Table 2. Meteorological statistics of the Istanbul Strait Region [24]

Months	Precipitation (mm)	Pressure (hPa)	Relative Humidity (%)	Wind Speed (Knot)	Temperature (°C)
January	99.6	1014.8	77.7	3.5	6.9
February	123.6	1012.3	83.6	3.6	7.0
March	61.2	1013.5	83.3	2.4	8.0
April	62.2	1013.9	72.7	2.7	11.3
May	56.0	1011.0	80.0	2.2	17.4
June	71.4	1010.9	82.3	2.4	20.8
July	26.4	1011.1	75.7	2.8	24.3

August	48.9	1009.9	76.1	3.0	26.1
September	96.1	1011.6	80.1	3.0	23.3
October	116.5	1015.9	82.3	3.0	17.5
November	55.7	1015.8	78.7	2.9	14.5
December	40.8	1026.1	79.3	2.9	8.8

3. Methodologies

Regression analysis helps us to find a relationship between dependent and independent variables. We used the multiple linear regression analysis to obtain the best prediction due to the number of independent variables (wind speed, temperature, relative humidity, pressure, precipitation) which can be expressed as:

$$Y=A+B_1X_1+B_2X_2+B_3X_3+B_4X_4+B_5X_5+E$$

where A is the constant of regression and B is the coefficient of regression. The NO_X, SO_X, and PM are considered as dependent variables while the meteorological factors are considered as independent variables. The values of the constant and the coefficients are determined using the least-squares method which minimizes the error, appearing as E in the above regression equation. The significance level of the constant and coefficients is statistically tested using the t distribution [25].

Correlation analysis is a statistical method used to determine the coexistence and direction of the relationship between two different variables based on regression analysis. The correlation value range varies between $-1 < R^2 < +1$, and $R^2 = 0$ is not a linear relationship, the linear relationship is weak when the R^2 value approaches 0, it is a positive relationship when it approaches + 1, It states that there is a negative (inverse) directional relationship with the approach. According to the correlation coefficient, if the ratio between dependent and independent variables is up to 50%, there is a weak relationship between these variables, between 51% and 70% there is a moderate relationship between these variables, and between 71% and 100%, there is a strong level. It states that there is a relationship [25].

4. Results and discussion

Regression and correlation analysis has been conducted to understand whether there is a relationship between the concentration of exhaust gas emission caused by transit ship traffic in the Istanbul Strait and meteorological factors. In the analysis, the meteorological factors (air temperature, precipitation, relative humidity, wind, and air pressure) were included in the calculation as independent variables, and ship exhaust gas emissions (NO_X, SO_X, and PM) as dependent variables. The amount of exhaust gas emissions (NO_X, SO_X, and PM) caused by transit ship traffic and meteorological factors were calculated month by month and included in the analysis. The analysis was carried out by using Microsoft Excel programme. When included all the necessary data such as monthly NO_X, SO_X, PM emissions, and meteorological factors, regression and correlation analysis were implemented by the programme. The programme presented all the related equations for NO_X, SO_X, PM emissions which covered all the coefficients and constants, and regression and correlation analysis were performed with the help of these coefficients and constants. The dependent and independent variables used in the stepwise multiple linear regression analysis and correlation analysis were presented in Table 3.

The multiple regression equation obtained for the NO_X is expressed as:

$[NO_X]$= -6747,21 - 0,818 x [Precipitation] + 8,151 x [Pressure] + 2,675 x [Relative Humidity] - 56,535 x [Wind Speed] + 1,331 x [Temperature] (R^2=0.80)

Accordingly, it has been observed that there is a "relatively strong relationship" between NO_X and precipitation and wind speed, precipitation and wind speed have an inverse effect on NO_X increasing or decreasing, NO_X decreases when precipitation and wind increases, NO_X increases when precipitation or wind decreases. It has been found that there is a "weak relationship" between NO_X and air pressure, relative humidity, and temperature, and has no effect on NO_X. It has been evaluated that there is a "relatively weak relationship" between air pressure and NO_X, and this relationship is due to the high pressure (1013 hPa), which manifests itself particularly in winter. 80% of NO_X depends on meteorological parameters and 20% of NO_X is indeterminate. There is a relatively strong relationship between NO_X and meteorological parameters.

The multiple regression equation obtained for the SO_X is expressed as:

$[SO_X]$= -689,836 - 0,404 x [Precipitation] + 1,381 x [Pressure] + 1,828 x [Relative Humidity] -23,390 x [Wind Speed] -1,114 x [Temperature] (R^2=0.84)

The SO_X regression analysis resulting from this formula is in parallel with the NO_X regression analysis. There is a "directly proportional" relationship between SO_X and air pressure and relative humidity, and an "inversely proportional" relationship between precipitation, wind, and temperature. SO_X values will increase with the increase of air pressure and relative humidity values, on the contrary, SO_X values will decrease with the decrease in air pressure and relative humidity values. One unit of decrease in precipitation, wind, and temperature values will cause an increase in SO_X value inversely. With this analysis, the SO_X emission pollution value of the desired day can be found by entering the meteorological data in the formula. 84% of SO_X depends on meteorological parameters and 16% of SO_X is indeterminate. There is a strong relationship between SO_X and meteorological parameters.

