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*Article*

# Risk Analysis of Sulfur Dioxide ($SO_2$) Gas Exposure to Traders at Purabaya Terminal

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**Abstract**
Purabaya Terminal is characterized by high vehicle density, making it a potential source of air pollution, particularly from fossil fuel-powered vehicles, such as diesel, which emit sulfur dioxide ($SO_2$) gas. Exposure to $SO_2$ poses health risks to traders nearby, leading to symptoms such as shortness of breath, watery eyes, and dizziness. This study aimed to analyze the health risk levels associated with $SO_2$ exposure to traders at Purabaya Terminal. The research utilized an Environmental Health Risk Analysis (EHRA) approach with a quantitative descriptive design and a cross-sectional method. A sample of 32 traders was selected using purposive sampling techniques. Air sampling was conducted at four locations within the terminal, and data analysis assessed exposure levels and potential health risks to traders. The average $SO_2$ concentration was found to be 0.018 mg/m$^3$, which is below the threshold limit set in the Minister of Manpower Regulation No. 5 of 2018. The average air temperature was 29.9 °C, with humidity at 78.7% and wind speed at 1.14 m/s from the west. Intake exposure values ranged from 0.0007 to 0.0033 mg/kg/day, while the reference dose (RfC) was 0.026 mg/kg/day. Risk characterization calculations (RQ) indicated that all respondents had RQ values ≤ 1. The study concludes that $SO_2$ exposure levels for traders remain within acceptable health risk range and do not pose a non-carcinogenic health risk. However, it is recommended that traders use personal protective equipment such as masks and that terminal management conducts regular air quality monitoring.

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## Introduction

Air pollution is one of the most urgent environmental issues currently facing the world, especially in urban areas experiencing rapid growth. The increase in population, industrial activities, and the development of the transportation sector significantly contribute to air pollution [1]. United Nations Environment Programme notes that around 90% of air pollution in urban areas comes from motor vehicle emissions, making it a major contributor to global air pollution [2]. The World Health Organization emphasizes that 99% of the world's population is exposed to polluted air, with 6.7 million deaths each year due to the effects of air pollution, most of which occur in the Southeast Asia region [3].

Indonesia is among the countries with high levels of air pollution. According to reports, Indonesia ranks first in Southeast Asia and 14th globally, with an average Air Quality Index (AQI) reaching 105 [4]. East Java province, one of the most densely populated provinces, contributes significantly to high levels of air pollution, with an average AQI exceeding 150, which falls into the unhealthy category. In urban areas, emissions from motor vehicles are known to be a major contributor to air pollution, especially pollutants such as sulfur dioxide ($SO_2$), carbon monoxide (CO), nitrogen dioxide ($NO_2$), particulates (TSP), lead (Pb), and non-methane hydrocarbons (NMHC) [5]. Efforts for control through the establishment of Threshold Values (NAB) in the Regulation of the Minister of Employment of the Republic of Indonesia Number 5 of 2018 are crucial as a form of occupational health protection [6].

Purabaya Terminal or Bungurasih Terminal, located at the border of Surabaya City and Sidoarjo Regency, is one of the largest bus terminals in Southeast Asia. This terminal serves more than 58,000 passengers and thousands of vehicles every day [7]. The dense activity of vehicles, especially those powered by diesel, produces large amounts of $SO_2$ emissions. This gas is irritating, very soluble in water, and easily inhaled into the upper respiratory tract [8], with the potential to cause respiratory problems, coughing, chest pain, and eye irritation.

Purabaya Terminal during peak hours (3:00 PM – 6:00 PM), vehicle activity is very dense in the terminal area, especially in the bus arrival zone, which recorded 44 buses in three hours. Measurements of $SO_2$ concentration at four terminal points show that the bus arrival area has the highest concentration of 0.026 mg/m$^3$, followed by the Intercity Intra-Province and Intercity Inter-Province shelters at 0.018 mg/ m$^3$ each, and the parking area at 0.015 mg/ m$^3$. In addition, interviews with 32 permanent traders who have worked for more than two years at the terminal revealed that 63% experienced eye irritation, 50% experienced respiratory issues, and 38% experienced shortness of breath due to exposure to vehicle emissions. These numbers indicate a significant impact on the health of traders who are routinely exposed to air pollution.

