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RESEARCH ARTICLE

Emission Estimation of Ship Traffic in the Dardanelles

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Abstract: Ships, which form the backbone of world trade, are also a major source of pollutants. These pollutants can cause very important health problems, especially in areas with a high human population and in tourism areas. Therefore, detection and prevention of ship emissions must be considered, carefully. Dardanelles and Bosporus, known as the Turkish Straits, are one of the locations where the impact of ship emissions is felt the most as narrow and densely populated waterways. In this study, the data of the ships passing through the Dardanelles in 2020 were processed and the emissions generated by these ships were calculated as 545,373.3 t. Based on these data, the damages caused by these emissions to the environment and solutions were discussed. In addition, the potential effects of ship traffic on marine life are also discussed.

Anahtar kelimeler:

Gemi emisyonları
Çanakkale Boğazı
Emisyon tahmini

Çanakkale Boğazı Gemi Trafiğinin Emisyon Tahmini

Öz: Dünya ticaretinin bel kemiğini oluşturan gemiler, aynı zamanda büyük kirletici kaynağıdır. Bu kirleticiler, özellikle insan nüfusunun yoğun olduğu bölgelerde ve turizm bölgelerinde çok önemli sağlık sorunlarına yol açabilir. Bu nedenle, gemi emisyonlarının tespiti ve önlenmesi dikkate alınması gereken çalışmalardır. Türk Boğazları olarak bilinen Çanakkale ve İstanbul Boğazları, dar, yoğun nüfuslu ve yoğun gemi trafiğine sahip su yolları olarak gemi emisyonlarının etkisinin en çok hissedildiği konumlardan birisidir. Bu çalışmada, Çanakkale Boğazı'ndan 2020 yılında geçen gemilere ait veriler işlenerek bu gemilerin oluşturduğu emisyonlar 545.373,3 t olarak hesaplanmıştır. Bu verilerden yola çıkılarak, bu emisyonların çevreye verdikleri zararlar ve çözüm yolları üzerinde tartışılmıştır. Buna ek olarak, gemi trafiğinin deniz yaşamı üzerindeki potansiyel etkileri de tartışılmıştır.

Introduction

About 3% of the world's emissions are caused by ship-related emissions and it continues to increase constantly. Although the rate seems low, cities and people are adversely affected by maritime transport (Acciaro & Wilmsmeier, 2015; Bayırhan et al., 2019; Gibbs et al., 2014; Misra et al., 2017). It has been suggested that approximately 70% of the emissions from ships occur within 400 km of the coastal area (Eyring et al., 2010). Various types of emissions including carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxide (NO_x), volatile organic compounds (VOC's), sulfur dioxide (SO_2), particulate organic particles (POM), and black carbon (BC) are released into the environment (Kesgin & Vardar, 2001; Kuzu et al., 2021; Merico et al., 2021). These harmful gases emitted not only negatively affect the environment but also human health, especially in regions where the population is dense (Ekmekçioğlu et al., 2022; Guo et al., 2015; Nunes et al., 2017).

Emission values for Samsun Port in 2018 were 52 t PM, 37 t VOC, 411 t SO_2, 903 t NO_x, and 51.129 t CO_2 for a period of 1 year (Tokuşlu, 2021). It has been determined that 91% of the emissions in the port originate from general cargo, ro-ro cargo and tanker ships. In addition, it has been determined that 64,000-150,000 people living within 1-2 km of the port are adversely affected by these emissions (Tokuslu, 2021). Ekmekcioglu et al., (2019) examined the Ports of Izmir and Mersin for a year. Emissions in Izmir Port amounted to 900 t/yr NO_x, 589 t/yr SO_2, 45320.5 t/yr CO_2, 49.7 t/yr VOC, 77.7 t/yr PM, and 36.9 t/yr COwhere as in Mersin Port, 1998 t/year NO_x,

