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*Research Article*

# Study to simulate the dispersion of air pollution and propose solutions to mitigate pollution from the Cat Lo Vung Tau fishing port, Ba Ria - Vung Tau province

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**Abstract:** The formation and development of seaports are closely related to the economic development of the region and localities with ports. However, in addition to the positive impacts on economic and social development, the operation of seaports also leads to negative effects on air quality in the area and public health. In addition to seaport activities, fishing ports also contribute significantly to the problem of air pollution in the port area. Therefore, it is necessary to study and estimate the air pollution emissions inventory from port activities, simulate the dispersion of air pollution from the Cat Lo Vung Tau fishing port to the surrounding areas and propose solutions to manage the air quality at the Cat Lo Vung Tau fishing port. The results of the emission inventory show that NOx emitted from fishing vessels and trucks is 2.463 tons/year, $SO_2$ is 1.520 tons/year; CO is 0.377 tons/year; $PM_{2.5}$ is 0.251 tons/year; $PM_{10}$ is 0.273 tons/year. Emissions from fishing vessel activities are mainly at the port. The results of air quality simulation using the TAPM-AERMOD model system show that the environmental quality of the port area is not polluted and has not negatively affected surrounding areas. The study also proposed some solutions to prevent and minimize pollution, while supporting the sustainable development of Cat Lo Vung Tau fishing port in the future.

**Keywords:** Air pollution; Cat Lo Vung Tau fishing port; TAMP-AERMOD.

## 1. Introduction

Currently, transportation activities in general and waterway transportation in particular contribute a large amount of emissions, causing environmental pollution, increasing the greenhouse effect and climate change in the world. Faced with this situation, international organizations and scientists have conducted many related research projects, some of which can be mentioned as follows:

Research on air pollution in port areas: The study [1] dentified the sources of air pollution in ports, assessed the level of impact on human health and proposed some measures to prevent pollution; The study [2] assessed the pollution impacts from the operation of vehicles in ports, based on the review of clean air strategies of six major ports in the world (in the US, Europe and Korea). The study [3] evaluated the effectiveness of proposed strategies to reduce air pollution in port areas. The study showed that the strategy of reducing ship speed was the most effective in reducing fuel consumption and costs, as well as emissions; The study [4] used the AERMOD model to simulate air pollution dispersion in Hawkesbury Port, Canada; The study [5] used the TAMP-City Chem model to simulate the air emission dispersion of vessels operating in the port of Hamburg in 2013. The study [6] estimated the emissions from the seaport and considered the emissions from the seaport as part of the emissions from the city to monitor and change the policies and technologies applied at the seaport to contribute to climate change mitigation. Similarly, there is the study [7] conducted in the Black Sea. The study [8] focused on estimating the emissions from fishing vessels in Iskenderun Bay, Turkey in 2016 and from there proposed solutions to minimize air pollution emissions at the port. Similarly, there is the study [9] conducted at Yangshan port, China in 2021 [10]. The study [11] showed that the combination of establishing ECA and RSZ had a great impact on reducing $SO_x$ emissions by 95.95% when there were no regulations on ECA and RSZ areas. The study [12] construct of an ecological fishing port model with current conditions and regulations of Indonesia, applied at the coastal fishing port of Pondokdadap. Similarly, there is the study [13] develop of a sustainable fishing port model in East Java province, Indonesia.

Some other studies such as: The study [14] assessed the current status of the seaport environment and proposed solutions to reduce environmental pollution in seaport activities in Khanh Hoa province. In addition, the study raised the urgency of sustainable seaport development. The study [15, 16] on the negative impacts caused by the construction and exploitation of seaports on the environment of the port area and neighboring sea areas, thereby finding positive solutions to minimize negative impacts on the environment. The study [17] showed that emissions from air pollutants from ships are mainly due to the process of anchoring at the port for a long time. The results of air quality simulation (using the FVM-TAPOM model system) showed that the concentrations of air pollutants are lower than the permit. Similarly, the study [18] conducted at 34 ports in Ho Chi Minh City, using the TAMP-AERMOD model system to simulate air pollution dispersion.

Methods for calculating emissions from port operations often use the emission factor method according to US-EPA [19] or EMEP/EEA [20]. In this study, the emission factor method of US-EPA will be chosen. Using the SPD model to calculate emissions from ships and vehicles using internal combustion engines operating at ports. Within the framework of the project “Sustainable development of seaports in the ASEAN region”, the German Technical Cooperation Organization (abbreviated as SPD) has developed a model for calculating emissions at seaports to forecast and control emissions at major seaports in major cities in the Southeast Asian region towards sustainable development of seaports. The model for calculating emissions from seaports (SPD) is based on calculations from US-EPA and the World Ports Climate Initiative (WPCI). This method is considered to be most suitable for current data conditions at ports and has better reliability than the rapid assessment method of the World Health Organization [21, 22].

