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Original Research Article

Short-Term $PM_{2.5}$ and PM_{10} Patterns and Public Perceptions at Tanjung Priok Port

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Abstract

This exploratory study examined short-term particulate matter ($PM_{2.5}$ and PM_{10}) levels and community perceptions of air pollution at Tanjung Priok Port. $PM_{2.5}$ and PM_{10} were measured at one fixed point in the port gate and truck terminal zone, between the quay and residential areas, during three daily sessions of about two hours (07:00–09:00, 12:00–14:00, and 15:00–17:00 WIB) over 18 days (March 31–April 24, 2026; n = 54); these are not 24-hour measurements. Perceptions were collected from 40 purposively selected residents using a 14-item Likert questionnaire on environmental and port operational factors. Data were summarized with descriptive statistics and Pearson's correlation, and classified with the hourly particulate categories of BMKG Regulation No. 8 of 2022 as an indicative reference only. Mean $PM_{2.5}$ (22.80 µg/m³) fell in the "Moderate" category (15.6–55.4 µg/m³), whereas mean PM_{10} (29.37 µg/m³) fell in the "Good" category (0–50 µg/m³). Concentrations were highest in the morning session. $PM_{2.5}$ and PM_{10} were strongly correlated (r = 0.9909), consistent with a possible combustion influence but not identifying sources. Residents' perceptions of environmental impacts were moderate (35–68% agreement per item), while 85–98% wanted greater transparency, supervision, pollution control, and dialogue. Continuous multi-point monitoring is needed to confirm these findings.

Keywords: Emission; likert; maritime; perception; PM_{10}; $PM_{2.5}$

1. Introduction

As the world's largest archipelago with more than 17,000 islands and a coastline of approximately 108,000 km, Indonesia holds a strategic position in international trade routes, particularly in the Indo-Pacific region. However, to date, Indonesia's maritime infrastructure remains uneven in terms of quality, geographic distribution, and logistics integration (Syarifuddin and Nurcahyani, 2021), particularly in major hubs such as the Port of Tanjung Priok. As Indonesia's largest and busiest port, Tanjung Priok plays a strategic role in national and international logistics distribution. More than 80% of global merchandise trade volume is handled by container ports, with nearly two-thirds of them located in developing countries (United Nations Conference on Trade and Development [UNCTAD], 2018). The Port of Tanjung

Priok, located in North Jakarta, handles more than 7 million twenty-foot equivalent units (TEU) per year (Astuti et al., 2023) and serves as a major hub for national maritime trade. Ports not only play a vital role in the technical sector but also play a central role in a country's economic growth, as port areas are crucial to human well-being, including the provision of direct and indirect jobs (Roh et al., 2016).

In 2018, approximately 98,140 ships transported 11 billion metric tons of goods via maritime trade, representing about 80% of global trade volume and 60–70% of global trade value (UNCTAD, 2019). However, if the growth of trade through these maritime regions is not accompanied by improvements in sustainability, including cargo handling, vessel traffic, and heavy-duty vehicle operations, this could result in significant environmental impacts, particularly on air quality. In general, ports generate environmental impacts through their various functions related to cargo handling, connectivity to maritime and land transportation networks, industrial and semi-industrial activities, logistics and distribution activities, as well as energy production and distribution (Notteboom and Pallis, 2020). Therefore, port management must act responsibly to provide efficient services while minimizing negative impacts on the global environment (Luo and Yip, 2017). With the establishment of standards for port transformation that focus not only on the economic sector but also on the environmental sector, the Green Port concept aims to achieve a balance between environmental impacts and economic benefits through a "green economy" growth strategy, long-term stakeholder participation, and development that anticipates the needs of future generations (Maritz et al., 2014; Ahmadi et al., 2016).

The transportation sector is a widely recognized source of negative environmental impacts. Globally, the shipping sector accounts for approximately 15% of NOx emissions and 5–8% of SOx emissions (Zis et al., 2016), which have serious adverse effects on human health and the environment. Long-term exposure to air pollution can reduce quality of life, shorten life expectancy, and increase the burden of disease (Laksono and Afiyani, 2023). Ports are recognized as a major source of air pollutant emissions, including fine particulate matter ($PM_{2.5}$ and PM_{10}), SO_2, NO_2, and greenhouse gases; $PM_{2.5}$ emissions, in particular, pose a significant threat to public health (Pane and Usiono, 2024). The maritime transportation sector emits CO, SOx, NOx, fine particulate matter, and greenhouse gases (Lv et al., 2018), and empirical studies show that ship emissions significantly increase $PM_{2.5}$ concentrations in and around port areas (Xu et al., 2018). Therefore, a comprehensive emissions inventory is a crucial step toward controlling air pollution in ports (Kim et al., 2022), a point further reinforced by previous research demonstrating a link between $PM_{2.5}$ exposure and public health impacts, including elevated blood pressure and chronic health conditions in urban areas (Madrigano et al., 2024).

