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The Relationship Between $PM_{2.5}$ and PM_{10} Dust Exposure and Respiratory Disorders Among Limestone Mining Workers in Kebumen Regency

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Abstract: Limestone mining activities have an impact on respiratory disorders among workers due to the presence of dust particles smaller than 10µ. Workers experiencing respiratory issues are at risk of occupational diseases, especially as limestone mining operations continue. The presence of particulates (PM2.5 and PM10) not only causes respiratory problems but also other health issues, as a large number of particulates entering the body over a long period can increase the risk of death. The purpose of this study is to analyze the relationship between exposure to PM10 and PM2.5 dust and respiratory disorders among limestone mining workers in Kebumen Regency. This study is an analytical observational study with a cross-sectional approach, involving a population of 62 workers spread across 11 locations. The results showed a relationship between work duration (p-value = 0.024), length of exposure (p-value = 0.007), smoking habits (p-value = 0.015), use PPE (p-value = 0.003), and disease history (p-value = 0.000) with respiratory disorders. Meanwhile, age, PM2.5, and PM10 levels did not show a relationship with respiratory disorders as the p-values were > 0.05. The variables predominantly associated with respiratory symptoms were work duration (OR=5.100), length of exposure (OR=22.277), completeness of PPE (OR=17.330), and disease history (OR=7.536). Conclusion this study that $PM_{2,5}$ and PM_{10} do not have a significant relationship with respiratory disorders among limestone mining workers in Kebumen Regency.

Keywords: Limestone mining; PM2.5; PM10; Respiratory disorders

Introduction

Mining, as a leading industry, plays an important role in the shift of economic trends in various countries and is crucial for the growth of industrialization. On the other hand, mining activities are also responsible for contributing to air pollution (Asif et al., 2016). In industrial areas, air quality is relatively poor, as the air is already contaminated due to various types of pollutants. Among these pollutants, there are five components that have a significant impact on air pollution in industrial areas, including: Carbon Monoxide (CO), Nitrogen Oxides (NOx), Sulfur Dioxide (SOx), Hydrocarbons (HC), and Particulate Matter (PM) (Wardhana, 2013). Particulate Matter (PM) is a critical issue for sustainable development. The United Nations (UN) expects to achieve the Sustainable Development Goals (SDGs) by 2030 (World Health Organization, 2017).

Particulates that are harmful to health are those that range in size from 0.1 to 10 microns. PM10 refers to particles that are less than 10 microns in diameter. When inhaled, these particles can enter the respiratory tract and adhere to the mucous membranes of the upper respiratory tract. Meanwhile, PM2.5 consists of particles smaller than 2.5 microns in diameter. These particles can

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penetrate deeper into the respiratory tract and settle in the bronchioles of the middle respiratory tract (Hashim et al., 2020).

Air pollution caused by PM in Bangladesh can reduce life expectancy by up to 6.8 years. In China, often regarded as successful in controlling air pollution, there is still potential for a reduction of 2.5 years in life expectancy. In developed countries like the United States, PM air pollution can reduce life expectancy by up to 3.6 months. In Indonesia, especially in Jakarta, life expectancy is estimated to be reduced by 2.4 years (WHO, 2023).

The level of PM pollution in Indonesia from 2000 to 2021 shows that the average concentration of PM exceeds the standards set by national regulations and the WHO. The highest pollution level in Indonesia occurred in 2015, with a concentration of 25 $\mu g/m^3$, while the national standard is 15 $\mu g/m^3$ and the WHO standard is 5 $\mu g/m^3$ (BBC Indonesia, 2023).

The average concentration in major cities in Indonesia in 2022 was 23.32 $\mu g/m^3$, which exceeds the WHO standard of 5 $\mu g/m^3$. Acute Respiratory Infections (ARI) are among the top 10 most common diseases in healthcare facilities, ranging from mild conditions like rhinitis to more serious diseases that could lead to outbreaks or pandemics, such as influenza, and fatal conditions like pneumonia (BBC Indonesia, 2023).

Limestone mining is one of the industries that causes significant air pollution, which can have negative health impacts on miners and surrounding communities. The limestone mining industry generates air pollution in the form of dust, including Total Suspended Particulates (TSP), particulate matter (PM 2.5), and particulate matter (PM 10). TSP consists of particles with a diameter <100 µm, PM 2.5 consists of particles with a diameter <2.5 µm, and PM 10 consists of particles with a diameter <10 µm (Nurfadillah et al., 2023).

