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Environmental health risk assessment of particulate matter ($PM_{2,5}$) and sulfur dioxide (SO_2) exposure at workers in production unit of a cement plant in indonesia

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Abstract

Sulfur dioxide (SO_2) and particulate matter ($PM_{2.5}$) are pollutants that are present in cement factories, particularly in the production units. The purpose of this study is to examine the potential risks to workers' health from exposure to SO2 and PM2.5 at the PT Semen Tonasa Production Unit. This study used a descriptive quantitative approach utilizing the Environmental Health Risk Analysis (EHRA) methodology. This study used two different types of samples: accidently selected 95 employees from PT Semen Tonasa Production unit V and environmental samples that included PM2.5 and SO2 levels from the ambient air. According to the research's findings, SO_2 concentrations ranged from 0.0424 to 0.0660 mg/m3, with the Packer area having the highest concentrations; on the other hand, PM2.5 concentrations ranged from 0.0679 to 0.1762, with the Packer area having the highest concentrations and the Kiln area having the lowest. Moreover, the SO_2 RQ value <1 was obtained for the entire study, indicating that workers exposed to SO_2 in the range of 0,0424 – 0,0660 mg/m^3, exposure time 3,22 hours, exposure frequency for 265 days, exposure duration 9,38 years, with an average body weight of 66,22 kg, are not at risk; however, 47 workers obtained the $PM_{2.5}$ RQ value >1, indicating that they may be at risk for health problems as a result of exposure to 0,0679 – 0,1762 mg/m^3, exposure time 3,22 hours, exposure frequency for 265 days, and exposure duration 9,38 years with an average body weight of 66,22 kg. Furthermore, the production area's PM2.5 material percentage of silica (SiO2) ranges from 12.82 to 28.08%. The Raw Mill area has the lowest silica (SiO2) content (12.82%), while the Coal Mill area has the highest (28.08%). For workers exposed to SO2 gas, the environmental health hazards are RQ ≤ 1 or no risk; for workers exposed to PM2.5, the risks are RQ > 1 for 47 workers (49,47%) and RQ ≤ 1 for 48 people.

Keywords: Cement plant, EHRA, fine particulate matter, sulfur dioxide, workers.

Full length article *Corresponding Author, e-mail: achmad.parela@yahoo.com

1. Introduction

For many years, air pollution has become a critical issue in environment [1]. Air pollution is broadly recognized as one of environmental aspects that is harmful for health [2] and considered a potential risk to public health which also brings adverse effects on economic growth [3]. World Health Organization (WHO) has reported that in 2019, there are around 4.2 million premature deaths in the world due to ambient air pollution [4]. The air consists of various several pollutants, such as Particulate Matter (PM), Carbon monozide (CO), Carbon dioxide (CO_2), ozone (O_3), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), exposed to human and attack their body though inhalation process and cause various deseases, for instance respiratory disorder, cance, stroke, etc [5]. One of the major sources of air pollution is cement industry. Cement factory produces a large amount of pollutants in the form of dust emissions in industrial areas as well as nitrogen emissions [6]. Cement is an important adhesive agent for the construction industry and is produced in large quantities in the world [7]. It is an important part of construction materials. Cement is the basic material for building and constructions. As a result, cement industry plays a crucial role in the development of economic in a nation [8]. Cement factory production units such as raw mills, preheated, kilns, coal mills, cement mills, storage silos & packing sections are point sources of emission pollution such as particulate matter (PM), nitrogen oxides (NO_X) and sulfur dioxide (SO_2). One of the pollutants found in cement plan is Particulate matter ($PM_{2,5}$). Partiuclate Matter 2.5 ($PM_{2,5}$) is a type of air pollutant with a diameter of ≤2.5 µm, characterized by small particles [9]. It can be derived from the Raw mill, Coal mill, Kiln and Finish mill areas [10]. Apart from these areas, particulate matter can remain suspended in the air in the form of dust and soot produced from the process quarrying, hauling, crushing, grinding of raw material and clinker, fuel preparation, clinker grinding and cement packing in the cement manufacturing process [11]. $PM_{2,5}$ can reduce visibility and the purity of air in the environment become less [12]. In addition to $PM_{2,5}$,Sulfur Dioxide Gas (SO_2) is also commonly found in cement industry. It is released in the preheater due to the oxidation of sulfides and organic sulfur in the Raw Mill, while the remaining SO_2 is released in the precalciner and kiln due to the oxidation of sulfides and organic sulfur in the fuel as well as the decomposition of sulfates from raw materials and fuel [13]. SO_2 is an air pollutant gas which consists of sulfur and oxygen. SO_2 is formed when fuels containing sulfur such as coal, oil, or diesel are burned [14]. Sources of exposure to $PM_{2.5}$ and Sulfur Dioxide Gas (SO_2) in cement factories can be found in production units, such as the reclaimer, raw mill, combustion (pre-heater, rotary kiln and cooler), finish mill and packhouse [15]. Inhaling SO_2 causes throat irritation, nose irritation and can cause death in high concentrations. SO_2 exposure can also cause respiratory and cardiovascular diseases [16]. SO_2 gas emissions are also a major contributor to acid deposition or acid rain [17]. Health risk analysis of Particulate Matter ($PM_{2.5}$) exposure is considered important because long-term and short-term exposure to $PM_{2.5}$ can cause respiratory problems. Particles smaller than 2.5 micrometers can penetrate and be deposited in the pulmonary system, especially in the alveoli. $PM_{2,5}$, even at relatively low concentration, can lower pulmonary function and increasing emphysema and lead chronic obstructive pulmonary disease (COPD) [18]. The dominant sources of $PM_{2.5}$ pollutant come from energy use, burning fossil fuels and biomass for electricity generation, motor vehicle exhaust emissions, household activities such as burning using stoves and fireplaces, smoke from burning, smoking, and factory activities in various industries [19]. Numerous studies have investigated the existance of particulate matter ($PM_{2.5}$) in cement industry. In Indonesia, the $PM_{2.5}$ concentration in the Batching Plant area exceeded the established quality standards and World Health Organization (WHO) air quality guidelines in which the health risk value obtained is RQ = 0.412 and in real time which is classified as "not dangerous", however, for lifelong workers or a working duration of around 25 years or in the next 9 years, a value of RQ = 1.096 will be obtained [20]. In addition, a high concentration of $PM_{2.5}$ was found in the cement industry in Indonesia that is higher that WHO standards and United State Environmental Protection Agency (US EPA) standards which lead almost a quarter of workers have abnormal lung restrictions, obstruction and even both [21]. Thus, it is necessary to recognize the impacts of pollutants in the cement industry on environment for the controlling purposes (Elehinafe 2022 Cement industry – Associated emissions, environmental issues and measures for the control of the emissions [22]. Apart from $PM_{2.5}$, the large amount of Sulfur dioxide (SO_2) was also found in cement factory which can be harmful to health. Short term SO_2 exposure for workers has been associated with respiratory morbidity in adults and children, especially asthmatics and the elderly people [23]. Nevertheless, the research invesitagated SO_2 exposure for workers in cement factories is still limited. EHRA is the process of estimating the nature and possibility of harmful health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future [24]. EHRA is used to assess the various hazards that have occurred, the current threats, and the risks that will happen in the future. EHRA can be done to monitor non-carcinogenic effects called Risk Quotients (RQ). If the RQ value is at least 1, then the risk needs to be controlled, but if the RQ is less than 1, the risk does not need to be controlled but is maintained so that the RQ does not exceed 1 [25]. EHRA for workers in the cement industry is important in order to determine the current and future environmental health risks of workers so that policies and risk mitigation efforts can be taken to reduce the number of occupational diseases which can affect worker productivity and factory production capacity, specifically the risk of $PM_{2.5}$ and SO_2 exposure to workers in production units. In addition, it is also important to analyze the material content contained in each area of the production unit which focuses more on the levels of silica, iron metal and other heavy metals since these compounds are used as raw materials and auxiliary materials in making cement. PT Semen Tonasa is one of the largest cement producers in Eastern Indonesia which operates an integrated cement factory with a capacity of 7.4 million tons/year in Pangkep Regency, South Sulawesi with coordinate points 4°48'58"S and 119°29'32"E. PT Semen Tonasa has cement bagging factories spread across Eastern Indonesia, including Makassar (South Sulawesi), Bitung (North Sulawesi), Palu (Central Sulawesi), Mamuju (West Sulawesi), Kendari (Southeast Sulawesi), Ambon (Maluku), Oba (North Maluku), Samarinda and Balikpapan (East Kalimantan) and Sorong (West Papua). Measurement of $PM_{2.5}$ and SO_2 concentration was carried out at 5 sampling points, they are Raw mill/Raw Process, Kiln, Coal Mill, Finish Mill and Packer areas (Figure 1). Based on the description above, this research aims at investigating environmental health risk analysis due to exposure to $PM_{2.5}$ and SO_2 gas in workers at the PT Semen Tonasa Production Unit. This research is expected to be a preliminary study for the company to prepare the mitigation management to reduce health risks for the workers in the plant.