Several previous studies have examined $SO_2$ exposure among traders in public areas such as markets and terminals, with results showing that the RQ values generally fall below 1, however respiratory complaints were still reported among traders [9][10][11]. On the other hand, a study by Shabrina and Pratama indicated RQ values above 1 although $SO_2$ concentrations were still below the quality standard, leading to inconsistencies in findings related to health risks [12]. Although many studies have examined the impact of $SO_2$ exposure on health, there is a research gap that has not been thoroughly investigated, particularly focusing on air quality in the working environment of stationary traders exposed directly at bus terminals.

The main issue in this research is the high potential exposure to $SO_2$ gas in the Purabaya Terminal environment due to emissions from motor vehicles and the lack of specific data regarding health risk levels for permanent traders who regularly and long-term carry out activities in that location. Findings of complaints related to respiratory issues and the effects resulting from $SO_2$ gas exposure among traders indicate a potential risk for respiratory health disturbances. Therefore, this study aims to analyze the risk level of $SO_2$ gas exposure for traders at the Purabaya Terminal using the Environmental Health Risk Analysis (EHRA) approach, in order to obtain a scientific picture that can be used as a basis for interventions and policies to control air quality in informal work environments.

## Materials and Methods

**Research Design and Setting.** This research is a quantitative descriptive study with an Environmental Health Risk Analysis (EHRA) approach aimed at calculating or estimating the risk factors of $SO_2$ gas exposure on the health of traders in the Purabaya Terminal area, using a cross-sectional design. The research was conducted from January to May 2025.

**Participants.** The population in the study consists of a subject population, namely all traders operating at Purabaya Terminal, totaling 283 individuals, as well as an object population in the form of air quality parameters and surrounding physical environmental conditions. The subject sampling was conducted using non-probability sampling techniques with purposive sampling methods based on inclusion criteria, which are permanent traders who work at least 6 hours a day during peak hours (3:00 PM - 6:00 PM), aged above 19 years, and have worked for more than two years. Based on these criteria, the number of subject samples that met the requirements amounted to 32 individuals.

**Source and Measurements.** Air samples in this study were collected from four strategic points according to the requirements of Indonesia National Standardization 19-7119.6-2005, which represent areas with high activity of traders and vehicles, namely the bus arrival area, Intercity Intra-Province bus shelter, Intercity Inter-Province bus shelter, and bus parking area, with a sampling radius ranging from 3 to 15 meters from the emission sources and the location of traders [13]. The process of taking and analyzing the concentration of $SO_2$ gas was carried out by the Surabaya Institute of Technology Environmental Engineering laboratory team using the pararosanilin method according to Indonesia National Standardization 19-7119.7-2017, with midget impinger equipment and readings through a spectrophotometer [14]. Environmental factor data such as temperature, humidity, wind direction, and wind speed were also collected using a thermohygrometer, windsock, and anemometer.

The research instruments used in this study include direct observation sheets of the working environment conditions of traders, observation sheets for measuring physical air (temperature, humidity, wind direction, and wind speed), observation sheets for measuring $SO_2$ gas concentration, and interview sheets to determine respondents' individual characteristics to gather data on exposure time, exposure frequency, exposure duration, individual characteristics (body weight, age, gender, smoking habits, and personal protective equipment usage habits), because individual characteristic data is only used as a supportive variable in risk estimation and is not analyzed inferentially, the interview instrument did not undergo a formal validity and reliability testing process but was compiled based on the national guidelines of EHRA guidelines from the Directorate General of Disease Prevention and Control Ministry of Health Republic of Indonesia 2012 [15]. Data collection techniques include interviews, direct measurements, field observations, documentation, and laboratory examinations.