The limestone mining industry uses limestone as the primary material to be extracted. During the mining process, particulate matter (PM) is generated. Particles found in the air in the form of dust, smoke, dirt, and soot are referred to as PM. Particles smaller than 2.5 microns (PM2.5), when inhaled, move deeper into the respiratory system, passing through the bronchi where gas exchange occurs. Exposure to PM2.5 in limestone mining is associated with arsenic (As), mercury (Hg), lead (Pb), and a significant amount of silica crystals. Short-term exposure can lead to silicosis, cardiovascular effects, and other dangerous respiratory conditions (Nurfadillah et al., 2023).

Dust smaller than 10 microns that contains silica can also cause silicosis or pneumoconiosis. Therefore, exposure to PM10 can cause serious health issues and requires attention. The threshold limit value (TLV) for PM10 exposure is 75$\mu g/m^3$, while the TLV for PM2.5 exposure is 55$\mu g/m^3$ (PP, 2021).

Kebumen Regency has a karst area located in the western region, which has been designated by the local government in the Spatial Planning (RTRW) document. This karst area spans 40 km^2 and is located across three subdistricts: Buayan, Rowokele, and Ayah (Amalia et al., 2016).

Mining activities in this area often lead to air pollution, which can cause health problems, particularly respiratory issues among limestone miners. According to an initial survey of 9 workers, 5 (56%) of them reported experiencing respiratory symptoms. Nearly all of the limestone miners do not use personal protective equipment (PPE) such as goggles, gloves, masks, and boots. If a limestone worker develops respiratory issues, the risk of work-related diseases and even death increases.

Respiratory problems develop gradually as a result of the cumulative exposure received by an individual's lungs. In addition to environmental exposure, respiratory problems can be influenced by the characteristics of the worker, such as age, gender, history of lung disease, duration of exposure, smoking habits, years of employment, and the use of protective equipment such as masks or cloths. If a limestone worker develops respiratory issues, the risk of work-related diseases and even death increases (Nuraeni et al., 2022).

Based on the above explanation, the researcher conducted a study titled "The Relationship between PM2.5 and PM10 Exposure and Respiratory Disorders in Limestone Mining Workers in Kebumen Regency."

Method

The type of research used is observational analytic because this study aims to determine the risk factors of PM exposure on disease occurrence. This research uses a cross-sectional approach. In this study, the independent variables (risk factors) and dependent variables (effects) that occur in the study subjects will be measured and collected simultaneously, and observed at one point in time across several variables. This approach is carried out using a survey method to observe the actual conditions in the field, total dust particulate measurement using a particulate counter to observe the particles in the industrial environment, and interviews with workers in the industrial area. Data processing is then conducted in a univariate, bivariate, and multivariate manner.

Univariate analysis is performed by processing the data analytically. For variables with ratio and nominal data scales, the univariate analysis presented includes the count and percentage of each variable. The univariate analysis is presented in tables and narrative form. The purpose of univariate analysis is to describe or explain the characteristics of each research variable (Sugiyono, 2019).

Bivariate analysis in this research involves creating categorical variables, both nominal and ordinal, and then analyzing them using SPSS version 25 with the chi-square test (x2), with a significance level of α = 0.05 and a 95% Prevalence Ratio (PR), as well as calculating the risk estimates for each independent variable in relation to the dependent variable using the Odds Ratio (OR) (Sugiyono, 2019).

Multivariate analysis is used to examine the relationship between independent and dependent variables that have a greater influence. This analysis is performed by linking the independent and dependent variables simultaneously. Since the variables are categorical, the analysis used in this study is logistic regression (Sugiyono, 2019). The probability formula used in this multivariate analysis is:[39]

$$P = \frac{1}{1+e^{-(\alpha+\beta 1x1+ \beta 2x2+\cdots+\beta pxp)}} \quad (1)$$

Where, e: Constant 2,718

The results are then interpreted in detail to determine whether each variable studied has a relationship with respiratory disorders in industrial workers.

Results and Discussion

Results

General Overview

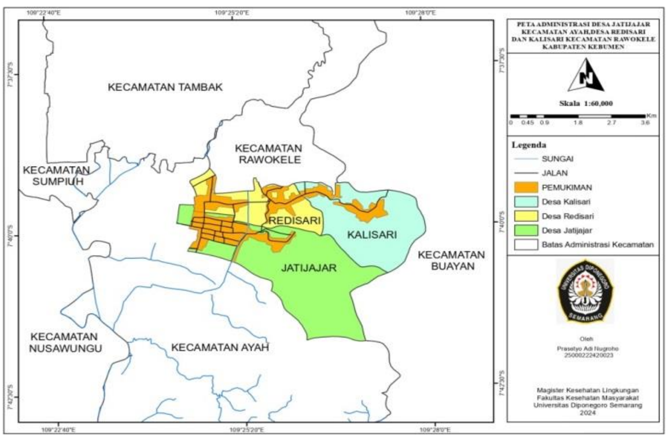

Figure 1. Map of the research distribution: Jatijajar Village, Ayah Subdistrict, Redisari Village, and Kalisari Village, Rowokele Subdistrict, Kebumen Regency 2024