2. Methods

2.1. Sampling Process

The method of this study is descriptive quantitative using the EHRA approach. This study investigated risk of $PM_{2,5}$ and SO_2 exposure at workers in production unit of a cement plan in Pangkep Regency, South Sulawesi, Indonesia and was conducted in September-October 2023. There are two kinds of sample in this reserach, namely workers and environment. The population of workers in this study were all workers whose activities were outdoor in the PT Semen

Tonasa Production unit V which was located in the Raw mill/Raw Process, Kiln, Coal Mill, Finish Mill and Packer areas, totaling 124 workers. The number of samples taken in this research is calculated using the Slovin formula with a standard error of 5%. Distribution of the number of workers in each area can be seen in table 1. The inclusion criteria are works in the PT Semen Tonasa Production unit unit V, either permanent or contract employees, age between 18-55 years old dan working activities are outdoor. The subject of research for workers was selected using accidental sampling technique with the consideration that every worker in each area has been exposed by the same pollutants so that each of them can represent the health risk that was analyzed. The data about workers, such as body weight (BW), age, exposure time (ET), exposure frequency (EF), exposure duration (ED), average non-carcinogenic exposure time (AT), were obtained through interview. The sample of environment in this study was the ambient air quality with parameters of $PM_{2.5}$ and SO_2 in the production unit of PT Semen Tonasa Unit V which includes the Raw mill/Raw Process, Kiln, Coal Mill, Finish Mill and Packer areas. In each area, 3 (three) points of ambient air quality ($PM_{2.5}$ and SO_2 parameters) were taken so that the total number of air quality points is 15 (fifteen) points. The time for taking air quality for each sampling point is 24 hours of measurement. This was done to determine the quality of ambient air during the day and night, and the number of points taken can represent each work area at PT Semen Tonasa unit V. The concentrations of $PM_{2.5}$ and SO_2 were measured by installing sampling equipment in each production work area. TISCH High Volume Air Sampler with Impactor $PM_{2.5}$ was utilized for $PM_{2.5}$ concentration, while for SO_2 sampling was done using a volume air sampler with mid impinger. Air volume was taken for 24 hours for the $PM_{2.5}$ test according to SNI 7119.14-2016, and measurements were carried out for 24 hour for the SO_2 test according to SNI 7119.7-2017. Then, the sampling results were taken to the PT Sucofindo Laboratory for analysis. $PM_{2.5}$ analysis is carried out by weighing filter paper and looking at the difference before and after sampling and comparing with the volume of air sampled, while for SO_2 analysis the colorimetric method uses a UV-VIS spectrophotometer. The concentrations obtained are in units of µg/m^3. The $PM_{2.5}$ solids attached to the filter paper was analyzed for the compounds contained therein, such as the concentration of Metal Oxides and the content of Silica (SiO_2) using X-ray Fluorescence (XRF).

2.2. Data Analysis

The data were analyzed through univariate analysis and risk analysis. Univariate analysis was carried out to describe the characteristics of each variable. Data were displayed in the form of a frequency table. These data include respondent characteristics, exposure time (hour), frequency of exposure (day), duration of exposure (year), and average time of exposure. Risk analysis was done through calculating intake which is intended to determine the level of risk to workers. Calculation of intake is obtained based on $PM_{2.5}$ and SO_2 concentration data (µg/m3), inhalation rate (m^3/hour), frequency of exposure (days/year), duration of exposure (real time and lifetime) in years, body weight (kg), average time period (30 years x 365 days/year for non-carciogenic effects and 70 years x 365 days/year for carcinogenic effects). The equation for analyzing non-carcinogenic environmental health risks for the inhalation route can be seen in the following equation (3):

$$ADD = \frac{C_{air}\ x\ InhR\ x\ ET\ x\ EF\ x\ ED}{BW\ x\ AT}$$

(equation 1)

2.3. Description

ADD = Acceptable Daliy Dose (mg/Kg/day)
Cair = Air concentration of $PM_{2,5}$ and SO_2 (mg/m^3)
InhR = Inhalation Rate (m^3/day)
ET = Exposure time (Hour)
EF = Exposure Frequency (Day)
ED = Exposure Duration (Year)

Risk Quotient or Risk characterization is the amount of acceptable daily dose compared with Reference Concenration (RfC) of pollutants. The formula to determine risk quotient is as follows:

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

(equation 2)
RQ = Risk Quotient
RfC = Reference Concenration (mg/m^3)

RfC for SO_2 is 0.026 mg/kg/day (26) and for $PM_{2,5}$ is 0.0012 mg/kg/day which is derived from recommended Air QualityGuideline (AQG) level issued by WHO in 2021, that is 0.0015 mg/m^3. Chronic SO_2 for the human are harmful and must be managed if RQ > 1. Safe category is represented by RQ ≤ 1 which means it is not risky for human.

3. Results

Measurements of air quality parameters SO_2 and $PM_{2.5}$ in 5 areas such as the Raw Mill area, Coal Mill area, Kiln area, Finish Mill area and Packer area were carried out at 15 monitoring points consisting of 3 monitoring points for each area of the research location. The worker interview survey was conducted on 95 respondents consisting of 10 respondents in the Coal Mill area, 18 respondents in the Finish Mill area, 9 respondents in the Kiln area, 40 respondents in the Packer area or cement bagging unit, and 18 respondents in the Raw Mill area. The characteristics of the respondents used in this study were classified based on the worker's age, weight, and length of working time at PT Semen Tonasa. Information regarding respondents was obtained through interviews using questionnaires. Table 2 presents that the ages of respondents in this study ranged from 21 – 55 years old. The majority of respondents were in the productive age range, 26 - 35 years old, they are 56 people (58.9%), followed by the 36-45 years age group (17.9%), 46 - 55 years old (12.6%) and 16 – 25 years old (10.5%). Table 3 describes that SO_2 concentration was in the range of 0.0424 – 0.0702 mg/m$_3$ and the the highest concentration was found in the Packer area. Meanwhile, $PM_{2.5}$ the concentration was in the range of 0.0679 – 0.1762 mg/m3 and the highest concentration was in the Packer area and the lowest was in the Kiln area. It can be seen from Figure 2 that $PM_{2.5}$ concentration in the Coal mill, Finish mill, Packer and Raw mill areas is greater than the SO_2 gas concentration; while, in the Kiln area, SO_2 gas concentration is greater than the $PM_{2.5}$ concentration. The Risk Quotient (RQ) calculation for workers in the PT Semen Tonasa Production area is carried out by comparing the daily dose received or Accepted Daily Dose (ADD) by the worker with the reference concentration

