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Environmental Health Risk Assessment (EHRA) of Air Pollution from Transportation Activities at Bus Terminals in Medan City

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ABSTRACT
Air pollution from transportation activities at bus terminals poses significant environmental health risks, particularly in densely populated urban areas. This study aims to assess the health risks associated with exposure to air pollutants among individuals working at bus terminals in Medan City, Indonesia. A quantitative descriptive approach using Environmental Health Risk Assessment (EHRA) was applied. Data were collected through direct measurements of carbon monoxide (CO), nitrogen dioxide (NO_2), and particulate matter (PM2.5), as well as interviews to determine exposure duration, frequency, and body weight. The study involved 60 respondents, including traders, drivers, and terminal officers. Risk characterization was conducted using the Risk Quotient (RQ). The results indicated that the concentrations of CO and PM2.5 exceeded WHO air quality standards during peak hours. The RQ values for a majority of respondents were greater than 1, indicating potential non-carcinogenic health risks. The highest risk was observed among traders due to prolonged exposure duration. These findings highlight the urgent need for emission control strategies, improved environmental management, and health protection measures for vulnerable populations. In conclusion, EHRA is an effective tool to evaluate environmental health risks in transportation hubs.

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INTRODUCTION

Air pollution is widely recognized as one of the most critical environmental challenges in urban areas, with direct and measurable impacts on human health. Major air pollutants, including particulate matter (PM2.5), carbon monoxide (CO), and nitrogen dioxide (NO_2), have been strongly associated with respiratory and cardiovascular diseases, as well as increased global mortality rates (World Health Organization, 2021). These pollutants can penetrate deep into the respiratory system and bloodstream, leading to both acute and chronic health effects. In developing countries, rapid urbanization and economic growth have significantly increased the number of motor vehicles, making transportation a dominant contributor to declining ambient air quality (Kumar et al., 2023). As a result, urban populations are increasingly exposed to hazardous air conditions on a daily basis.

The transportation sector plays a major role in the emission of air pollutants in urban environments. Emissions from motor vehicles, particularly under congested traffic conditions, generate elevated concentrations of harmful pollutants such as CO and PM2.5. These pollutants tend to accumulate not only in open environments but also in semi-enclosed areas where air circulation is limited (Zhang et al., 2019). Continuous exposure to such pollutants poses chronic health risks, especially for individuals who spend extended periods near emission sources. The persistence of these pollutants in the air further exacerbates their impact on human health and environmental quality.

Bus terminals represent one of the most critical nodes of transportation activity, characterized by a high density of vehicles and continuous movement. These areas have a strong potential to generate significant air pollution due to constant vehicle operations, including frequent idling where engines remain running while stationary. This condition contributes to the accumulation of pollutants in the surrounding environment, leading to elevated concentrations of harmful gases and particulate matter (Irniza et al., 2014). Consequently, bus terminals can be categorized as high-risk environments, particularly for individuals who work within these areas on a daily basis.

Certain occupational groups, such as street vendors, drivers, and terminal staff, experience higher levels of exposure compared to the general population. This increased exposure is largely due to prolonged working hours and close proximity to emission sources. Previous studies have demonstrated that long-term exposure to PM2.5 and CO can result in Risk Quotient (RQ) values exceeding safe thresholds, indicating the presence of non-carcinogenic health risks (Pangestika et al., 2020). Such findings highlight the vulnerability of these occupational groups and emphasize the importance of assessing health risks in transportation-related environments.

Environmental Health Risk Assessment (EHRA) is a widely used methodological framework for evaluating health risks associated with environmental pollutants. This approach consists of several key stages, including hazard identification, dose–response assessment, exposure assessment, and risk characterization. Through these steps, EHRA provides a quantitative estimation of potential health risks based on measured exposure levels and established reference values (Rahmawati, 2023). The application of EHRA is particularly relevant in urban settings where complex interactions between environmental factors and human activities influence exposure patterns.

Although numerous studies have been conducted in major cities across Indonesia, most of them primarily focus on general urban air pollution and do not specifically address micro-environmental conditions within transportation hubs such as bus terminals. Furthermore, previous studies have often applied the Environmental Health Risk Assessment (EHRA) framework in a relatively generalized manner, with limited integration of detailed individual exposure variables and without explicitly linking the findings to national air quality standards. This indicates a critical research gap in understanding site-specific exposure dynamics and health risks in high-intensity transportation microenvironments, particularly in rapidly growing cities such as Medan.

