Revealing the Pollution Discharge Characteristics of Foeryan Port in Chongqing Based on Correlation Analysis

Zhongbo Peng[1], Han Zou[1,*], Yutong Su[2], Liang Tong[1] and Lumeng Wang[1]

[1]Chongqing Jiaotong University, 66 Xuefu Avenue, Nan 'an District, Chongqing, China
[2]hongqing Haizhuang Wind Power Engineering Technology Co., Ltd, Building 2, No. 30 Jinyu Avenue, North New Area, Chongqing, China

*Corresponding author. Email:zouhan9903@163.com

Abstract. Inland shipping has made a great contribution to China's economic development, and the discharge of inland shipping has also posed a threat to the health of residents along the coast. In this study, the automatic identification system (AIS) data are processed, and the air data of Foeryan Port in Chongqing are collected at the same time. The pollutant emissions from ships in Foeryan Port from September to December 2021 were obtained, and the correlation between ship emissions and port air quality was analyzed through the collected data to understand the impact of ship emissions on port air quality. The results show that the pollutant emissions from ships are highly correlated with the air quality concentration in Foeryan port, and even some are significantly correlated. Therefore, emissions from ships can be reduced through the use of clean energy, the use of shore power and the establishment of deceleration zones to reduce the impact on port air quality.

Keywords: Shipping Emission, Air Pollution, Correlation Analysis, AIS Data.

1   Introduction

China is a country with extremely rich inland shipping resources, ranking first in the world. At the same time, the growing prosperity of inland trade has also brought serious environmental problems, and ship emissions have become an important factor affecting the air quality of China's inland ports.

Ship emission inventories help identify major emission sources and provide a basis for assessing the impact of emission sources on regional air quality. Using AIS data to analyze the pollution emission of ships, the accuracy of the ship emission inventory can be improved. Therefore, the "bottom-up" algorithm based on AIS has gradually become the mainstream method for calculating air pollutant emissions from ships. In 2016, Li developed a high-resolution ship emission inventory for the Pearl River Delta region through the "bottom-up" approach based on AIS, and quantitatively estimated the uncertainty of the ship emission inventory [1]. In 2019, Ryohei Nakatsubo analyzed the

impact of ship emissions on atmospheric $PM_{2.5}$ in Japan [2]. The above studies mainly focus on coastal ports, while there are relatively few studies on ship emission inventories of inland ports [3].

Inland navigation areas are often adjacent to cities and towns, and the population is relatively concentrated, which will directly affect the urban ambient air quality and residents' health. Therefore, this study focuses on the use of correlation analysis to reveal the specific impact of ship emissions on air quality near ports, so as to provide policy references for ports to reduce ship air pollutant emissions.

The second chapter introduces the research object, data collection and calculation method of this paper. In chapter 3, the ship emission inventory and its correlation with port air quality are calculated based on the study of Chongqing Foeryan Port area. The fourth chapter gives some suggestions on the research results. The fifth chapter is the conclusion.

2   Methods

2.1   Research area and research time

The research area of this paper is the Foeryan port area of Chongqing (106.47° E-106.52 °E, 29.24° N-29.39 °N), as shown in Figure 1. The base year is 2021, the research time is from September to December, and the research period includes three periods: dry season, middle season and flood season. The air pollutants studied included CO, NO_X, PM_{10}, $PM_{2.5}$, SO_X and the greenhouse gas CO_2. According to the field investigation, the main sources of air pollutant discharge from single ship in this area include ship main engine and ship generator. At the same time, through the air quality and pollutant concentration published on the Internet, you can obtain the air quality data of Foeryan port from September to December.
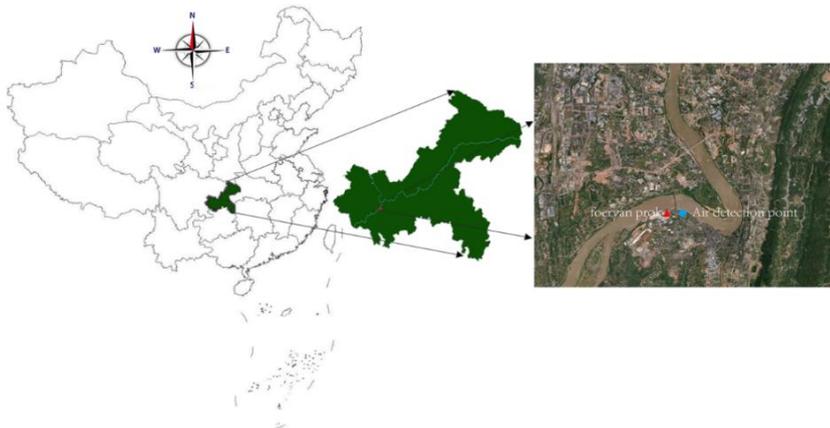