(RfC). The daily dose received by workers is the result of calculations from the concentrations of SO_2 and $PM_{2.5}$ parameters measured in the air in the working area and consdering worker characteristics, such as body weight, time of exposure in a day, frequency of exposure, duration of exposure, and average time period for non-carcinogenic effects. Based on table 4, it can be seen that the average exposure time for workers is 3 hours per day, and the exposure time range is 1 – 6 hours per day. 72 workers (75.79%) had an exposure time of 3 - 4 hours per day, 10 workers (10.53%) had an exposure time of 1 - 2 hours per day, and 13 workers (13.68%) had an exposure time of 5 – 6 hours per day. In addition, the average worker exposure frequency is 264 days, and the exposure frequency range is 258 – 290 days. 30 workers (31.58%) had an exposure frequency of 262 days, 25 workers (26.32%) had an exposure frequency of 260 days, 24 workers (25.26%) had an exposure frequency of 263 days, 11 workers (11.58%) had an exposure frequency of 290 days, 3 workers (3.16%) had an exposure frequency of 259 days, and 2 workers (2.10%) had an exposure frequency of 258 days. Moreover, the average duration of worker exposure is 10 years, and the range of exposure duration is 1 – 35 years. 41 workers (43.16%) had exposure duration in the range 11 – 15 years, 27 workers (28.42%) had exposure duration in the range 6 – 10 years, 22 workers (23.16%) had exposure duration in the range 1 – 5 years, 4 workers (4.21%) had an exposure duration of more than 20 years, and 1 worker (1.05%) had an exposure duration in the range of 16 – 20 years. Furthermore, the average worker's body weight is 67 kg, and the worker's weight range is 45.6 – 115.6 kg. A total of 48 workers (50.5%) had a body weight in the range of 60.1 – 75.0 kg, 29 workers (30.5%) had a body weight in the range of 45.0 – 60.0 kg, 14 workers (14, 7%) had a body weight in the range of 75.1 – 90.0 kg, and 4 workers (4.2%) had a body weight of more than 90.0 kg. Based on table 5, the average ADD of SO_2 value for workers in the Raw Mill area is 0.0004 mg/kg/day, the Coal Mill area is 0.0005 mg/Kg/day, the Kiln area is 0.0006 mg/Kg/day, Finish Mill area is 0.0002 mg/Kg/day, and Packer area is 0.0008 mg/Kg/day. The ADD $PM_{2.5}$ value of workers in the Raw Mill area is 0.0008 mg/Kg/day, the Coal Mill area is 0.0013 mg/Kg/day, the Kiln area is 0.0006 mg/Kg/day, the Finish Mill area is 0 .0008 mg/Kg/day, and the Packer area is 0.0020 mg/Kg/day. In addition, the RQ of SO_2 value obtained in the Raw Mill area is in the range 0.0012 – 0.0020, the Coal Mill area is in the range 0.0123 – 0.0268, the Kiln area is in the range 0.0072 – 0.0393, the Finish Mill area is in the range 0.0023 – 0.0154, and the Packer area in the range 0.0018 – 0.0474. The SO_2 RQ value of workers in all areas has an RQ value < 1 or is not at risk. Moreover, the $PM_{2.5}$ RQ value obtained in the Raw Mill area is in the range 0.0557 – 1.0139, the Coal Mill area is in the range 0.6940 – 1.5124, the Kiln area is in the range 0.1501 – 0.8242, the Finish Mill area in the range 0.1914 – 1.3062, and the Packer area in the range 0.1042 – 2.7408. There are several RQ $PM_{2.5}$ values for workers that have RQ > 1, such as in the Raw Mill area, Coal Mill area, Finish Mill area, and Packer area, while RQ $PM_{2.5}$ workers in the Kiln area have an RQ value < 1. To be clearer, the numbers of workers who have the RQ of $PM_{2.5}$ value > 1 in each area can be seen in table 6. Table 6 presents the information that RQ value of SO_2 for all workers in the production unit is <1 or the no risk category. In the Raw Mill area, it was obtained that 17 workers had the RQ value of $PM_{2.5}$ >1 and 1 worker had the RQ value of $PM_{2.5} \leq 1$. Besides, 8 workers in the Coal Mill area had the RQ $PM_{2.5}$ value > 1, while 2 workers had the RQ value of $PM_{2.5} \leq 1$. Moreover, in the Finish Mill area, it was obtained that 6 workers had the RQ value of $PM_{2.5}$ > 1 and 12 workers had the RQ value of $PM_{2.5} \leq 1$. In addition, in the Packer Area, it was found that 32 workers had the RQ value of $PM_{2.5}$ > 1 whereas 8 workers had the RQ value of $PM_{2.5} \leq 1$. Furthermore, in the Kiln area, there is no worker found who had the RQ value of $PM_{2.5}$ > 1. The RQ value for each worker in each area in the PT Semen Tonasa Production unit can be seen in Figure 3. Based on Figure 3, RQ value of SO_2 for workers in all areas is obtained RQ ≤ 1 or not at risk, while for RQ value of $PM_{2.5}$, it was obtained that several workers had the RQ value > 1 or was at risk. In Raw mill area, there is 1 worker with RQ value = 1.0139. In the Coal Mill area, there are 8 people, and the largest RQ value is 1.5124. In the Finish Mill area, there are 6 workers and the largest RQ value is 1.3062. The Packer area has 32 workers, and the largest RQ value is 2.7408. Table 7 shows that the content of metal oxides such as iron oxide (Fe_2O_3) and Titan Oxide (TiO_2) is obtained in all production areas. Apart from metal oxides, Silica (SiO_2) material was also obtained with a concentration range of 12.82 – 28.08%. The highest Silica (SiO_2) content is in the Coal Mill area (28.08%) and the lowest is in the Raw Mill area (12.82%).

4. Discussion

Sulfur Dioxide (SO_2) gas emission is produced from the raw material grinding process and the combustion process in the kiln, while $PM_{2.5}$ can occur due to raw material mining, vehicle mobilization, clinker cooling, cement grinding (finish mill), and packaging processes [27]. The highest SO_2 concentration in the Kiln area was 0.0702 mg/m^3 and the highest $PM_{2.5}$ concentration in the Packer area was 0.1762 mg/m^3. SO_2 gas is a pollutant produced by various industries, especially the power generation industry, oil and gas industry, mineral processing industry, diesel engine vehicles and burning fossil fuels which contain sulfur [28]. Sulfur dioxide comes from the combustion of sulfur-containing fuels and the oxidation of the sulfur present in the raw materials. The sulfur in the raw material is oxidized to SO_2 and SO_3 at a heating point between 370ºC and 420ºC in the preheating kiln. Sulfur dioxide is formed by the thermal decomposition of calcium sulfate in clinker and SO_3 quickly decomposes into SO_2 and O_2 [13]. Research by [29] found that SO_2 concentrations in residential areas around the cement industry ranged from 0.023 – 0.0664 mg/m3 while [28] found that SO_2 concentrations in residential areas around the cement industry ranged from 0.005 – 0.029 mg/Nm^3. In this study, $PM_{2.5}$ concentrations in production areas range from 0.0679 – 0.1762 mg/Nm^3. This condition is in line with (20) which found the $PM_{2.5}$ concentration in the cement production area was 0.120 mg/Nm3. Apart from that, [21] also found the $PM_{2.5}$ concentration in the production area at a cement factory of 0.1513 mg/Nm^3. The $PM_{2.5}$ concentration around the cement industry was the highest, that was 0.07099 mg/m^3 [3]. RQ or Risk Characterization is calculated to determine the level of risk for workers exposed to SO_2 and $PM_{2.5}$ gas. If the RQ value is <1 then the exposure is not at risk, whereas if the RQ value is >1 it is considered a risky exposure [20].