In addition, few studies have systematically combined real-time pollutant measurements with individual exposure characteristics such as duration, frequency, and occupational variability within a terminal setting. Moreover, limited attention has been given to comparing observed pollutant concentrations and associated health risks with national regulatory standards, such as Government Regulation No. 22 of 2021 on Ambient Air Quality Standards in Indonesia.

Air pollution exposure in transportation microenvironments has also been increasingly recognized as a critical determinant of individual health risk due to its spatial and temporal variability. Unlike general ambient air quality, microenvironmental exposure such as in bus terminals can result in significantly higher pollutant concentrations due to proximity to emission sources and limited dispersion. Studies have shown that individuals in transport-related microenvironments may experience pollutant levels several times higher than urban background concentrations, thereby increasing cumulative exposure and associated health risks (Morawska et al., 2018; Goel & Kumar, 2015). This highlights the importance of assessing exposure at a localized scale rather than relying solely on city-level air quality data.

In addition, recent studies have emphasized the importance of integrating personal exposure assessment with environmental monitoring to obtain a more accurate estimation of health risks. Traditional approaches that rely solely on ambient monitoring stations may underestimate actual exposure levels experienced by individuals in high-risk environments. The incorporation of activity patterns, occupational characteristics, and time–activity data has been shown to significantly improve the precision of exposure and risk estimation (Steinle et al., 2013; Buonanno et al., 2014). Such integrated approaches are particularly relevant in dynamic environments like bus terminals, where exposure levels fluctuate rapidly depending on traffic conditions and human activities.

Furthermore, policy-oriented studies have highlighted that effective air quality management requires not only compliance with international guidelines but also alignment with national regulatory frameworks and local environmental conditions. In many developing countries, including Indonesia, discrepancies often exist between measured pollutant concentrations and regulatory enforcement, particularly in transportation hubs. Comparative analyses between international standards and national regulations are therefore essential to identify gaps in policy implementation and to support targeted interventions (HEI, 2020; GBD, 2019). This reinforces the need for studies that explicitly incorporate both global and national benchmarks in evaluating environmental health risks.

Therefore, this study aims to assess environmental health risks associated with air pollution from transportation activities at bus terminals in Medan City using the EHRA approach. The novelty of this study lies in its site-specific assessment of a terminal microenvironment, the integration of detailed exposure variables across occupational groups, and the comparison of measured pollutant levels with national and international air quality standards. The findings are expected to provide a more comprehensive understanding of exposure risks among vulnerable populations and to support evidence-based strategies for improving air quality and protecting public health in transportation hubs.

METHODS

This study employed a quantitative descriptive approach using the Environmental Health Risk Assessment (EHRA) framework to evaluate potential health risks associated with exposure to air pollution from transportation activities. This method was selected because it enables systematic integration of environmental measurements and individual exposure characteristics for quantitative risk estimation.

1. Study Area and Population

The study was conducted at the Amplas Bus Terminal in Medan City, Indonesia, from January to March 2026. This location was selected due to its high transportation intensity, which contributes to elevated levels of air pollutants. A total of 60 respondents were included in the study, consisting of street vendors, drivers, and terminal staff. The sample size was determined based on the minimum sample requirement for environmental health risk studies using purposive sampling, ensuring representation of high-exposure groups (Lemeshow et al., 1990). Inclusion criteria required participants to have worked in the terminal area for at least one year and to have direct exposure to vehicle emissions.

2. Data Collection

Primary data were obtained through direct environmental measurements and structured interviews. Air pollutant concentrations were measured using a calibrated portable air quality monitor (e.g., Aeroqual Series 500, Aeroqual Ltd., New Zealand). The instrument was calibrated prior to use following the manufacturer's standard calibration procedures to ensure measurement accuracy. Measurements were conducted at multiple points within the terminal area, including arrival, departure, and waiting zones, and at different times (morning, midday, and afternoon) to capture temporal variations. Structured interviews were conducted using a validated questionnaire to collect respondent characteristics, including exposure duration (hours/day), exposure frequency (days/year), length of employment (years), and body weight (kg).