Fig. 1. Research area

2.2   Data collection and processing

Public AIS data and air quality concentrations at Chongqing Foeryan Port were obtained via the Internet. The main operations for AIS data: First, determine the scope: Obtain the ship data in the study area within the scope required in this paper. Secondly, data cleaning: AIS data should be cleaned, abnormal data should be automatically identified, and missing data should be supplemented. Finally, based on AIS data and power method, the distribution characteristics report of regional air pollution emission inventory of ships is calculated by making full use of static and dynamic information of ships. At the same time, the collected air quality includes CO, $PM_{2.5}$, PM_{10}, NO_X, SO_X and other concentrations. At the same time, the collected air quality concentration data of Chongqing Foeryan Port from September to December will be cleaned, abnormal data will be corrected, missing data will be supplemented, and then stored in the database for easy processing.

2.3   Data collection and processing

In this paper, a "bottom-up" algorithm [4] is chosen to calculate the atmospheric pollutant emissions of ships in Chongqing port area, in which the emission factor is an important part of the ship emission inventory. Bai et al. selected an ocean-going ship for monitoring, obtained the average emission factors under six working conditions, and solved the problem of insufficient emission data of such ships under anchoring conditions [5]. Fu et al. measured the emissions of seven ships with different engine power in the Grand Canal, and derived distance-based and fuel-based emission factors based on the operating state of the ships [6]. Based on the relevant research results at home and abroad, this paper comprehensively determined the basic emission coefficient of ship main and auxiliary engines of Chongqing Foeryan Port (detailed steps after determining the emission coefficient), and calculated the ship emission inventory of Chongqing Port area according to Peng [7] 's improved model, as shown in the following formula (1);

$$E_j(k) = \Sigma M \, C \sum_{i=1}^{4} R_{(k)} \times LF_i(k) \times EF_i j(k) \times FCF \times DP \times DU \times T_i \times 10^{-6} \qquad (1)$$

Among them, i, j, k are driving modes, pollutant type and engine type respectively. E is pollutant discharge (t); MCR is power (kW); LF is the load factor; EF is the emission coefficient; F is the fuel correction coefficient; DP is the matching coefficient of turbine and propeller; DU is the host low load correction factor; T is the time (h).

3   Results

3.1   Emission Inventory and Characteristics

The pollutant discharge from ships in Chongqing Foeryan Port from September to December 2021 is calculated, as shown in Table 1.

Table 1. Total pollutant discharge in Foeryan Port (unit: t)

Pollutant	SO_X	NOx	PM_{10}	$PM_{2.5}$	CO	CO_2
Discharge amount	0.48	9.39	0.28	0.21	2.59	756.25

It can be seen that in the past four months, CO_2 emissions were the highest, reaching 756.25t, much higher than other pollutants, followed by NO_X, reaching 10.01t, $PM_{2.5}$ is the lowest, only 0.21t.

3.2   Time characteristics

According to the data of ship activities in different months, different types of pollutants in each month were calculated, and then the monthly variation characteristics of different types of pollutants were analyzed, as shown in Table 2. The emissions of atmospheric pollutants CO, HC, NO_X, PM_{10}, $PM_{2.5}$, SO_X and CO_2 from September to December 2021 are shown in Table 3, and the monthly variation characteristics are shown in Figure 2.