Currently, there are a number of models that can be used to simulate air pollution in port areas such as TAPOM [17], AERMOD [4, 18], CMAx, ISCST3, AUSPLUME, CALPUFF [23] etc. However, among them, the AERMOD model is more commonly used in researches, so in this study, the AERMOD model is used in combination with the TAPM meteorological model. The TAPM model is a model of the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO). This model has two main functions: Used to simulate meteorological conditions and air pollution concentrations in 3D space. The model is affirmed by some researchers to have advantages over Gaussian models and the function of calculating air pollution simulation when there are chemical reactions gives more accurate results. This model is used in many places such as Melbourne, Australia [24], Cabauw Tower, Netherlands, etc [25]. The advantage of the TAPM model is that the model serves the forecasting and research of air pollution in 3D space; forecasts all meteorological parameters and can provide meteorological data for a number of other propagation models; The AERMOD model is specially designed to support the EPA's management program, including 3 components: AERMOD, AERMAP and AERMET. AERMET processes meteorological data on the surface and on different layers. AERMAP integrates models related to terrain, the effects of smoke trails when in contact with obstacles on the surface of the simulation area. From the above data, AERMOD will produce simulation results in the form of 2D and 3D spatial images and export them via Google Earth, helping users easily see the impacts of emissions on the survey area. The AERMOD model is a tool to support the simulation of the dispersion of air pollutant concentrations for the research area and is applied to many studies [26–29].

In general, there have been some studies related to emission inventory and simulation of air pollution dispersion at seaports. These studies have provided both general and detailed data on emission sources from major seaports in the world, as well as some seaports in Vietnam. Seaport and vessel activities contribute to the emission of air pollutants both globally and locally within the port area, leading to environmental pollution and negatively impacting socio-economic development and public health. Numerous studies have proposed solutions to reduce air pollution, aiming for the sustainable development of seaports in the future. However, there are few studies on emission inventories and air pollution simulations at typical fishing ports, such as Cat Lo Vung Tau fishing port. Therefore, this study was conducted to inventory emissions, simulate, and assess the level of air pollution dispersion and propose solutions to mitigate pollution at Cat Lo Vung Tau fishing port.

## 2. Materials and Methods

### *2.1. Study area*

#### 2.1.1. Overview of Cat Lo Vung Tau fishing port

Cat Lo Vung Tau Fishing Port belongs to the Branch of Bien Dong Seafood Exploitation Service Company Limited - Cat Lo Vung Tau Fishing Port. It is located at coordinates 10$^{o}$24’45” N, 107$^{o}$07’51” E, at 1007/34, 30/4 Street, Ward 11, Vung Tau City, Ba Ria - Vung Tau Province. The port is managed by the Ministry of Agriculture and Rural Development, has been operating since 1997. It is currently the largest fishing port among the 03 fishing ports operating in Vung Tau City. Cat Lo Vung Tau Fishing Port is a type 2 port with an area of 69,000 $m^2$, of which the water surface area is 6,000 $m^2$ and the land area is 63,000 $m^2$; There are 03 wharves with lengths of 50 m, 70 m, and 120 m, and a design capacity of 75,000 tons/year. The port can accommodate ships with a tonnage of up to 4,500 DWT. The number of employees is 70, and the port's operations have shifted from being originally designed as a general port to primarily serving fishing logistics services. In 2022, the port received 1,739 ship arrivals, mostly fishing vessels.


**Figure 1.** Location of Cat Lo Vung Tau fishing port area.

#### 2.1.2. Current status of air quality in the port area

There are 3 main sources of air pollution arising from the port, including: (i) Emissions from ships and other means of transport operating at the port, with main components including $SO_2$, CO, $NO_x$, TSP, ... (ii) The process of decomposing organic substances in surface water, accumulated mud in the port area, wastewater, domestic waste, waste and spilled seafood that are not collected at the port and odors from the centralized wastewater treatment system at the port, with main components including $CH_4$, $H_2S$, $CO_2$, ... and (iii) The characteristic odor of the port. The results of monitoring ambient air quality and air quality inside the port area in 2021 and 2022 [30] provided by the Branch of Bien Dong Seafood Exploitation Services Company Limited - Cat Lo Vung Tau Fishing Port show that the parameters of TSP, $SO_2$, $NO_2$ and CO are all within the permissible limits [31].

### *2.2. Research content*

To meet the objectives of the study, the following contents will be implemented:

- Collecting data on the number and types of fishing vessels, means of transport, cargo handling, and other machinery using internal combustion engines operating at Cat Lo Vung Tau fishing port; Results of air environment monitoring in Cat Lo Vung Tau fishing port area.
- Applying the SPD model to calculate emissions from fishing vessels, means of transport, cargo handling, and other machinery operating at Cat Lo Vung Tau fishing port.
- Applying the TAPM-AERMOD model system to simulate and assess the impact of emissions from fishing vessels, means of transport, cargo handing, and other machinery used in operations at Cat Lo Vung Tau fishing port on the ambient air quality.
- Proposing measures to mitigate air pollution from fishing vessels, means of transport, cargo handling, and other machinery operating at Cat Lo Vung Tau fishing port.

### *2.3. Methodology*

#### 2.3.1. Investigation and survey methods

Through a survey at the port, it was found that vehicles and machinery using internal combustion engines entering and leaving Cat Lo Vung Tau fishing port include fishing vessels, heavy trucks, light trucks, cars, motorbikes of all kinds and backup generators. However, during the investigation and data collection process, cars and motorbikes are not allowed to operate within the port premises. In addition, the port uses one backup generator with a capacity of 700 KVA, fueled by DO, but the generator was not used in 2022. Therefore, emissions from port activities are mainly from fishingvessels, followed by heavy trucks and light trucks. Relevant information for calculating emissions is collected through a survey form, presented in detail in section 2.4.

