Journal of Epidemiology and Public Health (2025), 10(01): 126-133
Masters Program in Public Health, Universitas Sebelas Maret

Research
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Hazard Quotient Association of SO_2 Exposure to Respiratory Symptoms: Study on Scavengers in Sarimukti Landfill, West Bandung Regency, East Java, Indonesia

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Received: 3 November 2024; Accepted: 8 December 2024; Available online: 16 January 2025

ABSTRACT

Background: The WHO reported that airborne diseases were responsible for 39 million deaths, accounting for 57% of the total 68 million deaths worldwide in 2021. Landfills are a significant source of air pollution, producing sulfur dioxide (SO2) gas, which is harmful to respiratory health, particularly the lungs. This study aims to examine the relationship between the hazard quotient of SO2 exposure and respiratory symptoms among scavengers at the Sarimukti landfill in West Bandung Regency, using an environmental health risk analysis approach.
Subjects and Method: The research contributes to exposure risk management by establishing safe thresholds for SO2 concentration, exposure time, and frequency for scavengers. This study adopts a correlation design with a longitudinal approach. The sample consisted of 101 scavengers selected through accidental sampling. Pollutant measurements were taken at two locations within the Sarimukti landfill. The independent variable in this study is the hazard quotient value of SO2 exposure, while the dependent variable is respiratory symptoms in scavengers.
Results: The results indicated a (OR= 15.83; 95% CI= 1.10 to 226.67; p= 0.008). Risk management is based on a safe SO2 concentration limit of 14.18 µg/m³, an exposure time of 15 hours, and an exposure frequency of 637 days over 30 years.
Conclusion: The measurement result of SO2 concentration of 7.38 µg/m³ is still below the specified quality standard of 150 µg/m³. However, through the calculation of the hazard quotient, the concentration exceeds the safe limit (HQ >= 1). The implication of this study in preventing the occurrence of respiratory symptoms in waste pickers is the use of PPE, limiting working hours and days in the landfill.

Keywords: Air pollution, hazard quotient, respiratory symptoms, sulphur dioxide

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Cite this as:
Parulian TS, Firmansyah YW, Niman S (2025). Hazard Quotient Association of SO2 Exposure to Respiratory Symptoms: Study on Scavengers in Sarimukti Landfill, West Bandung Regencyia. J Epidemiol Public Health. 10(1): 126-133. https://doi.org/10.26911/jepublichealth.2025.10.05.12.

BACKGROUND

WHO revealed that airborne diseases are the cause of 39 million deaths or 57% of the total 68 million deaths worldwide in 2021 (WHO, 2024). Among the various air pollutants that can trigger air poisoning is sulfur dioxide

(SO2). Short-term exposure to this pollutant has been shown to cause morbidity in adults and children, as well as in the asthmatic and elderly (Anastasopolos et al., 2021). Variations in SO2 concentrations have various toxicities, such as a study conducted in China in 2018, SO2 concentrations of 10 g/m3, and an increase in the average SO2 concentration over two days contributed to the rise in mortality of 0.59% (Wang et al., 2018). The pollutant contributes significantly to health problems in several developing countries (Serbula et al., 2021).

Sulfur dioxide is toxic to respiratory function, especially the lungs. Material Safety Data Sheet (MSDS) revealed that a concentration of 20 ppm of the pollutant can cause eye, nose, throat, sinus irritation, pulmonary edema, and even death (Nurhisanah and Hasyim, 2022). Other impacts of the pollutant are decreased lung function and risk factors for asthma. The sources of sulfur dioxide pollutants are diverse, and this study focuses on assessing the risk of these pollutants to scavengers at the Sarimukti landfill in West Bandung Regency.

Landfills employ a variety of waste management methods, of which open dumping has the greatest negative impact, mainly through gas emissions. These gases come from the anaerobic decomposition of organic matter in municipal waste. These gas emissions adversely impact human well-being and ecosystem sustainability (Vaverková, 2019). Identified that landfill gas mainly consists of methane (CH4) and carbon dioxide (CO2), and contains harmful pollutants such as hydrogen sulfide (H2S), water vapor (H2O), ammonia, and siloxane. Uncontrolled landfill gas emissions can harm plant biota, cause soil degradation, and alter its mineral composition (Vaverková, 2019). In addition, CO2 in the gas can contaminate water sources and degrade their quality. Landfill gas releases also exacerbate the greenhouse effect, which negatively impacts global climate change. Due to the significant environmental and health impacts, mitigating landfill gas emissions is a top priority. Modern technologies are now used to monitor and reduce these emissions, with an emphasis on biogas capture and utilization as energy as part of prevention strategies (Barros et al., 2018; Ciuła et al., 2023a; Scheutz and Kjeldsen, 2019) (Barros et al., 2018).