The research was conducted in 2 subdistricts and 3 villages: Jatijajar Village in Ayah Subdistrict, Redisari Village, and Kalisari Village in Rowokele Subdistrict, Kebumen Regency. The total area of these three villages is approximately 950 hectares with a population of about 13,000 people. These three villages have 11 active limestone mining industry sites that are continuously operating to this day. Below is the administrative map of the research location.

Univariate Results

Based on Table 1, it was found that the number of male respondents is higher, with 39 male respondents (62.9%) and 23 female respondents (37.1%). Regarding the education level of respondents, the majority are graduates of elementary and junior high schools, with 42 respondents (67.7%), while 20 respondents (32.2%) are graduates of senior high school or university.

Table 1. Distribution of Respondent Characteristics

Characteristic	N	Percentage (%)
Gender		
Male	39	62.9
Female	23	37.1
Education Level		
Low (Elementary and Junior High)	42	67.7
High (Senior High and University)	20	32.2

Table 2. Distribution of Respondent Experience

Variable	n	Percentage (%)
Respiratory Disorders		
There's a Disturbance	25	40.3
No Distractions	37	59.7
Age		
≥30 years	52	83.9
<30 years	10	16.1
Work Experience		
≥5 years	42	67.7
<5 years	20	32.3
Exposure Duration		
≥8 hours/day	49	79
<8 hours/day	13	21
Smoking Habits		
Yes	41	66.1
No	21	33.9
PPE Completeness		
Yes	33	53.2
No	29	46.8
History of Lung Disease		
Yes	24	38.7
No	38	61.3
PM2.5		
Above NAB	16	25.8
Below NAB	46	74.2
PM10		
Above NAB	31	50
Below NAB	31	50
Temperature		
Above NAB	47	75.8
Below NAB	15	24.2
Humidity		
Above NAB	6	9.7
Below NAB	56	90.3

Based on Table 2, it was found that 25 respondents (40.3%) experienced respiratory disorders, while 37 respondents (59.7%) did not have respiratory disorders. The majority of respondents were over 30 years old, with 52 respondents (83.9%), while 10 respondents (16.1%) were under 30 years old. Regarding work experience, 42 respondents (67.7%) had more than 5 years of experience, while 20 respondents (32.3%) had less than 5 years of experience. Exposure duration was mostly over 8 hours, with 49 respondents (79%) and less than 8 hours with 13 respondents (21%). Smoking habits were present in 41 respondents (66.1%) and absent in 21 respondents (33.9%). Complete use of Personal Protective Equipment (PPE) was reported by 33 respondents (53.2%), while 29 respondents (46.8%) did not have complete PPE. A history of lung disease was found in 24 respondents (38.7%), while 38 respondents (61.3%) had no such history. PM2.5 levels above the threshold limit value (TLV) were observed in 16 respondents (25.8%), while 46 respondents (74.2%) had PM2.5 levels below TLV. PM10 levels above the TLV were observed in 31 respondents (50%), and 31 respondents (50%) had PM10 levels below TLV. The temperature was above the TLV for 47 respondents (75.8%) and below for 15 respondents (24.2%). Humidity was above the TLV for 6 respondents (9.7%) and below the TLV for 56 respondents (90.3%).

Bivariate Results

Based on Table 3, the results show that among respondents aged ≥30 years, 23 respondents (44.2%) experienced respiratory disorders, while 29 respondents (55.8%) did not have respiratory disorders. Among respondents aged <30 years, 2 respondents (20%) had respiratory disorders, and 8 respondents (80%) did not have respiratory disorders. The results of the chi-square test indicate that there is no relationship between age and respiratory disorders, as evidenced by the significance value (p-value = 0.153).