The International Maritime Organization (IMO) has emphasized the need to control emissions from the shipping sector to minimize environmental and health impacts (IMO, 2014), although implementation in developing countries still faces challenges related to technology and enforcement. Active public participation in decision-making helps ensure that environmental concerns are optimally considered, thereby creating a balance between the economic, social, and environmental aspects of port operations (Karagkouni and Boile, 2024). MARPOL regulations are increasingly tightening rules to prevent pollution from oil-based chemicals and hazardous substances, ballast water, and ship or port emissions (Roh et al., 2016), and the IMO is committed to reducing shipping sector emissions by 50% by 2050 (Rickard and Jason, 2019). Therefore, sustainable port environmental management is a key indicator of maritime port performance (ESPO, 2019), and both academics and practitioners play a role in realizing green ports and green networks (Zhen et al., 2019).

Port authorities are increasingly recognizing that ports are a significant source of carbon emissions, making the transition from fossil fuels to renewable energy critically important (Oniszczuk-Jastrząbek et al., 2018). Long-term exposure to $PM_{2.5}$ has been associated with an increased risk of cardiovascular disease, respiratory disorders, noncommunicable diseases, and premature mortality (Burnett et al., 2018; Chen and Hoek, 2020). Although there is a wealth of literature on port-related air pollution, few studies appear to have combined short-term ambient PM monitoring with community perception data in the context of major container ports in Southeast Asia, particularly Tanjung Priok in

Indonesia. The novelty of this study therefore lies in combining time-stratified $PM_{2.5}$ and PM_{10} measurements with community perception data at a major Southeast Asian container port. Theoretically, the study contributes preliminary empirical evidence on intraday particulate patterns in a port-city setting and on how community concerns relate to the air quality context of a port. Practically, it provides a baseline that can guide the design of continuous 24-hour, zone-specific monitoring and community-inclusive green port management at Tanjung Priok and comparable ports.

The objective of this study was to describe short-term particulate matter levels and to examine community perceptions of air pollution in the Tanjung Priok Port area by assessing: (i) $PM_{2.5}$ and PM_{10} concentrations measured during three limited daily sessions over an 18-day campaign; (ii) how these session-level concentrations are classified, for indicative purposes only, by the hourly air quality categories of BMKG Regulation No. 8 of 2022 (BMKG, 2022); and (iii) community perceptions and self-reported concerns about air pollution among residents living near the port.

2. Materials and Methods

This study employed a mixed-methods research design, which collects, analyzes, and integrates quantitative and qualitative data within a single research framework (McGregor and Farrugia, 2019). The quantitative component analyzed concentrations of fine particulate matter ($PM_{2.5}$ and PM_{10}), selected because these fractions are the pollutants most consistently linked to combustion-related port and vehicle emissions and to adverse respiratory and cardiovascular health outcomes (Chen and Hoek, 2020; Madrigano et al., 2024). The community component explored residents' perceptions of air pollution and port operations with a Likert-scale questionnaire.

2.1 Study Area and Monitoring Point

The study was conducted in the Tanjung Priok Port area, North Jakarta, DKI Jakarta, an area of heavy operational activity and vehicle traffic that is surrounded by densely populated residential neighborhoods. The location was selected because it combines various emission sources, such as ships at berth, loading and unloading operations, and the movement of heavy vehicles and freight trucks, with nearby residential areas, which makes it relevant for assessing air quality and the potential for pollutant exposure. The study area was divided into three zones based on the proximity of locations to emission sources, the types of activities taking place, and the presence of communities and facilities around the port (Figure 1).