This study focuses on Sarimukti Landfill to address the critical issue of sulfur dioxide (SO_2) exposure through an Environmental Health Risk Assessment (EHRA). The risk assessment incorporates key parameters, including the concentration of SO_2 in the air, the inhalation rate, duration of exposure, and working hours of scavengers. While EHRA methodologies have been widely applied in various occupational settings, such as the study by Nurhisanah and Hasyim (2022) on Combined Cycle Power Plant (CCPP) workers, a notable research gap exists in the context of landfill scavengers. Specifically, this study uniquely calculates the hazard quotient (HQ) for individual scavengers at Sarimukti Landfill, located in West Bandung Regency, an approach not extensively explored in prior research. Additionally, this study statistically examines the correlation between the HQ and the prevalence of respiratory symptoms among scavengers, providing a novel perspective on the health risks posed by SO_2 exposure. By filling this gap, the study aims to quantify the hazard quotient and establish the relationship between SO_2 exposure and respiratory health, contributing valuable risk management insights into occupational health in landfill environments.

SUBJECTS AND METHOD

1. Study Design

This research is categorized in correlation, which is to determine the relationship between hazard quotient and respiratory symptoms in scavengers at Sarimukti Landfill, West Bandung Regency. The design used is longitudinal, namely the value of sulfur dioxide concentration measured with two repetitions landfill Sarimukti area.The independent variable in this study is the hazard quotient value of SO2 exposure with the dependent being respiratory symptoms in waste pickers. The study was conducted on November 12, 2024. SO2 pollutant analysis was conducted by the laboratory of the Bandung Occupational Safety and Health Center, Ministry of Manpower of the Republic of Indonesia.

2. Population and Sample

The study subjects were people who met the following inclusion criteria. The sample size was calculated using the GPower application with a 5% error rate, 95% confidence interval, and an effect size of 0.5, resulting in 101 people as the sample. This study used a non-random sampling technique with the accidental sampling method, where the sample was selected based on inclusion criteria, ease of access, and respondent willingness. The results of the GPower plot calculation with the following inclusion criteria, willing to be a respondent, located in the active zone of the landfill, aged 17-55 years.

3. Study Variables

The dependent variable in this study was respiratory symptoms in scavengers at Sarimukti Landfill in West Bandung Regency, while the independent variable was the hazard quotient.

4. Operational Definition of Variables

The hazard level: is quantified numerically, with the unit µg/m3, which represents the ratio between intake and the reference dose/concentration of the risk factor, particularly for non-carcinogenic risks. This measurement can also be understood as an indication of the safety or hazard posed by the risk factor to an organism, system, or subset/population.

The respiratory symptoms: are respiratory problems felt by Scavengers and workers during their stay at Sarimukti Landfill in West Bandung Regency.

5. Study Instrument

The pollutants were measured at the testing laboratory of the Bandung Occupational Safety and Health Center, Ministry of Manpower of the Republic of Indonesia. The hazard quotient was obtained using the environmental health risk analysis (EHRA) method. Respiratory symptoms are measured by anamnesis (nursing diagnosis).

6. Data Analysis

The data scale in this study is dichotomous (ordinal) on both variables. Data were transformed from ratio to category. The correlation test was conducted with Kendall tau statistics because the sample was more than 50 people. Descriptive analysis (minimum, maximum, mean, and standard deviation) was conducted to determine the safe sulfur dioxide concentration, time, and frequency of exposure in scavengers.

7. Research Ethics

The ethics in this study were issued through the Ethics Committee of the University of Santo Borromeus through number 165/-USTB/Etik/Has./XI/2024. All data confidentiality such as names and informed consent are used in research and cannot be accessed by the public, if the respondent wants the results, it will be given.

RESULTS

The results of the SO2 concentration test are presented in Table 1 below. Furthermore, the calculation of the intake value for each

respondent was carried out so that the hazard quotient value obtained was for each respondent. Respiratory symptoms were measured with a questionnaire. Table 2 is the result of the relationship test between hazard quotient and respiratory symptoms.

