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HEALTH RISK ASSESSMENT OF SO_2 AND $PM_{2.5}$ EXPOSURE AMONG PARKING ATTENDANTS IN NORTH JAKARTA

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ABSTRACT

Health Risk Assessment of SO_2 and $PM_{2.5}$ Exposure Among Parking Attendants in North Jakarta. *Air pollution has significant adverse effects on human health, particularly on the respiratory system. Prolonged exposure to pollutants such as fine particulate matter ($PM_{2.5}$) and sulfur dioxide (SO_2) can lead to respiratory damage. Boulevard Raya Street in North Jakarta is an industrial area with heavy traffic, where parking attendants spend long hours outdoors and are continuously exposed to ambient air pollutants. This study aims to assess the health risk posed by $PM_{2.5}$ and SO_2 exposure to parking attendants working along Boulevard Raya Street, Kelapa Gading, North Jakarta, in 2024. A quantitative approach was used, employing the Environmental Health Risk Analysis (EHRA) method with 18 respondents. Variables analyzed included gender, age, body weight, working hours, and exposure duration. The analysis showed that most respondents were aged between 18–50 years, with exposure durations of up to 8 hours/day, 350 days/year, over a 30-year period. The estimated average intake of $PM_{2.5}$ was 10.88 mg/kg/day, with a Risk Quotient (RQ) of 1.83—indicating a potential non-carcinogenic health risk. In contrast, the average intake of SO_2 was 3.56 mg/kg/day with an RQ of 0.22, which falls within the acceptable safety threshold. In conclusion, $PM_{2.5}$ exposure among parking attendants in the study area exceeds safe limits and poses a health risk, while SO_2 exposure remains within tolerable limits.*

INTRODUCTION

Air pollution remains a significant environmental issue, comprising particles and chemical substances in the air that can harm humans, animals, and plants. Sources of air pollution originate from various human activities such as industries, motor vehicles, and forest or land fires during the dry season. Air pollution contains several pollutants including carbon monoxide (CO), particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), and ozone (O_3), which are highly detrimental to human health. According to Ertiana [6] air pollution is one of the main causes of lung cancer, heart disease, and acute and chronic respiratory diseases. The

population growth and high urbanization rate in the Jakarta metropolitan area have resulted in increased energy demand, transportation, and industrial activities, which contribute to rising emissions of air pollutants. The high volume of motor vehicles during peak hours leads to significant exhaust emissions, and excessive use of vehicle fuel can increase air pollutant emissions [25],

Based on WHO data in 2021, globally, air pollution causes approximately 6.7 million deaths annually due to heart disease, lung cancer, and acute respiratory infections such as pneumonia. Pollutants $PM_{2.5}$ and SO_2 originate from various sources; $PM_{2.5}$ particles are very small, measuring $_{2.5}$ microns (micrometers), and sulfur dioxide (SO2) gases typically come from motor vehicles, industrial activities, and household combustion appliances. $PM_{2.5}$ and SO2, when entering the human respiratory system, cause respiratory problems and cardiovascular diseases [12],. According to the final report of the Directorate of Disease Prevention and Control, Ministry of Health of the Republic of Indonesia, in 2023 there were 1.5 to 1.8 million cases of acute respiratory infections (ARI) in Indonesia, with Jakarta alone experiencing a rise of up to 100,000 ARI cases per month within six months.

The increasing incidence of ARI in Jakarta is attributed to the deteriorating air quality in the city. Based on the Air Pollution Standard Index (ISPU) report from the Ministry of Environment and Forestry in October 2023, Jakarta is among five regencies/cities with unhealthy ISPU values. These cities include Palembang (208) classified as very unhealthy, South Tangerang, Serpong (135) unhealthy, Bekasi (119) unhealthy, Cirebon (115) unhealthy, and DKI Jakarta (115) unhealthy. This is further supported by the 2023 final report of air quality monitoring in Jakarta Province, where the Kelapa Gading area ranked third with an ISPU value of 77 (Directorate of Air Pollution Control, 2023) [4],.