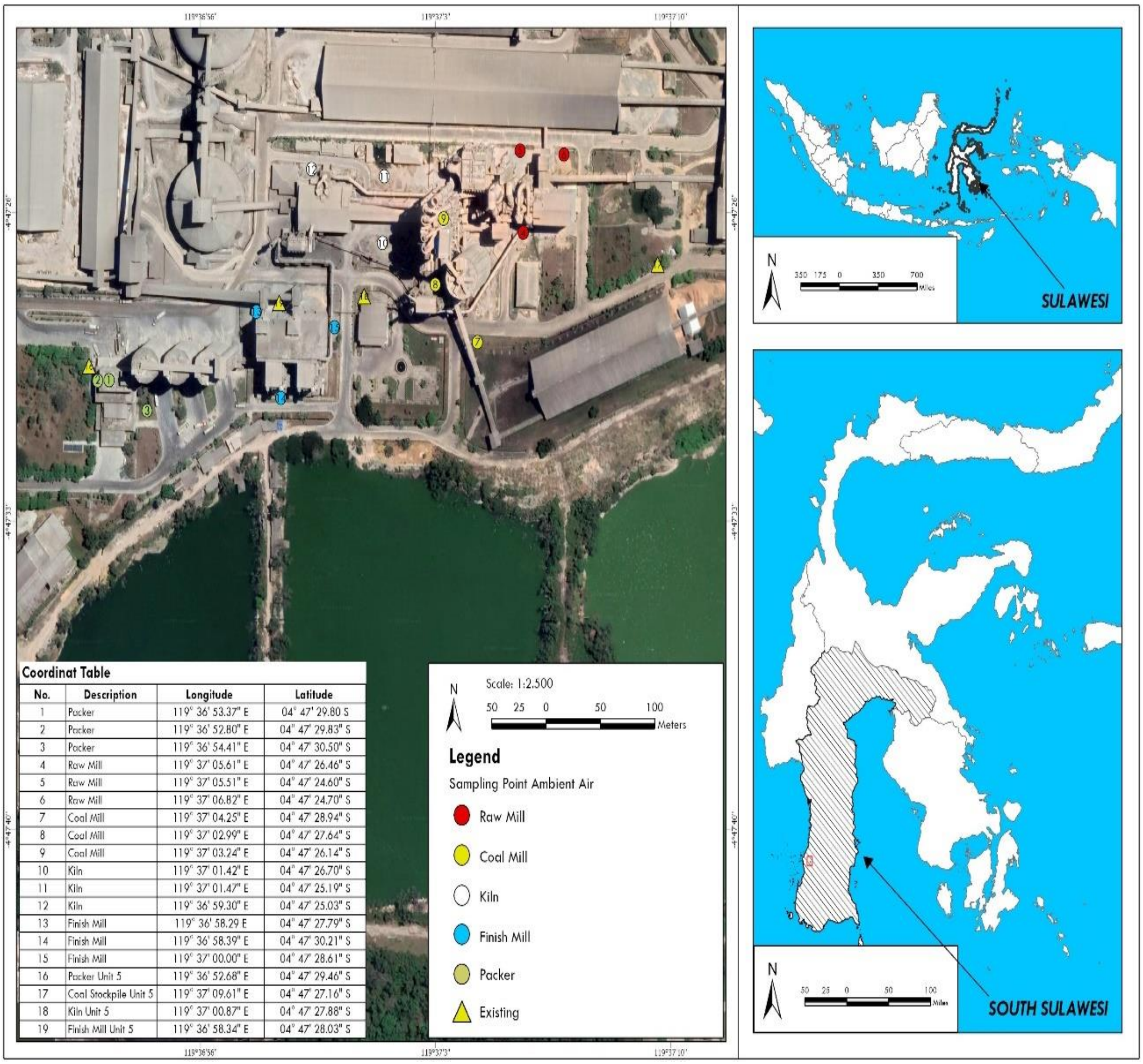


Figure 1: Geographic location of the study area along with the sampling locations of $PM_{2.5}$ and SO_2 in the five area of production unit at the cement plant in Pangkep Regency, Indonesia

Table 1: Distribution of the number of workers in the Production Unit of PT Semen Tonasa Unit V

Area in the Production Unit	Number of Workers (people)	Number of Sample
Raw Mill	24	18
Kiln	12	9
Coal Mill	12	10
Finish Mill	24	18
Packer	52	40
Total number of workers	**124**	**95**

Soruce: Secondary Data, 2024

Table 2: Characteristics of Respondents in the Unit V Production area of PT Semen Tonasa (N=95)

Characteristics	Area					%
Sex	*Coal Mill*	*Finish Mill*	*Kiln*	*Packer*	*Raw Mill*	
Male	10	18	9	40	18	100
Female	0	0	0	0	0	0
Age (year)						
16-25	1	3	1	2	3	10,5
26-35	6	11	6	22	11	58,9
36-45	0	3	1	10	3	17,9
46-55	3	1	1	6	1	12,6

Source: Primary Data, 2024

Table 3: Concentration of Sulfur Dioxide gas (SO2) and Particulate Matter 2.5 microns (PM2.5) in the production area of unit V PT Semen Tonasa

Parameter	Production Area				
	Raw Mill	*Coal Mill*	*Kiln*	*Finish Mill*	*Packer*
SO_2(mg/m^3)	0,0543	0,0544	0,0748	0,0422	0,0595
	0,0435	0,0589	0,0672	0,0405	0,0761
	0,0455	0,0605	0,0685	0,0444	0,0625
Average	***0,0478***	***0,0579***	***0,0702***	***0,0424***	***0,0660***
$PM_{2.5}$(mg/m^3)	0,1075	0,1685	0,0786	0,1598	0,1985
	0,0981	0,1445	0,0652	0,1667	0,1789
	0,0990	0,1388	0,0598	0,1705	0,1512
Average	***0,1015***	***0,1506***	***0,0679***	***0,1657***	***0,1762***

Source: Primary Data, 2024

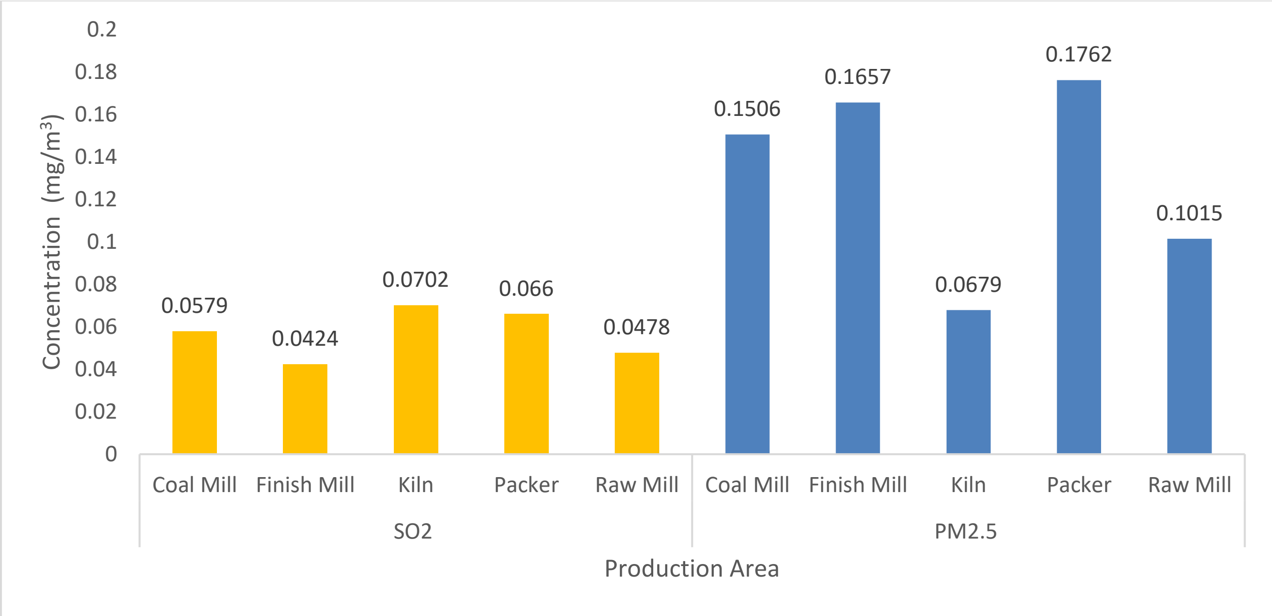


Figure 2: Concentration of Sulfur Dioxide (SO_2) gas and Particulate Matter 2.5 microns ($PM_{2.5}$) in the production area of unit V PT Semen Tonasa

Table 4: Worker characteristics in production area unit V PT Semen Tonasa (N=95)