Table 3. Relationship Between Age and Respiratory Disorders

Age	Respiratory disorders							
	Yes		No		J Number n (%)		*p-value*	PR (95% CI)
	F	%	f	%	F	%		
≥30 years	23	44.2	29	55.8	52	100	0.153	2.212
<30 years	2	20	8	80	10	100		(0.617-7.927)
Total	25	40.3	37	59.7	62	100		

Table 4. Relationship Between Work Experience and Respiratory Disorders

Work Experience	Respiratory Disorde							
	Yes		No		N total (%)		*p-value*	PR (95% CI)
	F	%	f	%	F	%		
≥5 years	21	50	21	50	42	100	0.024	2.500
<5 years	4	20	16	80	20	100		(0.989-6.319)
Total	25	40.3	37	59.7	62	100		

Based on Table 4, it shows that among respondents with work experience ≥5 years, 21 respondents (50%) experienced respiratory disorders, while 21 respondents (50%) did not. Among respondents with work experience <5 years, 4 respondents (20%) had respiratory disorders, and 16 respondents (80%) did not. The chi-square test analysis shows that there is a relationship between work experience and respiratory disorders, with a significant p-value (p-value = 0.024). Based on the PR value (95% CI), those with more than 5 years of work experience have 2.5 times the risk of experiencing respiratory disorders compared to those with less than 5 years of experience.

Table 5. Relationship Between Duration of Exposure and Respiratory Disorders

Duration of Exposure	Respiratory Disorder				J Total (%)			
	Yes		No				*p-value*	PR (95% CI)
	F	%	F	%	F	%		
≥8 hours	24	49,0	25	51.0	49	100	0.007	6.367
<8 hours	1	7.7	12	92.3	26	100		(0.948-42.769)
Total	25	40.3	37	59.7	62	100		

Based on Table 1.5, it shows that among respondents with exposure duration ≥8 hours, 24 respondents (49%) experienced respiratory disorders, and 25 respondents (51%) did not. Among respondents with exposure duration <8 hours, 1 respondent (7.7%) had respiratory disorders, and 12 respondents (92.3%) did not. The chi-square test analysis indicates a relationship between exposure duration and respiratory disorders, with a significant p-value (p-value = 0.007). Based on the PR value (95% CI), those with exposure duration of more than 8 hours are at 6.3 times higher risk of experiencing respiratory disorders compared to those with exposure of less than 8 hours.

Table 6. Relationship Between Smoking Habit and Respiratory Disorders

Smoking Habits	Respiratory Disorder				Total (%)		p- value	PR (95% CI)
	Yes		No					
	F	%	F	%	F	%		
Yes	21	51.2	20	48.8	41	100	0.015	2.689
No	4	19.0	17	81.0	18	100		(1.060-6.822)
Total	21	61.4	41	38.6	62	100		

Based on Table 6, it shows that among respondents with smoking habits, 21 respondents (51.2%) experienced respiratory disorders, while 20 respondents (48.8%) did not. Among respondents without smoking habits, 4 respondents (19%) had respiratory disorders, and 17 respondents (81%) did not. The chi-square test analysis indicates a relationship between smoking habits and respiratory disorders, with a significant p-value (p-value = 0.015). Based on the PR value (95% CI), those with smoking habits are 2.6 times more likely to experience respiratory disorders compared to those without smoking habits.

Table 7. Relationship between PPE Completeness and Respiratory Disorders

PPE Usage	Respiratory Disorder				J Total (%)		p- value	PR (95% CI)
	Yes		No					
	F	%	F	%	F	%		
Yes	19	57.6	14	42.4	33	100		2.783
No	6	20.7	23	79.3	29	100	0.003	(1.288-6.013)
Total	25	40.3	37	59.7	62	100		

Based on Table 7, it shows that among respondents with complete PPE, 19 respondents (57.6%) experienced respiratory disorders, and 14 respondents (42.4%) did not. Among respondents with incomplete PPE, 6 respondents (20.7%) experienced respiratory disorders, and 23 respondents (79.3%) did not. The chi-square test analysis indicates a relationship between PPE completeness and respiratory disorders, with a significant p-value (p-value = 0.003). Based on the PR value (95% CI), incomplete PPE poses a 2.7 times higher risk of experiencing respiratory disorders compared to complete PPE.

Table 8. Relationship between Disease History and Respiratory Disorders

Disease History	Respiratory Disorder				J Total (%)		p- value	PR (95% CI)
	Yes		No					
	F	%	f	%	F	%		
Yes	17	70.8	7	29.2	24	100		3.365
No	8	21.1	30	78.9	38	100	0.000	(1.727-6.556)
Total	25	40.3	37	59.7	62	100		

Table 9. Relationship between PM2.5 Levels and Respiratory Disorders

PM2.5 Levels	Respiratory Disorder				Total (%)		p- value	PR (95% CI)
	Yes		No					
	F	%	f	%	F	%		
Above NAB	5	31.3	11	68.7	16	100	0.390	0.719
Below NAB	20	43.5	26	56.5	46	100		(0.324- 1.596)
Total	25	40.3	37	59.7	62	100		

Based on Table 8, it shows that among respondents with a history of illness, 17 respondents (70.8%) experienced respiratory disorders, and 7 respondents (29.2%) did not. Among respondents without a history of illness, 8 respondents (21.1%) had respiratory disorders, and 30 respondents (78.9%) did not. The chi-square test analysis indicates a relationship between disease history and respiratory disorders, with a significant p-value (p-value = 0.000). Based on the PR value (95% CI), having a history of illness poses a 3.3 times higher risk of experiencing respiratory disorders compared to those without a history of illness.