Zone 1 is the Quayside Operational Zone (orange). It is located within the operational area of the docks and container terminals, which serve as the primary locations for ship activities, loading and unloading, and the use of port operational equipment. Ships at berth can be a source of emissions through the operation of auxiliary engines and other activities while docked (Xu et al., 2018; Lv et al., 2018). In addition, cargo handling and the use of cargo-handling equipment have the potential to generate particulate matter and gaseous pollutants. Zone 2 is the Port Gate and Truck Terminal Zone (yellow). It is characterized by high vehicle activity, particularly trucks, trailers, and freight vehicles entering and exiting the port area, and high-frequency vehicle movement has the potential to contribute to particulate emissions (Xu et al., 2018). Zone 3 is the Residential/Receptor Zone (blue). It is located adjacent to the port area, encompasses residential areas and public facilities, and is considered a receptor area because residents and activities within it are potentially exposed to pollutants originating from port operations and surrounding transportation. The presence of healthcare facilities around this zone is also a consideration in characterizing the sensitivity of the area to air quality.

Air quality measurements were made at a single fixed point in Zone 2. Zone 2 was chosen because it lies at the interface between Zone 1, where ships berth and cargo is loaded and unloaded, and Zone 3, where residents live, and because it is the access route of the heavy vehicles entering and leaving the port. Measurements at this point are therefore intended to represent the combined influence of port activities at the boundary between the emission sources and the residential receptors; they do not describe

conditions in each zone. Zone 2 was taken as the nearest point between the quayside loading and unloading zone and the residents' houses. According to Minister of Industry Regulation No. 35 of 2010, the minimum distance between an industrial activity site and settlements is 2,000 m (2 km), which is intended to avoid adverse effects of industrial waste and pollutants on the surrounding environment (Ministry of Industry, 2010). Aprillia (2014) reported that the nearest distance at which communities perceived pollution from industrial activity was 500 m from the industrial site, and Damayanti (2010) noted that industrial areas affect the surrounding environment within a radius of 1–2 km. These distances indicate that emissions from port activities may reach nearby settlements.



Figure 1. Emission-exposure zoning map of Tanjung Priok Port showing the three zones; air quality measurements were made at one fixed point in Zone 2.

Source: Authors' own illustration

2.2 Particulate Matter Measurement

Particulate matter concentrations in ambient air were measured using a portable particulate matter monitor (AMTAST AMF079; to measure $PM_{2.5}$ (aerodynamic diameter ≤ 2.5 µm) and PM_{10} (aerodynamic diameter ≤ 10 µm), expressed in µg/m³, at the monitoring point in the Tanjung Priok Port area. The instrument works on the laser light scattering principle, in which the interaction between airborne particles and a laser beam is detected to estimate particulate concentration. According to the product specification, the AMTAST AMF079 has a measurement range of 0–1,000 µg/m³ with a resolution of 1 µg/m³. The portable instrument allowed direct measurement at the observation point, so that variations in particulate concentration during the daily periods of port activity could be identified.

Measurements were conducted in three daily sessions: morning (07:00–09:00 WIB), midday (12:00–14:00 WIB), and late afternoon (15:00–17:00 WIB). These time windows were selected based on the daily operational cycle of the port and the objective of examining temporal variations in particulate matter ($PM_{2.5}$ and PM_{10}) concentrations during periods of port activity. The morning session was

intended to capture conditions during the start of daily activities, when truck movements and cargo-handling operations may contribute to particulate emissions. The midday session represented conditions during the middle of the working day, while the late-afternoon session was intended to capture particulate concentrations during the later phase of daytime operations. The three sessions therefore provided a practical framework for comparing particulate concentrations across different periods of the port's daily operating cycle. However, the selected time windows were based on the study's operational observation schedule and were not intended to represent universally established peak-pollution periods. Each reported value represents the average concentration measured during one session, rather than a 24-hour average.

A total of 54 measurement records were collected over 18 measurement days between March 31 and April 24, 2026, covering weekdays (Monday–Friday) under normal port operating conditions. The dataset (n = 54; 18 days × 3 sessions per day) consists of session-level observations from a temporal measurement design at a single location, rather than a population sample. The campaign covered a limited period and was not assumed to represent seasonal or annual conditions. Meteorological data, including rainfall, wind speed and direction, temperature, and humidity, were not recorded; therefore, the influence of meteorological conditions on particulate concentrations could not be evaluated. Vessel berthing-duration records for April 2026, which covered most of the measurement campaign, were obtained from port records. However, detailed vessel schedules and truck traffic counts were unavailable.

