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Jurnal Kesehatan Lingkungan
Journal of Environmental Health
Vol. 16 No. 4
DOI: 10.20473/jkl.v16i4.2024.302-311
ISSN: 1829 - 7285 | E-ISSN: 2040 - 881X

ORIGINAL RESEARCH Open Access

RISK ANALYSIS OF SULFUR DIOXIDE (SO_2) EXPOSURE TO PUBLIC HEALTH AROUND KOLAKA DISTRICT NICKEL PROCESSING PLANT

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Article Info

Submitted	: 20 May 2024
In reviewed	: 20 August 2024
Accepted	: 7 October 2024
Available Online	: 31 October 2024

Keywords : *Air pollution, Environmental health risk analysis, Nickel, Sulfur dioxide*

Published by *Faculty of Public Health Universitas Airlangga*

Abstract

Introduction: *Sulfur dioxide (SO_2) is an air pollutant that is mostly sourced from burning fossil fuels. Data from the Pomalaa Health Center in 2019 indicates a high incidence of Acurate Respiratory Infection (ARI), with 1,943 reported cases. This study aims to assess the respiratory health risk for communities near the nickel processing plant in Pomalaa District.* ***Methods:*** *This research employs an observational cross-sectional design alongside Environmental Health Risk Analysis (EHRA), the study sampled 122 out of 13,207 respondents using simple random sampling. The analysis was carried out with the kolmogorov-smirnov test and EHRA.* ***Results and Discussion:*** *EHRA results show an inhalation rate of 0.63 m^3/hour, with an exposure time of 24 hours/day, an exposure frequency of 365 days/year, and exposure durations of 25 years for real-time projections and 30 years for lifetime projections. SO_2 levels have surpassed national quality standards, with the highest concentration recorded at Point 4, measuring 0.576 mg/m^3. Dose-response analysis, based on US-EPA data, indicates a level of 0.21 mg/m^3. The average intake value for real-time exposure is 0.081 mg/kg/day, and the average intake value for 30-year lifetime is also 0.081 mg/kg/day. Kolmogorov-smirnov test results show a p-value of 0.200 for body weight, while p-values for exposure duration, exposure time, exposure frequency, SO_2 concentration, intake rate, age group, intake value, and RQ are all 0.000.* ***Conclusion:*** *Most respondents in this study had health risks that were within safe limits. Nickel processing plant companies and local governments should conduct regular monitoring and control emissions from mining activities, including SO_2.*

INTRODUCTION

Along with the continuously increasing population growth and high growth rate, human needs are also becoming greater (1). Therefore, development and industrialization efforts are considered solutions to address and accelerate the fulfillment of human needs (2). However, this also has a direct impact on the increasing level of environmental pollution at a significant pace (3).

The role of economics in the mining sector is very important in spurring economic growth in Indonesia (4). Nevertheless, the impact of mining activities on the natural environment, especially the extraction of rare earth elements (REE), has received attention due to the scale and technology used (5). While this increases the country's economic growth, it certainly increases the level of environmental pollution. The increasing presence of mining operations and the types of technology used may exacerbate environmental problems (6). Therefore, mining while providing economic growth has several environmental problems associated with it and therefore requires serious consideration to link economic benefits with environmental protection (7).

According to data released by the World Health Organization (WHO) in 2019, air pollution is responsible for around 6.7 million premature deaths each year, with 4.2 million of those linked to ambient air pollution (8). Prevalence data compiled by the Ministry of Health through the 2018 Basic Health Research findings suggest that the prevalence of Acute Respiratory Infections (ARI) is 9.3% among diseases caused by environmental

Cite this as :
Azis SD, Azizah R, Jalaludin J. Risk Analysis of Sulfur Dioxide (SO_2) Exposure to Public Health Around Kolaka District Nickel Processing Plant. *Jurnal Kesehatan Lingkungan*. 2024;16(4):302-311. https://doi.org/10.20473/jkl.v16i4.2024.302-311

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factors (air). In Southeast Sulawesi Province, the prevalence of ARI in 2018 was 8.8% (9). In 2019, ARI ranked first among the top 10 diseases with the greatest number of cases in Southeast Sulawesi, totaling 115,331 cases (40.26%) (10). Similarly, in Kolaka Regency, ARI remains a significant public health issue that requires special attention. Each year, ARI prevalence consistently ranks first in health centers, with 1,172 cases reported in 2018 (11). In 2019, ARI also ranked as the number one disease among the top 10 at Pomalaa Health Center, Kolaka Regency, with 1,943 cases (12).