**Data Analysis.** The data obtained was then processed by organizing it into tables and calculating the intake value and Risk Quotient (RQ). Data analysis was conducted univariately to describe the distribution of respondent characteristics and research variables, including age, gender, smoking habits, use of personal protective equipment, body weight, duration, and frequency of exposure, as well as air quality conditions. Subsequently, risk analysis was performed through four stages of EHRA, namely hazard identification, dose-response analysis using an RfC value of $SO_2$ of 0.026 mg/kg/day, exposure analysis to calculate intake. The calculation of non-carcinogenic intake values through the inhalation pathway can use the following equation or formula:

$$\text{Ink} = \frac{\text{C x R x tE x fE x Dt}}{\text{Wb x tavg}} \qquad \text{(A)}$$

Description:

Ink : Value of non-carcinogenic (mg/kg/day)

C : Concentration of $SO_2$ gas in the air working environment ($mg/m^3$)

R : Rate of air inhalation by a default value 0.83 ($m^3$/hour)

tE : Time of exposure per day (hours/day)
fE : Frequency of exposure (days/year)
Dt : Duration of exposure (years)
Wb : Weight of the respondent (Kg)
$t_{avg}$ : Average time period of non-carcinogenic effects by Dt x 365 days (days)

Health risk characterization is expressed through the Risk Quotient (RQ) value as an indicator of the level of non-carcinogenic health risk due to $SO_2$ exposure, by comparing the intake value to the RfC to assess the risk level for non-carcinogenic effects. The formula used is as follows:

$$RQ = \frac{Ink}{RfC} \quad \text{(B)}$$

Description:
RQ : *Risk Quotient* (Risk level)
Ink : *Intake* (Value of non-carcinogenic)
RfC : References dose $SO_2$ gas based on US-EPA $2.6E^{-2}$ (0.026) (Inhalation exposure)

The results of the RQ calculation are then used to determine the level of health risk, where RQ > 1 indicates a potential risk of health disorders, while RQ ≤ 1 indicates no significant risk for traders in the terminal environment.

The Environmental Health Risk Analysis (EHRA) approach focuses on the identification and calculation of health risk levels due to exposure to $SO_2$ gas in informal work environments, without conducting inferential analysis to test the significance of the relationship between individual characteristics and RQ, as the design of this study is not intended to test the relationships between variables.

**Research Ethics.** This research has been declared ethically appropriate by the 7 (seven) WHO 2011 Standards published by the Health Assessment Ethics Commission (KEPK) of the Polytechnic Ministry of Health Surabaya with number EA/3392 /KEPK-Poltekkes_Sby/V/2025.

## Results

### Concentration of Sulfur Dioxide ($SO_2$) Gas

**Table 1**

Concentration of $SO_2$ Gas at Purabaya Terminal

| Location | Concentration $SO_2$ Gas | |
|---|---|---|
| | **Quality Standard*** | **mg/m³** |
| Point 1 (Bus Arrival Area) | 0.25 mg/m³ | 0.026 |
| Point 2 (Intercity Intra-Province Bus Shelter) | | 0.018 |
| Point 3 (Intercity Inter-Province Bus Shelter) | | 0.018 |
| Point 4 (Bus Parking Area) | | 0.015 |

Table 1 shows that the measurement of $SO_2$ gas concentration in the workplace air was conducted directly, the average $SO_2$ concentration across all four sampling locations was 0.018 mg/m³, which is within the threshold of the quality standards according to the Minister of Manpower Regulation Number 5 of 2018 concerning Occupational Safety and Health in the Workplace, which is 0.25 mg/m³ [6]. These findings indicate that the ambient $SO_2$ levels in the traders' working environment are within acceptable limits as per national occupational health standards.

**Quality of Physical Air Environment**

**Table 2**

Quality of Air Environment at Purabaya Terminal

| Location | Temperature (°C)* | Humidity (%)* | Wind Speed (m/s) |
|---|---|---|---|
| Point 1 (Bus Arrival Area) | 31 | 73.3 | 0.5-1.8 |
| Point 2 (Intercity Intra-Province Bus Shelter) | 29.2 | 76.5 | 0.5-1.5 |
| Point 3 (Intercity Inter-Province Bus Shelter) | 29.4 | 85.4 | 0.1-1 |
| Point 4 (Bus Parking Area) | 30 | 79.5 | 1-2.7 |

Table 2 shows that the results of measuring the quality of the physical air environment indicate that from 4 monitoring points, the highest recorded temperature was 31°C with humidity at 85.4% and wind speed reaching 2.7 m/s. Meanwhile, the lowest measurement showed a temperature of 29.2°C, humidity of 73.3%, and wind speed of only 0.1 m/s. The average across all measurement points recorded a temperature of 29.9°C, humidity of 78.7%, and wind speed of 1.14 m/s, with the dominant wind direction coming from the west.