Variable ***Exposure Time* (hour)**		**%**
1 – 2	10	10,53
3 – 4	72	75,79
5 – 6	13	13,68
7 – 8	0	0
***Exposure Frekuensi* (Day)**		
258	2	2,10
259	3	3,16
260	25	26,32
262	30	31,58
263	24	25,26
290	11	11,58
***Exposure Duration* (year)**		
1 – 5	22	23,16
6 – 10	27	28,42
11 – 15	41	43,16
16 – 20	1	1,05
>20	4	4,21
***Body Weight* (Kg)**		
45,0-60,0	29	30,5
60,1-75,0	48	50,5
75,1-90,0	14	14,7
>90,0	4	4,2

Source: Primary Data, 2024

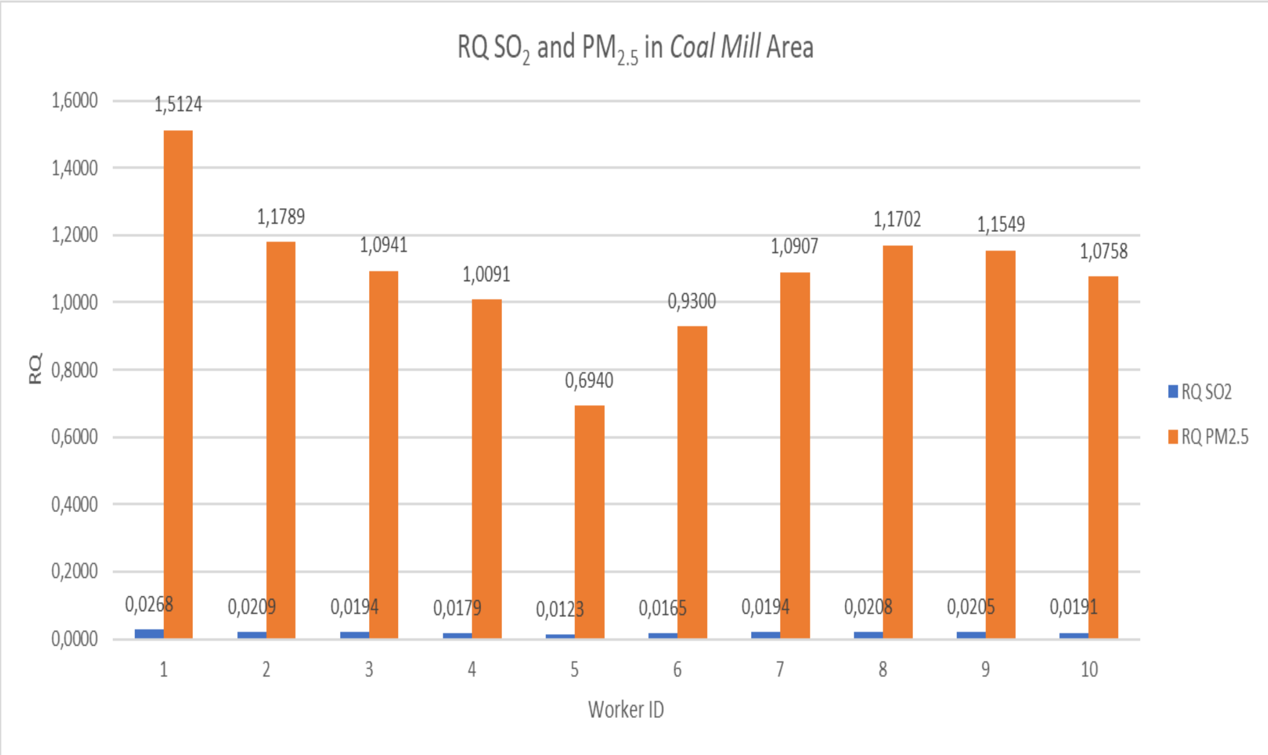
Table 5: Acceptable Daily Dose (ADD) and Risk Quotient (RQ) values for Sulfur Dioxide (SO_2) gas and Particulate Matter 2.5 microns ($PM_{2.5}$) for workers in the production area of unit V PT Semen Tonasa

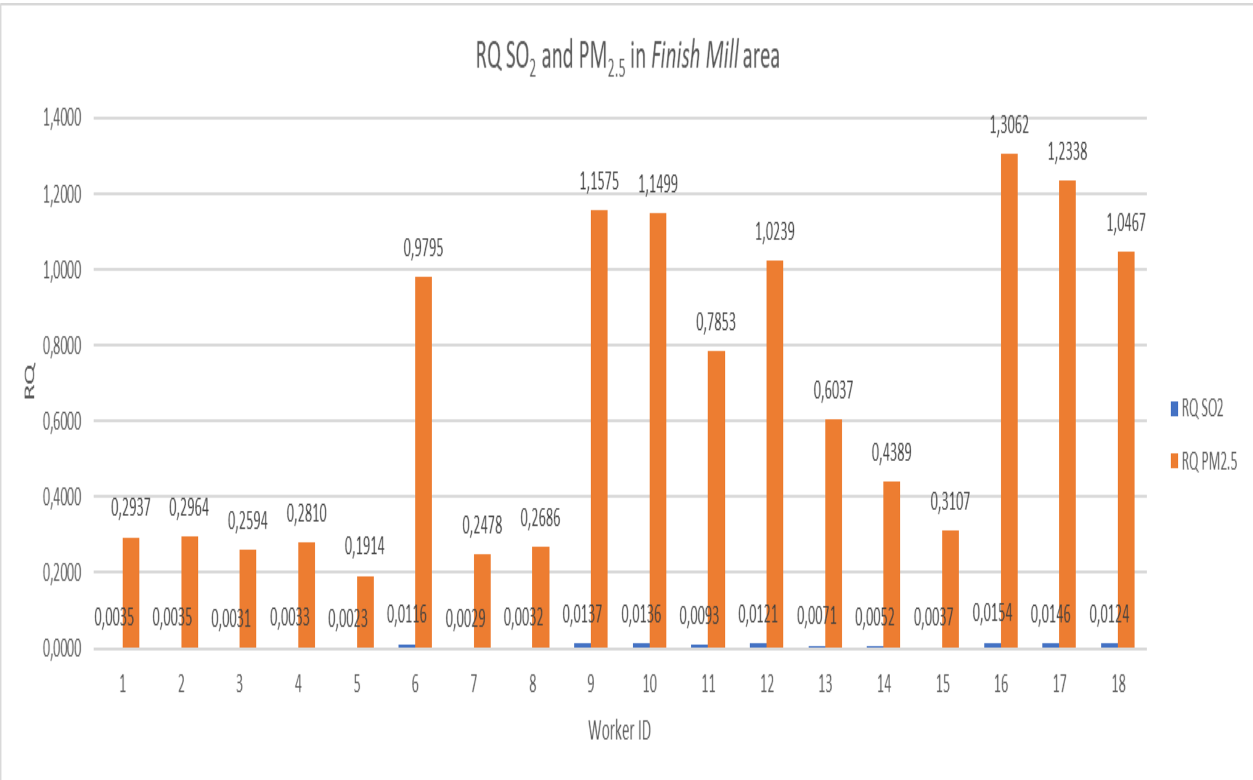
Production Area	**Result**		
	Minimum	*Maximum*	*Average*
ADD (mg/kg/day)			
SO_2			
Raw Mill	0.00003	0.0006	0.0004
Coal Mill	0.0003	0.0007	0.0005
Kiln	0.0002	0.0010	0.0006
Finish Mill	0.0001	0.0004	0.0002
Packer	0.00005	0.0012	0.0008
$PM_{2.5}$			
Raw Mill	0.0001	0.0012	0.0008
Coal Mill	0.0008	0.0018	0.0013
Kiln	0.0002	0.0010	0.0006
Finish Mill	0.0002	0.0016	0.0008
Packer	0.0001	0.0033	0.0020
***Risk Quotient* (RQ)**			
SO_2			
Raw Mill	0.0012	0.0220	0.0137
Coal Mill	0.0123	0.0268	0.0194
Kiln	0.0072	0.0393	0.0221
Finish Mill	0.0023	0.0154	0.0078
Packer	0.0018	0.0474	0.0292
$PM_{2.5}$			
Raw Mill	0.0557	1.0139	0.6317
Coal Mill	0.6940	1.5124	1.0910
Kiln	0.1501	0.8242	0.4630
Finish Mill	0.1914	1.3062	0.6597
Packer	0.1042	2.7408	1.6912