The mining sector is the largest industry driving the economy of Kolaka Regency among 16 other business sectors, with one of the key sectors being the nickel processing plant in Pomalaa District, Kolaka Regency (13). In the analysis of particulate and gas emissions from nickel mining activities, it was found that the largest emissions from stationary sources (stacks) are SO_2. The sources of SO_2 emissions can be identified as secondary neutralization (57.14%), atmospheric leaching (21.43%), and nickel drying (21.43%) (14).

The long-established and operational nickel processing plant produces waste containing exhaust gases, particularly SO_2, released by the stacks within the plant area (15). This has environmental impacts that can affect the health of the surrounding community due to mining activities (16). SO_2 emissions predominantly impact the health conditions of the nearby community, particularly causing respiratory diseases such as ARI, bronchitis, asthma, and emphysema (17). Research conducted in Pomalaa indicated that respiratory diseases, such as coughing (20.31%), are common among residents of Pomalaa District due to air pollution from mining activities. This is supported by a causality study on SO_2 pollutants in Bogor, West Java in 2023, which found that increased sulfur dioxide levels are associated with a higher prevalence of respiratory diseases (18).

Based on ambient air pollutant monitoring in Pomalaa District conducted by the Kolaka Environmental Agency in front of Pomalaa Health Center, the SO_2 air pollution level was found to be 0.2461 μg/Nm^3/1 hour. In predicting the risk magnitude of SO_2 gas emissions from the nickel processing plant activities in Pomalaa District, this data is not representative for conducting a comprehensive risk analysis for the community around PT Antam Pomalaa (19). Thus, additional measurements are needed to evaluate the predicted SO_2 exposure risk in the vicinity of nickel processing plant (20). A previous study in 2022 had been conducted along the Bone Bolanga road segment and found that children risk level of SO_2 exposure was RQ>1 in four study locations (21).

The Environmental Health Risk Analysis (EHRA) study is aimed at predicting health risks due to exposure to SO_2 in ambient air (22). Using this approach, it can be known whether residents living near nickel processing plants are or are not at risk of exposure to SO_2. Risk calculations were based on SO_2 concentration, respiratory rate, duration and frequency of exposure, respondents' body weight and reference concentration values (RfCs) (23). The EHRA approach in this study was also used to project the level of risk over the next 30 years, assuming that SO_2 concentrations and other variables had the same value at the time of this study.

METHODS

This study investigates the health risks associated with SO_2 exposure for people living near a nickel-processing plant, employing the environmental health risk analysis method. The research includes hazard identification, exposure assessment, dose-response analysis, and risk characterization. Appropriate risk mitigation strategies are also considered if the Risk Quotient (RQ) is greater than one (RQ>1).

This method involved observational research that used a cross-sectional design, whereby all the variables were studied together. The research was conducted in Pomalaa District, residentials around the nickel processing plant from April until May 2021. More specifically, this was one in a set of assays performed based on those that were within a radius of <3000 m from the pollutant sources (four sampling points), which is located around the Pomalaa nickel processing factory, which consists of Dawi-Dawi Village, Kumoro Village, Tonggoni Village, and Pelambua Village.

The determination of the location and number of sampling points was based on the population in an area, considering the presence of residential settlements. The determination of the distance of sampling points from the pollution source was based on the study conducted in Pangkep Regency, South Sulawesi Province in 2020, which found that the distribution level of SO_2 emissions peaks at a radius of 1 km and then decreases up to 3 km, which found that the distribution level of SO_2 emissions peaks at a radius of 1 km and then decreases up to 3 km. Therefore, there are four sampling points (Figure 1), namely Point I located at 121˚36'43.679"E and 4˚10'32.557"S; Point II at 121˚36'12.068"E and 4˚11'39.681"S; Point III at 121˚36'59.336"E and 4˚10'25.014"S; and Point IV at 121˚37'34.179"E and 4˚10'37.69"S.