#### 2.3.2. Emission calculation methods

Use the SPD model to calculate emissions from vessels and vehicles with internal combustion engines operating at the port. The input data for the SPD model includes information collected from the port, such as: (i) data on vessels (e.g., vessel type, departure date, arrival date, load capacity, main engine capacity, auxiliary engine capacity, time spent anchored, etc.); (ii) data on trucks (e.g., number of vehicles entering and leaving the port, vehicle type, time spent operating the engine in the port, year of manufacture, tonnage, fuel used, etc.); and (iii) data on other vehicles and machinery (e.g., operating capacity, vehicle type, engine number, load capacity, year of manufacture, number of operating hours in the port, etc.) The general formula for calculating emissions from fishing vessels is as follows:

$$E = P \times LF \times A \times EF \quad (1)$$

where E is the emission load (g); P is the maximum capacity (kW); LF is the load factor (%); A is the operating time (hours); EF is the emission factor (g/kWh) which is the amount of emissions a vehicle emits per kilometer traveled. The emission factor depends on the vehicle’s year of manufacture, speed, and fuel type used.

$$\text{Load fator } LF = (AS/MS)^3 \quad (2)$$

where LF(%) is the load factor; AS is the normal speed (knots); MS is the maximum speed (knots). Emissions from road vehicles can be calculated using the following formula:

$$E = e \times A \quad (3)$$

where E is the emission amount (g); e is the emission factor (g/km); A is the total distance traveled by the vehicle, calculated using the formula: $A = M \times N = F \times L$ (4)

where N is the number of vehicles (vehicles); M is the distance traveled by the vehicle (km), F is the traffic volume (vehicles); L is the length of road that the vehicle can travel on (km).

In this study, the emission factors of the air pollutants are referenced from EMEP/EEA Air pollutant Emission Inventory Guidebook [20]. The output of the SPD emission calculation model is the input emission source data of the AERMOD model.

2.3.3. Modeling method

a) TAPM (The Air Pollution Model):

The TAPM model was developed by CRISO of Australia and is used to predict meteorological conditions and air pollution concentrations in 3D space. The advantage of the TAPM model is that it runs on the Windows platform, is easy to use, and does not take much time when running simulations.

Steps to set up and run the TAPM model: Install the meteorological model, TAPM_V4.0_ setup. Meteorological data for the TAPM model is downloaded from the website ftp://ftp.csiro.au/ TAPM/SYNOPTIC_DATA/ → Declare input data for the model → Run the model and export the results. To obtain meteorological data for the Cat Lo Vung Tau fishing port area, the study conducted a simulation for the Ba Ria-Vung Tau province area. The boundary conditions were selected appropriately for the study area as shown in the figures and described as follows: Determine the central coordinates of the Cat Lo Vung Tau fishing port area (Latitude 10.413470 and Longitude 107.132034); The simulation period was from January 01, 2022 to December 31, 2022. The TAPM model simulates detailed meteorology using nested grid cells. The number of simulation domains selected in this study is three, with sizes that ensures detailed simulation for the Ba Ria-Vung Tau province area, including the outermost domain (Domain 1) shown in the interface with 25 x 25 grid cells, each grid cell size is 30km x 30km; The second domain (Domain 2) shown in the interface with 25 x 25 grid cells, each grid cell size is 10km x 10km; The final domain (Domain 3) is represented in the interface with 25 x 25 grid cells, each grid cell size is 3km x 3km; The number of grid cells according to altitude in this study ranges from 10 m to 8,000 m and is divided into 25 vertical grid cells (nz = 25).

b) AERMOD (The AMS/EPA Regulatory Model):

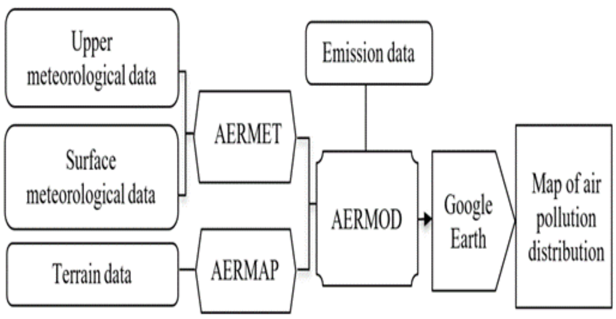


**Figure 2.** Diagram of steps to implement the AERMOD modeling.

The AERMOD model was developed by the US Meteorological Agency and the Environmental Protection Agency and is currently widely used worldwide; It consists of three components: AERMOD (Dispersion Model - AERMIC), AERMAP (Terrain Tool) and AERMET (Meteorological Tool). The model is used to simulate air quality affected by emission sources, with many options and common applications.

