



# The Correlation of Limestone Dust Exposure to Lung Function Impairment in Limestone Mining's Workers, Centre Java, Indonesia

Suyud Warno Utomo<sup>1,2</sup>, Zulfahatun Ni'mah<sup>1</sup>, Al Asyary<sup>1\*</sup>

<sup>1</sup>Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Depok, Indonesia; <sup>2</sup>Study Program of Environmental Science, School of Environmental Sciences, Universitas Indonesia, Depok, Indonesia

## Abstract

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**\*Correspondence:** Al Asyary, Department of Environmental Health, Faculty of Public Health, Universitas Indonesia, Indonesia. E-mail: [al.asyary@ui.ac.id](mailto:al.asyary@ui.ac.id)  
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**BACKGROUND:** Limestone dust is produced by limestone mining activities, one of them is PM<sub>2.5</sub>. Exposure of PM<sub>2.5</sub> can cause lung function impairment.

**AIM:** The purpose of this study was to determine the correlation exposure of PM<sub>2.5</sub> with lung function impairment in workers.

**METHODS:** This study used a cross-sectional study with total sampling technique of 30 workers. The instruments in this study used questionnaires for interviews, Dusttrak II TSI to measure PM<sub>2.5</sub> concentration and spirometry to measure lung function.

**RESULTS:** Based on the results of the study, the highest PM<sub>2.5</sub> concentration values were 987 µg/m<sup>3</sup> and the lowest were 14 µg/m<sup>3</sup>. The results of the analysis using Chi-square obtained a correlation between the use of personal protective equipment with lung function impairment (p = 0.000). Furthermore, the results using the Fisher's exact test, there was a correlation between PM<sub>2.5</sub> concentration and pulmonary function impairment (p = 0.002) and years of work with pulmonary function impairment (p = 0.000).

**CONCLUSION:** Further research is needed using environmental health risk analysis to estimates based on intake.

## Introduction

Industrial is one of the many aspects which boosts public's economy and welfare. As the population grows, human's needs increases, causing industrial development to become more rapid. One of the industries which have big potential for its product utilization is limestone mining. The existence of limestone mining does not only bring luck for people but can also bring harms because the industrial activities may potentially cause air pollution [1].

Air pollution becomes one of the biggest deaths causes in the world. Based on data [1], there are 7 million deaths happen every year due to ambience (outdoor) air pollution. In 2016, there were 4.2 million deaths in the world due to air pollution in low- and middle-income countries with 90% death [2]. As many as, 92% world population lives in places with air quality which exceeds the safe threshold value set by the WHO [3], and in 98% cities in low and middle-income countries, there are more than 100.000 citizens live in places which does not fill in the air guideline criteria [2]. One of the air pollutants is PM<sub>2.5</sub> [4].

Exposure PM<sub>2.5</sub> in a certain period of time can cause impaired pulmonary function [5]. Based on lung examination survey which was conducted by Central Java Department of Health (2013) in five regencies (Semarang, Jepara, Cilacap, Rembang, and Pekalongan), it is found that as many as 83.75% formal workers and 95% informal workers are experiencing an impaired pulmonary function. It shows that informal workers are at more risks to experience impaired pulmonary function compare to formal workers due to the lack of labors safety and health protection [6].

The industry of limestone mining is one of informal industries which process is done in a traditional way and is managed by people with a simple technology and is not really touched by legislation law. Thus, the impacts caused by it as well as the law that is related to the health protection and work safety gets less attention from the government [6]. Waste produced from the limestone mining activities is not processed nicely and caused many environmental pollutions from the processing of limestone [7]. Therefore, there is a need of research on lime dust exposure particularly PM<sub>2.5</sub> and measurement of lungs function on limestone mining workers in Karang Dawa village district of Margasari, Tegal Regency.