The study population comprises residents aged 17 years and older who have lived for more than 2 years and do not work at the nickel processing plant in Pomalaa, within a radius of <3000 meters, exposed to SO_2 at the time and prior to this study, totaling 13,207 individuals. All interviews were conducted with informed consent. The sample for this research was selected using the average estimation method for simple random sampling

$$n = \frac{N\, Z^2_{1-\alpha/2}\, \sigma 2}{(N-1)d2 + Z2_{1-\alpha/2}\, \sigma 2}$$

$$n = \frac{13.207\ (1,96)^2.\ (0,6)^2}{(13.207-1).\ (0,15)^2 + (1,96)^2.\ (0,6)^2} \times \text{Deff} = 61 \times 2 = 122$$

The minimum total sample required is 122 samples, with sample distribution in each village determined using the proportion formula for known populations. Therefore, the breakdown is as follows: 59 people from Dawi-Dawi Village, 17 people from Kumoro Village, 18 people from Tonggoni Village, and 28 people from Pelambua Village. SO_2 sample collection refers to SNI 19-7119.7-2005 concerning the determination of SO_2 sampling locations, conducted at the sampling points.

This research was granted ethical approval by the relevant committee of Universitas Mandala Waluya and issued to the Kolaka Regency National Unity and Political Body with Number: 8237/UMW.01/II/2021. It was also approved by the Investment and One-Stop Integrated Services Office Number: 070/99/DPM-PTSP/IV/2021 and the Kolaka Regency Government, Pomalaa District Number: 070/12.

To improve the clarity and structure of this paper, some sections of the text were revised and reorganized with the help of artificial intelligence technology, specifically ChatGPT. This tool assisted in simplifying sentence structures without altering the meaning or technical content of the study. The researchers then reviewed and edited the generated text to ensure accuracy and consistency with the research findings.

Non-carcinogenic inhalation intake of SO_2 entering the human body is calculated using the following formula:

$$Ink = \frac{C \times R \times tE \times fE \times Dt}{Wb \times tavg} \quad \text{(Formula 1)}$$

Risk characterization in this study is calculated based on the intake value and the *RfC* (Reference Concentration value, using the formula below:

$$RQ = \frac{I}{RfC} \quad \text{(Formula 2)}$$

Description

- *Ink* : Inhalation intake, mg/kg/day
- *C* : Concentration of SO_2, mg/m^3
- *R* : Inhalation rate, m^3/hour
- *Te* : Daily exposure time, hours/days
- *Fe* : Daily exposure frequency, day/year
- *Wb* : Body weight of the respondent, Kg
- *Dt* : Exposure duration, real-time & 30 years for *Lifetime*
- *TAVG*: The typical duration, 30 years × 365 days/year
- *Rfc* : Reference value, for value *Rfc* SO_2 taken from EPA/NAAQS (2010), which is 0.21 mg/kg
- *RQ* : Risk Quotient

RESULTS

Individual Characteristics

The attributes of the participants in this research are described in general terms according to the gender, age, educational background, and occupation category. The breakdown of participants by gender in Table 1 indicates that the most of the participants are female, totaling 72 respondents (59%). Meanwhile, the Attributes of respondents categorized by age group are dominated by those under 40 years old, totaling 65 individuals (53.3%). The distribution of respondents by education level is highest among high school graduates, with 36 respondents (61.5%). The largest occupational group among respondents is Housewives, totaling 37 individuals (30.3%).

Table 1. Characteristics of Respondents Based on Gender, Age, Educational Background and Type of Work in Settlements Around the Nickel Processing Factory, Pomalaa District

Respondent Characteristics	Frequency (n)	Percentage (%)
Sex		
Man	50	41
Woman	72	59
Age		
Man	57	47
Woman	65	53
Educational Background		
No in School	2	2
Not Completed in Elementary School	1	1
Elementary School	5	4
Junior High School	22	18
Senior High School	75	62
Associate Degree/Bachelor Degree, etc	17	14
Work		
Civil Servant	6	5
Unemployed	19	16
BUMN Employee	5	4
Private Employee	7	6
Enterpreneur/Trader	31	25
Laborer	3	3
Housewife	37	30
Students	5	4
Pensioner	5	4
Village Apparatus	2	2
Nanny/Babysitter	1	1
Nurse	1	1
Total	**122**	**100**

Environmental Health Risk Assessment

Table 2 depicts the distribution of environmental health risk analysis variables for the community living in residential areas around the Nickel Processing Plant in Pomalaa District. The reference values presented are adjusted to the data distribution, where only the body weight variable follows a normal distribution, so the reference value used is the mean. The other variables do not follow a normal distributed, so the reference value used is the median.