Table 2. Monthly emission of air pollutants from ships (unit: t)

Waste gas	CO	NO_X	PM_{10}	$PM_{2.5}$	SO_X	CO_2
September	0.58	2.12	0.08	0.05	0.10	176.41
October	0.73	2.65	0.08	0.058	0.14	237.17
November	0.71	2.61	0.07	0.06	0.14	195.37
December	0.57	2.01	0.05	0.05	0.10	147.30

It can be seen from table 2 that the pollutants discharged from ships in the region are mainly CO_2 and NO_X, with the least $PM_{2.5}$ It is mainly because the navigation of ships is affected by the level of ship activities in the Three Gorges reservoir area of the Yangtze River, hydrological characteristics of channel environment, autumn and winter, flood period and dry season, etc. The navigation conditions in dry season and flood period are poor, and the ship flow is relatively small, while the navigation conditions in mid-water period are better and the ship flow is large. October is the mid-water period, with moderate water level, which is the best period for navigation conditions throughout the year. Therefore, during this period, the ship flow increased, which led to the increase of the regional ship discharge, accounting for 27.59% of the total discharge. In December, the water level was low, the flow rate was slow, the navigation conditions were poor, which led to the lower pollutant discharge, resulting in the lowest discharge in December, accounting for 21.05% of the total discharge.
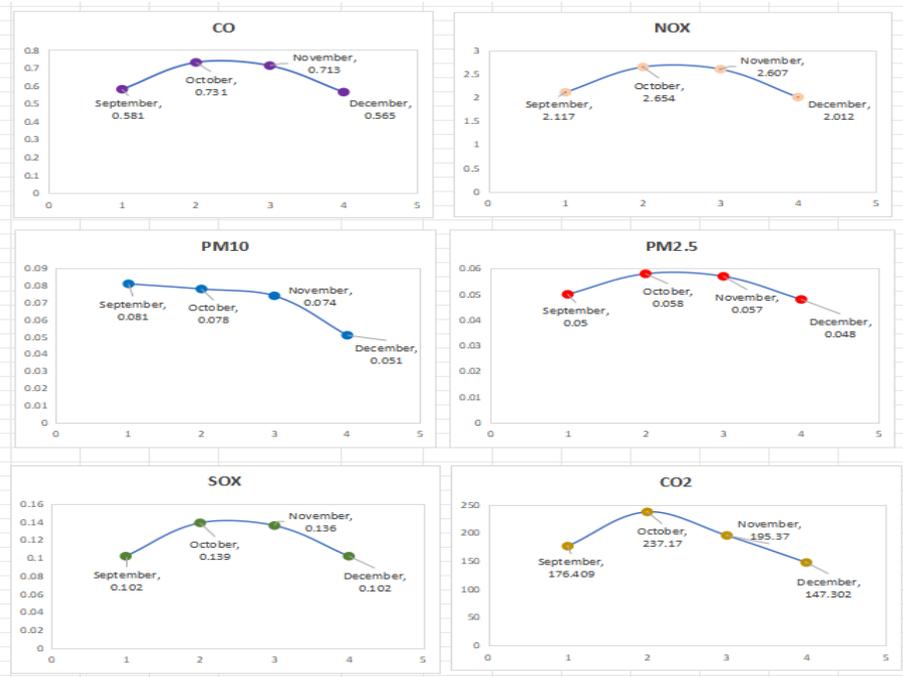
Fig. 2. Monthly variation characteristics of pollutant discharge

As can be seen from the figure, the emission laws of CO, NO_X, $PM_{2.5}$, SO_X and CO_2 are basically the same, with the largest contribution in October and the smallest in December; PM_{10} emission law is inconsistent with other emissions, with the highest emission in September and the lowest in December.

