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Environmental Health Risk Analysis of Carbon Monoxide (CO) Exposure Among Traders at Purabaya Terminal In 2025

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Abstract

Air pollution caused by motor vehicle emissions is an environmental problem that affects human health, especially among groups working near emission sources, such as traders at Purabaya Terminal. This study aimed to analyze the health risk level of carbon monoxide (CO) exposure among traders in the area. The research employed a descriptive analytical method with a cross-sectional design and an Environmental Health Risk Analysis (EHRA) approach, which included the stages of hazard identification, dose–response analysis, exposure analysis, and risk characterization. The sample consisted of 32 permanent traders selected through purposive sampling. The results showed an average CO concentration of 180,332.9 µg/m³, which exceeded the ambient air quality standard of 10,000 µg/m³ as regulated by the Ministry of Health. In addition, 62% of traders reported eye irritation, followed by headaches (44%), shortness of breath (37%), and nausea (16%), indicating early symptoms of CO exposure. The CO intake values among traders ranged from 5,8217556543 to 44,79081128 mg/kg/day, exceeding the reference dose (RfC) of 1.207 mg/kg/day. The Risk Quotient (RQ) values ranged from 4,819848006 to 37,1092057 mg/kg/day, with an average RQ greater than 1 (RQ > 1), indicating non-carcinogenic health risks due to direct CO exposure. It is recommended that vehicle emissions and ambient air be monitored regularly, and that traders consistently use KN95 masks to reduce the risk of direct CO inhalation.

Keywords: Risk Analysis, Exposure, Carbon Monoxide (CO), Traders, Purabaya Terminal

Introduction

Air pollution is an environmental issue that remains a global concern, particularly in developing countries with rapid urbanization and transportation growth. According to 2019 data from the World Health Organization (WHO), approximately 99% of the world's population breathes air that does not meet quality standards, causing more than 4.2 million deaths each year [1]. In Indonesia, East Java was recorded as the province with the highest air pollution levels in 2023, with an average Air Quality Index (AQI) exceeding 150, categorized as unhealthy [2].

Carbon monoxide (CO) is the most dominant type of emission produced by motor vehicle activities in urban areas, contributing approximately 64% of total air pollutant emissions [3]. This gas is colorless, odorless, and easily binds with hemoglobin in the blood, forming carboxyhemoglobin (COHb), thereby inhibiting the blood's ability to transport oxygen throughout the body. When the body experiences oxygen deprivation, various health issues can arise, ranging from mild symptoms like headaches and nausea to heart problems, central nervous system damage, and even death [4]. Prolonged or repeated exposure to low concentrations of CO can also lead to chronic fatigue, cognitive decline, and cardiovascular stress, particularly among individuals with pre-existing conditions such as anemia or heart disease. The severity of health effects depends on multiple risk factors, including pollutant concentration, duration and frequency of exposure, ventilation conditions, smoking habits, and individual susceptibility such as age, nutritional status, and body weight [5].

Incomplete combustion of vehicle fuel produces large amounts of CO gas, especially in developing countries with high levels of traffic congestion and vehicle idle time. Terminals are one of the areas with the highest levels of air pollution exposure, due to the large number of vehicles waiting to depart, stopping, and parking with their engines running (idling). Research by Rachmawati (2022) shows that carbon monoxide (CO) levels in the environment of Tirtonadi Terminal, Surakarta, are quite high, caused by the large number of vehicles, especially buses, that are parked or waiting with their engines idling, resulting in significant CO emissions accumulation [6].

Purabaya Terminal is one of the largest Type A terminals in Indonesia with high vehicle traffic activity. In November 2024, a total of 28,003 buses were recorded entering and exiting the terminal, with an average of 2,155 buses per day during peak hours. Buses, as the primary mode of transportation at this terminal, typically use diesel fuel, which has the potential to produce carbon monoxide (CO) gas. A study by Tosun & Gökçeli (2025), noted that vehicles using diesel fuel emit higher levels of carbon monoxide (CO) [7]. Exposure to CO gas in areas with high traffic density poses significant health risks to the population in those areas [8].