Some key steps to consider when declaring AERMOD input data include: selecting the calculation domain; inputting terrain conditions and land use into the model; providing meteorological data (from the TAMP model); selecting the simulation time; declaring the emission source; choosing the terrain type of the simulation area; declaring the center coordinates; specifying the number of grid cells (100), each with a grid size of 500x500m; selecting the pollutants to simulate; choosing the terrain for the study area to run the Terrain Processor module; and finally, running the simulation and exporting the results.

c) Model calibration and validation:

The study uses monitoring results from the research area and data collected from the automatic air monitoring station at the Gieng Nuoc intersection (in Ward 7, Vung Tau City), managed by the Department of Natural Resources and Environment of Ba Ria - Vung Tau Province, to support the model verification process. This process is evaluated using indicators such as the correlation coefficient ($R^2$) and the percentage simulation error (S). A value of $-15\% \leq S \leq 15\%$ indicates that the simulation results are close to the actual conditions.

2.3.4. Developing a database for emission calculation

a) Emissions from fishing vessels

The data that needs to be collected and used from fishing vessels in the calculation process at the port include the date of arrival, date of departure, engine capacity, and other relevant details. Data collected during the survey and interview process includes information such as the time and distance at which the vessel reduces speed before entering the port (Reduced Speed Zone - RSZ), the time and speed of the vessel approaching the anchor (Maneuver), and the engine operating time while anchored at the port (Hotel). Additionally, the study also gathers other necessary information, such as the vessel owner, registration number, vessel type, and engine capacity...

Distribution of survey forms: Through the total number of ships collected from the port operation log, it shows that Cat Lo Vung Tau port receives vessels with a capacity of 250 CV or more up to 1,250 CV; The vessels are divided into 05 groups according to engine capacity: Group 1 includes vessels from 250 to 450 CV, group 2 includes vessels from 450 CV to 650 VC, group 3 includes vessels from 650 VC to 850, group 4 includes vessels from 850 CV to 1050 CV, group 5 includes vessels from 1,050 CV or more. Calculating the percentage of vessels in each group shows that the proportion of vessels in the above 05 groups is similar. From there, the study divided the survey forms equally among each group, with each group conducting a survey and interviewing 20 vessel owners. After organizing the survey and collecting data, Excel software and interpolation method were used to calculate the average of the parameters that need to be collected to put into the SPD model.

b) Emissions from transport vehicles in the port

For the transport vehicles, the collected data includes: Vehicle type, number of vehicles (using camera data at the port entrance to count the number of vehicles entering and exiting in a day and night); Length of the road the vehicle travels in the port (in km), time the vehicle travels in the port (in hours), vehicle speed (in km/h) obtained through direct surveys at the port.

## 3. Results and discussion

### *3.1. Current state of air quality in the port area*

The study measured the current status of air quality in the port area on April 17, 2023, to provide a basis for evaluating, calibrating, and verifying the model used in the study. The sampling location was the internal road of Cat Lo Vung Tau fishing port (Coordinates: X: 1151667; Y: 432141). The results of air quality measurements show that the parameters $PM_{10}$, $NO_2$, $SO_2$, and CO are all within the allowable limits of QCVN 05:2023/BTNMT (Table 1).

**Table 1.** Results of air quality monitoring at Cat Lo Vung Tau fishing port (µg/m$^3$).

| No. | Parameter | 7:30 | 9:00 | 10:30 | 12:00 | 13:30 | 15:00 | 16:30 | 18:00 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | $SO_2$ | 22.4 | 31.1 | 29.6 | 30.2 | 33.7 | 33.2 | 29.8 | 21.5 |
| 2 | CO | ND | 7,209 | 6,211 | 6,236 | 7,280 | 7,265 | 6,161 | ND |
| 3 | $NO_2$ | 24.4 | 37.5 | 37.2 | 37.3 | 39.6 | 39.3 | 33.5 | 23.7 |
| 4 | $PM_{10}$ | 29.4 | 37.2 | 32.0 | 33.4 | 44.1 | 40 | 31.8 | 30.6 |

Note: ND: Not detected.

## *3.2. Results of the port emission inventory*

Through a survey at the port, the study selected and inventoried emission sources from fishing vessels and some types of transport vehicles (heavy and light trucks). The specific results are as follows:

### 3.2.1. For fishing vessels

a) Collected information for calculation:

**Table 2.** Results of the collection and calculation of average parameters, including time, speed at each stage of the vessel's operation, and fuel consumption.

| Fuel | Operate | | | | |
|---|---|---|---|---|---|
| **Main engine** | **Stage** | **Duration of each mode** (h) | **Actual speed for each mode** (knots) | **Normal speed** (knots) | **Maximum speed** (knots) |
| SSD RO 2.7%S | RSZ | 0.39 | 1,2 | 5 | 8 |
| SSD RO 2.7%S | Maneuver | 0.16 | 0,4 | 5 | 8 |
| SSD RO 2.7%S | Hotel | 0.50 | 0 | 5 | 8 |

The total number of vessels that arrived at the port in 2022 is 1,739. The results of collecting and calculating the average of some necessary information for calculating emissions from 100 questionnaires and surveys for vessel owners are as follows: The distance from the point where the vessel begins to slow down in preparation for entering the port is approximately 500 meters, with the average speed after the vessel slows down being 1.2 nautical miles per hour. The results of collecting and calculating the average parameters of time, speed during each stage of the vessel's operation and the fuel used by the vessel; the average engine operating time of the vessels before, during and after preparing to leave the port are summarized in Table 2. In this study, all surveyed vessels used RO oil with a sulfur content of 2.7% as fuel for engine operation.

b) Results

Total emissions of some major air pollutants in the exhaust gas from vessel engines operating at Cat Lo Vung Tau fishing port for the entire year of 2022 (Table 3) are as follows: The total emissions of NOx are the highest among the air pollutants inventoried, with 2.192 tons/year, followed by $SO_2$ with 1,503 tons/year, CO with 0.264 tons/year, $PM_{10}$ with 0.261 tons/year, and $PM_{2.5}$ with 0.240 tons/year.