To ensure data quality:

a. Content validity was assessed through expert judgment
b. Reliability testing was performed using Cronbach's Alpha, with a value of >0.70 indicating acceptable reliability

3. Data Analysis

Data analysis followed the standard stages of the Environmental Health Risk Assessment (EHRA), including hazard identification, dose–response assessment, exposure assessment, and risk characterization. The hazard identification stage focused on determining the main pollutants of concern, namely CO, NO_2, and PM2.5, which are known to have adverse health effects.

a. Exposure Assessment

During the exposure assessment stage, the intake of pollutants was calculated using the following equation (US EPA, 2009):

$$\text{Intake} = (C \times IR \times EF \times ED) / (BW \times AT)$$

where:

- C = pollutant concentration
- IR = inhalation rate (0.83 m^3/hour for adults)
- EF = exposure frequency (days/year)
- ED = exposure duration (years)
- BW = body weight (kg)
- AT = averaging time (30 years × 365 days for non-carcinogenic risk)

b. Risk Characterization

Risk characterization was performed by calculating the Risk Quotient (RQ) using the equation:

$$RQ = \text{Intake} / \text{Reference Dose (RfD)}$$

RfD values were obtained from the US Environmental Protection Agency. An RQ value ≤ 1 indicates that the exposure is within acceptable limits, whereas an RQ value > 1 suggests a potential non-carcinogenic health risk (US EPA, 2009). The results were analyzed descriptively to identify risk levels across respondent groups and to determine key factors influencing exposure and health risk.

4. Statistical Analysis

In addition to descriptive analysis, inferential statistical tests were conducted to strengthen the analysis:

a. Correlation analysis (Pearson test) to examine the relationship between exposure duration and RQ
b. One-way ANOVA to compare RQ values across occupational groups
c. Statistical significance was set at $p < 0.05$

5. EHRA Parameter Reference

Table 1. Key exposure parameters and reference values applied in the Environmental Health Risk Assessment (EHRA) model

Parameter	Value	Unit	Source
IR	0.83	m^3/hour	US EPA (2009)
EF	250–350	days/year	Field data
ED	1–10	years	Field data
BW	55–70	kg	Respondent data
AT	10,950	days	US EPA (2009)

RESULTS

1. Air Pollutant Concentrations

The results of air quality measurements in the terminal area indicate that pollutant concentrations varied depending on sampling time and location. In general, the highest concentrations were observed during peak hours (morning and afternoon), corresponding with increased vehicle activity and traffic density. This temporal variation suggests that transportation intensity plays a crucial role in determining local air quality conditions.

The average concentrations of the measured pollutants were as follows:

a. Carbon monoxide (CO): 12–25 ppm
b. Nitrogen dioxide (NO_2): 80–120 μg/m^3
c. Fine particulate matter (PM2.5): 45–85 μg/m^3

At several monitoring points, particularly during peak hours, the levels of CO and PM2.5 exceeded the air quality guidelines established by the World Health Organization (WHO). These findings indicate that transportation-related emissions significantly contribute to air quality degradation within the terminal environment (World Health Organization, 2021; Zhang et al., 2019).

Table 2. Air Pollutant Concentrations Compared with Standards

Parameter	Average	WHO Standard	Indonesian Standard (PP No. 22/2021)	Measurement Time	Source of Standard	Remark
CO (ppm)	18.5	10 ppm	10 ppm	Morning–Afternoon	WHO (2021); KLHK (2021)	Exceeds

NO_2 (µg/m³)	100	200 µg/m³	200 µg/m³	Morning–Afternoon	WHO (2021); KLHK (2021)	Near limit
PM2.5 (µg/m³)	65	15 µg/m³	55 µg/m³	Morning–Afternoon	WHO (2021); KLHK (2021)	Exceeds

a) Health Risk Assessment

The results of the Risk Quotient (RQ) calculations reveal that a substantial proportion of respondents experienced significant health risks due to exposure to air pollutants. Out of 60 respondents, 39 individuals (65%) had RQ values greater than 1, indicating the presence of potential non-carcinogenic health risks. The distribution of RQ values varied across occupational groups and exposure durations. Individuals with longer daily exposure tended to have higher RQ values, suggesting a direct relationship between exposure duration and health risk. This finding is consistent with previous studies demonstrating that prolonged exposure to PM2.5 and CO increases the likelihood of adverse health outcomes (Pangestika et al., 2020).