**Characteristics of Respondents**

**Table 3**

Characteristics of Traders at Purabaya Terminal

| Characteristics | Amount (n) | Percentage (%) |
|---|---|---|
| **Age** | | |
| Late Adolescence (19-25) | 3 | 9 |
| Early Adulthood (26-35) | 9 | 28 |
| Late Adulthood (36-45) | 12 | 38 |
| Early Senior (46-55) | 5 | 16 |
| Late Senior (56-65) | 3 | 9 |
| **Total** | **32** | **100** |
| **Gender** | | |
| Male | 30 | 94 |
| Female | 2 | 6 |
| **Total** | **32** | **100** |
| **Smoking Habit** | | |
| Smoking | 21 | 66 |
| Not Smoking | 11 | 34 |
| **Total** | **32** | **100** |
| **Mask Usage Habit** | | |
| Wearing Mask | 8 | 25 |
| Not Wearing Mask | 24 | 75 |
| **Total** | **32** | **100** |

Table 3 shows the characteristics of traders in the Purabaya Terminal area, where the majority are in the late adult age group (36-45 years) with an average age of 39 years, mainly male (94%). Furthermore, 66% of traders have a habit of smoking, and 75% do not use personal protective equipment in the form of masks while working.

**Description of Environmental Health Risk Analysis Variable**

**Table 4**

Description of Environmental Health Risk Analysis Variable in Traders at Purabaya Terminal

| Variable | Amount (n) | Percentage (%) |
|---|---|---|
| **Body Weight (Wb)** | | |
| < 60 Kg | 15 | 47 |
| ≥ 60 Kg | 17 | 53 |
| **Total** | **32** | **100** |
| **Inhalation rate (R)** for adults 0,83 $m^3$/hours [15] | | |
| **Exposure time (tE)** | | |
| < 8 hours/day | 5 | 16 |
| 8 hours/day | 27 | 84 |
| **Total** | **32** | **100** |
| **Exposure frequency (fE)** | | |
| 150-221 days | 4 | 13 |
| 222-293 days | 3 | 9 |
| 294-365 days | 25 | 78 |
| **Total** | **32** | **100** |
| **Exposure duration (Dt)** | | |
| 3-9 years | 12 | 38 |
| 10-16 years | 11 | 34 |
| 17-25 years | 9 | 28 |
| **Total** | **32** | **100** |

Table 4 shows that the majority of traders have an average body weight of ≥ 60 kg. The inhalation rate used is 0.83 $m^3$/hour, referring to the standard adult value for open work environments. There are 84% of traders working for 8 hours/day, and 78% are exposed for more than 294 days/year, with the majority of traders having worked between 3-9 years.

**Distribution of $SO_2$ Gas Exposure Intake Values**

**Table 5**

Distribution of $SO_2$ Gas Exposure Intake Values in Traders at Purabaya Terminal

| Location | Minimum | Average | Maximum |
|---|---|---|---|
| Point 1 (Bus Arrival Area) | 0.0021 | 0.0027 | 0.0033 |
| Point 2 (Intercity Intra-Province Bus Shelter) | 0.0009 | 0.0016 | 0.0024 |
| Point 3 (Intercity Inter-Province Bus Shelter) | 0.0007 | 0.0015 | 0.0021 |
| Point 4 (Bus Parking Area) | 0.0013 | 0.0015 | 0.0018 |

Table 5 shows that the distribution intake values of $SO_2$ gas at the four observed locations indicate that the highest average intake occurred at point 1 (Bus Arrival Area) with 0.0027 mg/kg/day, followed by point 2 (Intercity Intra-Province Bus Shelter) at 0.0016 mg/kg/day, and both point 3 (Intercity Inter-Province Bus Shelter) and point 4 (Bus Parking Area) at 0.0015 mg/kg/day.