**Table 3.** Emissions inventory of air pollutants from fishing vessel operating at Cat Lo Vung Tau fishing port, in 2022 (tons/year).

| Category | $NO_2$ | $PM_{10}$ | $PM_{2.5}$ | CO | $SO_2$ |
|---|---|---|---|---|---|
| Fishing vessel | 2.192 | 0.261 | 0.240 | 0.264 | 1.503 |
| Reduced speed zone - RSZ | 1.164 | 0.133 | 0.122 | 0.153 | 0.641 |
| Maneuver | 0.648 | 0.076 | 0.069 | 0.077 | 0.438 |
| Hotel | 0.379 | 0.051 | 0.047 | 0.033 | 0.423 |

The largest contributor to total emissions is the period when the vessel begins to slow down to move into port. Although during this period, the time the vessel operates the engine is not as long as the time when the vessel is preparing to leave port, but because at this time the vessel is usually fully loaded with goods - the largest load and the vessel's driver has to adjust the vessel's position to dock in the right position, the engine capacity must operate at a high level, consuming a lot of fuel, leading to greater emissions than the remaining stages. The second stage with the highest emissions is the period when the vessel approaches the anchorage. The reason is that, although at this time the vessel has unloaded all the goods, the engine force must be used to push the vessel back to the anchorage area, so it consumes more fuel than the time the vessel is anchored at the port (hotel) - generating more emissions; on the other hand, because the time the engine is operated during this period is not as long as when the vessel enters the port, the amount of emissions is not as much as when the vessel enters the port. The lowest emission in the three calculation periods is when the ship is anchored at the port, because at this time the ship operates the engine but is almost not running, so the emission is the lowest.

3.2.2. For transport vehicles

As presented above, the study only focused on inventorying emission sources from heavy trucks and light trucks, excluding emissions from smaller vehicles due to their insignificant number. According to the survey conducted by the port management unit, the number of vehicles entering and leaving the port in 2022 and 2023 is similar. Therefore, the statistical results from 2023 can be used to calculate and simulate emissions for 2022.

**Table 4.** Summary results of some parameters of heavy and light trucks at the port.

| **Vehicle type** | **Number of vehicles** | **Running distance in port** (km) | **Average speed** (km/h) | **Average time in port** (h) | **Duration of non-operational time in port** (h) |
|---|---|---|---|---|---|
| Light truck | 12,775 | 1.20 | 15.0 | 1.25 | 0.23 |
| Heavy truck | 6,935 | 1.25 | 12.5 | 1.50 | 0.23 |

The total vehicle count for the year is as follows: 6,935 heavy trucks and 12,775 light trucks. Regarding the management of the road network in the port, the parameters of average speed, operating time, and rest time for both heavy and light trucks at the port were obtained from the survey forms. The total emissions (Table 5) of pollutants from road traffic sources (light and heavy trucks) for the entire year of 2022 are low, with NOx being the highest at 0.271 tons/year.

3.2.3. Total emission sources

Based on the emission calculation results (Table 5), it shows that the largest emissions come from fishing vessels, while emissions from transport vehicles are much lower. Among the air pollutants inventoried, $NO_x$ emissions are the highest with 2.463 tons/year, followed by $SO_2$ at 1.520 tons/year, CO at 0.377 tons/year, $PM_{10}$ at 0.273 tons/year, $PM_{2.5}$ at 0.251 tons/year. The reason for these results is that the number of fishing vessels, their engine capacities and their operating time are larger than those of transport vehicles. Additionally, fishing vessels use diesel fuel with a higher sulfur content than the fuel used by road transport vehicles.

## *3.3. Air quality simulation*

3.3.1. Meteorological simulation with the TAPM model

Calibration and validation of the TAPM model: The TAPM model was developed by CSIRO, Australia, with coefficients suitable for the meteorological conditions in Australia. Therefore, when simulating data for the study area in each locality, these coefficients need to be adjusted accordingly. Coefficients related to ocean surface temperature, soil moisture, kinetic energy, etc., are developed by the author through multiple scenarios (each scenario uses a different set of coefficients) to achieve the most optimal results in various areas. In this study, temperature and wind speed data collected from the Gieng Nuoc automatic air monitoring station (located in Ward 7, Vung Tau city) are used to validate the model. A Comparion of the observed and simulated results shows that the temperature between the two data results is within the allowable error limit with a correlation coefficient $R^2$ of 0.80, which is acceptable.