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1339 t/yr SO_2, 102330 t/yr CO_2, 114.5 t/yr VOC, 178.5 t/yr PM, and 82.5 t/yr CO. For the Mersin Port 1998 t/yr NO_x, 1339 t/yr SO_2, 102330 t/yr CO_2, 114.5 t/yr VOC, 178.5 t/yr PM, and 82.5 t/yr CO were determined (Ekmekçioğlu et al., 2019). Deniz and Kilic investigated ship emissions in Ambarli Port in 2005. They concluded that emissions amounted to 845 t/yr NO_x, 242 t/yr SO_2, 2127 t/yr CO, 78590 t/yr CO_2, 504 t/yr VOC, and 36 t/yr PM. In addition, the ships in the port of Ambarli released 55 µg m^{-3} SO_2 and 100 µg m^{-3} NO_x into the air from a distance of 2 km from the port. They estimated that 60,000 people living around the port are affected by this emission (Deniz & Kilic, 2010). Tzannatos Ernestos (2010) studied emissions from ports in Greece. In the study, emissions were calculated based on the amount of fuel sold between 1984 and 2008. It has been determined that there is an annual increase of approximately 2.85% in emission inventory. In addition, the emission value in 2008 was calculated as 12.9 million tons in total. Emissions from local ships due to fuel sales and international ships due to ship traffic in the Greek seas, on the other hand, amount to 7.4 million tons (Tzannatos Ernestos, 2010). Isakson et al., (2001) studied ship emissions and their impact on the port of Gothenburg. They estimated 115 $kgkm^{-2}$/yr NO_2 and 220 $kgkm^{-2}$/yr SO_2 accumulation (Isakson et al., 2001). Alver et al., (2018) examined ship emissions in Samsun Port between 2010-2015. In their study, 6 different types of ships in different operations were investigated. They estimated emissions of NO_x as 728 tons, SO_2 as 574 tons, HC as 32 tons, and PM_{10} as 64 tons. It has been estimated that the highest emission values belonged to general cargo ships. In addition, about 80% of the total emissions in ro-ro ships occur when the main engine is running (Alver et al., 2018). Chen et al. (2016) analyzed the emissions that occurred at the Tianjin Port in China in 2014 according to AIS data. The authors calculated $2.93*10^4$ tons of SO_2, $4.13*10^4$ tons of NO_x, $4.03*10^3$ tons of PM_{10}, and $3.57*10^3$ tons of CO emissions. The total CO_2 emission value was calculated as $1.97*10^6$ tons. Container and dry bulk carriers accounted for approximately 70% of NO_x, SO_2 and PM_{10} emissions (Chen et al., 2016). Saraçoğlu et al., (2013) examined the ship-driven emissions at the Izmir Port in 2007 and determined 1923 t/yr NO_x, 82753 t/yr CO_2, 1405 t/yr SO_2, and 165 t/yr PM emission values.

The emissions have negative effects on the environment and human health. For example, while NO_x damages the environment as acid rain, it also causes diseases such as bronchitis and emphysema in humans (Vu et al., 2020). SO_x, on the other hand, harms the environment and human health with the sulfate aerosol it creates in the atmosphere (Hassellöv et al., 2013). CO_2 is caused by diesel fuel used in ships (Allal et al., 2019) and creates a greenhouse gas effect (Valera-Medina et al., 2021). PM causes many diseases such as heart attack, asthma, and premature death (Johnson et al., 2017; Zhao et al., 2021).

It is known that ship traffic causes serious damage to marine life, especially in coastal areas. It has been observed that environmental damage caused by various factors is at high levels in the Mediterranean, especially in Spain, Southern France, Eastern Italy, and the Aegean Sea, and ship traffic has been identified as one of the biggest contributing factors (Micheli et al., 2013). There are many studies indicating the noise caused by ship traffic has negative effects on marine organisms especially marine mammals. A significant number of these focused on the sensitive marine areas of the Arctic and Antarctic waters. (Davidson et al., 2018; Erbe et al., 2019; Ivanova et al., 2019; Pirotta et al., 2019; Schwemmer et al., 2011). Similarly, the effects of ship traffic on the coastal ecosystem (Xue et al., 2021) and the spread of invasive species (Letschert et al., 2021; Ruiz et al., 2013) were also investigated in detail.

The Dardanelles, which connects the Sea of Marmara and the Mediterranean, is one of Turkey's most important straits. According to the latest studies, although the number of ships passing through the strait has decreased, there has been an increase in the amount of cargo carried (Mersin, 2020).

In this study, emission values originating from ship traffic through the Dardanelles in 2020 were estimated and the potential impacts of these emissions and the reduction methods were discussed.

Material and Methods

The Turkish Straits are two important waterways that separate Europe and Asia, and they connect the Black Sea to the Mediterranean and Dardanelles is located at 40.2° N and 26.4° E. The transit routes of Dardanelles are given in Figure 1.