Research by Nair et al (2017)[9] found that traffic officers in polluted areas have significantly higher levels of carboxyhemoglobin (COHb) compared to non-field workers. This aligns with the findings of Hayati et al (2023), who found that workers at the Bulupitu Terminal, both smokers and non-smokers, had COHb levels above the normal range, with an average of 5.87%, due to exposure to vehicle emissions in the terminal area, which operates 24 hours a day [10]. Health risks from CO exposure are not only influenced by CO concentration in the air but also by exposure duration, ventilation levels, and individual health conditions [11].

A study by Rangkuti et al (2022) at Giwangan Terminal, Yogyakarta, showed that all respondents had a Risk Quotient (RQ) value greater than 1, indicating a non-carcinogenic risk due to CO exposure [12]. However, different results were found by Cahyono et al (2024) at Bulupitu Terminal, Purwokerto, indicating that CO concentrations remained within safe limits due to lower vehicle volume and better ventilation [13]. On the other hand, research conducted by Devy et al (2024) on parking attendants showed that although CO concentrations were still below the threshold, regular monitoring was still necessary to ensure worker safety [14].

Measurement data at Purabaya Terminal showed an average CO concentration of 180,332.9 μg/m³, far exceeding the quality standards set by Ministry of Health Regulation No. 2 of 2023 for a measurement period of 1 hour. Interviews with traders revealed health complaints such as watery eyes, headaches, shortness of breath, and nausea, indicating early symptoms of CO poisoning. The high CO concentration increases health risks for people active around the terminal, especially traders who spend more than six hours a day at the location.

Although several studies have assessed CO exposure risks in transportation areas such as Giwangan, Tirtonadi, and Bulupitu terminals, no Environmental Health Risk Analysis (EHRA) has been specifically conducted for traders at Purabaya Terminal, despite its high traffic intensity and dense commercial activity. This study was conducted to analyze the level of health risks due to CO exposure among traders using the Environmental Health Risk Analysis (EHRA) approach, as an effort to provide comprehensive scientific data to support risk mitigation policy-making in the terminal area.

Materials and Methods

Research Design and Type

This research is a descriptive analytical design with a cross-sectional design and an approach using the Environmental Health Risk Analysis (EHRA) method to calculate or interpret the health risks of traders due to exposure to harmful CO gas in the environment. The EHRA approach was chosen because it provides a systematic framework for identifying hazards, quantifying exposure, and estimating risk levels for populations exposed to environmental pollutants. However, this study has certain limitations, particularly the absence of biological monitoring such as the measurement of carboxyhemoglobin (COHb) levels in the blood, which could have provided more direct evidence of CO absorption in the body. In addition, individual factors such as diet, physical activity, and underlying health conditions were not analyzed in detail, which may influence the accuracy of risk estimation results.

Location and Time

This research was conducted in the Purabaya Terminal area from January to June 2025. Air sampling was carried out by measuring CO concentrations using a midget impinger for 1 hour per sampling point, as well as measuring meteorological parameters including temperature, humidity, wind speed, and wind direction. Sampling was conducted during peak activity hours at the terminal, specifically from 3:00 PM to 6:00 PM WIB. Sampling points were established at four locations:

a. Point 1 (one) in the bus arrival area.
b. Point 2 (two) in the bus parking area.
c. Point 3 (three) Intraprovincial intercity bus shelter area
d. Point 4 (four) Interprovincial intercity bus shelter area