Table 1. Measurement results of SO_2 parameter in Sarimukti Landfill, West Bandung Regency in 2024

Location Sampling	Coordinate Point	Result of Measurement (µg/m³)	Standard (µg/m³)
1	S : 06° 48' 003" E : 107° 20' 892"	6.34	150
2	S : 06° 48' 117" E : 107° 21' 168"	8.42	
Average		7.38	

Table 1 shows the results of the SO2 concentration testing at the two locations. The first location showed a test result of 6.37, while the second location was 8.42 with an average of 7.38 in µg/m³. These results are still below the quality standards set according to the Government Regulation of the Republic of Indonesia number 22 of 2021 with a quality standard of 150 µg/m³. Although these concentrations still meet the regulations, further risk assessment is needed with the environmental health risk analysis approach presented in Table 2 and Table 3.

Table 2. Results of the Hazard Quotient Value of SO2 Exposure to Scavengers at Sarimukti Landfill in West Bandung Regency in 2024 (N= 101)

Hazard Quotient Value of SO2 Exposure	Range	Min	Max	Mean	SE	SD	Variance
HQ SO2 Realtime	44.92	9.29	54.22	31.85	0.90	9.09	82.76
HQ SO2 30 Tahun	29.56	0.02	29.57	8.74	0,67	6.77	45.89

Table 2 presents statistics showing the distribution of HQ SO2 values in two groups of data: Realtime SO2 HQ and 30-year SO2 HQ. HQ value is an indicator of health risk due to exposure to a substance, in this case SO2. HQ values greater than 1 indicate a higher potential health risk. The average Realtime SO2 HQ value is 31.86. The range of HQ values is quite wide, ranging from 9.29 to 54.22. The 30-Year SO2 HQ mean value is much lower than the Realtime SO2 HQ, at 8.74.

Table 3. Statistical Test Results of the Relationship between Hazard Quotient and Respiratory Symptoms in Scavengers at Sarimukti Landfill, West Bandung Regency in 2024

Hazard Quotient 30 Years	Symptoms of Respiratory				Total		OR	CI 95%		p
	No		Yes					Lower limit	Upper Limit	
	N	%	N	%	N	%				
HQ <1	1	25.0	3	75.0	4	4				
HQ ≥1	2	2.1	95	97.9	97	96	15.83	1.10	226.67	0.008
Total	3	3.0	98	97.0	101	100				

Table 3 displays the results of statistical analyses conducted to assess the relationship between the 30-year hazard quotient (HQ) and respiratory symptoms among scavengers at the Sarimukti Waste Disposal Site West Bandung Regency, in 2024. The haz-

ard quotient serves as a health risk indicator, derived by comparing chemical exposure levels to a predefined threshold. The statistical tests revealed a significant association between HQ and respiratory symptoms in scavengers (p= 0.008), suggesting that the observed relationship is unlikely to be due to random chance. The odds ratio (OR) of 15.83 indicates that scavengers with an HQ of 1 or greater (HQ ≥ 1) are 15.83 times more likely to experience respiratory symptoms compared to those with an HQ below 1 (HQ < 1). The majority of scavengers (97 individuals) with a high hazard quotient reported respiratory symptoms, while only a few (3 individuals) with a low hazard quotient experienced similar issues. Risk management efforts can be carried out by calculating the safe limits of pollutant concentration, exposure time, and frequency. Table 4 below explains the safe limits.

Table 4. Safe SO_2 Concentration, Time, and Frequency of Exposure for Scavengerss at Sarimukti Landfill in West Bandung Regency in 2024

Descriptive Statistics	Min	Max	Mean	SD
SO_2 concentration in ambient air that is still safe (30 years)	0.25	447.75	14.18	63.71
SO_2 safe exposure time in hours	0.30	364.02	14.86	64.78
Days/year of SO_2 safe exposure in hours	11.36	20385.35	636.52	2902.38

Table 4 provides descriptive statistics for the safe concentration of sulfur dioxide (SO2), the duration, and the frequency of exposure to SO2 for scavengers at the Sarimukti Landfill in West Bandung Regency in 2024. The table shows that the SO2 concentration in ambient air that remains safe for exposure over 30 years has a minimum value of 0.25, a maximum of 447.75, with an average of 14.18, and a standard deviation of 63.71. This indicates a wide range in the concentration levels, with a relatively high level of variation from the mean. Regarding the safe exposure time, the minimum duration is 0.30 hours, with a maximum of 364.02 hours, a mean of 14.8640 hours, and a standard deviation of 64.78. The exposure time shows a similar wide variation. Additionally, the number of days per year that scavengers can safely be exposed to SO2 has a mean of 11.36 days, with a minimum of 3 days, and a maximum of 20385.35 days. The data also displays a high variation in the number of days, suggesting differences in the exposure durations. Overall, the data highlights the variability in SO2 concentration and exposure time among scavengers at the Sarimukti Landfill.