2.3 Community Perception Survey

Community perception data were collected from residents living in neighborhoods surrounding Tanjung Priok Port, Jakarta, Indonesia, using purposive sampling. A total of 40 residents were initially included in the community survey. Respondents were selected based on their residence in the surrounding community and their familiarity with local environmental conditions associated with port activities. However, specific numerical eligibility thresholds for residential distance from the port and minimum length of residence were not documented. Therefore, the findings are interpreted as the perceptions of the surveyed community rather than as statistically representative estimates for all residents surrounding the port.

A structured questionnaire comprising 14 statements was administered using a five-point Likert scale (5 = strongly agree, 4 = agree, 3 = moderately agree, 2 = disagree, and 1 = strongly disagree). The instrument was developed by the authors based on field observations and preliminary data collection. It covered environmental factors, particularly air pollution (nine statements), and port and container-terminal operational factors (five statements). Questionnaire validity was assessed using the corrected item–total Pearson correlation, with an item considered valid when its correlation coefficient exceeded the critical value at the 5% significance level (two-tailed). Internal consistency reliability was assessed using Cronbach's alpha. Following data screening, 37 respondents were included in the validity and reliability analyses. Twelve of the 14 items met the validity criterion, whereas items 9 and 14 did not. Cronbach's alpha was 0.916 for the original 14-item instrument and increased to 0.935 after the two invalid items were excluded. The environmental dimension had a Cronbach's alpha of 0.919, while the operational dimension had a value of 0.780. The survey findings are interpreted as community perceptions and self-reported environmental concerns rather than as direct measurements of individual exposure or evidence of causal health effects.

2.4 Data Analysis

Data were analyzed using descriptive statistics (mean, minimum, maximum, standard deviation, median, and coefficient of variation) to describe the distribution of session-level concentrations, and temporal variation was assessed by comparing the three daily sessions and the daily averages. Pearson's correlation analysis was used to examine the relationship between $PM_{2.5}$ and PM_{10}. Concentrations were classified according to the hourly particulate concentration ranges and categories in Appendix II of BMKG

Regulation No. 8 of 2022 (BMKG, 2022) as an indicative reference only, because each value is a session-level average of about two hours and not a one-hour average; 24-hour guideline or regulatory values were not used because the data are not 24-hour averages. Because all observations were taken at one location, no spatial comparison between zones or hotspot analysis was made. Questionnaire responses were analyzed descriptively (mean score and percentage of responses per category) and compared narratively with the measurement results; no statistical association between the measurements and the responses was tested.

3. Results and Discussion

3.1 Descriptive Statistics

Descriptive statistics were calculated for the entire dataset (n = 54) and for each measurement session. A summary is presented in Table 1. All session-level PM_{10} concentrations (26–32 μg/m³) were low, with a mean of 29.37 μg/m³, and all session-level $PM_{2.5}$ concentrations (20–25 μg/m³) had a mean of 22.80 μg/m³. The coefficients of variation were similar for the two fractions (about 7%), indicating limited variability among sessions. The $PM_{2.5}/PM_{10}$ ratio of 0.776 indicates that fine particles made up most of the measured PM_{10} mass.

Table 1. Descriptive statistics of session-level particulate matter concentrations at Tanjung Priok Port (number of observations = 54)

Parameter	n	Mean ± SD (μg/m³)	Min	Max	Median	CV (%)	BMKG hourly "Good" limit (μg/m³)
PM_{10}	54	29.37 ± 2.03	26	32	30	6.91	50
$PM_{2.5}$	54	22.80 ± 1.59	20	25	23	6.99	15.5
$PM_{2.5}/PM_{10}$ ratio	54	0.776	–	–	–	–	–

Note: n = number of observations; SD = standard deviation; CV = coefficient of variation. The BMKG limits are the upper bounds of the "Good" category in the hourly particulate ranges of BMKG Regulation No. 8 of 2022 (Appendix II); the comparison is indicative only because the values are session-level (about two-hour) averages.
Source: Authors' own data (2026)

3.2 Temporal Variation Across Daily Sessions

A comparison of average concentrations across the three daily sessions identified intraday differences (Table 2). The highest mean concentrations occurred in the morning session (PM_{10} 31.22 μg/m³; $PM_{2.5}$ 24.28 μg/m³), with maximum single-session values of 32 μg/m³ for PM_{10} and 25 μg/m³ for $PM_{2.5}$, and concentrations decreased through the afternoon and evening sessions.