In 2020, the number of passages made through Dardanelles is 42,037 (9,958,822 gross tons). The average transit time is 3.4 hours. In the emission calculations, all the passages made by the ships in the north-south and south-north directions are included in the calculation. Since the fuel consumption data was not recorded, the calculations were carried out according to the engine power method.

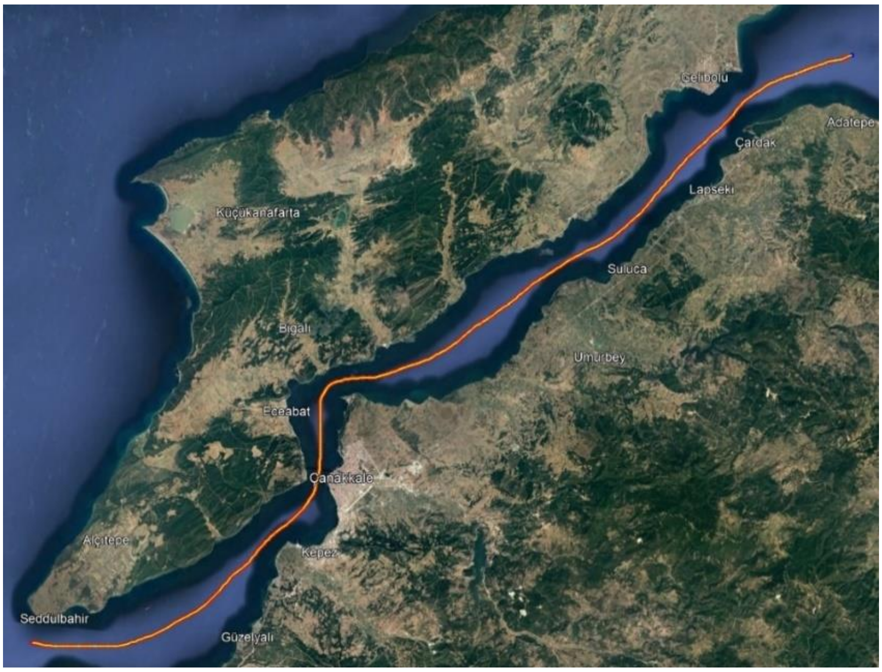

Figure 1. Route for Dardanelles (UK Hydrographic Office, 2017)

The formula suggested as follows (IPCC, 2006):

$$E_{Trip,i,j,m} = \sum_p \left[T_p \sum_e \left(P_e \times LF_e \times EF_{e,i,j,m,p}\right)\right]$$

where;

E_{Trip}: Total emission (t)

T: Voyage duration (h)

P: Engine power (kW)

LF: Load factor (%)

EF: Emission factor (g/kWh or g/MJ)

p: Voyage phases

e: Engine category

i: Pollutant type

j: Engine type

m: Fuel type

Since there is no engine power of the ships in the data obtained regarding the strait passages, the equations presented in Table 1 were used to find the engine power depending on the gross tonnage.

Since the gross tonnage value of the ships is known, the approximate engine power of the ships can be obtained by using the equations presented in Table 1.

The cruise time, which is another variable in the formula, is kept separately for each ship and is available as a data set. The engine load of the ships was accepted as 0.8 during cruising. The last variable, emission factors are presented as 588, 1.85, 1.0, 0.6, 14.4, and 0.2 g/kWh for CO_2, SO_2, CO, HC, NO_x, and PM, respectively (Moldanová et al., 2005).

Table 1. Engine power-gross ton equations (y as engine power, x as gross ton)

Ship Types	Equation	Reference
General Cargo	$y = 5.3799x^{0.7633}$	Chengfeng et al., 2007
Bulk Carrier	$y = 66.728x^{0.4826}$	
Tanker	$y = 18.189x^{0.6093}$	
Container Ship	$y = 2.5008x^{0.8801}$	
Reefer	$y = 1.2462x^{0.9783}$	
Ro-Ro	$y = 692.09x^{0.2863}$	
Passenger	$y = 0.6379x + 1411.5$	
Fishing	$y = 19.266x^{0.6658}$	
Other	$y = 77.806x^{0.5283}$	
Tugs	$y = 27.303x^{0.7014}$	Maimun et al., 2013

Results and Discussion

Emissions were calculated as 529,129.5, 1664.9, 899.9, 540.0, 12959.0 and 180.0 t for CO_2, SO_2, CO, HC, NO_x and PM, respectively (Table 2). Table 2 also presents emission values reported by other authors from earlier studies.