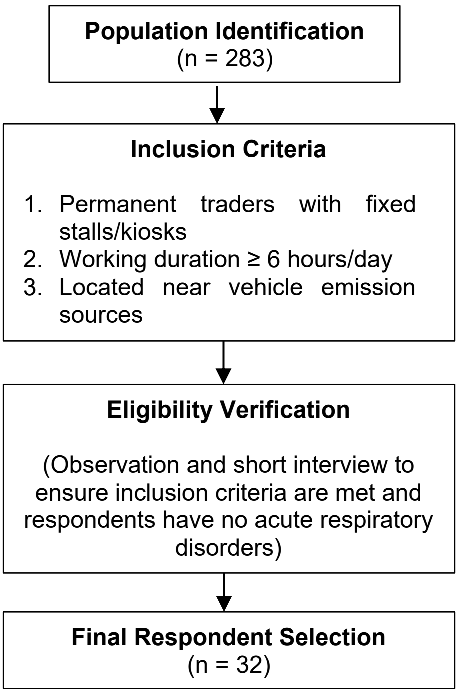
Respondents

The sample in this study consisted of permanent traders operating in the lobby area of Purabaya Terminal. Of the total 283 traders registered by the terminal traders' association, 32 permanent traders were selected as respondents using purposive sampling. The selection of this sample was based on specific criteria, namely traders who have been operating at the location for a minimum of 6 (six) hours per day and are directly exposed to CO emissions from motor vehicles. Permanent traders were chosen because their sales locations are closer to bus traffic routes, resulting in higher CO exposure levels compared to itinerant traders. The purposive sampling method was applied to ensure that the respondents represented the group with the highest potential exposure intensity and health risk, aligning with the objective of the Environmental Health Risk Analysis (EHRA) approach, which emphasizes exposure among high-risk populations.

Sources and Measurement

Data collection in this study included observation, interviews, sampling, laboratory analysis, and documentation. Observations were conducted to identify hazards related to CO exposure at the terminal. Structured interviews using questionnaires were carried out to collect data on respondents' characteristics such as age, body weight, working duration, exposure frequency, and health complaints related to CO exposure. CO concentration measurements were conducted in accordance with the Indonesian National Standard (SNI) 19-7119.8-2005: Methods for Testing CO Gas in the Air Using Non-Dispersive Infrared (NDIR). Laboratory analysis was performed to examine the collected air samples in order to obtain accurate CO concentration data as the basis for risk assessment.

Respondent



Data Analysis

The data in this study were analyzed using the Environmental Health Risk Analysis (EHRA) stages, which include hazard identification, dose-response analysis, exposure analysis, and risk characterization. Hazard identification was carried out by assessing the sources of CO exposure from motor vehicle activities around the Purabaya Terminal and their impact on the health of traders. Dose-response analysis was performed using calculations in accordance with the EHRM guidelines, namely 1.207 mg/kg/day. Next, exposure analysis was conducted by calculating the intake (Ink) value using the following formula:

$$\text{Ink} = \frac{\text{CxRxtExFexDt}}{\text{Wbxtavg}}$$

Information:
Ink : Intake Rate (mg/kg/day)
C : CO Concentration (mg/m³) for air medium
R : Inhalation Rate (m³/hour)
tE : Time of Exposure
fE : Frequency of Exposure
Dt : Duration of Exposure
Wb : Body Weight
t_{vag} : Average Time Period

The final step is risk characterization by calculating the Risk Quotient (RQ) using the following formula::

$$RQ = \frac{Ink}{RfC}$$

Information:
RQ : Risk level
Ink : Intake Rate (mg/kg/day)
RfC : Reference Dose (mg/kg/day)

According to ARKL guidelines, the Risk Quotient (RQ) value is used to determine the non-carcinogenic risk level resulting from exposure to pollutants. If the RQ value is less than or equal to one (RQ ≤ 1), exposure is considered safe and does not pose a health risk. However, if the RQ value exceeds one (RQ > 1), this indicates a potential non-carcinogenic health risk because the intake of the contaminant exceeds the safe threshold (RfC).

Research Ethics

This study has been declared ethically sound in accordance with the seven WHO Standards of 2011 published by the Health Research Ethics Commission (KEPK) of the Surabaya Ministry of Health Polytechnic of Health with the number No. EA/3440./KEPK-Poltekkes_Sby/V/2025.