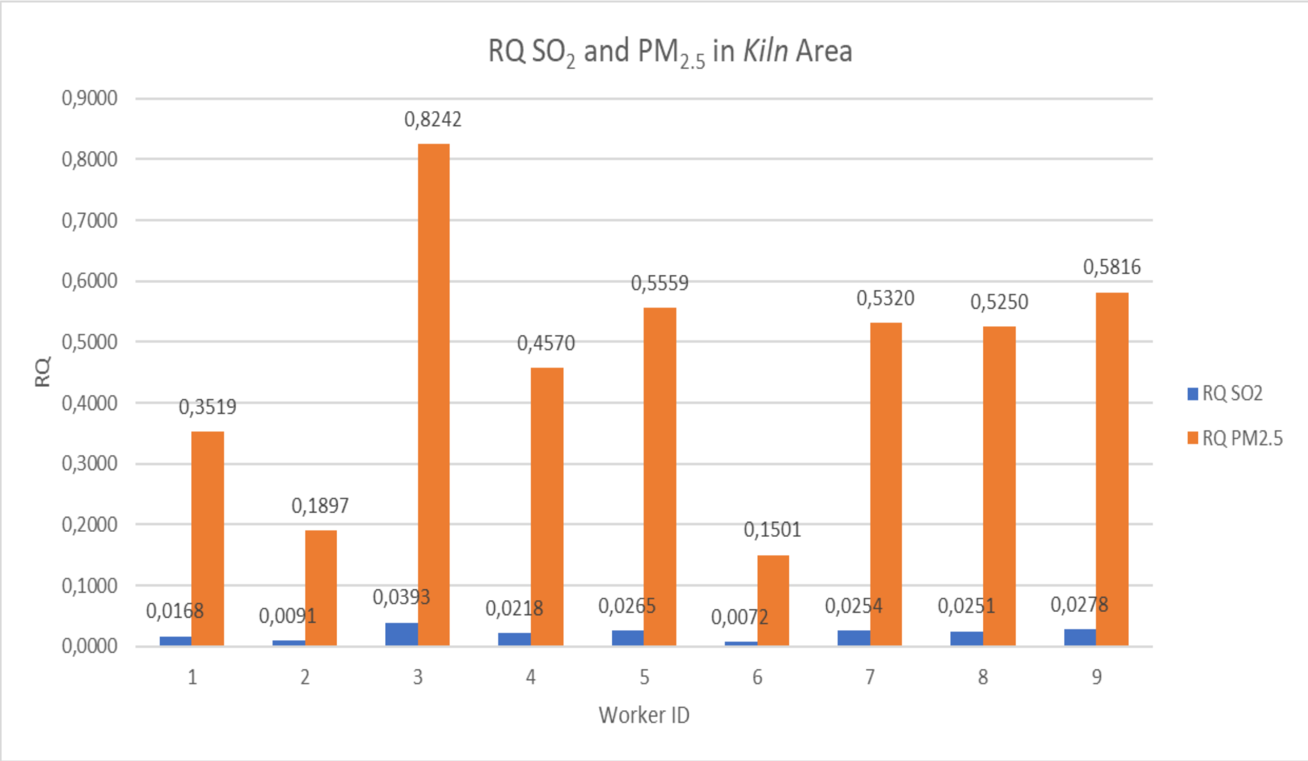
Table 6: Distribution of Risk Quotient (RQ) values for Sulfur Dioxide gas (SO2) and Particulate Matter 2.5 microns (PM2.5) among workers in the production area of unit V PT Semen Tonasa

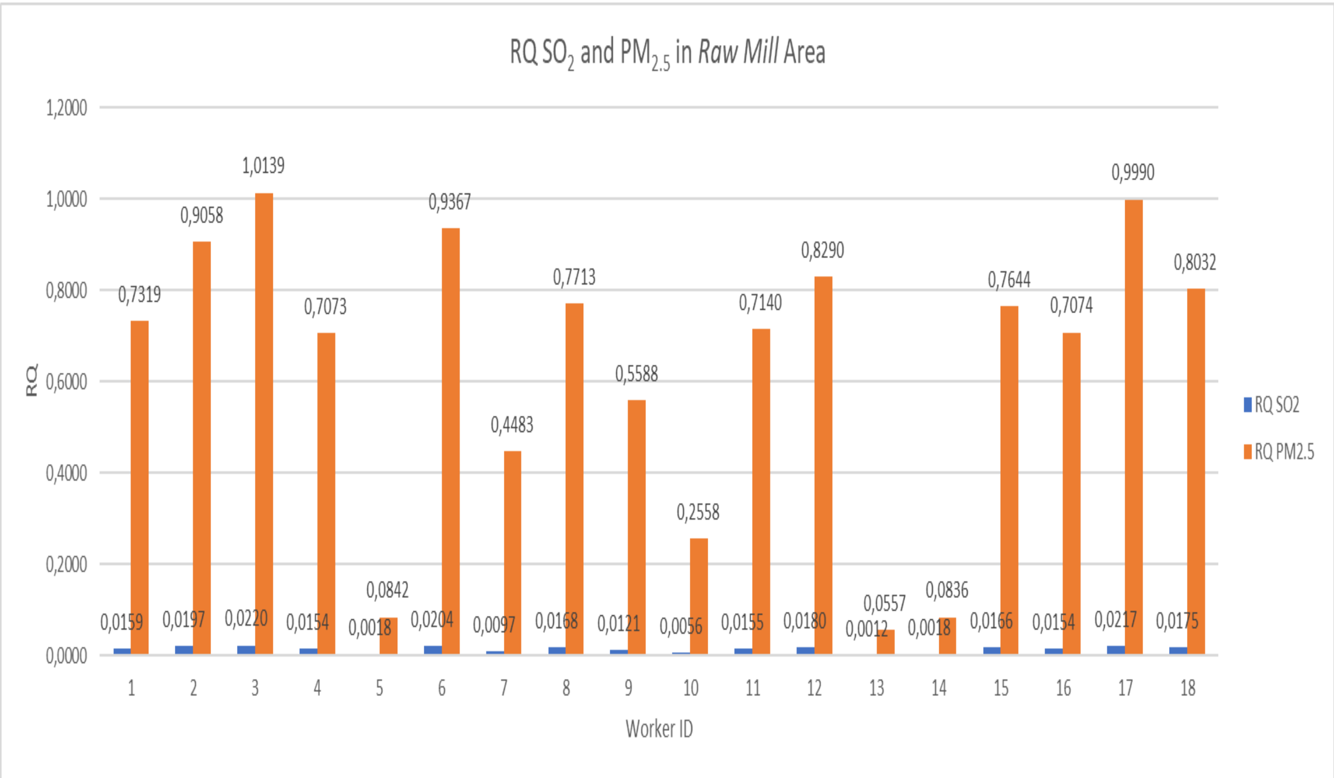
Risk Quotient	**Production Area (Worker)**				
	Raw Mill	*Coal Mill*	*Kiln*	*Finish Mill*	*Packer*
SO_2					
RQ ≤ 1	18	10	9	18	40
RQ > 1	0	0	0	0	0
$PM_{2.5}$					
RQ ≤ 1	17	2	9	12	8
RQ > 1	1	8	0	6	32