## Materials and Methods

This research was conducted in the limestone mining industry in Karang Dawa, Tegal Regency. This research uses study design of cross-sectional. The independent variable in this research is the  $PM_{2.5}$ , while the dependent variable is the impaired pulmonary function. Population in this research is all workers of the limestone mining which is as many as 30 people. The research sample is the workers located in the burning site who are more prone to the risk of being exposed with  $PM_{2.5}$ . The sample size is determined by formulation:

$$n = \frac{z^2 (1-\alpha / 2). p(1-p) N}{d^2 (N-1) + z^2 (1-\alpha / 2). p(1-p)}$$

$$n = \frac{1,96^2 \times 0,56 \times 0,44 \times 30}{0,1^2 (30-1) + 1,96^2 \times 0,56 \times 0,44} = 22,95 \rightarrow 23$$

Based on the sample calculation above, obtained at least as much as 23 workers' sample. However, this research uses total sampling which is as many as 30 workers. The instrument used in this research is structured questionnaire which is used to obtain the individual characteristic data. This research uses Dusttrak II TSI tool to measure  $PM_{2.5}$  concentration and spirometry to measure the impaired pulmonary function on the workers.

The obtained data are processed with SPSS Version 21 software. The result is analyzed in univariate and bivariate ways. Bivariate analysis uses the Chi-square and Fisher's Exact test to see the correlation between  $PM_{2.5}$  concentrations with  $p < 0.005$  value. In this research, the covariate variable (age, nutrition status, history of disease, smoking habit, the use of personal protective equipment [PPE], and length of working) is also analyzed to see its correlation with the impaired pulmonary function. Meanwhile, spearman correlation test is used to analyze the environmental factors (temperature and humidity) with the environmental factors which have  $PM_{2.5}$  concentrations.

## Results

In these past several months, the impaired pulmonary disease placed in the top three disease which is found in Karang Dawa health center. That is affected by the existence of limestone mining activity which uses the mix of hazardous and toxic materials (B3) waste in its process. The wide of the limestone mining location in Karang Dawa is about  $\pm 30$  hectare with 15.365 population (7638 males and 7727 females).

However, only 30 people work around the burning site or chimneys of limestone mining location. The limestones burning and processing activity operates for 24 h a day.

### Individual characteristic

The average age of the workers is 36 years old (95% CI: 33.84–43.22) with 12.561 deviation standard. The estimated interval result shows that 95% workers are sure to be in the age of 33.84–43.22 years old, with 39 years old as the median and 25 year old as the modus in the workers (Table 1).

**Table 1: Distribution of respondent based on numeric variable (age, height, and weight) of limestone mining worker in Karang Dawa Village Tegal Regency**

Variable	Mean	Median	Modus	DS	Min–Max	95% CI
Age	36.53	39.00	25	12.561	18–61	33.84–43.22
Height (cm)	161.83	160	160	7.091	150–176	159.19–164.48
weight (kg)	55.13	55.00	55	7.528	40–71	52.32–57.94

Based on the workers' height, it is found that the average height of the workers is 161.83 cm (95% CI: 159.19–164.48) with deviation standard of 7.091. The interval result shows that 95% workers are sure to have the average height of 159.19–164.48 cm, with 176 cm as the median and 160 cm as the modus in the workers (Table 1).

From the data analysis, it is found that the average weight of the workers is 55.13 kg (95% CI: 52.32–57.94) with deviation standard of 7.091. The interval result shows that 95% workers are sure to have the average weight of 52.32–57.94 kg, with 55 kg as the median and the modus in the workers (Table 1).

### Nutrition status, workers behavior characteristic, job's characteristic, and the impaired pulmonary function

Table 2 shows that the distribution of nutrition status of the workers. It is obtained that workers with low nutrition status is as many as 5 workers (16.7%),

**Table 2: Distribution of respondents based on categorical variable of limestone mining workers in Karang Dawa Tegal Regency**

Variable	Frequency	Percentage
Nutrition status		
Less (<18.5)	5	16.7
Normal (18.5–25)	21	70.0
Higher (>25)	4	13.3
Disease history		
No disease	27	90.0
With disease	3	10.0
Smoking habit		
Non-active smoker	2	6.7
Active smoker	28	93.3
The use of PPE		
Not using PPE	19	63.3
Using PPE	11	36.7
Working hour		
8 h	1	3.3
>8 h	29	96.7
Working period		
>5 years	23	76.7
≤5 years	7	23.3
Impaired pulmonary function		
No disorder	14	46.7
With disorder	16	53.3

PPE: Personal protective equipment.

normal nutrition status as many as 21 workers (70%), and higher nutrition status as many as 4 workers (13.3%). Meanwhile, the distribution of disease's history is shown in Table 2, it is found that workers with no disease's history is as many as 27 workers (90.0%) and workers with diseases history is as many as 3 workers (10.0%) (Table 2).