Table 2. Distribution of EHRA Variables Based on Body Weight, Intake Rate, Exposure Time, Exposure Frequency, Exposure Duration and SO_2 Exposure Intake in Residential Communities Around the Pomalaa District Nickel Processing Factory

EHRA Variables	Measurement Point 1		2		3		4	
	n	%	n	%	n	%	n	%
Body Weight (kg)								
≥ 62.7	29	49.15	11	64.71	9	50	13	46.43
< 62.7	30	50.85	6	35.29	9	50	15	53.57
Intake Rate (m^3/day)								
≥ 0.63	29	49.15	11	64.71	9	50	13	46.43
< 0.63	30	50.85	6	35.29	9	50	15	53.57
Exposure Time (hour/day)								
≥ 24	51	86.44	16	94.12	18	100	28	100
< 24	8	13.56	1	5.882	0	0	0	0
Exposure Frequency (days/year)								
≥ 365	37	62.71	17	100	12	66.67	21	75
< 365	22	37.29	0	0	6	33.33	7	25
Exposure Duration (years)								
≥ 25	28	47.46	6	35.29	12	66.67	16	57.14
< 25	31	52.54	11	64.71	6	33.33	12	42.86
Intake SO_2								
≥ 0.080	29	49.15	6	35.29	8	44.44	20	71.43
< 0.080	30	50.85	11	64.71	10	55.56	8	28.57
Total	**59**	**100**	**17**	**100**	**18**	**100**	**28**	**100**

Dose-Response Assessment

The activity patterns in this study were measured using questionnaires through interviews with respondents. The median daily exposure time for respondents is 24 hours/day, with A frequency of exposure of 365 days per year and a duration of exposure lasting 25 years. The anthropometric characteristics of the respondents consist of body weight and intake rate. In this study, body weight was assessed using both digital and manual. The average body weight measurement across 4 locations yielded a mean value of 62.7 kg. In this study, the intake rate was determined using the formula y = 5.3 Ln(x) – 6.9, leading to a median intake rate of 0.63 m^3/hour. The Reference Concentration (RfC) for SO_2, as spesicified by the Environmental Protection Agency/National Ambient Air Quality Standards (EPA/NAAQS) in 2010, is 0.21 mg/kg. The estimated intake of SO_2 concentration is 0.08 mg/kg/day.

Table 3. SO_2 Exposure Concentrations in Residential Communities Around the Nickel Processing Factory, Pomalaa District

Measurement location	Consentration (µg/Nm^3)	Median (mg/m^3)*	Quality Standards (Government Regulation of the Republic of Indonesia) No. 22/2021 (1 Hour)**
Point I	470.42	0.470	150 µg/m^3
Point II	514.72	0.515	
Point III	368.74	0.369	
Point IV	575.96	0.576	

**) Conversion Value : 1 µg/Nm^3 = 0.001 mg/m3*

****) Government Regulation of the Republic of Indonesia, Number 22, 2021*

Table 3 shows the SO_2 concentration values at four points: 470.42 µg/Nm^3 at Point I, 514.72 µg/Nm^3 at Point II, 368.74 µg/Nm^3 at Point III, and 575.96 µg/Nm^3 at Point IV. The highest SO_2 concentration value is 0.576 mg/m^3, the lowest is 0.369 mg/m^3, and the median is 0.470 mg/m^3. Data were obtained from measurements taken over one hour on the same day (from morning to evening) using the pararosaniline method and a spectrophotometer. Since the SO_2 concentrations were not normally distributed, the median was employed as the representative value for SO_2 concentration.

Intake Values

Table 4 shows the distribution of calculated SO_2 concentration intake values received by respondents up to the time of the study and projected over the next 30 years. The average SO_2 intake in this study is 0.132 mg/kg/day. The median intake of SO_2 received by participants, used as the reference value in this research, is 0.081 mg/kg/day. Lifetime exposure durations are divided into 5, 10, 15, 20, 25, and 30 years, with the maximum lifetime SO_2 intake of 30 years results in an intake value of 0.189 mg/kg/day for 61 respondents (50%).