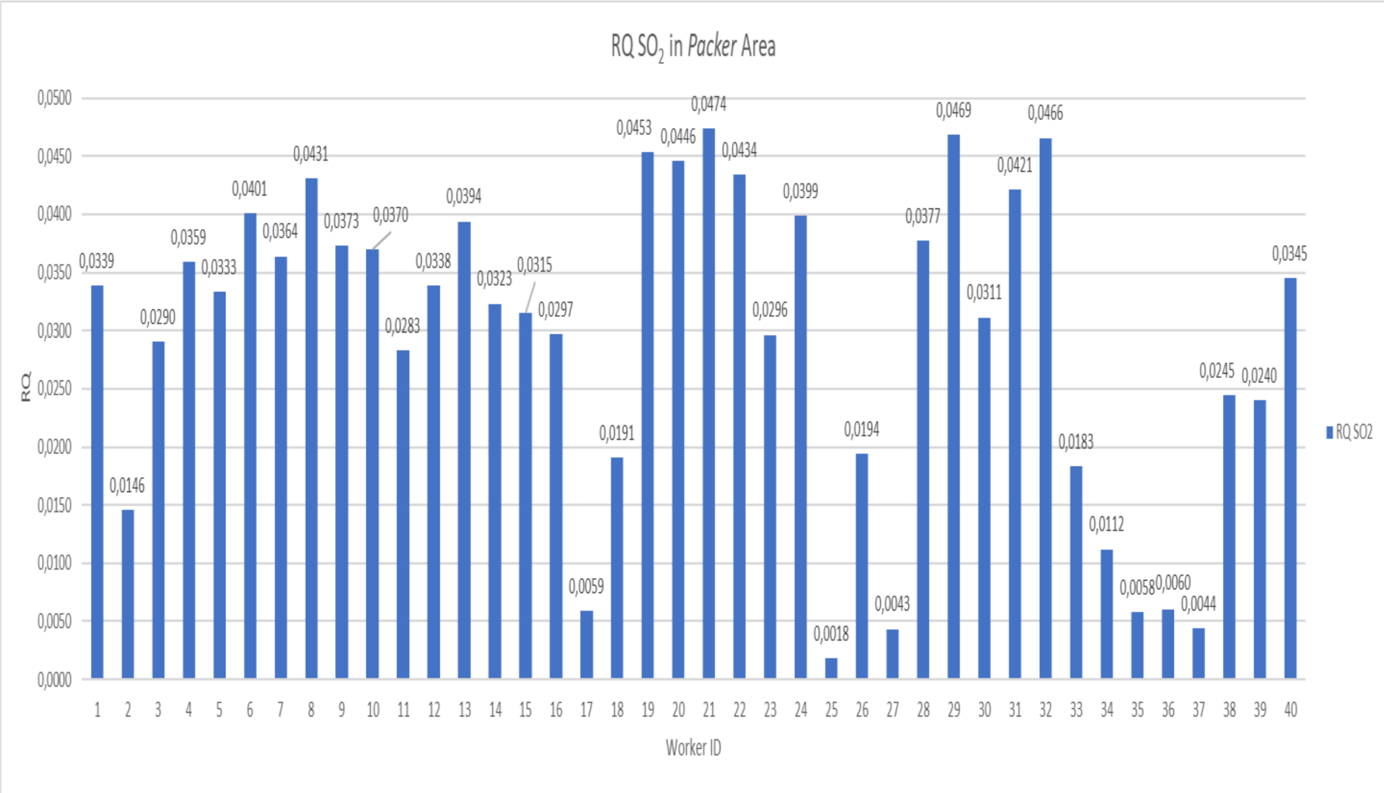
Source: Primary Data, 2024


RQ SO2 and PM2.5 in Coal Mill Area
RQ
Worker ID
RQ SO2
RQ PM2.5
1,5124
1,1789
1,0941
1,0091
0,6940
0,9300
1,0907
1,1702
1,1549
1,0758
0,0268
0,0209
0,0194
0,0179
0,0123
0,0165
0,0194
0,0208
0,0205
0,0191


RQ SO2 and PM2.5 in Finish Mill area
RQ
Worker ID
RQ SO2
RQ PM2.5
0,2937
0,2964
0,2594
0,2810
0,1914
0,9795
0,2478
0,2686
1,1575
1,1499
0,7853
1,0239
0,6037
0,4389
0,3107
1,3062
1,2338
1,0467
0,0035
0,0035
0,0031
0,0033
0,0023
0,0116
0,0029
0,0032
0,0137
0,0136
0,0093
0,0121
0,0071
0,0052
0,0037
0,0154
0,0146
0,0124


RQ SO2 and PM2.5 in Kiln Area
RQ
Worker ID
RQ SO2
RQ PM2.5
0,3519
0,1897
0,8242
0,4570
0,5559
0,1501
0,5320
0,5250
0,5816
0,0168
0,0091
0,0393
0,0218
0,0265
0,0072
0,0254
0,0251
0,0278


RQ SO2 and PM2.5 in Raw Mill Area
RQ
Worker ID
RQ SO2
RQ PM2.5
0,7319
0,9058
1,0139
0,7073
0,0842
0,9367
0,4483
0,7713
0,5588
0,2558
0,7140
0,8290
0,0557
0,0836
0,7644
0,7074
0,9990
0,8032
0,0159
0,0197
0,0220
0,0154
0,0018
0,0204
0,0097
0,0168
0,0121
0,0056
0,0155
0,0180
0,0012
0,0018
0,0166
0,0154
0,0217
0,0175



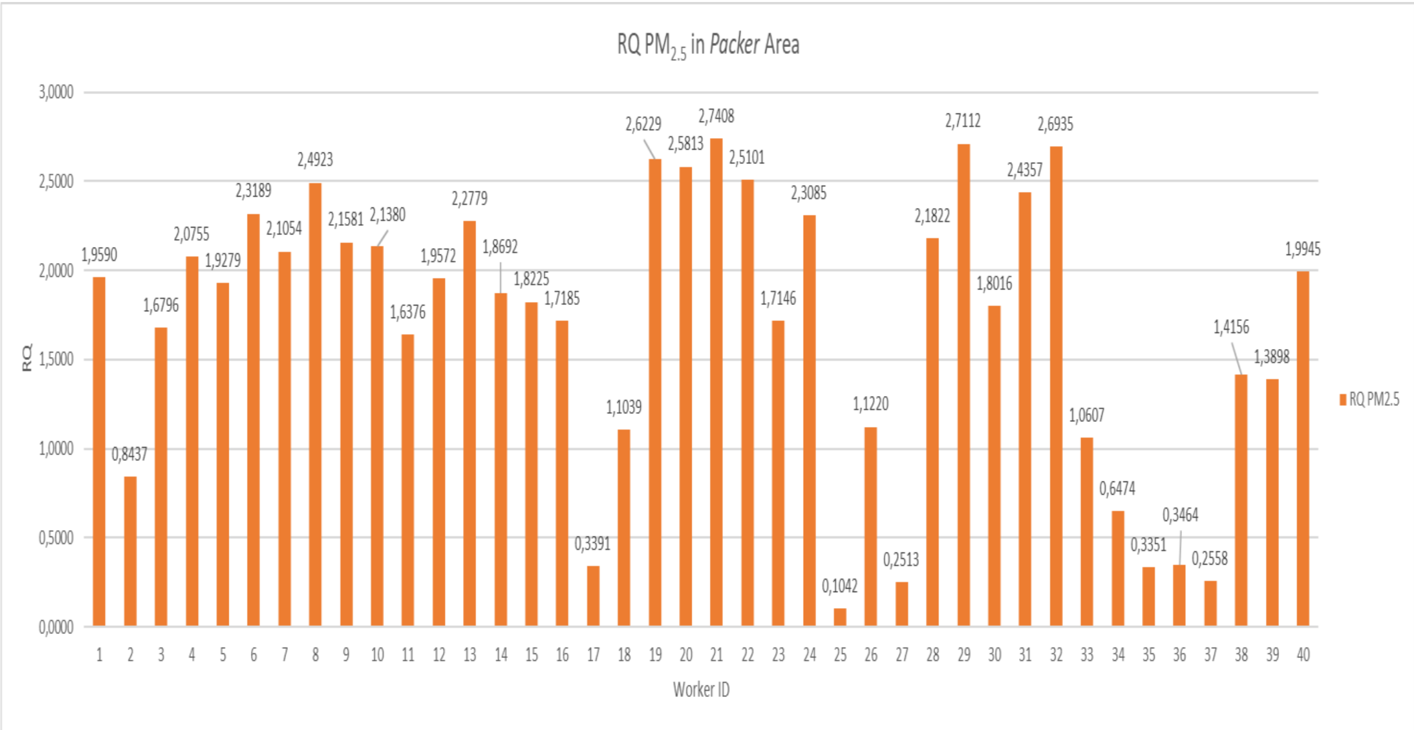


Figure 3: RQ values of SO_2 and $PM_{2.5}$ for each worker in each area of production unit