Meteorological simulation results: The results of meteorological simulation show that: The rainy season starts from May to October, influenced by the Southwest monsoon; the average wind speed is about 2 - 3.5 m/s, the maximum speed is about 11 - 13.5 m/s; The dry season starts from November to April of the following year, influenced by the Northeast monsoon, with an average speed of about 2 - 3.5 m/s, the maximum speed is about 10 - 12 m/s. The air temperature in the study area is at average and fluctuates little over the months of the year.

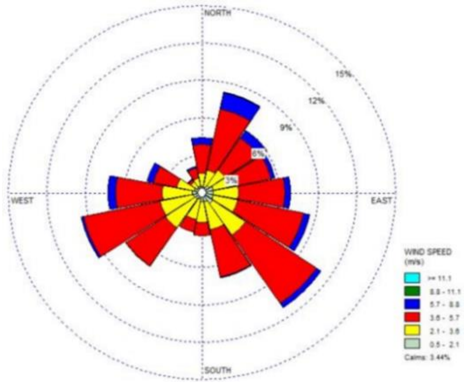


**Figure 4.** Wind rose in the study area.

3.3.2. Air quality simulation with the AERMOD model

Input parameters for the AERMOD model include: Meteorological data (TAPM model output meteorological data); Simulation scope at the port (According to GIZ, when calculating port emissions, it is necessary to calculate emissions for activities generating emissions from the land area and water surface area of the port area within 500 m before the port and 500 m after the port [17]); Topographic data (Topographic data of the study area is processed directly from the AERMOD model. The grid resolution and study area are 50 km × 50 km. With the number of grid cells being 100 grid cells × 100 grid cells, the size of a grid cell is 500m × 500m. In general, the terrain of the study area and neighboring areas is relatively flat, the elevation of the study area is about 0 to 5m above sea level; Emission source data (this is the result of the SPD emission calculation model, including: Coordinates, port length (m), port width (m), port area ($m^2$), load emissions per unit area ($g/s.m^2$),…) (Table 5).

**Table 5.** Emission data of air pollutants from sources.

| Category | $NO_2$ | $PM_{10}$ | $PM_{2.5}$ | CO | $SO_2$ |
|---|---|---|---|---|---|
| Fishing vessels (tons/year) | 2.1919 | 0.2614 | 0.2403 | 0.2637 | 1.5033 |
| Vehicles (tons/year) | 0.2709 | 0.0112 | 0.0110 | 0.1135 | 0.0168 |
| Total (tons/year) | 2.4628 | 0.2727 | 0.2514 | 0.3773 | 1.5202 |
| Total emissions (g/s) | 0.0780 | 0.0086 | 0.0079 | 0.0119 | 0.0482 |
| Total emissions ($g/s/m^2$) | $1.132 \times 10^{-6}$ | $0.125 \times 10^{-6}$ | $0.116 \times 10^{-6}$ | $0.173 \times 10^{-6}$ | $0.699 \times 10^{-6}$ |

Model calibration and validation: The validation results of the AERMOD model show that the error values between simulation and observation for air pollutants (with the S index) range from 3.668% to 10.6%, with an average of 3.6% within the range of $-15\% < S < 15\%$. Therefore, the AERMOD model can be applied to simulate the dispersion of air pollution from the port area with high reliability.

Simulation results of air pollution dispersion: The highest 1-hour average concentration of $PM_{2.5}$ in the port area was 22.9 µg/$m^3$. The highest 24-hour average concentration was 15.3 µg/$m^3$, lower than the limit of QCVN 05:2023/BTNMT (50 µg/$m^3$); The highest 1-hour average concentration of $PM_{10}$ in the port area was 33.6 µg/$m^3$. The highest 24-hour average concentration was 24.0 µg/$m^3$, lower than the limit of QCVN 05:2023/BTNMT (100 µg/$m^3$); The highest 1-hour average concentration of $NO_2$ right at the port area was 128.9 µg/$m^3$, lower than the limit of QCVN 05:2023/BTNMT (200 µg/$m^3$). The highest 24-hour average concentration value was 39.5 µg/$m^3$, lower than the permit limit (100 µg/$m^3$); The highest 1-

hour average concentration of $SO_2$ at the port area was 67.8 µg/m$^3$, lower than the limit of QCVN 05:2023/BTNMT (350 µg/m$^3$). The highest 24-hour average concentration value was 37.0 µg/m$^3$, lower than the permit limit (125 µg/m$^3$).