The multiple regression equation obtained for the PM is expressed as:

[PM]= -125,143 - 0,060 x [Precipitation] + 0,177 x [Pressure] + 0,247 x [Relative Humidity] -3,246 x [Wind Speed] -0,185 x [Temperature] (R^2=0.82)

The result we obtained in PM regression analysis is in line with the results of NO_X and SO_X regression analysis. There is a "directly proportional" relationship between PM and air pressure and relative humidity, and an "inversely proportional" relationship between precipitation, wind speed, and temperature. With increasing air pressure and relative humidity values, PM values will increase or, conversely, decrease. One unit of decrease or increase in precipitation, wind, and temperature values will cause an increase or decrease in PM value inversely. PM emission pollution rate for the desired day can be calculated by entering the meteorological data we have in the formula. 82% of PM depends on meteorological parameters and 18% of PM is indeterminate. There is a relatively strong relationship between PM and meteorological parameters.

The results obtained from the correlation analysis were presented in Table 3. The correlation of NO_X and SO_X with meteorological parameters is very similar to the relation of PM with meteorological parameters. There is a negative correlation between pollutants (NO_X, SO_X, PM) concentrations and wind speed, precipitation. As seen in Table 3., there is only a strong relation between the SO_X and wind speed, and a relatively strong relationship between the NO_X, PM and wind speed, precipitation. It has a value of 72% with the highest coefficient of correlation. This situation shows that when wind speed is high, NO_X, SO_X, and PM pollutants dilute by dispersion. NO_X concentration has a relatively weak level of relationship with the pressure. There is a weak level of relationship between the NO_X and temperature, relative humidity. SO_X concentration has a moderate level of relationship with the precipitation. There is a weak level of relation between the SO_X and temperature, relative humidity, and pressure. As regards the PM concentration, there is a moderate level of relation with precipitation. The relationship of PM with temperature, relative humidity, the pressure is also weak.

Table 3. The Correlation Analysis

Dependent Variables	**Independent Variables**	**R^2 (Adjusted R Square) (%)**	**Level of Relationship**
NO_X	Wind speed	- 68	Relatively Strong
	Temperature	13	Weak
	Relative humidity	- 12	Weak
	Pressure	38	Relatively Weak
	Precipitation	- 63	Relatively Strong
SO_X	Wind speed	- 72	Strong
	Temperature	- 13	Weak
	Relative humidity	13	Weak
	Pressure	34	Relatively Weak
	Precipitation	- 57	Moderate
PM	Wind speed	- 69	Relatively Strong
	Temperature	- 17	Weak
	Relative humidity	12	Weak
	Pressure	34	Relatively Weak
	Precipitation	- 56	Moderate

5. Conclusion

Exhaust gas (NO_X, SO_X, and PM) emissions generated from ships have direct harmful effects on human health, the ecosystem, and the environment. 35% of the population of Istanbul, where approximately 15 million people live, live at a distance of approximately 4/5 km to the Bosphorus. It is very important to examine the relationship between the transit ship traffic emission concentrations in the Bosphorus and the meteorological factors in the region and to determine the effects of this relationship on human health. In this study, the relationship between the one-year ship traffic emission results (NO_X, SO_X, and PM) and meteorological factors in the Bosphorus were examined by using stepwise multiple linear regression analysis and correlation analysis. As a result of the analysis, it has been determined that there is a good relationship between the ship pollutants (NO_X, SO_X, PM) concentrations and meteorological factors.

While the pollutants (NO_X, SO_X, PM) concentrations have a strong relationship with wind speed, they are showing a significant correlation with precipitation. The temperature, relative humidity, and pressure are also weakly correlated with NO_X, SO_X, and PM. On the days when the meteorological factors (precipitation and wind) increase, air pollution will decrease in parallel. These meteorological factors (precipitation and wind) will clean the atmosphere and the air pollution.

According to the common result of the regression analysis, a "directly proportional" relationship between NO_X, SO_X, and PM emissions and relative humidity and air pressure, and an inversely proportional relationship between precipitation, wind, and temperature. One unit increase or decrease in air pressure and relative humidity values will increase or decrease the effect of NO_X, SO_X, and PM emissions, and a one-unit increase or decrease in precipitation, wind, and temperature values will decrease or increase the effect of NO_X, SO_X and PM emissions in inverse. Considering that air pressure and relative humidity are seen at high levels in winter and spring months, other city emissions (vehicle traffic, industry, and domestic heating, etc.) also increase in these months, it is evaluated that the harmful effects of NO_X, SO_X and PM emissions from transit ships will be felt more on the city.

Similar results were obtained in the correlation analysis. Accordingly, a "strong relationship" was found between NO_X, SO_X, and PM and precipitation and wind speed, and meteorological factors had an inverse effect on NO_X, SO_X, and PM in the direction of increase or decrease. A "weak relationship" has emerged between NO_X, SO_X, and PM and air pressure, relative humidity, and temperature. The reason why the air pressure, relative humidity, and temperature values have a weak relationship is that the effect of these meteorological factors is not seen at a high level to contribute to the cleaning of pollutant concentrations in the air. When rain and wind speed increase, the pollutant concentrations will be cleared from the air and their harmful effects will be reduced.

6. Acknowledgments

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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