Based on Table 9, it shows that among respondents with PM2.5 levels above the NAB, 5 respondents (31.3%) experienced respiratory disorders, and 11 respondents (68.7%) did not. Among respondents with PM2.5 levels below the NAB, 20 respondents (43.5%) had respiratory disorders, and 26 respondents (56.5%) did not. The chi-square test analysis shows that there is no relationship between PM2.5 levels and respiratory disorders, as evidenced by the significance value (p-value = 0.390).

Table 10. Relationship Between PM10 Levels and Respiratory Disorders

PM10 Levels	Respiratory Disorder				J Total (%)		p- value	PR (95% CI)
	Yes		No					
	f	%	F	%	F	%		
Above NAB	11	35.5	20	64.5	31	100	0.437	0.786
Below NAB	14	45.2	17	54.8	31	100		(0426-1.450)
Total	25	40.3	37	59.7	62	100		

Based on Table 10, it shows that among respondents with PM10 levels above the NAB, 11 respondents (35.5%) experienced respiratory disorders, and 20 respondents (64.5%) did not. Among respondents with PM10 levels below the NAB, 14 respondents (45.2%) had respiratory disorders, and 17 respondents (54.8%) did not. The chi-square test analysis shows that there is no relationship between PM10 levels and respiratory disorders, as evidenced by the significance value (p-value = 0.437).

Multivariate Results

A bivariate analysis was conducted between each independent variable and the dependent variable. If the bivariate analysis results have a p-value <0.05, the variable can be included in the multivariate model.

Table 11. Multivariate Logistic Regression Table with Complete Variables

Variable	B	Df	P value	OR
Age	1.363	1	0.282	3.910
Length of Service	1.534	1	0.164	4.635
Duration of Exposure	3.186	1	0.033	24.184
Smoking Habits	0.979	1	0.292	2.662
PPE Complementeness	3.503	1	0.002	33.224
Disease History	1.815	1	0.034	6.144
PM2.5	1.127	1	0.378	3.086
PM10	-2.014	1	0.133	0.133
Constant	-14.830	1	0.001	0.000

The variables that were considered important and included in the model were selected by retaining those with a p-value <0.05 and excluding those with a p-value >0.05. This process was carried out step by step, starting with the variables that had the largest p-value.

The multivariate logistic regression modeling, using the enter method, was conducted to assess the exposure of independent variables to respiratory disorders (dependent variable). The results show that the variables included in the multivariate model were length of service, disease history, PPE completeness, and disease history. Other variables, such as PM2.5, smoking habit, age, and PM10, were excluded from the model.

Table 12. Results of Multivariate Logistic Regression Modeling

Variable	B	Df	P value	OR	95% CI
Age	1.629	1	0.082	5.100	0.814 – 31.935
Length of service	3.104	1	0.018	22.277	1.717 – 289.095
Disease History	2.852	1	0.001	17.330	3.129 – 95.984
PM2.5	2.020	1	0.010	7.536	1.627 – 34.905
Constant	-12.492	1	0.000	0.000	

Thus, the following logistic regression equation was obtained:

Logit Y = $\beta_0 + \beta_1 X_1 + \ldots\ldots + \beta_p X_p$
= -12,492+1,629(MK)+3,104(LP)+2,852 (KA)+2,020(RP)
= -12,492+1,629(1)+3,104(1)+2,852 (1)+2,020(1)

Logit Y = $\beta_0 + \beta_1 X_1 + \ldots\ldots + \beta_p X_p$
= -12,492+1,629+3,104+2,852 +2,020
= -2,887

Prediction of the likelihood of respiratory disorders in respondents:

$$P = \frac{e^{B0} + B1x}{1 + e^{B0} + B1x}$$

$$P = \frac{e^{-2,887}}{1 + e^{-2,887}}$$

$$P = 0.0557$$

$$P = 5.57$$

$$P = 100\% - 5.57\%$$

$$P = 94.43\%$$

Based on the multivariate analysis results, it was found that if the length of service increases, the likelihood of respiratory disorders will increase by 5.1 times. If the exposure duration increases, the likelihood of respiratory disorders will increase by 22.2 times. If PPE completeness decreases, the likelihood of respiratory disorders will increase by 17.3 times. If there is a history of disease, the likelihood of respiratory disorders will increase by 7.5 times. The logistic regression equation calculation shows that for workers with a history of disease, a length of service ≥5 years, exposure ≥8 hours/day, and incomplete PPE, the predicted probability of experiencing respiratory disorders is 94.43%.