Various efforts have been undertaken by the Environmental Agency of DKI Jakarta Province to control air pollution, including the installation of additional Air Quality Monitoring Stations (SPKU) to expedite air pollution management. The Air Quality Monitoring System (SPKU) serves to identify locations in Jakarta with high pollution levels. Besides increasing SPKU installations, the Environmental Agency also conducts tree planting activities for reforestation. Cross-sectoral collaboration has been implemented through the expansion of Low Emission Zones (LEZ) to mitigate air pollution impact. There are two LEZ areas in Jakarta: the Old Town Jakarta area and the LEZ Tebet Eco Park area on Tebet Timur Raya and Tebet Barat Raya Streets. Furthermore, the Environmental Agency also conducts Large Scale Social Collaboration (KSBB) involving various sectors from government and private parties utilizing technology to enhance monitoring and evaluation of air quality, pollution control policies, pollution impact assessment, and law enforcement related to air pollution [18].

The Boulevard Raya Street area in North Jakarta is a densely trafficked area lined with many shophouses. Moreover, the Boulevard Raya area, Kelapa Gading, is surrounded by industrial zones with numerous large industries. Based on observations in Boulevard Raya, Kelapa Gading, North Jakarta, this area frequently experiences daily traffic congestion, typically during peak hours between 07:00-09:00 AM and 16:00-19:00 PM. In addition to heavy traffic, many parking attendants are scattered along Boulevard Raya Street, having worked for years and thus potentially exposed to air pollutants. To determine the impact of air pollutants on public health, further analysis is required. This study aims to assess the health risk values among parking attendants exposed to air containing $PM_{2.5}$ and SO_2 in the Boulevard Raya Street area, Kelapa Gading, North Jakarta, in 2024.

MATERIALS AND RESEARCH METHODS

This research employs a quantitative approach using the Environmental Health Risk Analysis (EHRA) method. The EHRA consists of several stages, namely hazard identification, dose-response analysis, exposure assessment, and risk characterization. The study was conducted in Boulevard Raya Street, Kelapa Gading, North Jakarta, in January 2024. Secondary data were used, consisting of ambient air quality monitoring data conducted by the Environmental

Agency of DKI Jakarta Province through the Ambient Air Quality Monitoring Station (SPKUA) DKI2 - Kelapa Gading, North Jakarta. The sample consisted of 18 individuals meeting the inclusion and exclusion criteria, namely aged 17-60 years, having worked at least one year, and being permanent parking attendants on Boulevard Raya Street, North Jakarta. The variables in this study include $PM_{2.5}$ and SO_2 concentrations and respondent characteristics such as gender, age, body weight, working hours, and Environmental Health Risk Analysis. Data processing was conducted following the EHRA guidelines with the following formula equations (EHRA guidelines):

$$I_{nk} = \frac{C \; x \; R \; x \; t_E \; x \; f_E x D_t}{W_b \; x \; t_{avg}}$$

Explanation / Notes:

Ink	: intake (mg/kg/day)
C	: risk agent concentration
R (rate)	: volume of inhaled air
tE	: exposure duration (hours/day)
fE	: exposure frequency (days/year)
Dt	: exposure duration (years)
Wb	: body weight (kg)
tavg	: average time period

RESEARCH RESULTS AND DISCUSSION

The Boulevard Raya area in Kelapa Gading, North Jakarta, is located within an industrial zone and is densely populated. This area has numerous shophouses lined up and includes the vicinity of Summarecon Mall Kelapa Gading. The rows of shophouses generate significant employment for both formal and informal parking attendants. Additionally, temperature and air measurements were conducted during the study. The recorded average temperature ranged from 29°C to 35°C. Higher air temperatures cause air to expand and reduce pollutant concentration; therefore, lower pollutant conditions tend not to cause respiratory disturbances [13] Air quality measurements were conducted during peak traffic hours in the Boulevard Raya area, North Jakarta. In accordance with Government Regulation No. 22 of 2021 concerning the Implementation of Environmental Protection and Management, the concentrations of both parameters were calculated and compared with ambient air quality standards. The average SO_2 concentration was categorized as good, whereas the $PM_{2.5}$ concentration was categorized as unhealthy.