Results

Carbon Monoxide (CO) Concentration

The carbon monoxide (CO) air quality measurements obtained at Purabaya Terminal were summarized in the following table:

Table 1 : Results of CO Gas Concentration Measurements at Purabaya Terminal in 2025

No.	Sampling Point	CO Gas Concentration (µg/m³)
1.	Point 1 (Bus arrival area)	355117,1
2.	Point 2 (Bus parking area)	70283,6
3.	Point 3 (Intraprovincial intercity bus shelter area)	129469,7
4.	Point 4 (Interprovincial intercity bus shelter area)	166461,1
Average Value		**180332,9**
Maximum Value		**355117,1**
Minimal Value		**70283,6**

Based on Table 1, the highest concentration of carbon monoxide (CO) was recorded at Point 1 (bus arrival area), with a value of 355,117.1 µg/m³. Conversely, the lowest CO concentration was observed at Point 2 (bus parking area), measuring 70,283.6 µg/m³. The mean CO concentration across all sampling locations was calculated at 180,332.9 µg/m³.

Meteorological Factors

The results of the meteorological factor measurements at Purabaya Terminal, including temperature, humidity, wind speed, and wind direction, were presented in Table 2 below.

Table 2 : Results of Meteorological Factor

Measurements at Purabaya Terminal in 2025

No.	Sampling Point	Temperature (°C)	Humidity (%)	Wind Speed (m/s)
1.	Point 1 (Bus arrival area)	31	73,3	0,5-1,8
2.	Point 2 (Bus parking area)	30	79,5	1,0-2,7
3.	Point 3 (Intraprovincial intercity bus shelter area)	29,2	76,5	0,5-1,5
4.	Point 4 (Interprovincial intercity bus shelter area)	29,4	85,4	01-1,0
Average Value		**29,9**	**78,6**	**1,14**
Maximum Value		**31**	**85,4**	**2,7**
Minimal Value		**29,2**	**73,3**	**0,1**

The highest ambient temperature was recorded in the parking area at 31°C, while the lowest was observed at the intra-provincial (AKDP) bus shelter at 29.2°C. The mean air temperature across all sampling locations was approximately 29.9°C. Relative humidity peaked at the interprovincial (AKAP) bus shelter, reaching 85.4%, whereas the lowest humidity level was measured at the bus arrival area, at around 73.3%, with an overall average of approximately 78.6%. The highest wind speed was documented at the bus parking area at 2.7 m/s, while the lowest, 0.1 m/s, was recorded at the AKAP bus shelter. The mean wind speed across all sites was 1.14 m/s, with prevailing winds predominantly originating from the west.

Characteristics of Respondents

Based on the questionnaire results, the characteristics of traders are as follows:

Table 3 : Characteristics of Traders in Purabaya Terminal

Category	Amount (n)	Percentage (%)
Age		
Adolescents (17-25)	3	9%
Adults (26-45)	21	66%
Older Adults (46-65)	8	25%
Total	**32**	**100%**
Sex Distribution		
Male	30	94%
Female	2	6%
Total	**32**	**100%**
Smoking Habits		
Smoked	21	66%
Did not smoke	11	34%
Total	**32**	**100%**
Mask Usage		
Wore a mask	8	25%
Did not wear a mask	24	75%
Total	**32**	**100%**

The characteristics of the traders at Purabaya Terminal indicated that the majority of respondents were adults aged 28–45 years (66%) and predominantly male (94%). A total of 66% of the respondents reported having a smoking habit, while only 25% regularly used masks during work.

Anthropometric Characteristics and Activity Patterns of Respondents

The anthropometric characteristics and activity patterns of the street traders at Purabaya Terminal were presented in the table below. These data reflected the physical profiles and daily exposure-related behaviors of the respondents during the study period.

Table 4 : Anthropometric Characteristics and Activity Patterns of Respondents at Purabaya Terminal

Variable	Amount (n)	Percentage (%)
Body Weight (Wb)		
< 60	15	47%
≥ 60	17	53%
Total	**32**	**100%**
Inhalation Rate (R) for adults was 0,83 m^3/hour		
Time of Exposure (tE)		
< 8 hours/day	5	16%
≥ 8 hours/day	27	84%
Total	**32**	**100%**
Frequency of Exposure (fE)		
150 – 221 days	4	13%
222 – 293 days	3	9%
294 - 365 days	25	78%
Total	**32**	**100%**
Duration of Exposure (Dt)		
3 - 9 years	11	34%
10 - 16 years	12	38%
17 - 25 years	9	28%
Total	**32**	**100%**

Referring to the data presented in Table 4, approximately 53% of the respondents had a body weight of ≥60 kg, while the remaining 47% weighed less than 60 kg. The inhalation rate (**r**) applied in this study was 0.83 m³/hour for adults. The majority of traders (84%) experienced exposure durations exceeding 8 hours per day, with 78% of them working between 224 and 325 days per year. The most common length of occupational duration was 17–25 years (53%), followed by 3–9 years (34%), and 10–16 years (13%).