Discussion

Relationship Between Age and Respiratory Disorders

The analysis using the chi-square test showed that there is no relationship between age and respiratory disorders, with a significance value (p-value = 0.153). This study found that age does not impact respiratory disorders because these disorders do not discriminate based on age—both young and old individuals are equally at risk of experiencing respiratory symptoms, depending on their immune system and resistance in the limestone mining industry in Kebumen Regency. Based on the PR value (95% CI), age is significant as a protective factor against respiratory disorders. This finding aligns with a study conducted on waste pickers at the Sanggrahan Landfill in Temanggung Regency in 2021, which found no significant relationship between age and respiratory disorders (p-value = 0.206). The lack of a relationship between age and respiratory disorders is due to the majority of workers who have worked for more than 5 years but did not experience respiratory disorders (Prasetyowati et al., 2023). This contradicts the theory that states as a person ages, there is an increased susceptibility to diseases, particularly respiratory disorders, in workers exposed to air pollutants continuously. The increase in age leads to a decrease in organ function due to cellular degeneration, so as a person ages, the disorders in the body also increase (Fauziah et al., 2020).

Relationship Between Length of Service and Respiratory Disorders

The analysis using the chi-square test showed that there is a relationship between length of service and respiratory disorders, with a significance value (p-value = 0.024). Based on the analysis, 21 respondents (50%) with ≥ 5 years of service experienced respiratory disorders. The PR value obtained was 2.500, meaning that respondents who worked for ≥ 5 years have a 2.5 times greater risk of experiencing respiratory disorders compared to respondents who worked for < 5 years. This study is in line with a study conducted on workers in the furniture industry in Abepura in 2023 (p-value = 0.000). Length of service refers to the duration a worker has been working in a particular work environment, calculated from the time they started working until the study was conducted. A person who has worked for a long time is at a higher risk of exposure to hazards in their workplace (Medyati et al., 2023). Longer service periods lead to more health problems for workers due to the environment or materials they are exposed to, which accumulate over time (Sulfiana et al., 2020).

Relationship between Exposure Duration and Respiratory Disorders

The analysis using the chi-square test showed that there is a relationship between exposure duration and respiratory disorders, with a significance value (p-value = 0.007). Based on the analysis, 24 respondents (49%) with exposure duration ≥ 8 hours/day experienced respiratory disorders. The PR value obtained was 6.367, meaning that respondents who worked with exposure ≥ 8 hours/day have a 6.3 times higher risk of experiencing respiratory disorders compared to those who worked with exposure < 8 hours/day. The long work duration is due to workers being employed on a piece-rate system, where their wages depend on the amount of production collected. They believe that the longer they work, the more they will earn. This study is in line with research conducted on brick kiln workers in Talang Belido Village, Muaro Jambi Regency in 2021, which found (p-value = 0.001) (Ainurrazaq et al., 2022). The longer workers are exposed, the greater the risk of respiratory dysfunction. Longer working periods lead to varying intensities of exposure and the amount of dust inhaled by each worker in the brick kiln, so workers who have been involved in their work for a long time are likely to inhale more dust compared to those who have not been involved for long. Workers who work > 8 hours/day and have no respiratory complaints likely do so because they always pay attention to safety measures and are accustomed to using masks while working (Annashr et al., 2022).

Relationship between Smoking Habits and Respiratory Disorders

The analysis using the chi-square test showed that there is a relationship between smoking habits and respiratory disorders, with a significance value (p-value = 0.015). Based on the analysis, 21 respondents (51.2%) with smoking habits experienced respiratory disorders. The PR value obtained was 2.689, meaning that respondents who smoke have a 2.6 times higher risk of experiencing respiratory disorders compared to those who do not smoke. The impact of cigarette smoke, both for active and passive smokers, poses a health risk. Workers who smoke are at a higher risk of developing subjective complaints of respiratory problems or lung disorders. Smoking habits in adults can cause various respiratory system disturbances such as lung cancer, acute irritant symptoms, asthma, chronic respiratory symptoms, and respiratory infections (Yunus et al., 2020). This study is also in line with research conducted on coal mining workers at PT. Gorby Putra Utama in

2024, which found (p-value = 0.004). Smoking is a significant factor in the occurrence of acute respiratory infections (ARI). Side-stream smoke is more toxic than mainstream smoke, especially in causing irritation to the mucous membranes of the respiratory tract and increasing the likelihood of ARI. Mainstream smoke also contains free radicals that contribute to tissue damage. Cigarette smoke is an irritant that can lead to respiratory infections. Smoking habits increase the risk of ARI by 3.5 times (Amila et al., 2021; Aryani, 2016).