The highest SO_2 concentration was recorded at 18:00 hours with a value of 35 $\mu g/m^3$, while the highest $PM_{2.5}$ concentration was recorded at 17:00 hours with a value of 108 $\mu g/m^3$. These times correspond to the highest recorded values for SO_2 and $PM_{2.5}$, as the period between 16:00 and 19:00 hours represents peak motor vehicle traffic, including public transportation, private cars, trucks, and heavy-duty vehicles traversing this route. During heavy traffic, motor vehicles emit higher amounts of pollutants detected by air quality sensors [8]

Based on the Environmental Health Risk Analysis (EHRA), the risk agents SO_2 and $PM_{2.5}$ can cause non-carcinogenic effects, with $PM_{2.5}$ posing an unsafe risk to health. PT Voda Stell, located 300 meters from the residential area of The Gading Residence, is the primary pollutant source in the Boulevard Raya area, Kelapa Gading, North Jakarta. Iron smelting industries and motor vehicle combustion are the causes of these pollutants. The smokestack emissions from iron smelting conducted by PT Voda Stell lack complete pollution control equipment, resulting in $PM_{2.5}$ and SO_2 particles affecting the ambient air quality in the surrounding area.

Exposure to $PM_{2.5}$ is often associated with increased incidence and mortality from diseases such as stroke, ischemic heart disease, Chronic Obstructive Pulmonary Disease (COPD), and lung cancer. Premature death can occur if the body is exposed to $PM_{2.5}$ over prolonged periods, especially in individuals with chronic heart or lung diseases [2] Meanwhile, SO_2 exposure can be harmful to the body, particularly for asthma sufferers, and can also cause pulmonary edema and fluid accumulation in the lungs. To determine the toxicity levels of the risk agents $PM_{2.5}$ and SO_2, dose-response assessment needs to be conducted. Dose-response assessment is the most crucial component in the Environmental Health Risk Analysis (EHRA).

Table 1. Measurement Results of $PM_{2.5}$ and SO_2 at Boulevard Raya Street, Kelapa Gading, Jakarta

Measurement Time	$PM_{2.5}$ concentration (µg/m3)	SO2 concentration (µg/m^3)
08.00 – 09.00	102 µg/m3	34 µg/m3
16.00 – 17.00	105 µg/m3	34 µg/m3
17.00 – 18.00	106 µg/m3	35 µg/m3
18.00 – 19.00	108 µg/m3	35 µg/m3

The measurement results indicate that the SO2 parameter remains below the ambient air quality standard based on Government Regulation No. 22 of 2021 concerning Environmental Protection and Management, which is set at 150 µg/m^3. Meanwhile, the $PM_{2.5}$ parameter standard is 55 µg/m^3. Therefore, when compared to these standards, the SO_2 concentration still complies with the quality standard, whereas the $PM_{2.5}$ concentration does not meet the standard.

Table 2. Dose-Response Values of Risk Agents $PM_{2.5}$ and SO_2

Risk Agent	Rfc Value	Adverse Effects
Particulate Matter PM2.5	15 µg/m^3	Respiratory tract disorder
Sulfur Dioksida (SO_2)	2,6E-2	Respiratory tract disorder

Source: www.epa.gov.iris and *National Ambient Air Quality Standart (NAAQS)*

The toxicity value of the risk agents is expressed as the Reference Concentration (RfC) via the inhalation route, which is obtained from literature sources, namely the U.S. Environmental Protection Agency (EPA) Integrated Risk Information System (IRIS) for non-carcinogenic effects. The dose-response value (RfC) of the risk agents can be calculated directly or referenced from previous studies. The toxicity values of the risk agents $PM_{2.5}$ and SO_2 are presented in Table 2. The next stage involves exposure analysis, which can be calculated through the intake values of $PM_{2.5}$ and SO_2 exposure, based on ambient air quality measurement results. Ambient air quality monitoring at Boulevard Raya Street, Kelapa Gading, North Jakarta, was conducted four times, with each measurement lasting one hour, producing minimum, maximum, and average concentrations of the risk agents $PM_{2.5}$ and SO_2 at a single measurement location.

Respondents in this study were parking attendants spread along Boulevard Raya Street, Kelapa Gading, North Jakarta, who are potentially exposed to $PM_{2.5}$ and SO_2 air pollutants located up to 300 meters from the air quality monitoring point. The respondents' average exposure time to pollutant concentrations was greater than 8 hours per day. Body weight measurements were conducted by the researchers using a scale, yielding an average respondent body weight of 62 kilograms. To calculate the intake of risk agents among parking attendants, exposure time and respondent body weight were used as reference parameters in the calculation.