Table 2. Temporal variation in session-level particulate matter concentrations by daily measurement period

Period	n	Average PM_{10} (μg/m³)	SD of PM_{10}	Average $PM_{2.5}$ (μg/m³)	SD of $PM_{2.5}$	$PM_{2.5}/PM_{10}$ ratio
Morning (07:00–09:00)	18	31.22	1.06	24.28	0.89	0.778
Afternoon (12:00–14:00)	18	28.83	1.58	22.39	1.14	0.777
Evening (15:00–17:00)	18	28.06	1.86	21.72	1.45	0.774
Total	54	29.37	2.03	22.80	1.59	0.776

Source: Authors' own data (2026)

This pattern is consistent with, but not shown to be caused by, the start of port operations and the associated vehicle traffic in the morning. Truck counts and vessel schedules were not recorded. Vessel berthing records for April 2026 show 81 vessel calls (42 domestic and 39 ocean-going). Domestic vessels

stayed at berth for 73.0 hours on average (median 71.8; range 9.0–135.5), and ocean-going vessels for 21.2 hours (median 20.0; range 10.0–37.0). Ships at berth keep their auxiliary engines running during the stay, which is a recognized source of port emissions (Xu et al., 2018; Lv et al., 2018); the long berthing durations mean that ships were present at the quay throughout the days of the campaign. The records cover the whole month and do not give the time of day, so they cannot explain the intraday differences. A shallower atmospheric boundary layer in the early morning may also have contributed, but this was not evaluated because no meteorological data were analyzed. Because the monitoring point lies at the interface between quayside and truck-gate activities, the intraday differences are interpreted as temporal patterns that may coincide with the port's activity cycle, not as evidence of a specific source.

The higher morning levels are in line with studies reporting that ship activities and port operations raise $PM_{2.5}$ in and around ports (Xu et al., 2018; Lv et al., 2018), although those studies relied on longer monitoring periods or emission inventories (Kim et al., 2022), so a direct numerical comparison with the present short-term data is limited

3.3 Correlation Between $PM_{2.5}$ and PM_{10}

Pearson's correlation coefficient (r) was calculated to assess the strength and direction of the linear relationship between $PM_{2.5}$ and PM_{10}. A very strong positive correlation was found ($r = 0.9909$, $p < 0.001$), showing that the two fractions varied together across the 54 observations. Because $PM_{2.5}$ is a component of PM_{10}, a strong correlation is expected and does not by itself show that the two fractions come from the same source. It is consistent with a possible common influence of combustion-related emissions, but identifying the sources would require source apportionment or direct activity and emission data, which were not available in this study. The average $PM_{2.5}/PM_{10}$ ratio of 0.776 is compatible with a possible influence of combustion emissions, but the ratio alone cannot confirm diesel combustion or distinguish it from other fine-particle sources. The ratio was similar across the three sessions (0.774–0.778; Table 2).

3.4 Indicative Classification by Hourly Air Quality Categories

The measured concentrations were classified using the hourly particulate concentration ranges and categories in Appendix II of BMKG Regulation No. 8 of 2022 (BMKG, 2022), which amends the regulation of the Meteorology, Climatology, and Geophysics Agency on the provision and dissemination of air quality information. For PM_{10}, the ranges are 0–50 μg/m³ (Good), 51–150 (Moderate), 151–350 (Unhealthy), 351–420 (Very Unhealthy), and >420 (Hazardous); for $PM_{2.5}$, they are 0–15.5 (Good), 15.6–55.4 (Moderate), 55.5–150.4 (Unhealthy), 150.5–250.4 (Very Unhealthy), and >250.4 μg/m³ (Hazardous). Because the present measurements are session-level averages of about two hours and not one-hour concentrations, the classification is indicative only (Table 3).