Relationship between PPE Usage and Respiratory Disorders

The analysis using the chi-square test showed that there is a relationship between PPE usage and respiratory disorders, with a significance value (p-value = 0.003). Based on the analysis, 19 respondents (57.6%) with ≥ 5 years of service experienced respiratory disorders. The PR value obtained was 2.783, meaning that respondents who worked without complete PPE have a 2.7 times higher risk of experiencing respiratory disorders compared to respondents who worked with complete PPE. This study is in line with research conducted on limestone industry workers at CV Sumber Rejeki in 2020, with a result (p-value = 0.020). The main function of PPE is to protect workers from health hazards (Heriana et al., 2020). Generally, respondents wore PPE that covered the nose and mouth, but the type of protection used was not a mask or PPE that met the required standards. Limestone industry workers only used cloth tied around their heads to cover their face, nose, and mouth. Even though workers used a cloth mask (kaos), there was no guarantee they would be protected from respiratory disorders because the type of mask used did not meet standards. Respondents who did not use complete PPE while working felt uncomfortable wearing full PPE and found it disruptive during the lime burning process. Workers only wore long-sleeved shirts, long pants, and head coverings. Meanwhile, protective equipment such as masks, boots, gloves, and goggles were rarely used, and in some cases, almost never used during work (Risma Sri Damayanti et al., 2023).

Relationship between Medical History and Respiratory Disorders

The analysis using the chi-square test showed that there is a relationship between medical history and respiratory disorders, with a significance value (p-value = 0.000). Based on the analysis, 11 respondents (55%) with a history of respiratory diseases experienced respiratory disorders. The PR value obtained was 2.310, meaning that respondents with a medical history have a 2.3 times higher risk of experiencing respiratory disorders compared to respondents with no medical history. This study aligns with research conducted on the community around the Pakusari TPA, Jember Regency, in 2021, with a result (p-value = 0.036). In that study, of 46 respondents with respiratory disorders, the majority were those without a history of respiratory problems (38 respondents, or 83%). However, most respondents with a medical history experienced respiratory disorders, with 8 out of 9 respondents who had a medical history experiencing respiratory issues. The medical history included asthma and tuberculosis (Haq et al., 2021).

Relationship between PM2.5 Levels and Respiratory Disorders

The analysis using the chi-square test showed that there is no relationship between PM2.5 levels and respiratory disorders, with a significance value (p-value = 0.390). Based on the analysis, 11 respondents' points (above the threshold) and 16 respondents' points (below the threshold) did not experience respiratory disorders. This study aligns with research conducted on aluminum industry workers in 2018, which showed (p-value = 0.507). For PM2.5 levels less than 5 mg/m^3, 17 workers (41.5%) experienced mild respiratory complaints and 6 workers (54.5%) experienced moderate complaints. While for PM2.5 levels greater than 5 mg/m^3, 24 workers (58.8%) experienced mild respiratory complaints and 5 workers (45.5%) experienced moderate complaints. PM2.5 is a byproduct of industrial activities and contains many materials, including heavy metals. These materials can cause various respiratory disorders, including respiratory infections and even lung cancer. Exposure to PM2.5 levels above the threshold poses a high risk for respiratory disorders (Suwanto, 2021). However, this study does not align with this theory, as there is no relationship between PM2.5 levels and respiratory disorders among limestone mine workers in Kebumen Regency.