DISCUSSION

Sulfur dioxide (SO2), as one of the harmful air pollutants, has a serious impact on the human respiratory system (Cao et al., 2022). When inhaled, SO2 can trigger inflammation that causes irritation and swelling of the airways (Soltan-Abad et al., 2021). In addition, SO2 can also cause bronchial spasm, which is a muscular contraction of the bronchial walls that leads to airway narrowing and breathing difficulties (Wu et al., 2020). These disorders are further exacerbated by damage to the elastic tissue of the lungs, which reduces the ability of the lungs to inflate and deflate efficiently (Shen et al., 2020). As a result, the vital capacity of the lungs decreases and gas exchange becomes suboptimal (Mercan et al., 2020). Long-term exposure to SO2 can lead to chronic obstructive pulmonary disease (COPD) and other irreversible lung problems (Niu et al., 2021). In addition to health impacts, SO2 also contributes to environmental problems,

such as acid rain that damages ecosystems and buildings.

Sulfur dioxide (SO2) is formed in landfills through the complex process of decomposition of organic waste (Ndagiman et al., 2024). Decomposing bacteria break down the organic compounds in the waste and produce various gases, including hydrogen sulfide (H_2S). The hydrogen sulfide formed then reacts with oxygen in the air, producing sulfur dioxide. This process is influenced by various factors such as waste composition, environmental conditions, and microorganism activity (Ndagiman et al., 2024). High and dense waste piles, as well as poor landfill management, can accelerate the formation of SO2 (Yan et al., 2024). SO2 gas produced from landfills can pollute the air and cause health problems, such as respiratory problems and irritation to the eyes and skin. In addition, SO2 also plays a role in the formation of acid rain that damages the environment (D'Costa et al., 2024). To reduce SO2 production, better landfill management is needed, such as waste segregation, composting, and an effective landfill closure system.

The results of this study evaluated the relationship between hazard quotient (HQ) over 30 years and respiratory symptoms in Scavengers at the Sarimukti Waste Landfill (TPA), West Bandung Regency, in 2024. The Hazard Quotient serves as an indicator of health risk by comparing the level of chemical exposure to a predetermined safe limit. Statistical test results showed a significant association between HQ and respiratory symptoms in scavengers (p-value = 0.008), indicating that this association did not occur by chance. The odds ratio (OR) value of 15.833 indicates that scavengers with HQ of 1 or higher (HQ ≥ 1) have a 15.833 times greater risk of experiencing respiratory symptoms compared to scavengers with HQ less than 1 (HQ < 1). Risk management is carried out with a safe limit of SO2 concentration at 14.18 μg/m³; exposure time of 15 hours; and exposure frequency of 637 days in 30 years through the use of PPE, limiting-Scavengers' working hours and days to reduce the risk of SO2 exposure.

The measured concentration of SO2 pollutant is below the specified quality standard, if the accumulated exposure as expressed in the hazard quotient impacts the respiratory symptoms of waste pickers. The local government needs to further mitigate the risk by considering the results of this study to prevent the occurrence of respiratory problems in the local community. Further research exploration needs to be done by measuring other pollutants such as CH4, NO2, and O3 as the cause of a landfill fire

AUTHOR CONTRIBUTION

TSP conceptualization, writing - original draft, and validation; YWF methodology, writing - original draft, and writing - review & editing; SN investigation, resources, supervision.

ACKNOWLEDGMENT

The author would like to thank Universitas Santo Borromeus, Polytechnic of Kesdam VI Banjarmasin, and Universitas Sebelas Maret for supporting this study.

FUNDING AND SPONSORSHIP

This research was supported by research funds from the University of Santo Borromeus.

CONFLICT OF INTEREST

There are no conflicts of interest.

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