Table 3. Distribution of Risk Quotient (RQ) Values

RQ Category	Number of Respondents	Percentage (%)	Remark
RQ ≤ 1	21	35%	Low risk
RQ > 1	39	65%	At risk

b) High-Risk Groups

Analysis based on occupational categories shows that street vendors exhibited the highest RQ values compared to other groups. This is primarily due to their longer exposure duration, typically ranging from 8 to 10 hours per day, as well as their relatively fixed working locations in areas with high pollutant concentrations. In contrast, drivers experienced intermittent exposure due to mobility, while terminal staff had more varied working locations, resulting in relatively lower exposure levels compared to vendors. These differences highlight the importance of occupational characteristics in determining exposure intensity and associated health risks.

Table 4. Average RQ Values by Occupational Group

Group	Exposure Duration (hours/day)	Average RQ	Risk Category
Vendors	8–10	1.5	High
Drivers	5–7	0.9	Low
Staff	6–8	1.2	Moderate

c) Interview Results

Structured interviews revealed that the majority of respondents were exposed to air pollutants for prolonged periods, with 70% reporting daily exposure exceeding 6 hours. Additionally, 60% of respondents reported working near high-traffic zones within the terminal, while only 25% reported using any form of personal protective equipment such as masks. Furthermore, approximately 55% of respondents reported experiencing respiratory symptoms, including coughing and shortness of breath, particularly during peak hours. These findings support the quantitative results and highlight the real-world health implications of prolonged exposure to transportation-related air pollution.

d) Factors Influencing Health Risk

Several key factors were identified as influencing the level of health risk associated with air pollutant exposure in the terminal environment:

1) **Exposure duration**
   Longer time spent in the terminal area increases the cumulative dose of pollutants received by individuals, thereby elevating health risk.
2) **Vehicle density**
   Higher numbers of vehicles, particularly during peak hours, contribute to increased emissions and elevated pollutant concentrations.
3) **Environmental ventilation conditions**
   Areas with limited air circulation tend to accumulate pollutants more easily compared to open or well-ventilated spaces.

Overall, these findings indicate that health risks in bus terminal environments are determined by the interaction between environmental conditions and individual exposure characteristics (Kumar et al., 2023).

e) Uncertainty and Limitations

Despite providing important insights, this study has several limitations that may introduce uncertainty into the results. First, variability in sampling time may influence pollutant concentration measurements, as data were collected at specific periods (morning, midday, and afternoon) and may not fully represent daily fluctuations. Second, limitations of the measurement instruments, including sensitivity and detection range, may contribute to measurement bias. Third, the EHRA calculations rely on several assumptions, including standard values for inhalation rate (IR), averaging time (AT), and reference dose (RfD), which may not fully capture individual variability among respondents. Finally, exposure estimates are based on self-reported interview data, which may introduce recall bias. These uncertainties should be considered when interpreting the results and highlight the need for future studies incorporating continuous monitoring and more detailed exposure assessments.

DISCUSSION

The findings of this study demonstrate that transportation activities at bus terminals significantly contribute to elevated concentrations of air pollutants, particularly carbon monoxide (CO) and particulate matter (PM2.5). The high levels observed during peak hours can be primarily attributed to increased vehicle density, frequent stop-and-go traffic, and prolonged idling conditions. These operational characteristics lead to incomplete fuel combustion, which is a major source of CO emissions, as well as the generation of fine particulates from exhaust systems and road dust resuspension (Kumar et al., 2023; Zhang et al., 2019). Similar findings have been reported in urban transport hubs in cities such as Bangkok and Delhi, where peak-hour emissions significantly increased PM2.5 concentrations beyond safe thresholds (Bootdee et al., 2023; Kumar et al., 2023).