Table 3. Indicative classification of session-level particulate matter concentrations using the hourly air quality categories of the Indonesian Meteorology, Climatology, and Geophysics Agency

Parameter	Average (μg/m³)	Maximum (μg/m³)	BMKG "Good" range (μg/m³)	BMKG "Moderate" range (μg/m³)	Category of the mean	Category of the maximum
PM_{10}	29.37	32	0–50	51–150	Good	Good
$PM_{2.5}$	22.80	25	0–15.5	15.6–55.4	Moderate	Moderate

Note: Categories follow Appendix II of BMKG Regulation No. 8 of 2022 (hourly ranges). The classification is indicative only: values are session-level averages (about two hours), not one-hour concentrations.
Source: Authors' own data (2026) and BMKG (2022)

The session-level mean PM_{10} concentration was in the "Good" category, while the mean $PM_{2.5}$ concentration was in the "Moderate" category, above the "Good" upper limit of 15.5 μg/m³. No observation reached the "Unhealthy" category for either parameter ($PM_{10} \geq 151$ μg/m³; $PM_{2.5} \geq 55.5$ μg/m³). Given the

sampling design, this classification describes the air quality information category of the measured sessions only and does not by itself indicate compliance, exceedance, or health effects. Because $PM_{2.5}$ was consistently above the "Good" limit, continuous monitoring over full days is warranted to confirm these findings.

3.5 Daily Concentration Trends

Daily averages were calculated from the three sessions of each day to give a picture of day-to-day variation (Figure 2). During the 18-day campaign, the daily average of PM_{10} ranged from 26.7 to 31.0 µg/m³ and remained in the "Good" category, and the daily average of $PM_{2.5}$ ranged from 20.7 to 24.0 µg/m³ and remained in the "Moderate" category, with the $PM_{2.5}/PM_{10}$ ratio staying close to 0.78. Because each daily average is based on three limited sessions rather than 24 hours of measurement, these daily values should be interpreted cautiously.

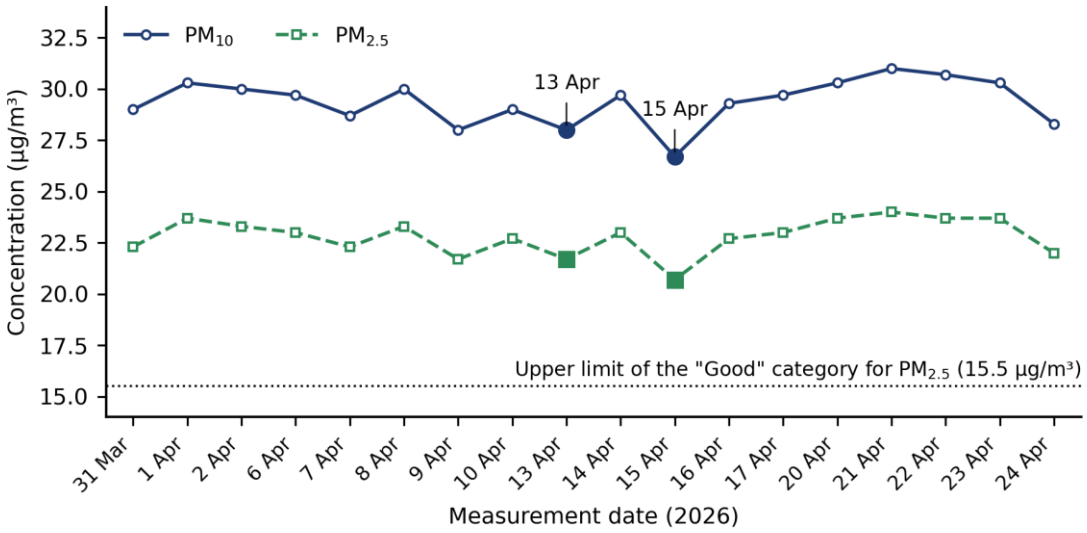


Figure 2. Trends in daily average (three-session) concentrations of fine and coarse particulate matter, March 31–April 24, 2026. The two lowest daily values (April 13 and 15) are labeled.
Source: Authors' own data (2026)

Day-to-day variability was small, and the two lowest daily averages of the campaign, recorded on April 13 and April 15, 2026, are the clearest departures from the campaign means. On April 13, the daily average PM_{10} (28.0 µg/m³) and $PM_{2.5}$ (21.7 µg/m³) were about 4.7% and 4.8% below the campaign means (29.37 and 22.80 µg/m³); on April 15, PM_{10} (26.7 µg/m³) and $PM_{2.5}$ (20.7 µg/m³) were about 9.1% and 9.2% below the campaign means. Both parameters reached their lowest values on the same dates, as expected from their strong correlation. Because no rainfall or other meteorological data were recorded and port-activity data are limited, the cause of these lower values could not be determined; they are reported as the lowest-value days of the campaign and should be examined in future studies with concurrent meteorological and activity data.