Table 4. Frequency Distribution of Intake Values and Characterization of Real-Time and Lifetime SO_2 Exposure Risks (5-30 years) in Residential Communities Around Nickel Processing Plants Pomalaa District

Variable	Frequency (n)	Percentage (%)
Intake (I) Real-time & Lifetime		
Real-time intake (mg/kg/day)		
≥ 0.081	61	50
< 0.081	61	50
Intakes lifetime 5 year (mg/kg/day)		
≥ 0.096	61	50
< 0.096	61	50
Intakes lifetime 10 years (mg/kg/day)		
≥ 0.111	61	50
< 0.111	61	50

Variable	Frequency (n)	Percentage (%)
Intakes lifetime 15 years (mg/kg/day)		
≥ 0.129	61	50
< 0.129	61	50
Intakes lifetime 20 years (mg/kg/day)		
≥ 0.147	61	50
< 0.147	61	50
Intakes lifetime 25 years (mg/kg/day)		
≥ 0.169	61	50
< 0.169	61	50
Intakes lifetime 30 years (mg/kg/day)		
≥ 0.189	61	50
< 0.189	61	50
Total	**122**	**100**

Risk Quotient

The Risk Quotient (RQ) calculations presented in Table 5 are derived from the ratio of intake to the SO_2 concentration dose (Formula 2). Based on real-time exposure duration, the reference RQ value for SO_2 exposure is 0.388 (RQ<1), indicating that the real-time SO2 exposure emitted from the stacks in the nickel processing plant area is still considered safe in terms of non-carcinogenic health impacts for the community with a body weight of 63 kg, inhaling SO_2 pollutants for 24 hours daily, 365 days annually, over a period of up to 25 years.

Table 5. Distribution of Estimated Risk Level (RQ) of SO_2 Exposure with Projected Exposure Duration in Real-Time and in the Future 30 Years Around the Nickel Processing Plant Pomalaa District

Exposure Duration	Risk Quotient*	n**	%	n***	%
Real-time	0.388	7	5.7	115	94.3
5 Years	0.455	10	8.2	112	91.8
10 Years	0.520	15	12.3	107	87.7
15 Years	0.615	20	16.4	102	83.6
20 Years	0.701	29	23.8	93	76.2
25 Years	0.805	31	25.4	91	74.6
30 Years	0.901	40	32.8	82	67.2

**) RQ value*
***) Number of Respondents with RQ≥1*
****) Number of Respondents with RQ<1*

Figure 1 compares the real-time RQ values with projections for the next 30 years (5, 10, 15, 20, 25, and 30 years) using both minimum and maximum values. The calculation results show a 27% increase in the number of respondents with unsafe risk levels (RQ≥1) if exposure duration is projected over the next 30 years, assuming that SO_2 concentration and other variables remain unchanged for the next 30 years.

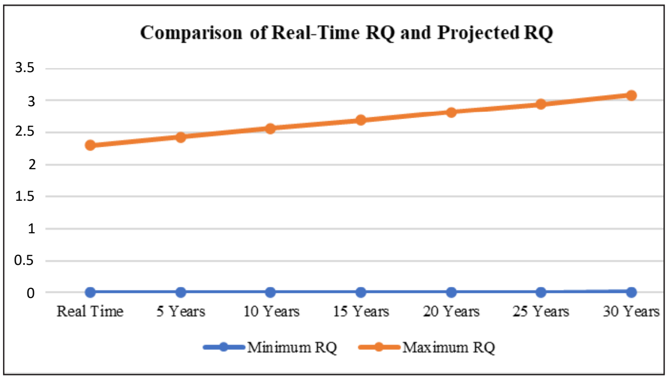

Figure 1. Estimated Risk Size for the Next 5, 10, 15, 20, 25 to 30 years

DISCUSSION

Individual Characteristics

Every mining activity poses risks to the health of the local community (24). One of the most detrimental aspects is the impact on the respiratory health of residents living near mining areas (25). Previous research indicates that health risks to communities around industrial areas exist within a radius of 2-3 km from the pollution source (26). This study shows that there is a risk of exposure to SO_2 pollutants from mining industry smokestacks, this is caused by pollutant gases being dispersed to reach residential areas (27). The risk analysis in this study describes the estimated risk quotient (RQ) value related to SO_2 exposure in the community around the nickel processing factory in Pomalaa District (28).

Environmental Health Risk Assessment

SO_2 concentrations measured at four locations significantly exceeded established ambient air quality standards based on Indonesian Regulation No. 22/2021, where the maximum SO_2 concentration is 150 μg/m^3 for a one-hour measurement. This regulation replaces previous regulation No. 41/1999 which has set the quality standard for SO_2 in ambient air as 900 μg/Nm^3 for one hour measurement. SO_2 concentrations in areas surrounding the Pomalaa District nickel processing plant can fluctuate and may exceed the average levels during this time. Several factors can influence this, including the production capacity of the factory, the prolonged operation of the fourth sustainable boiler, and the efficiency of ambient air gas emission management (29).