**Distribution of Risk Characterization (RQ) of $SO_2$ Gas Exposure**

**Table 6**

Distribution of Risk Characterization (RQ) of $SO_2$ Gas Exposure in Traders at Purabaya Terminal

| Location | Intake (mg/kg/day) | RfC (mg/kg/day) | RQ Value | Risk Level |
|---|---|---|---|---|
| Point 1 (Bus Arrival Area) | 0.0027 | 0.026 | 0.1041 | Safe (Not at Risk) |
| Point 2 (Intercity Intra-Province Bus Shelter) | 0.0016 | 0.026 | 0.0623 | Safe (Not at Risk) |
| Point 3 (Intercity Inter-Province Bus Shelter) | 0.0015 | 0.026 | 0.0597 | Safe (Not at Risk) |
| Point 4 (Bus Parking Area) | 0.0015 | 0.026 | 0.0607 | Safe (Not at Risk) |

Table 6 shows that the distribution of risk characterization values by calculating all RQ values obtained at the four observation points in the Purabaya Terminal area is within the range of ≤ 1, with the highest average RQ value of 0.1041 and the lowest value of 0.0597. These values indicate that the exposure level of $SO_2$ gas to traders in Purabaya Terminal is in the within acceptable health risk range and does not pose a non-carcinogenic health risk.

## Discussion

The results of measuring sulfur dioxide ($SO_2$) gas concentration at Purabaya Terminal show variations in pollution levels among monitoring points, with the highest concentration of 0.026 mg/m$^3$ observed in the bus arrival area, which has the highest traffic intensity. The activity of vehicles stopping without turning off their engines (idling) greatly contributes to $SO_2$ emissions, consistent with findings at other terminals that recorded high concentrations in vehicle entry or exit areas [8][16]. Meanwhile, the lowest concentration was recorded in the bus parking area, reinforcing that vehicle activity is directly proportional to pollutant concentration in the air. Although the RQ value at Bulupitu Terminal was recorded at <1, respiratory complaints were still found among vendors, indicating that cumulative risk due to repeated exposure may still occur [11]. In general, the air quality at Purabaya Terminal is still in the safe category according to the Minister of Manpower Regulation Number 5 of 2018 concerning Occupational Safety and Health in the Workplace [6], but the difference in pollutant distribution indicates an increased potential risk in locations with high vehicle activity.

The high concentration of $SO_2$ in certain areas is closely related to the type of vehicles operating around terminals, particularly diesel-powered buses. This type of fuel contains a higher sulfur content compared to gasoline, thus resulting in greater exhaust gas emissions. Another study conducted on the Arteri Road in Malang City reinforces this by showing that heavy vehicles such as trucks and buses contribute higher $SO_2$ emissions compared to private vehicles [17]. The presence of a large number of diesel-powered vehicles at Purabaya Terminal is a significant factor in the accumulation of pollutants. Although ambient $SO_2$ levels are still considered safe, continuous long-term exposure still has the potential to cause serious health impacts, especially for vulnerable groups such as traders. Therefore, it is important to conduct regular air quality monitoring, at least every six months, as a preventive measure to maintain a healthy work environment and ensure the safety of terminal users.

Measuring physical air parameters such as temperature, humidity, and wind speed is an important factor in determining the distribution pattern of pollutants, as regulated in the Minister of Health Regulation Number 2 of 2023 [18], The measurement results at Purabaya Terminal show that the highest temperature was recorded in the bus arrival area, which also has the highest concentration of $SO_2$, indicating that high temperatures can hinder vertical mixing of air and cause gas accumulation in the lower layers of the atmosphere [8][16]. Humidity across all observation points exceeds 70%, which has the potential to accelerate the dissolution and deposition of pollutants, in line with findings at the Manado Terminal indicating a negative relationship between humidity and $SO_2$ concentration. Wind direction and speed also affect the dispersion of pollutants; strong winds can distribute pollutants more evenly, while slow winds tend to cause gases like $SO_2$ to settle on surfaces, thereby increasing the potential for direct exposure for individuals active in the area [19].

Hazard identification is the initial stage in the process of environmental health risk analysis aimed at recognizing risk agents that could potentially cause health disturbances. In this study, the observed risk agent is sulfur dioxide ($SO_2$) gas which is toxic, highly reactive, colorless, and has a pungent odor. This gas is easily soluble in water and quickly absorbed through the upper respiratory tract, making inhalation the main entry route into the human body. The primary source of $SO_2$ in the Purabaya Terminal environment comes from emissions of diesel-powered vehicles, particularly buses. During the sampling period, a total of 137 bus units were recorded passing through the observation area, with the highest points in the bus parking area and arrival zone. The arrival point recorded the highest level of $SO_2$ at 0.026 mg/m$^3$, in line with the high frequency of vehicles stopping with their engines running for a long time (idle). This indicates that the concentration of $SO_2$ is greatly influenced by the number and activity of vehicles, as well as the duration of exposure to emissions at a certain point.