3.6 Community Perceptions

The 40 respondents were mostly men (32 of 40; 8 women) and aged 31–40 years (22 of 40; 20–30 years: 8; 41–50 years: 6; over 50 years: 4). Educational attainment was senior high school for 19 respondents, bachelor's degree for 15, master's degree for 3, junior high school for 2, and primary school for 1. None reported a chronic disease. The responses to each statement are summarized in Table 4.

Table 4. Community responses to the Likert-scale questionnaire (number of respondents = 40)

No	Statement	Mean score (1–5)	Agree (%)	Moderately agree (%)	Disagree (%)
Environmental factors (air pollution)					
1	I feel that air quality in my neighborhood has declined because of port activities	3.15	42.5	22.5	35.0
2	I often experience respiratory problems because of pollution from port activities	2.95	37.5	22.5	40.0
3	Dust and waste from the port often disturb my daily comfort	3.15	37.5	30.0	32.5
4	Odors from port activities often disturb my daily activities	2.98	37.5	20.0	42.5
5	I feel that children around the port are more vulnerable to health problems caused by pollution	3.33	52.5	17.5	30.0
6	Port activities cause traffic congestion that disturbs community mobility	3.85	67.5	17.5	15.0
7	Noise from the port disturbs the rest of my family and me	3.00	35.0	22.5	42.5
8	Assistance from the port for affected communities is still felt to be insufficient	3.38	52.5	22.5	25.0
9	I believe port activities provide job opportunities for the surrounding community	4.23	85.0	15.0	0.0
Operational factors of the port and container terminal					
10	I hope the port will be more transparent about the impacts of its activities	4.05	85.0	10.0	5.0
11	I feel the local government needs to supervise the environmental impacts of port activities more actively	4.30	95.0	2.5	2.5
12	I hope the port will make greater efforts to control air pollution	4.28	92.5	5.0	2.5
13	I feel a dialogue between the port and the community is needed to handle complaints	4.28	97.5	2.5	0.0
14	I believe the community can contribute positively to reducing the impacts of port activities	3.98	87.5	7.5	5.0

Note: Mean score uses 5 = strongly agree to 1 = strongly disagree. Agree = "agree" + "strongly agree"; Disagree = "disagree" + "strongly disagree". Statements 9 and 14 are favorable statements about the port and the community.
Source: Authors' own survey (2026)

Perceptions of the environmental impacts of the port were mixed to moderate (mean score 3.22 across the eight impact statements, close to the neutral midpoint). Agreement was highest for traffic congestion caused by port activities (67.5%; mean 3.85). About half of the respondents agreed that children near the port are more vulnerable to pollution-related health problems and that assistance to affected residents is insufficient (52.5% each). Agreement was lower for a decline of air quality in the neighborhood (42.5%; mean 3.15) and for dust and waste (37.5%), whereas for respiratory problems attributed to port pollution (37.5% agreed; 40.0% disagreed), odor (37.5%; 42.5%), and noise (35.0%; 42.5%) the share disagreeing was equal to or larger than the share agreeing. At the same time, 85.0% agreed that the port provides job opportunities for the surrounding community, which may explain why concern about impacts was not uniformly high. Expectations toward the port and the authorities were strong (mean 4.18 across the five operational statements): 85.0% wished for greater transparency about

the impacts of port activities, 95.0% felt that the local government should supervise the environmental impacts more actively, 92.5% hoped for greater efforts to control air pollution, 97.5% felt that a dialogue between the port and the community is needed, and 87.5% believed that the community can contribute positively to reducing the impacts. These results indicate that residents' concern about the environmental impacts of the port was moderate rather than uniformly high, whereas their expectations for transparency, supervision, pollution control, and dialogue were strong. The responses are self-reported; individual exposure and clinical health outcomes were not measured, so they do not show that the measured PM concentrations caused any health complaint.

3.7 Integration of Quantitative and Qualitative Findings

Quantitative and community findings were analyzed independently and compared during interpretation, following a parallel convergent mixed-methods approach. The measurements show $PM_{2.5}$ in the "Moderate" category and higher concentrations in the morning session, and residents' perceptions of environmental impacts were moderate (35.0–67.5% agreement per impact statement, highest for traffic congestion), while their expectations for greater transparency, supervision, pollution control, and dialogue were strong (85.0–97.5% agreement). The two sources are therefore compatible: neither indicates severe pollution, but both point to the need for continued monitoring and for communication between the port and the community. However, the design (40 purposively selected residents, session-level measurements at one point, and no individual exposure data) does not allow testing whether the measured concentrations explain residents' perceptions. The integration is therefore descriptive and indicates directions for future research on environmental justice and health communication in urban-port interface areas.