3.3   Air quality and characteristics

Daily air quality data for Fall Rock Port can be obtained by collecting air quality and pollutant concentrations published on the Internet. Average the data of the current month to obtain the air quality data of Foeryan Port from September to December (as shown in Table 3).

Table 3. Average monthly air quality concentration in Foeryan Port (unit: μg/m³)

Waste gas	CO	NO_X	PM_{10}	$PM_{2.5}$	SO_X
September	53.72	28.58	0.71	37.71	8.77
October	58.57	36.14	0.97	52.64	13.21
November	60.19	35.26	0.99	54.69	14.42
December	42.35	30.15	0.78	41.82	10.59

As shown in table 3. It can be seen that the main contribution month of all pollutants in Foeryan Port is November, with all of them reaching more than 25%, of which SO_X

reached the maximum of over 30% in November, and PM_{10} and $PM_{2.5}$ reached the minimum but also reached about 27%.

3.4   Air quality and characteristics

In order to study the relationship between ship and port pollution, different measures of energy conservation and emission reduction are formulated according to the different activity of ships in different ports. Taking Foeryan Port as the study area and port air quality as the standard, the correlation between ship pollutants and port air quality in Foeryan port from September to December was studied.

For analysis using Pearson correlation (as shown in equation (2)), the correlation coefficient is a ratio that is the ratio of the product of the covariance of two vector-values and the standard deviation of their values. This value indicates the degree of correlation. 0.8-1.0 is a significant correlation, 0.5-0.8 is a high correlation, 0.3-0.5 is a real correlation, and 0-0.3 is a small correlation (as shown in Table 4). The correlation between two sets of data can be obtained by specific values.

$$= \frac{\sum_{i=1}^{n}(X_i-\overline{X})(Y_i-\overline{Y})}{\sqrt{\sum_{i=1}^{n}(X_i-\overline{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i-\overline{Y})^2}} \tag{2}$$

Table 4. Correspondence table of Pearson correlation coefficient

Degree of correlation	Significant	Highly	Real	Micro
Correlation coefficient	$1.0 \leq r < 0.8$	$0.8 \leq r < 0.5$	$0.5 \leq r < 0.3$	$0.3 \leq r < 0$

The daily air concentration index of the main pollutants NOX, SOX, CO, PM2.5 and PM10 in Fallrock Port was obtained, and the monthly average concentration of each pollutant in a month was calculated, and the monthly average discharge of pollutants from ships was calculated. Taking the daily average concentration of pollutants in the port as the dependent variable and the monthly average discharge of pollutants from ships as the independent variable, the correlation between the monthly average discharge of pollutants from ships and the daily average concentration of pollutants in the port was studied, and the results were shown in Table 5.

Table 5. Correlation coefficient of average discharge of ships and average concentration of Foeryan Port

Port \ Ship	CO	SO_X	PM_{10}	$PM_{2.5}$	NO_X
CO	0.937	0.929	0.825	0.907	0.920
SO_x	0.932	0.938	0.826	0.908	0.924
PM_{10}	0.304	0.303	0.852	0.763	0.311
$PM_{2.5}$	0.878	0.867	0.887	0.949	0.857
NO_x	0.941	0.933	0.811	0.898	0.947

As shown in Table 5, the correlation analysis between the daily average emissions of ships and the air quality of Foeryan port shows that all pollutants except PM10 are highly correlated with the monthly average concentration of the air quality of Foeryan port, and even some pollutants have significant correlation. Although the average monthly PM10 from ships is only correlated with CO, SO_X, $PM_{2.5}$ and NO_X, it is highly correlated with the average monthly PM10 concentration in ports.

As can be seen from Table 5, the air quality of a port is closely related to the emission of nearby ships, and the port is also closely related to the health of nearby residents. Therefore, it is urgent to control the pollution of ships and ports.

4   Suggestions

Through the analysis of ship emission inventory, temporal and spatial distribution and correlation between ship emission and port air quality in Foeryan port of Chongqing, it can be seen that ship emission is significantly correlated with port air quality, which will directly affect the health of residents near the port. Therefore, ship emissions from ports cannot be ignored. In view of the above, the following policies are recommended.