Exposure to $SO_2$ gas in the air is known to cause various health symptoms, especially in the respiratory system. Based on interviews with 32 permanent traders at Purabaya Terminal, the most dominant complaint is eye irritation, experienced by 63% of respondents. In addition, 50% complained of respiratory disturbances due to the pungent smell of vehicle smoke, 44% experienced coughing, 38% shortness of breath, and 28% sore throat. These findings align with the toxicological characteristics of $SO_2$, which can cause acute to chronic effects on the respiratory system, especially in individuals with a history of lung disorders. The Centers for Disease Control and Prevention explains that exposure to $SO_2$ can lead to conjunctivitis and burns on the cornea at high concentrations, which supports the finding of eye irritation in this study [20]. In addition, the habit of smoking and not using personal protective equipment such as masks also increases the risk of respiratory disorders due to exposure to air pollution. Therefore, accurate identification of hazards related to the presence of $SO_2$ and understanding the symptoms that arise are essential foundations in formulating risk mitigation strategies for vulnerable groups such as terminal traders.

The dose-response analysis in this study aims to determine how much exposure to sulfur dioxide ($SO_2$) through inhalation can be tolerated by the body without causing harmful effects, particularly to the respiratory system. This stage produces a reference value used to compare actual exposure levels, known as Reference Concentration (RfC), which indicates the safe limit for long-term daily exposure. Based on official sources such as the Integrated Risk Information System (IRIS) and the U.S. Environmental Protection Agency National Ambient Air Quality Standards (U.S. EPA/NAAQS) from 1990, the RfC value for $SO_2$ as a non-carcinogenic pollutant is set at 0.026 mg/kg/day. If the exposure level received by an individual is below this figure, then the risk of health issues, particularly respiratory disorders, can be considered low or insignificant.

Exposure analysis was conducted to identify the pathways of $SO_2$ gas entering the body, considering individual characteristics that may affect the level of exposure. The individual characteristics in Table 3 show that age, gender, smoking habits, and the use of protective equipment such as masks affect the level of vulnerability to $SO_2$ gas exposure in the workplace. The majority of traders are in the late adult age group (36–45 years) with an average age of 39 years, who physiologically have experienced a decline in organ function, including the respiratory system, making them more susceptible to toxic effects [21]. Most of the respondents are male (94%), who tend to inhale more air due to larger lung capacity, thus having a higher potential for pollutant exposure [22][23]. Additionally, about 66% of traders have smoking habits that increase the risk of bronchial irritation and lung disorders [24][25]. As many as 75% of respondents do not use personal protective equipment such as masks while working, which increases the risk of pollutants entering the respiratory system. The lack of awareness or comfort in using masks poses a barrier to the implementation of self-protection, whereas the use of personal protective equipment is effective in reducing direct exposure to air pollution in the terminal environment.

Based on Table 4, it can be illustrated that factors such as body weight, inhalation rate, exposure time, frequency of exposure, and duration of exposure can determine the level of health risk due to $SO_2$ exposure at Purabaya Terminal. Most traders have an average weight above 60 Kg and generally fall into the underweight to ideal category, which physiologically tends to be more vulnerable to exposure to pollutants in the work environment [11]. The inhalation rate used is 0.83 $m^3$/hour, referring to the standard respiratory capacity of adults in open work areas [15]. Most traders (84%) work for 8 hours a day, while around 78% of them are exposed for more than 294 days a year. This high frequency of exposure increases the potential accumulation of health risks [26][27]. In addition, the long duration of work, with the majority ranging from 3 to 9 years or even some others more than 17 years, indicates chronic exposure that can potentially lead to long-term effects on the respiratory system [28]. The combination of these factors serves as the basis for accurately calculating intake values and risk characterization.