Relationship between PM10 Levels and Respiratory Disorders

The analysis using the chi-square test showed that there is no relationship between PM10 levels and respiratory disorders, with a significance value (p-value = 0.437). Based on the analysis, 8 respondents' points (25.8%) were above the threshold. Similar to PM2.5, PM10 has similar characteristics. PM10 is also found in the limestone mining industry, both during open mining and during the processing of limestone. Limestone mine workers are directly exposed to this particulate pollutant, and PM10 particles are larger than PM2.5, about 4 times larger. Some limestone miners use masks, and the researcher assumes that PM10 levels cannot penetrate the PPE used because of their larger size, so PM10 does not seem to be related to respiratory disorders in limestone miners in Kebumen Regency. This study aligns with research conducted on palm oil factory workers in West Kalimantan in 2019, which also found no relationship between average dust levels and respiratory disorders (p-value = 0.685) (Anselma et al., 2019). The average PM10 dust levels at PT. X from 2015 to 2019 were unstable, but the dust levels were still above the threshold (150 μg/Nm^3) each year. Based on the average PM10 dust levels graph at PT. X, the highest dust levels occurred in 2017 at 236.04 μg/Nm^3, followed by a decrease to 222.07 μg/Nm^3 in 2018 and further dropping to 215.03 μg/Nm^3 in 2018. The lowest PM10 dust levels at PT. X were recorded in 2015 at 200.51 μg/Nm^3. Fluctuating PM10 levels can affect the decline in lung function in factory workers (Firmanto et al., 2019)(Firmanto, 2019).

Multivariate Analysis to Identify the Most Dominant Variables Affecting Respiratory Disorders

The results of the multivariate analysis showed that the dominant variables related to respiratory disorders were work experience (OR = 5.1), exposure duration (OR = 22.2), completeness of personal protective equipment (PPE) (OR = 17.3), and medical history (OR = 7.536). Meanwhile, variables such as age, smoking behavior, PM2.5, and PM10 levels did not show significant values in relation to respiratory disorders. Additionally, based on the logistic regression model equation obtained, the formula is:

$$\text{Logit } Y = \beta_0 + \beta_1 X_1 + \ldots\ldots + \beta_p X$$
$$= -12{,}492+1{,}629+3{,}104+2{,}852+2{,}020$$

Based on the results of the multivariate analysis, it was found that an increase in work experience will increase the likelihood of respiratory disorders by 5.1 times, an increase in exposure duration will increase the likelihood of respiratory disorders by 22.2 times, a lack of complete PPE will increase the likelihood of respiratory disorders by 17.3 times, and an increase in medical history will increase the likelihood of respiratory disorders by 7.5 times. The logistic regression equation calculated the likelihood of respiratory disorder symptoms as follows: if a worker has a medical history, work experience ≥ 5 years, exposure ≥ 8 hours/day, and incomplete PPE, the probability of experiencing respiratory symptoms is 94.43%.

The multivariate data analysis statistically identified four variables, as follows: Work experience with a value of B = 1.629, OR = 5.100, CI 95% = 0.814 – 31.935, and p-value = 0.024, meaning there is a relationship between work experience and respiratory disorders. Workers with more than 5 years of work experience have a 5.1 times greater risk of respiratory disorders compared to respondents with less than 5 years of work experience.

Exposure duration with a value of B = 3.104, OR = 22.227, CI 95% = 1.717 – 289.095, and p-value = 0.018, meaning there is a relationship between exposure duration and respiratory disorders. Workers with more than 8 hours of exposure per day have a 22.2 times greater risk of respiratory disorders compared to respondents with less than 8 hours of exposure.

PPE completeness with a value of B = 2.852, OR = 17.33, CI 95% = 3.129 – 95.984, and p-value = 0.001, meaning there is a relationship between PPE completeness and respiratory disorders. Workers who do not use complete PPE have a 17.3 times greater risk of respiratory disorders compared to respondents who use complete PPE.

Medical history with a value of B = 2.020, OR = 7.536, CI 95% = 1.627 – 34.905, and p-value = 0.010, meaning there is a relationship between medical history and respiratory disorders. Workers with a medical history have a 7.5 times greater risk of respiratory disorders compared to respondents with no medical history.

The analysis of PM10 and PM2.5 exposure in relation to respiratory disorders among workers in the limestone mining industry in Kebumen Regency, based on multivariate data, concluded that these four variables can increase the probability of experiencing respiratory disorders by 94.43%.

Conclusion

Based on the results of the research and discussion outlined, it can be concluded that this study shows a relationship between work experience (p-value = 0.024), exposure duration (p-value = 0.007), smoking habits (p-value = 0.015), use of PPE (p-value = 0.031), and respiratory disease history (p-value = 0.001) with respiratory disorders. Meanwhile, age (p-value = 0.153), PM2.5 levels (p-value = 0.390), and PM10 levels (p-value = 0.457) did not show a relationship with respiratory disorders. The variables most associated with respiratory symptoms are the completeness of PPE (OR = 5, 95% CI) and medical history (OR = 11, 95% CI). These two variables increase the likelihood of respiratory disorders by 82.6% if the worker uses incomplete PPE and has a history of respiratory diseases. Therefore, it can be concluded that PM2.5 and PM10 levels are not related to respiratory disorders among limestone mining workers in Kebumen Regency.

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