In addition to CO and PM2.5, nitrogen dioxide (NO_2) levels in this study approached the threshold limits, indicating a potential emerging risk. Although NO_2 concentrations did not exceed the standards, their proximity to regulatory limits suggests cumulative exposure risks, particularly in semi-enclosed environments. Previous studies have shown that NO_2 is strongly associated with vehicle exhaust emissions and may contribute to respiratory inflammation even at moderate concentrations (Abidin et al., 2022). Therefore, while CO and PM2.5 remain the dominant pollutants, NO_2 should not be overlooked in long-term exposure assessments.

The Risk Quotient (RQ) values exceeding 1 for a significant proportion of respondents confirm the presence of potential non-carcinogenic health risks. This finding aligns with studies conducted in urban transportation environments in Indonesia and other developing countries, where prolonged exposure to PM2.5 has been linked to increased respiratory and cardiovascular risks (Pangestika et al., 2020; Sari et al., 2020). Compared to studies in developed countries, the risk levels observed in this study tend to be higher, which may be attributed to differences in emission control policies, vehicle standards, and environmental management practices.

The higher risk observed among street vendors can be explained by several interrelated factors. First, vendors experience longer exposure durations (8–10 hours/day), resulting in higher cumulative pollutant intake. Second, their relatively fixed working positions near traffic flow limit their ability to avoid high-exposure zones. Third, the lack of protective measures, such as the use of masks, further increases their vulnerability. These findings are consistent with studies in urban informal sectors, which highlight that occupational groups with prolonged and stationary exposure patterns tend to have higher health risks compared to mobile workers such as drivers (Kermani et al., 2022).

Micro-environmental conditions also play a critical role in influencing pollutant concentrations and exposure levels. Semi-enclosed terminal structures with limited ventilation can trap pollutants, leading to localized accumulation. Similar observations have been reported in transport terminals in Iran and China, where poor ventilation significantly increased pollutant concentrations compared to open-air environments (Kermani et al., 2022; Zhang et al., 2019). This suggests that not only emission sources but also environmental design significantly affect air quality.

When compared with other cities, the pollutant concentrations observed in this study are relatively higher than those reported in some regulated urban environments but comparable to conditions in rapidly developing cities. For example, PM2.5 levels in this study exceed those reported in certain European transport hubs but are similar to levels found in Southeast Asian cities with high traffic density and less stringent emission controls (Bootdee et al., 2023). These comparisons highlight the importance of contextual factors, including policy enforcement and infrastructure design.

From a policy perspective, these findings emphasize the need for integrated interventions targeting both emission sources and environmental conditions. Strategies such as stricter vehicle emission standards, reduction of idling practices, and improved traffic flow management are essential to reduce pollutant generation. In addition, structural improvements, including enhanced ventilation systems and increased green infrastructure, can help mitigate pollutant accumulation in terminal environments.

At the individual level, the promotion of personal protective equipment, such as high-efficiency masks, and increased awareness of exposure risks are critical measures to reduce health impacts. Regular health monitoring programs for high-risk groups, particularly street vendors, are also recommended as part of preventive public health strategies. Overall, this study highlights the complex interaction between environmental conditions, occupational exposure, and health risk. The application of the Environmental Health Risk Assessment (EHRA) framework provides a comprehensive and quantitative approach for evaluating these risks. The findings contribute to the growing body of evidence on transportation-related air pollution and offer practical insights for improving environmental health management in urban transport hubs.

CONCLUSIONS

This study demonstrates that air pollution resulting from transportation activities at bus terminals in Medan City poses a significant health risk, particularly for occupational groups with prolonged exposure durations such as street vendors and terminal workers. The concentrations of key pollutants, especially CO and PM2.5, exceeded recommended standards during peak hours, while NO_2 levels approached regulatory limits, indicating potential cumulative risks.

The EHRA analysis revealed that a substantial proportion of respondents had Risk Quotient (RQ) values greater than 1, confirming the presence of non-carcinogenic health risks associated with long-term exposure. The main determinants of risk include exposure duration, vehicle density, and environmental conditions such as limited ventilation.

These findings underscore the need for integrated mitigation strategies combining emission control, environmental design improvements, and occupational health protection. Future studies should incorporate seasonal variability, continuous monitoring, and broader pollutant parameters to enhance the robustness of risk assessment and support evidence-based policymaking.

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