Kesgin and Vardar conducted a study on transit ship emissions in the Turkish Straits in 2001. In their study, the emissions from the ships passing through the Dardanelles were calculated as 8461.0, 786.0, 337,590.0, 255.0, and 128 t/yr for NO_x, CO, CO_2, VOC, and PM, respectively (Kesgin & Vardar, 2001). In the study conducted by

Cengiz and Yalcın in 2008, emissions from ships passing through the Turkish Straits in 2003 were calculated. Emission values from the ships in transit and non-transit modes have been calculated. Emissions were calculated as 13,000, 10,806, 1494, 485, 578, and 640,331 t/yr for NO_x, SO_2, CO, VOC, PM, and CO_2, respectively (Deniz & Durmuşoğlu, 2008).

A total of 38,777, 42,668, and 42,037 ships in 2001, 2003 and 2020 passed through the Dardanelles, respectively. Although an increase in the number of ships is expected over the years, lower numbers in recent years is due to the decrease in demand for transportation as a result of COVID-19 pandemic. However, despite the decrease in the number of ships, the amount of cargo carried increased (Mersin, 2020) due possibly to the larger capacity of recently built cargo ships. In addition, the data indicated similar emission levels in 2003 and 2020 and suggest a correlation between the number of ships passing through the Dardanelles and emission levels.

Table 2. Emission values from the present study and earlier studies

Emission Types	Savaş and Bilgili	Ugur and Vardar	Cengiz and Yalcin*
CO_2 (t/yr)	529,129.5	337,590.0	640,331
SO_2 (t/yr)	1664.9	-	10,806
CO (t/yr)	899.9	786	1494
HC(t/yr)	540.0	-	-
NO_x (t/yr)	12959.0	8461.0	13,000
PM (t/yr)	180.0	128	578
VOC (t/yr)	-	255	485

* Emission values from the ships in transit and non-transit modes have been calculated.

The Dardanelles Strait is an important waterway connecting the Marmara and the Aegean Sea (hence the Black Sea and the Mediterranean), in a densely populated region. The region, particularly the Sea of Marmara, is a very important ecosystem in which marine organisms adapt and thrive as it is a transition zone between the Black Sea and the Aegean (Mediterranean) Sea. However, the extensive ship traffic in such a sensitive waterway threatens the marine life in this region. It has been suggested that emissions from ships cause marine pollution and mucilage-like formations (Zhang et al., 2021). In addition, there is evidence that microscopic organisms transported by ballast waters pose a threat to receiving marine ecosystems (Letschert et al., 2021; Ruiz et al., 2013) and therefore, invasive species have the potential to become a significant threat for the ecosystem of the Dardanelles Strait. Therefore, the ship traffic in the Dardanelles Strait can be considered as an important factor that threatens marine life.

Conclusions

The Dardanelles, which is one of the important settlements in northwest Turkey with a rich a historical texture and considerable tourism activity, is exposed to significant emissions due to heavy ship traffic in the region. Since approximately 70% of ship emissions occur within 400 km of the coastal areas (Eyring et al., 2010), coastal communities as well as the historical texture of Canakkale are vulnerable to ship-driven pollution.

In addition, the marine life in and around the Dardanelles Strait is under threat due to ship-borne pollution. Transfer of ship-driven emissions into the sea through atmospheric events, introduction of exotic species into the Dardanelles and the potential displacement of local marine organisms due to underwater noise caused by ship traffic are important issues that need to be addressed. Such problems can be mitigated by using larger capacity ships for marine transport and alternative routes to minimize effects on marine organisms. Scrubber applications or alternative fuel utilization may also help prevent potential effects. As stated in IMO 78/11, in addition to the Mediterranean, which is planned to be declared as ECA as of 01.01.2025, accelerating the efforts to declare the Sea of Marmara and the Turkish Straits as ECA is very important for the environmental improvement of the region (Marine Environment Protection Committee n.d.).

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Conflict of Interest

The authors declare that there are no conflicts of interest.

Author Contributions

All authors contributed to the preparation of the manuscript.

Ethics Approval

Ethics committee approval is not required for this study.

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