Hazard Identification

The identified risk agent was carbon monoxide (CO), with a measured average concentration of 180,332.9 µg/m³, exceeding the applicable ambient air quality standard. Factors influencing the concentration of CO, in addition to meteorological parameters, were also attributed to the number of vehicles passing through the area during the sampling period.

Table 5 : The total number of vehicles that passed through the area during the measurement period at Terminal Purabaya

No.	Sampling Point	Number of Vehucles (units)
1.	Point 1 (Bus arrival area)	44
2.	Point 2 (Bus parking area)	46
3.	Point 3 (Intraprovincial intercity bus shelter area)	30
4.	Point 4 (Interprovincial intercity bus shelter area)	17
	Total	**137**

The total number of vehicles recorded at all sampling locations was 137 units. In addition, several health complaints were reported by traders at Purabaya Terminal, as detailed below:

Table 6: Health-Related Symptoms Experienced by Traders at Purabaya Terminal

Health Complaints	Amount (n)	Percentage (%)
Nausea/vomiting	5	16%
Headache/dizziness	14	44%
Shortness of breath	12	37%
Watery eyes	20	62%

The most frequently reported complaint among the traders was watery eyes, experienced by 20 individuals (62% of the total respondents). Other reported symptoms included headaches or dizziness in 14 individuals (44%), shortness of breath in 12 individuals (37%), and nausea or vomiting in 5 individuals (16%).

Dose-Response Analysis

The dose-response analysis in this study was conducted by determining the Reference Concentration (RfC). Since the RfC for carbon monoxide (CO) was not available in the Integrated Risk Information System (IRIS) database of the U.S. Environmental Protection Agency (EPA), the CO concentration value was adopted from Ministry of Health Regulation No. 2 of 2023, which sets the threshold at 10,000 μg/m³. This value was then converted to 10 mg/m³ and substituted into the default parameters established by the Directorate General of Disease Prevention and Control, Ministry of Health, in 2012 [15].

Exposure Analysis

Exposure analysis was conducted by calculating the intake value. The calculation of carbon monoxide (CO) intake among traders was performed using Equation (I). The intake (I) of CO among traders at Purabaya Terminal is presented as follows:

Table 7 : Non-Carcinogenic Intake Values Among Traders at Purabaya Terminal in 2025

Sampling Point	Intake Values (mg/kg/hari)		
	Average	Maximal	Minimal
Point 1 (Bus arrival area)	36,726	44,790	29,211
Point 2 (Bus parking area)	7,0708	8,461	5,817
Point 3 (Intraprovincial intercity bus shelter area)	11,447	17,0781	6,804
Point 4 (Interprovincial intercity bus shelter area)	14,114	19,860	6,471

Sampling Point 1 had the highest average intake value of 38.72646789 mg/kg/day, with a maximum of 44.7081128 mg/kg/day and a minimum of 29.21139866 mg/kg/day. At Sampling Point 2, the average intake was 7.070891596 mg/kg/day, with a maximum value of 8.4161900426 mg/kg/day and a minimum of 5.817556543 mg/kg/day. Sampling Point 3 had an average intake of 11.41772477 mg/kg/day, while Sampling Point 4 showed an average intake of 14.1140519 mg/kg/day.