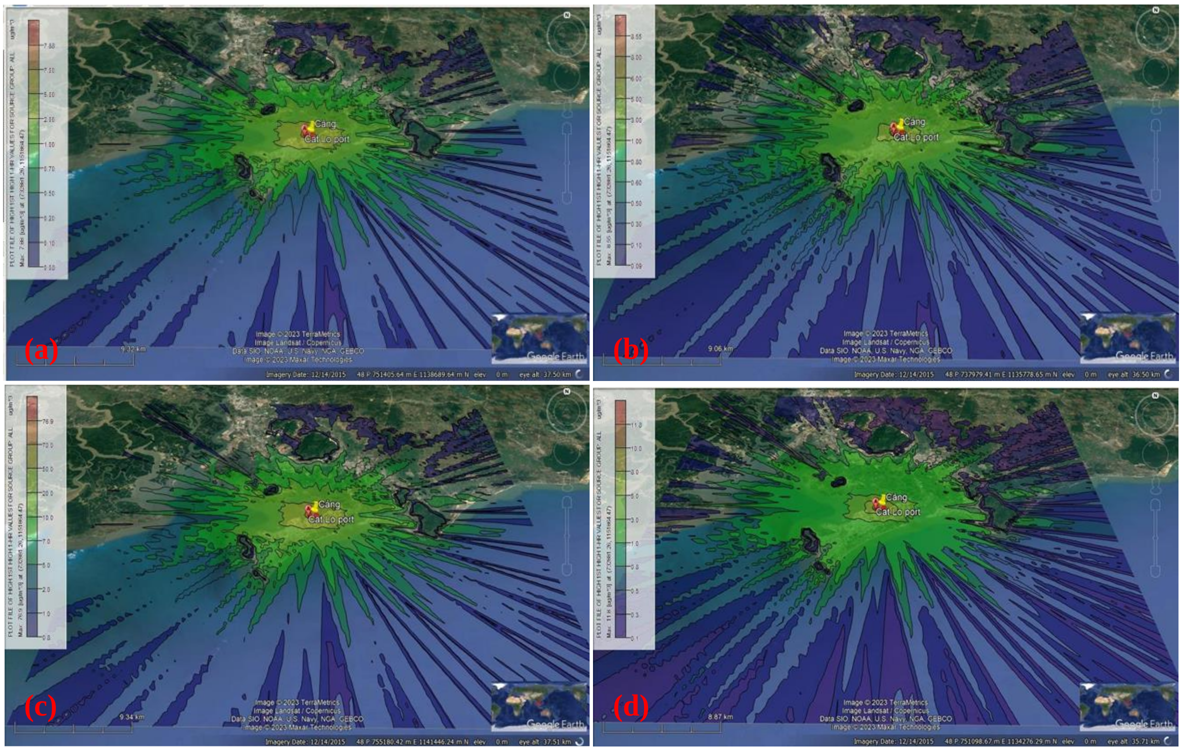


**Figure 6.** Map of the highest 1-hour average $PM_{2.5}$ (a), $PM_{10}$ (b), $NO_2$ (c), $SO_2$ (d) concentration during the year for the port.

The highest 1-hour average concentration of CO in the port area was 6,047 µg/m$^3$, lower than the limit of QCVN 05:2023/BTNMT (30,000 µg/m$^3$). The highest 8-hour average concentration value was 569 µg/m$^3$, lower than the permit limit (10,000 µg/m$^3$). All simulated air pollutants in the study area have concentrations lower than permissible limits, with some parameters at very low levels compared to the QCVN 05:2023/ BTNMT.

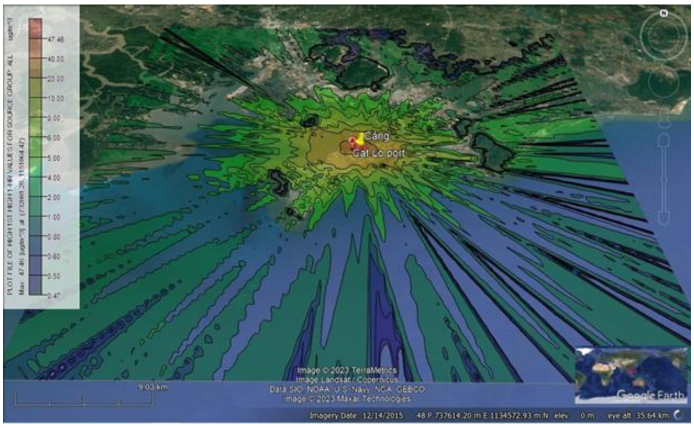

**Figure 7.** Map of the highest 1-hour average CO concentration during the year for the port.

**Table 6.** Results of air quality modelled at Cat Lo Vung Tau fishing port (µg/m$^3$).

| | | Simulated | | | QCVN 05:2023/ BTNMT | | |
|---|---|---|---|---|---|---|---|
| **No.** | **Parameter** | **1-hour average** | **8-hour average** | **24-hour average** | **1-hour average** | **8-hour average** | **24-hour average** |
| 1 | $SO_2$ | 67.8 | - | 37.0 | 350 | - | 125 |
| 2 | CO | 6,047 | 569 | - | 30,000 | 10,000 | - |
| 3 | $NO_2$ | 128.9 | - | 39.5 | 200 | - | 100 |
| 4 | $PM_{10}$ | 33.6 | - | 24.0 | - | - | 100 |
| 5 | $PM_{2.5}$ | 22.9 | - | 15.3 | - | - | 50 |

### *3.4. Propose solutions for pollution mitigation*

The research results show that the emission sources from machinery and vehicles operating at the port (fishing vessels and trucks) have not caused air pollution in the port area and surrounding regions. However, it is necessary to propose measures to reduce pollution at the port, aiming to minimize emissions from the sources identified in this study, as well as from other unaccounted-for emission sources, in order to support the port's sustainable development in the future.