4. Practical Application and Future Perspectives

4.1 Practical Application

The results can be applied in three practical ways. First, because $PM_{2.5}$ was consistently above the "Good" limit, the port authority and the local environmental agency can use the present data as a baseline to design continuous 24-hour monitoring at several replicated points across the quayside, port gate, and residential zones. Second, emission-reduction measures that are commonly proposed for ports, such as electrification of port equipment, low-sulfur fuel, shore power for ships at berth, greening of port areas, and digital environmental monitoring (Oniszczuk-Jastrząbek et al., 2018; Karagkouni and Boile, 2024; Zhen et al., 2019), can be prioritized for the quayside and truck-gate activities, and their effect at Tanjung Priok should be evaluated with appropriate monitoring. Third, the strong expectations of residents for transparency, supervision, and dialogue indicate that regular public reporting of air quality data and a standing forum between the port and the community would address a concern that residents raised directly.

In developing countries, where fixed monitoring networks near ports are often limited, portable monitors combined with simple community surveys can provide a low-cost first screening. This approach is useful only if the averaging time, calibration, and monitoring location are documented, and it cannot replace regulatory monitoring.

4.2 Limitations

This study has several limitations. First, PM was measured during three limited daily sessions and not continuously for 24 hours, and the BMKG hourly ranges used for classification were applied to session-level averages of about two hours; 24-hour guideline or regulatory values were therefore not used, and the classification is indicative only. Second, the 18-day campaign in late March–April covers a limited period and does not represent seasonal or annual conditions. Third, all measurements were made at a single fixed point in Zone 2, between the quayside and residential zones; the data therefore cannot be used to compare zones or to identify spatial hotspots, and they do not directly represent concentrations

at residents' homes. Fourth, no source apportionment, truck counts, vessel schedules, or meteorological data (including rainfall) were available, so source attribution and any meteorological influence remain untested. Fifth, the community findings are based on 40 purposively selected residents (32 men and 8 women) and self-reported perceptions, without measures of individual exposure or clinical outcomes, and cannot be generalized.

4.3 Future Research

Future research should apply continuous 24-hour monitoring at several replicated points across the quayside, port-gate, and residential zones, over multiple seasons; collect meteorological (including rainfall and wind) and port-activity data (vessel schedules, berthing durations, and truck counts); use source apportionment techniques, such as receptor modeling, to quantify the contributions of ship, vehicle, and cargo-handling emissions; and use larger, randomly sampled respondent groups to allow statistical testing of the association between measured pollution levels and community perceptions.

5. Conclusions

This exploratory study described short-term $PM_{2.5}$ and PM_{10} levels and community perceptions at Tanjung Priok Port. Measured at one point in the port gate and truck terminal zone, PM_{10} fell in the "Good" category and $PM_{2.5}$ in the "Moderate" category of the hourly categories of the Indonesian Meteorology, Climatology, and Geophysics Agency, with the highest levels in the morning session; this indicative classification does not establish compliance with 24-hour standards. The strong correlation between $PM_{2.5}$ and PM_{10} is consistent with a possible combustion influence but does not identify sources. The 40 residents surveyed perceived the environmental impacts of the port as moderate, whereas their expectations for transparency, supervision, pollution control, and dialogue were strong; these self-reported perceptions do not show that the measured particulate matter caused any health complaint. The study provides a baseline for continuous multi-point monitoring and for community-inclusive environmental management at Tanjung Priok Port.

Ethics Statement

This study was conducted in accordance with the ethical guidelines of the Research Ethics Committee, School of Environmental Science, Universitas Indonesia. Ethical approval was obtained under Approval Number KET-063/UN2.F13.D1.KE1/PPM.00/2025 (4 September 2025), granted after minor revisions (first submission on 25 July 2025; revised submission on 3 September 2025), for the research protocol covering air quality measurement and the community around the port. Data collection was conducted after this approval. Informed consent was obtained voluntarily from all respondents, and their identities and personal information were kept confidential. This study did not involve clinical trials, medical interventions, or animal experiments.

CRediT Author Statement

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