When the pollutants are discharged from the source of poolution, they can travel horizontally in air up to upto 3000 meters depending upon speed and direction of wind, especially SO_2 (30). In this case, meteorological conditions can be a factor in increasing pollutants in the air. This opinion is in line with the results of a case study of the impact of meteorogical conditions on ambient air quality in the Seoul Metropolitan Area, South Korea in 2019 (31). Those pollutants can sink to a body of water, through the soil, on vegetation or they can linger in the atmosphere. As such, it is crucial to understand these variables in order to effectively manage pollutants to promote ambient air quality (32). To control pollution efficiently, it is important to consider these dynamics and reduce impacts on the environment and health. We can predict and control pollution in the ambient air by studying to rise of pollutants, wind patterns and meteorological parameters, ways to precipitate the pollutants are analysed. This holistic technique underscores the critical role of advanced tracking of meteorologic data in environmental monitoring and public health protection (33).

Dose-Response Assessment

Body weight is a relevant anthropometric variable that modifies the actual dose (exposure) risk agent across an individual life (34). This can lower the risk of pollutant exposure, as overweight individuals would likely be prescribed higher nutrients thus resulting in them receiving less internal dose (35). The average weight of the subjects in this study was 62.7 kg throughout the eligiblemedian age (19–64). This is analogous to a study carried out in Tirtonirmolo, Bantul in 2024 where the average adult weight was 70 kg (36). According to the Integrated Risk Information System (IRIS), the average normal weight of Asian adults is 55 kg. This figure is used to calculate the Reference Concentration (RfC) and is derived from various studies conducted in Asia (37). In comparison, the average weight of respondents in this study was found to be 6% higher than the average weight of Asian adults (38).

The intake level was determined using the regression equation $y = 5.3\ \mathrm{Ln}(x) - 6.9$, where y represents the inhalation rate (m^3/day) and x is the weight obtained from direct measurements (39). The average total daily intake among participants was recorded at 0.63 m^3/day, which aligns with the default inhalation rate for Asian adults, set at 0.63 m^3/hour. When compared to the maximum intake level for adults, the average intake level observed in this study was 0.23% lower than the standard intake level for adults. This underscores the significance of accurately estimating individual intake levels when assessing the risk of exposure to environmental pollutants. The calculation of intake levels relies on weight measurement data and regression analysis, which aids in precisely determining an individual's intake level. Previous research has played a crucial role in shaping environmental health policies and practices aimed at safeguarding public health (40).

Community activity patterns, such as the timing, frequency, and duration of exposure, are crucial for evaluating the effects of air pollutants on public health, particularly regarding SO_2 exposure (41). The greater the concentration of pollutants in the environment, the higher the levels of inhaled pollutants, which can elevate the risk of respiratory health issues (42). Moreover, SO_2 exposure can irritate the respiratory system and impair lung function, especially in at-risk populations. Grasping these dynamics is essential for assessing and mitigating the health risks associated with air pollution. To implement effective environmental management strategies, it is vital to have a comprehensive understanding of the behaviors and patterns that influence exposure levels. This knowledge is key to developing targeted interventions aimed at reducing pollutant intake and minimizing adverse health effects (43).

In this study, the median daily exposure time was determined to be 24 hours, consistent with a 2024 study in Bengbu, China, which reported that individuals are exposed for an average of 24 hours each day (44). This alignment is supported by the similarities in respondent characteristics and pollution sources, which in both studies involved adult communities and emissions from processing plants. The median value reflects the maximum daily exposure time. The higher the exposure time, the higher the likelihood of respondents experiencing respiratory health issues (45).

The median exposure frequency for all points was 365 days/year. The exposure frequency received by the community is quite high, as 365 days/year represents the maximum exposure frequency humans can receive in a year (46). Similar to exposure time, the higher the exposure frequency, the higher the health risk. This is consistents with findings from a study conducted in Palembang in 2022, which stated that the longer a person is subjected to a risk factor, the higher the exposure level and the more significant the health risk to the community (47).

The median duration of exposure was 25 years, relatively high compared to the 30-year exposure duration issued by IRIS EPA. This is because the respondents are native to the study location, with many having lived there since birth until the study was conducted. The nickel processing plant of PT. Antam Tbk Pomalaa started production in early 1995 (26 years ago), indicating that not all respondents have been exposed to SO_2 since birth due to the plant's activities.