#### 3.3.1. Management solutions

a) For state management agencies: Pay more attention to propaganda and mobilization efforts to raise ship owners' awareness of the importance of environmental protection in their daily activities, This will encourage ship owners to invest in renewing their fishing fleets, operate ship engines more responsibly, reduce waste emissions and take actions to protect the marine ecosystem during seafood exploitation activities, contributing to reducing emissions and protecting the environment; Effectively implement the planning for fishing ports in the area. For ports that do not meet relevant legal regulations, it is necessary to boldly relocate and close them, in order to force fishing vessels to comply with legal regulations (including Cat Lo Vung Tau fishing port), allowing the port to be fully exploited, thereby increasing revenue, which in turn provides port owners with the financial resources to reinvest in infrastructure, ultimately reducing pollution; Strengthen environmental inspections and examinations of fishing ports to raise awareness among management units and workers operating at the port in environmental protection and pollution reduction.

b) For port management units: Review the port infrastructure and rearrange the functional areas in a more scientific manner, from piers to land-based infrastructure, ensuring that when ships arrive at the port, they will not need to move to other locations until they depart, in order to limit emissions; Upgrade internal roads within the port to facilitate the operation of transport vehicles, thereby reducing emissions from cargo vehicles operating within the port; Pay more attention to environmental protection at the port, including promoting propaganda and mobilization, having environmental protection regulations, punishing acts of environmental pollution to raise awareness and require individuals and organizations operating at the port to be responsible for protecting the environment, contributing to reducing emissions; Regularly inspect, maintain, and promptly repair any damage to machinery and equipment used in port operations; Strengthen sanitation efforts at the port, ensuring that waste generated is collected, managed, treated, and transferred for disposal in accordance with regulations and procedures to prevent backlogs and the generation of polluting gases. Conduct periodic monitoring of air quality in the port area, gradually moving towards automatic continuous monitoring.

#### 3.3.2. Technical solutions

Encourage fishermen to replace existing fishing vessels. New vessels must be designed to ensure that the water capacity of the fishing boat hull is reduced compared to the current one, the materials used to make the hull are lighter, etc. to save fuel when operating the vessels with the same capacity and load; at the same time, change the vessel engine to be able to use more environmentally friendly fuels; invest in additional exhaust treatment systems from the engines, etc.; Encourage fishermen to use more environmentally friendly fuels.

#### 3.3.3. Economic solutions

Use tax instruments and environmental protection fees for fuels containing high levels of pollutants. Reduce costs to the lowest possible level for environmentally friendly fuel products. Additionally, it is necessary to impose special consumption taxes on machinery and vehicles that use environmentally harmful fuels. For vehicles that use environmentally friendly fuels or implement emission reduction measures, regulatory agencies should consider lowering relevant fees when carrying out financial procedures, in order to encourage fishermen and business owners to modernize their vehicles, use more environmentally friendly fuels, and pay more attention to environmental protection. In the long term, clear policies and effective application of carbon credit trading should be established to ensure fairness between those who contribute to emission reductions and those who do not, with the ultimate goal of encouraging and obligating all parties to share the same responsibilities and awareness regarding environmental protection.

3.3.4. Education solutions

Change the forms of communication to ensure that the content reaches all relevant groups, from the leaders of state management agencies to the leaders of port management and operations, ship owners, pilots, and other key stakeholders. The goal is to raise awareness among these groups and translate that awareness into concrete actions, ultimately contributing to the reduction of emissions and the protection of the environment. In addition, organize training courses and specialized programs on environmental protection for key stakeholders who play a significant role in emission reduction. At the same time, promote a sense of responsibility among all involved parties.

## 4. Conclusion

The research results show that some major air pollutants from the activities of fishing vessels and transportation vehicles operating at Cat Lo Vung Tau fishing port, including $NO_2$, $SO_2$, CO, $PM_{2.5}$, and $PM_{10}$, were modeled, and all of them are within the permissible limits of the QCVN 05:2023/BTNMT. The total $NO_2$ emitted from fishing vessels and heavy and light trucks is 2,463 tons/year; $SO_2$ is 1,520 tons/year; CO is 0.377 tons/year; $PM_{2.5}$ is 0.251 tons/year; and $PM_{10}$ is 0.273 tons/year. Emissions from fishing vessels and vehicles operating at Cat Lo Vung Tau fishing port do not cause environmental pollution or negatively impact the surrounding areas. The study also proposed four groups of solutions (management, education, technology, and economic) to prevent and reduce pollution, while supporting the sustainable development of Cat Lo Vung Tau fishing port in the future.

However, due to the limited scope of this study, there are other emission sources not yet inventoried in this study, such as the decomposition of organic substances in wastewater, waste, and seafood spilled at the port; accumulated mud around the port; characteristic odors of fishing ports; emissions from internal combustion engines of motorbikes and three-wheeled vehicles, etc. Additionally, it is necessary to expand the study to assess the air pollution levels from other fishing ports in the Vung Tau city area to provide a comprehensive evaluation of the impact of fishing ports on the surrounding areas. The results of this study will be valuable for the management and planning efforts of state authorities.

**Author contribution statement:** Conceived and designed the experiments, analysis tools or data; modeled; wrote the draft manuscript and editing manuscript: H.M.D.

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