Risk Characterization

The following presents the calculation of the Risk Quotient (RQ) values for traders at the Purabaya Terminal:

Table 8 : Risk Quotient (RQ) Values Due to Carbon Monoxide (CO) Exposure Among Traders at Purabaya Terminal 2025

Lokasi Sampling	RQ Values (mg/kg/hari)		
	Average	Maximal	Minimal
Point 1 (Bus arrival area)	30,427	37,109	24,201
Point 2 (Bus parking area)	5,858	7,0106	4,819
Point 3 (Intraprovincial intercity bus shelter area)	9,484	14,149	5,637
Point 4 (Interprovincial intercity bus shelter area)	11,693	16,454	5,361

Based on the Risk Quotient (RQ) calculation of carbon monoxide (CO) exposure among traders at Purabaya Terminal, all respondents exhibited RQ values greater than 1, indicating unsafe conditions and a potential risk of non-carcinogenic health effects. The highest RQ value overall was observed at Point 1, with a maximum value of 37.1092057 mg/kg/day, while the lowest RQ value was found at Point 2, with a minimum value of 4.819848006 mg/kg/day.

Discussion

The measured concentration of carbon monoxide (CO) at Purabaya Terminal significantly exceeded the ambient air quality threshold. The average CO concentration reached 180,332.9 µg/m³, far surpassing the limit set by Ministry of Health Regulation No. 2 of 2023, which established a 1-hour exposure threshold of 10,000 µg/m³. The highest concentration was recorded at the bus arrival area, amounting to 355,117.1 µg/m³. These findings indicated that vehicle activities particularly diesel-fueled buses that remained idle for extended periods with engines running substantially contributed to CO emissions within the terminal. This observation aligned with a study by Guevara-Luna et al (2023) using a Monte Carlo CFD approach in Bogotá, which demonstrated that diesel bus emissions peaked during low-speed and idle conditions, increasing self-pollution exposure ratios by more than 50% under congested or stationary traffic scenarios [16]. These findings underscored the necessity for internal terminal traffic regulation, including limitations on engine-idling duration, mandatory vehicle emission testing, and routine ambient air quality monitoring.

Meteorological factors such as temperature, humidity, wind speed, and wind direction were measured to determine their influence on the dispersion and accumulation of CO gas. The results showed that wind speed had the most significant impact on elevated CO concentrations. Although temperature and humidity levels were relatively high, neither showed a meaningful correlation with CO accumulation. In contrast, low wind speed (approximately 1.14 m/s) hindered air dispersion, allowing CO to accumulate near ground level especially in densely congested areas such as the bus arrival area, which recorded the highest concentration of 355,117.1 µg/m³.

This finding aligned with Wirosoedarmo et al. (2020), who reported that wind speed contributed 61.68% to the reduction of CO concentration, indicating that lower wind velocities tend to cause pollutant accumulation in terminal environments [17]. Similarly, Rahmah et al. (2025) found that low wind speed in residential areas near emission sources led to the buildup of hydrogen sulfide (H_2S) in ambient air, worsening health complaints even though the pollutant levels remained below regulatory thresholds [18]. As a preventive measure, the implementation of green infrastructure such as vegetative walls on terminal buildings was recommended to improve pollutant dispersion and reduce CO exposure among traders and terminal users.

Hazard identification in this study confirmed that carbon monoxide (CO) was the primary risk agent within the Purabaya Terminal environment. CO is a toxic, colorless, and odorless gas that is easily inhaled through the respiratory tract, posing serious health risks when accumulated in the body over time. During the monitoring period, a total of 137 buses passed through the area within four hours, from an estimated 2,155 vehicles per day, reflecting a high traffic volume with substantial potential for increasing ambient CO concentrations. This directly affected traders working in the area. Interview data revealed that 62% of respondents experienced eye irritation, 44% reported headaches, 37% had difficulty breathing, and 16% experienced nausea or vomiting. The combination of high vehicle density and minimal air movement due to structural barriers and low wind speeds, created an environment with a considerable health risk for traders.

Dose-response analysis employed the Reference Concentration (RfC) value of 1.207 mg/kg/day as a benchmark for evaluating safe levels of long-term exposure. The results indicated that traders' intake values ranged from 5.81 to 44.79 mg/kg/day, meaning that all respondents had exposure levels exceeding the recommended threshold. Devy et al (2024) who observed that even when CO concentrations remained below air quality standards, cumulative effects still occurred among parking attendants over prolonged periods [14]. Accordingly, providing rest periods in low-pollution zones and conducting regular health check-ups were strongly recommended to reduce cumulative dose accumulation.