Intake Values

The intake value of SO_2 represents the actual dose of SO_2 entering the human body daily per kilogram of body weight. The median SO_2 intake was 0.08 mg/kg/day. This intake level rises proportionally with the concentration of SO_2, as well as the exposure time, inhalation rate, exposure frequency, and exposure duration. In contrast, it decreases in relation to body weight and the respondents' average time. Thus, the higher these values, the greater the intake, and vice versa. Factors affecting the intake entering the human body include age, gender, smoking behavior, and mask use (48).

The SO_2 intake value depends on the reference concentration (*RfC*) used. If the intake value does not exceed the reference concentration limit, respondents can safely inhale air contaminated with SO_2 pollutants, and vice versa. The reference concentration in this study stands at 0.21 mg/m^3, with a of 0.08 mg/kg/day. Thus, the SO_2 intake is below the reference concentration (Ink SO_2 < Rfc SO_2), indicating that respondents can safely inhale air contaminated with SO_2 from the chimneys/boilers of the nickel processing plant in Pomalaa.

Risk Quotient

Risk characterization in this study represents the numerical risk magnitude without units, calculated as the ratio of intake to the reference dose of SO_2 issued by IRIS EPA (2010) to interpret the safety of a risk agent. The median real-time SO_2 exposure risk was 0.388 (RQ < 1), which suggests that the current risk of SO2 exposure in in the surrounding air of the community near the nickel processing plant in Pomalaa is still safe. However, the estimated risk for the next 30 years (lifespan) with the assumption that the concentration, intake rate, body weight, exposure time, and exposure frequency stay consistent with the current study results, yields a risk value of 0.901 (RQ < 1), which is close to 1. This suggests that the longer respondents stay in the survey location, the higher their risk of SO_2 exposure.

High SO_2 concentrations at the study location are not solely from the chimneys of PT. Antam Tbk Pomalaa but also from transportation activities, including company vehicles supporting mining operations and private vehicles of residents around the study location. Additionally, several other companies, such as PD Aneka Usaha Kolaka, PT Wijaya Nikel Nusantara, PT Putra Mekongga Sejahtera, and PT Akar Mas International, also conduct mining activities in the area, contributing to the high SO_2 concentration during the study period.

Risk Management

Risk management for EHRA is conducted when RQ > 1. The calculated risk value is RQ < 1, at 0.390, indicating that the community around the nickel processing plant of PT. Antam Tbk Pomalaa is not at risk of respiratory health problems (49). However, preventive measures should be implemented to ensure the community remains safe. These measures include emission control as part of sustainable mining activities, in line as outlined in Presidential Regulation No. 61/2011 regarding the National Greenhouse Gas Reduction Action Plan and Presidential Regulation No. 71/2011 concerning the National GHG Inventory. PT. Antam Pomalaa Tbk has undertaken several efforts to reduce Greenhouse Gases (GHG) emissions, such as dry preparation systems, pollutant absorption through reclamation, optimizing the elution process, modernizing the gold main bar packaging process, and using Water Sponge Filters for scrubbing.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to the experts from the Environmental Agency of Kolaka Regency for their participation in the SO_2 concentration measurements, the Faculty of Health Sciences at Universitas Mandala Waluya, and PT. Antam Tbk Pomalaa for their support of this research.

AUTHORS' CONTRIBUTION

SDA was in charge of developing the concept, designing the methodology, conducting the formal analysis, overseeing the investigation, and drafting the initial manuscript. RA contributed to supervision, validation, and reviewing and editing the manuscript. JJ provided resources, technical support, and assisted in the reviewing and editing the manuscript.

CONCLUSION

This study indicates that the exposure risk to SO_2 concentration remains relatively safe with an RQ<1 value of 94%. However, if projected over the next 30 years, the RQ<1 value decreases to 62.7%. Meanwhile, the measured SO_2 concentrations recorded at all locations exceed the limits established by Indonesian

Government Regulation No. 22/2021. To reduce the risk for individuals continuously exposed to SO_2 over extended periods, it is crucial to implement effective risk management strategies for communities surrounding the nickel mining area in Pomalaa District. Efforts to address this include controlling greenhouse gas emissions through dry preparation systems, pollutant absorption via reclamation, optimization of the elution process, modernization of product packaging for gold main bars, and the implementation of scrubbing methods using Water Spons Filter devices.

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