Table 7: Content of $PM_{2.5}$ in the production area of unit V PT Semen Tonasa

$PM_{2.5}$ Contain	Production Area (%)				
	Raw Mill	*Coal Mill*	*Kiln*	*Finish Mill*	*Packer*
SiO_2	12.82	28.08	21.94	16.76	16.88
Al_2O_3	2.29	-	2.25	0.61	3.03
TiO_2	0.30	0.77	0.34	0.22	0.34
Fe_2O_3	2.04	4.51	2.34	2.12	2.08
MnO	0.08	-	0.07	0.08	0.07
Cr_2O_3	-	32.71	-	-	-

Source: Primary Data, 2024

The equation for analyzing non-carcinogenic environmental health risks for the inhalation route can be seen in the equation (1) and (2).

4.1. Inhalation Rate (InhR)

Inhalation rate and body weight can predict exposure for each individual. The Inhalation Rate value in this study uses the value set by the US-EPA, namely 0.83 m^3/hour.

4.2. Exposure time (ET)

Regulation of the Minister of Manpower and Transmigration No.5 of 2018 recommends that the number of working hours per day is 8 hours. If the concentration of pollutants in the air is still within normal limits, workers can be exposed to pollutants during 8 working hours; on the other hand, if the concentration of pollutants in the air is above normal values, it is necessary to regulate the exposure time for workers. The longer workers are exposed, the more likely they are to be exposed to unsafe health risks (30). In this study, even though the number of working hours for workers was 8 hours, workers were exposed to fewer working hours in the production area, that is around 1 – 5 hours, with an average exposure time of 3 hours.

4.3. Exposure Frequency (EF)

This research found that the average exposure frequency was 264 days, with an exposure frequency range of 258 – 290 days. 30 workers (32.61%) had an exposure frequency of 262 days, 25 workers (27.17%) had an exposure frequency of 260 days, 2 workers (2.17%) had an exposure frequency of 258 days, and 11 workers (11.96%) has an exposure frequency of 290 days. Some workers do not know their leave schedule, workers may apply for leave outside the leave schedule and national holidays so that the worker's exposure frequency value can change each year. Frequency of exposure is the main contributor to health risks to adults (23%) due to $PM_{2.5}$ exposure [31].

4.4. Exposure Duration (ED)

The result of this research shows that the real-time exposure duration of workers in the PT Semen Tonasa Unit V production unit ranges from 1 – 35 years, with the average duration of worker exposure being 9.55 years. This illustrates that workers in the production area of PT Semen Tonasa Unit V have been exposed to SO_2 and $PM_{2.5}$ gases from the time they started working until now.

4.5. Acceptable Daily Dose (ADD)

This study calculates the exposure intake (Acceptable daily Dose) both for the actual current time (real time) and for the duration of the worker's work (life time). The intake value of workers' SO_2 and $PM_{2.5}$ exposure is expressed in mg/Kg/day. The SO_2 gas exposure intake value for workers at PT Semen ***Tonasa*** unit V ranges between 0.00003 – 0.00123 mg/Kg/day with the average SO_2 gas exposure intake for workers being 0.00053 mg/Kg/day, while the intake value $PM_{2.5}$ exposure for workers is in the range of 0.00007 – 0.00329 mg/Kg/day with the average $PM_{2.5}$ exposure intake for workers in the PT Semen Tonasa production unit V.

4.6. Risk Quotient (RQ)

The RQ value of SO_2 for workers in production units (Coal mill, Finish Mill, Kiln, Packer and Raw Mill areas) has an RQ value <1, or 0.0012 – 0.0474. The lowest SO_2 RQ value is in the Raw Mill area, and the highest RQ value is in the Packer area. The RQ SO_2 value in the Packer area is high due to SO_2 gas emissions originating from diesel vehicles (trucks) and the duration of exposure of workers in this area is longer than in other production areas. Research by (26) shows that the RQ SO_2 value for workers in the Combine Cycle Power Plant (CCP) area is less than 1 (RQ<1), namely in real time the RQ value is 0.0959 and in lifetime or in the next 5 to 30 years the RQ SO_2 value of 0.2668. The $PM_{2.5}$ RQ value for workers in production units (Coal mill, Finish Mill, Kiln, Packer and Raw Mill areas) have an RQ value>1 or are at risk. The RQ value is 0.0557 – 2.7408. The highest RQ value is in the Packer area which is due to the high concentration of $PM_{2.5}$ in this area and the duration of exposure of workers in this area is longer than in other areas. Research by (20) shows that the RQ $PM_{2.5}$ value in the batching plant production area in real time is 0.412. However, the RQ value is> 1 if the exposure lasts for the next 9 - 25 years so it will be a risk for workers. Exposure to $PM_{2.5}$ particles can affect the lungs and heart, for instance non-fatal heart attacks, irregular heartbeat, asthma, decreased lung function, and increased respiratory symptoms, such as irritation of the respiratory tract, coughing or breathing difficulty [32]. Research by [33] found that in 2015 in China, $PM_{2.5}$ exposure contributed 40.3% to total deaths due to stroke, 33.1% to total deaths due to acute lower respiratory tract infections, 26.8 % of total deaths due to ischemic heart disease, and 18.7% of total deaths due to chronic obstructive pulmonary disease. Research by [34] showed that 63.9% of respondents had respiratory problems in the cement packing unit, and the total lung capacity had decreased. In this research, analysis of the compound content in each material in the production unit, such as metal oxides such as Fe_2O_3, Cr_2O_3, Al_2O_3, and silica content (SiO_2). Silica (SiO_2) levels in $PM_{2.5}$ in production areas are in the range of 12.82 – 28.08%. Metal oxides, such as Titan Oxide (TiO_2), Iron Oxide (Fe_2O_3) are also found in all production areas, and Chromium Oxide (Cr_2O_3) is found in the Coal Mill area at 32.71%. Determination of material content, especially silica (SiO_2) in $PM_{2.5}$, is required as the initial information for next researcher in order to find out the extent to which Silica concentration is met in terms of meeting the Threshold Limit Value (TLV) for workers according to Minister of Manpower Regulation number 5 of 2018, that is 0.025 mg/ m^3. Silica levels in all areas of a cement factory in Iran were greater than the required TLV and there were significant differences in Peak Expiratory Flow (PEF) parameters between two groups of workers who were exposed to and not exposed to dust [35]. The concentration of silica inhaled by construction workers was 0.0125 mg/m^3 and did not exceed the specified NAB, however underground construction workers who have been exposed to SiO_2 for more than 15 years may experience chronic silicosis compared to those working outdoors [36]. This research has limitations in the Inhalation rate value used, that is the US EPA default value, not a direct measurement for each worker which may affect the accuracy of the ADD value and RQ value.

5. Conclusion

Based on the results of research, it can be concluded that the highest SO_2 concentration is in the Kiln area which is 0.0748 mg/m^3 and the lowest is in the Finish Mill area, that is 0.0405 mg/m^3. The highest $PM_{2.5}$ concentration was in the Packer area which is 0.1985 mg/m^3, and the lowest was in the Kiln area, that is 0.0598 mg/m^3. Environmental health risks of SO_2 gas exposure at worker is RQ $\leq$ 1 or no risk while for $PM_{2.5}$ exposure is RQ> 1 for 47 workers and RQ $\leq$ 1 for 48 workers. The material content of $PM_{2.5}$ is the content of metal oxides and silica (SiO_2). The highest SiO_2 content was in the Coal Mill area, that is 28.08%, and the lowest was in the Raw Mill area which achieves 12.82%.

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