Exposure analysis in this study showed that individual characteristics significantly influenced the level of CO exposure among traders at Purabaya Terminal. Most respondents were male, within the productive age range (26–45 years), with body weights of ≥ 60 kg. Behavioral factors, such as smoking and the absence of protective gear (e.g., masks) increased vulnerability to inhaled pollutants. Furthermore, intense work patterns, with an average of 8 hours per day and more than 294 days per year, combined with work durations ranging from 3 to over 17 years, reflected consistent long-term exposure. Intake values calculated based on individual and environmental parameters varied between 5.82 and 44.79 mg/kg/day, with the highest levels observed in high traffic areas.

This pattern illustrated that duration, frequency, and intensity of exposure played critical roles in increasing the amount of CO entering the body via the respiratory system. Individuals with lower body weights and longer exposure durations tended to have higher intake values. This was corroborated by a study by Nurzahara et al (2024) on CO exposure risk among security and ticketing personnel at Safe N Lock, Sidoarjo, which found that officers with the lowest body weight (54 kg) and 9 hour workdays had the highest intake value of 4.258 mg/kg/day, while those with the highest body weight (100 kg) working the same duration recorded a lower intake of 2.876 mg/kg/day [19]. An individual's exposure level was strongly affected by pollutant concentration and the duration of time spent in contaminated areas, making personal exposure assessment essential in health risk evaluations [20]. The consistent use of KN95 respirator masks during work activities and the maintenance of an ideal body weight were identified as effective preventive strategies to reduce inhaled CO and overall intake levels, thereby minimizing long-term health risks.

Risk characterization for the traders at Purabaya Terminal revealed that all respondents (n = 32) had Risk Quotient (RQ) values greater than 1 (RQ > 1), indicating a potential for non-carcinogenic health effects due to CO exposure. These findings were in line with a study by Rangkuti et al (2022) at Giwangan Terminal, Yogyakarta, which also recorded RQ > 1 among all traders for both short-term and long-term exposure [12]. Conversely, research by Cahyono et al. (2024) at Bulupitu Terminal showed RQ ≤ 1, suggesting no significant health risk, likely due to lower CO concentrations stemming from lighter traffic density [13]. This comparison highlighted that risk characteristics are heavily influenced by both external factors (such as vehicle volume) and individual factors (such as work duration and activity location). These findings reinforced the necessity of continuous air quality monitoring and periodic risk assessments as a foundation for protecting informal workers' health in high-traffic transportation environments.

Nevertheless, this study has several limitations that must be considered when interpreting the findings. The lack of biological monitoring, such as assessing carboxyhemoglobin (COHb) levels in participants' blood, restricted the capacity to directly confirm CO absorption in the body. Furthermore, personal factors including diet, physical activity, smoking behavior, and pre-existing health conditions were not thoroughly examined, which could have affected the precision of the health risk assessment.

Conclusion

Carbon monoxide (CO) exposure among traders at Purabaya Terminal exceeded the safe threshold set by ambient air quality standards, with average concentrations reaching 180,332.9 μg/m³. Meteorological conditions particularly low wind speeds significantly contributed to limited pollutant dispersion, thereby increasing CO accumulation in high-traffic areas. CO was identified as the primary risk agent, originating from diesel-fueled motor vehicles, especially idling buses. Dose-response analysis, based on the Reference Concentration (RfC) of 1.207 mg/kg/day, showed that all intake values among traders ranged from 5.82 to 44.79 mg/kg/day, exceeding safe exposure limits. All respondents had Risk Quotient (RQ) values greater than 1, indicating a substantial non-carcinogenic health risk. Therefore, mitigation efforts, both technical and behavioral, such as reducing vehicle idle time, promoting the use of KN95 masks, and implementing green infrastructure are strongly recommended to minimize the health impact of CO exposure in the terminal environment.

Conflict of interest

Authors state no conflict of interest.

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