1. Use clean energy. Clean energy mainly refers to Liquefied Natural Gas (LNG). LNG ships can reduce CO2 emissions by 20%-30% while minimizing SOX and other emissions. At present, it has been widely promoted in developed areas abroad, and corresponding projects have been launched in Europe to promote LNG to replace traditional ships.
2. Use of port electricity. When the ship is docked in port, the ship's daily electricity is provided by Marine generators, which then produce pollutants. Moreover, when the ship is docked at the port for a long time, it will emit a lot of pollutants, which will directly affect the health of residents near the port. Therefore, Chongqing Foeryan port should directly use shore power, which will greatly reduce the emission of pollutants from ships.
3. Establish ship deceleration zones. According to the research, ship speed optimization is considered to be one of the most effective measures to reduce pollution.[8] For this reason, deceleration zones can be set up in front of several major ports in Chongqing, so as to reduce the discharge of pollutants from ships in port areas, and establish an incentive mechanism to subsidize or reward ships that voluntarily decelerate in deceleration zones.

5   Conclusion

According to the calculation of ship emission inventory, the total pollutant emission from ships in Chongqing Foeryan Port from September to December was 770.03t, of which CO2 emission was far ahead of other pollutants. This situation may be directly related to the conversion of fuel products. Among the pollutants discharged from September to December, the emissions in October were the highest, and the emissions in December were the lowest, basically in line with the ship activity level, river

environment and hydrological characteristics, flood season and dry season in the Three Gorges reservoir area of Chongqing. Port air quality is highly correlated with nearby ship emissions, indicating that one of the main sources of port pollution is ship emissions.

This article has some limitations. The emission factors selected in most ship emission inventories are those of developed countries such as Europe and the United States. At the same time, although the data used in this paper covers the main flood season of the Yangtze River, it does not cover the whole year, which is bound to have some differences with the discharge characteristics of the whole year. Therefore, when the data period covers one year, the characteristics of ship emissions can be determined and better measures of ship and port emissions can be developed.

Funding

References

1. Song, S. Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port. Atmospheric Environment,(82) 288-297(2014).
2. Chen, D.; Wang, X.; Nelson, P.; Li, Y.; Zhao, N.; Zhao, Y.; Lang, J.; Zhou, Y.; Guo, X. Ship emission inventory and its impact on the PM 2.5 air pollution in Qingdao Port, North China. Atmospheric Environment(166), 351-361(2017).
3. Yang, L.; Zhang, Q.; Zhang, Y.; Lv, Z.; Wang, Y.; Wu, L.; Feng, X.; Mao, H. An AIS-based emission inventory and the impact on air quality in Tianjin port based on localized emission factors. Sci Total Environ(783), 146869(2021).
4. Liao, T.; Gui, K.; Jiang, W.; Wang, S.; Wang, B.; Zeng, Z.; Che, H.; Wang, Y.; Sun, Y. Air stagnation and its impact on air quality during winter in Sichuan and Chongqing, southwestern China. Sci Total Environ,(635), 576-585(2018).
5. Bai, C.; Li, Y.; Liu, B.; Zhang, Z.; Wu, P. Gaseous Emissions from a Seagoing Ship under Different Operating Conditions in the Coastal Region of China. Atmosphere 2020, 11.
6. Fu, M.; Ding, Y.; Ge, Y.; Yu, L.; Yin, H.; Ye, W.; Liang, B. Real-world emissions of inland ships on the Grand Canal, China. Atmospheric Environment (81), 222-229(2013).
7. Peng, Z.; Wang, L.; Tong, L.; Zhang, C.; Zou, H. Establishment of Inland Ship Air Pollution Emission Inventory Based on Power Method Correction Model. Sustainability 2022, 14.
8. Beşikçi, E.B.; Kececi, T.; Arslan, O.; Turan, O. An application of fuzzy-AHP to ship operational energy efficiency measures. Ocean Engineering(121), 392-402(2016).