The Risk Quotient (RQ) value is used to indicate the risk level of pollutant agents and to show the toxicity level of risk agents entering the human body projected over a specific period. The RQ result can demonstrate whether the exposure is still within a safe category or not. If the result indicates an unsafe level, control measures are necessary. The formulas used to calculate intake and risk level in the Environmental Health Risk Analysis are as follows:

Table 3. Calculation Results of Intake and Non-Carcinogenic Risk Quotient (RQ) Values, and Safety Category with RQ ≥ 1 at Boulevard Raya Street, Kelapa Gading, North Jakarta

	Ink (Intake)		**RQ (Risk Quotient)**	
	PM2.5	SO_2	PM2.5	SO_2
Minimum	10,55	3,51	**1,77**	0,21
Maximum	11,17	3,62	**1,88**	0,22
Averange	10,88	3,56	**1,83**	0,22
Risk Management				
C_{nk} (safe)	55 µg/m^3			
tE_{nk} (safe)	4,18 hours/day			
fE_{nk}(safe)	183 days/year			
Dt_{nk}(safe)	16 year			

Note: The bolded values represent the concentration levels of the risk agent where RQ > 1.

Based on the calculation results presented in Table 3, it can be observed that there is an RQ value categorized as unsafe, indicated by an RQ ≥ 1 for the $PM_{2.5}$ parameter. This implies a potential non-carcinogenic effect on parking attendants working around Boulevard Raya Street, Kelapa Gading, North Jakarta. The exposure intake rate was recorded at 0.83 m^3/hour over an 8-hour daily period, 350 days per year, projected over a 30-year time frame. The average body weight of the parking attendants was 61.55 kg. Based on these calculations, there is a need for follow-up action.

According to Table 3, the safe concentration for $PM_{2.5}$ is 55 µg/m^3, with a safe exposure duration of 4 hours per day and an optimal exposure frequency of 183 days per year. The safe exposure duration is projected over a 16-year period.

Risk management is essential to address the $PM_{2.5}$ issue in the Boulevard Raya Street area, Kelapa Gading, North Jakarta. Several measures can be implemented to mitigate the problem, including regular measurement and continuous monitoring of ambient air quality, particularly PM2.5, to identify pollution levels in the Kelapa Gading area. Monitoring and enforcement efforts should be carried out by the Provincial Government of DKI Jakarta through the Environmental Office and the Transportation Agency, which can establish a dedicated unit for monitoring and enforcing air pollution regulations.

Given that the study area lies within an industrial zone, it is necessary for the DKI Jakarta Government to implement emission control policies targeting major sources of pollutants such as industrial facilities, motor vehicles, and waste burning. Additionally, installing Air Pollution Standard Index (ISPU) monitoring devices in high-traffic areas would serve as an important source of public information. Urban greening initiatives involving tall vegetation and food crops should also be considered to reduce air pollution and promote urban biodiversity through the development of green city concepts.

In addition to risk management, risk communication is also essential. This can be achieved through cross-sector collaboration, including with the Ministry of Environment and Forestry (KLHK), to reduce air pollution. Public outreach about the health impacts of air pollution should be disseminated via various media platforms, both online and offline.

CONCLUSIONS AND RECOMMENDATIONS

The findings indicate that parking attendants working on Boulevard Raya Street, North Jakarta, have an average age of 31.4 years, with a total of 18 individuals observed. The concentration of $PM_{2.5}$ in the area exceeded the ambient air quality standards set by Government Regulation of the Republic of Indonesia No. 22 of 2021, which is 55 µg/m^3. In contrast, SO_2 concentrations remained within safe limits. The average intake value for $PM_{2.5}$ was 10.88 mg/kg/day, while SO_2 was 3.56 mg/kg/day. The Risk Quotient (RQ) for $PM_{2.5}$ was 1.83, exceeding the safety threshold (RQ > 1), indicating a potential health risk. Meanwhile,

the RQ for SO_2 was 0.22, which remains within a safe range. The higher the level of exposure or intake, the higher the RQ value, thus increasing the potential health risk.
As a direct mitigation measure, it is recommended that the relevant agencies not only focus on long-term efforts such as reforestation and emission reduction but also prioritize immediate protection for parking attendants. One realistic approach is the provision of personal protective equipment (PPE), such as particle filtration masks (e.g., N95 masks), for workers stationed in high-pollution areas. Additionally, work schedules should be managed by implementing rotation systems or reducing outdoor working hours, particularly for workers who are exposed for more than 8 hours per day. These efforts should be supported by cross-sector collaboration between local governments, health agencies, and environmental authorities to ensure regular air quality monitoring and effectively minimize health risks.

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