The intake exposure values in Table 5 indicate the amount of $SO_2$ gas that enters the body through respiration, and this research shows variations based on the traders' work locations. The highest intake was recorded in the bus arrival area at 0.0033 mg/kg/day, while the lowest was in the AKAP bus shelter at 0.0007 mg/kg/day. This variation is influenced by the concentration of $SO_2$ at each point as well as individual characteristics such as body weight and duration of exposure [26]. Intake is directly proportional to pollutant concentration, inhalation rate, duration, and frequency of exposure, but inversely proportional to body weight, as individuals with higher body weight tend to have lower intake values [12].

The risk characterization value or Risk Quotient (RQ) is the result of calculations established as an interpretation to determine health risks. Table 6 shows that all observation points at Purabaya Terminal indicate RQ values $\leq 1$, with the lowest value at 0.0273 and the highest at 0.1269, which means that all traders are not experiencing non-carcinogenic health risks due to $SO_2$ exposure. This value indicates that the daily exposure received by traders is still within safe limits according to the US EPA criteria. This finding is consistent with studies conducted on traders at Bulupitu Terminal and at gas station staff, where all RQ values were also below one [11][26]. In contrast, a study conducted on the community in the Yogyakarta region reported RQ values > 1 at several points, indicating that environmental conditions and pollutant concentrations significantly affect the risk characterization results [29].

The risk level analysis indicates that the low RQ value at Purabaya Terminal is influenced by a combination of various factors, including a relatively low concentration of $SO_2$ that remains well below the quality standard set by the Minister of Manpower of the Republic of Indonesia Number 5 of 2018 at 0.25 $mg/m^3$ [6], as well as individual characteristic factors such as body weight, exposure time, exposure frequency, and exposure duration. These results indicate that, in general, the non-carcinogenic health risk posed is classified as low. The EHRA analysis also serves as a predictive tool, thus long-term exposure still needs to be monitored, especially considering that some traders have worked for over 10 years in an environment that potentially exposes them to pollutants. Therefore, these results become an important basis for developing preventive measures and ongoing monitoring of the health of informal workers in the terminal environment.

Preventive measures are recommended to minimize the impact of long-term exposure, such as the routine use of masks as personal protective equipment and periodic lung function checks. Additionally, the active role of terminal managers is also needed, for example, by implementing restrictions on the duration of vehicle engines idling, traffic management to avoid congestion in crowded areas, and adding green open spaces. Research indicates that plants in green open spaces can absorb sulfur dioxide pollutants, showing that vegetation such as the Java Tamarind tree (*Tamarindus indica*) has the highest $SO_2$ absorption ability up to $5.06 \times 10^9$ $mg/m^3$, making it a strategic choice for planting around the terminal [30]. The use of these pollutant-absorbing plants can be part of an ecological and sustainable risk mitigation strategy in controlling air quality in public transportation areas.

## Conclusions

This research shows that the average concentration of $SO_2$ gas at the Purabaya Terminal is 0.018 mg/m3, which is still below the threshold standard based on the Regulation of the Ministry of Manpower Republic of Indonesia No 5/2018, with the physical environmental characteristics of the air such as temperature, humidity, and wind speed that can affect the dispersion of pollutants. Exposure to $SO_2$ originating from motor vehicle emissions, especially diesel fuel buses, has the potential to cause respiratory disturbances, although the intake values and risk characterization (RQ) obtained remain within acceptable health risk range ($RQ \leq 1$), indicating that the non-carcinogenic health risk to traders is still considered low. However, preventive efforts are still needed through regular air quality monitoring, increasing awareness of the use of personal protective equipment such as masks, and optimizing green open spaces around terminals as natural filters for pollutants. Terminal managers are also advised to implement technical policies such as limiting engine idle time and planting $SO_2$ absorbing vegetation that has proven effective, in order to create a healthier and more sustainable working environment. This study makes an important contribution by focusing on the informal workforce population, which has not been widely studied in terms of environmental health risks, thereby expanding the scope of EHRA research. The results of this study can serve as a preliminary reference for policymakers in formulating strategies to control air quality in terminal areas and developing protection policies for vulnerable groups such as street vendors. In addition, this research opens up opportunities for further studies that integrate analytical approaches and biomonitoring to strengthen the evidence of the long-term impact of $SO_2$ exposure.

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## Informed Consent Statemen

Informed consent was obtained from all subject involved in the study.

**Conflicts of Interest**

The authors declare no conflict of interest.

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