In Table 2, the distribution of smoking habit and the use of PPE in the workers are obtained from data analysis based on workers behavior characteristic. In smoking habit, it is obtained that workers who are not active in smoking is as many as 2 workers (6.7%) and the active ones are as many as 28 workers (93.3%). Meanwhile, in the distribution of PPE usage, it is obtained that workers who do not use PPE is are many as 19 workers (63.3%) and those who use it are as many as 11 workers (36.7%).

Meanwhile, based on job's characteristic, respondent who has 8 h of working hour a day is 1 worker (3.3%) and those with more than 8 h a day are 29 workers (96.7%). Then, workers whose working period are more than 5 years are 23 people (76.7%) and those whose working period is <5 years are 7 people (23%) (Table 2).

The result of pulmonary function measurement to people who work in the limestone mining show that workers with no pulmonary disorders are 14 workers (46.7%) and those with impaired pulmonary function are 16 workers (53.3%) (Table 2).

**PM<sub>2.5</sub> concentration at limestone mining**

The measurement result of PM<sub>2.5</sub> concentrations at limestone mining location at Karang Dawa village Tegal Regency in 5 location points show that three sample points have concentration value (Threshold value) that is more than normal, which is 65 µg/m<sup>3</sup> as stated on the Act of RI number 41 year 1999 about Air Pollution Control. The location of the sample point such as point 1 which covers chimney 2 obtains PM<sub>2.5</sub> concentrations as big as 83 µg/m<sup>3</sup>, point 2 which covers chimney 4, 5, 6, 7, and 8 obtains PM<sub>2.5</sub> concentrations as big as 987 µg/m<sup>3</sup>, also point 3 which covers chimney 9, 10, and 11 obtains PM<sub>2.5</sub> concentrations as big as 202 µg/m<sup>3</sup>. Meanwhile, the measurement of PM<sub>2.5</sub> from two sample points shows that the concentration result which is under limit value 65 µg/m<sup>3</sup> is found such as, in point 4, which is located in a residential area ±300 m away from the mining location, is found to have

**Table 3: Measurement result of PM<sub>2.5</sub> at limestone mining location in Karang Dawa Regency Tegal**

Sample location	Concentration of PM <sub>2.5</sub> (µg/m <sup>3</sup> )	Level of concentration value (Threshold)	Annotation
Measurement result			
Point 1	83	65	More than threshold
Point 2	987	65	More than threshold
Point 3	202	65	More than threshold
Point 4	14	65	Under threshold
Point 5	39	65	Under threshold

\*Level of concentration value is based on government regulation of RI number 41 year 1999 about air pollution control

concentration result as high as 14 µg/m<sup>3</sup> and point 5, which is located in the enter gate of the mining location and residential area, is found to have concentration result as high as 39 µg/m<sup>3</sup> (Table 3).

**PM<sub>2.5</sub> concentration and environmental factors (temperature and humidity)**

Based on data analysis, it is obtained that the average PM<sub>2.5</sub> concentrations are as big as 455.63 (95% CI: 289.39–621.87) from the distribution of PM<sub>2.5</sub> concentrations at 5 limestone mining location points. From 95% interval analysis result, it is believed that the average concentration of PM<sub>2.5</sub> is from 289.39 to 621.87 with deviation standard of 445.201 and median of 202.00 µg/m<sup>3</sup>. The lowest concentration value of PM<sub>2.5</sub> is 14 µg/m<sup>3</sup> and the highest is 39 µg/m<sup>3</sup> (Table 4).

**Table 4: Distribution of PM<sub>2.5</sub> concentration and environmental factors (temperature and humidity) at limestone mining location in Karang Dawa Tegal Regency**

Variable	Mean	Median	DS	Min–Max	95% CI
PM <sub>2.5</sub> concentration	455.65	202.00	445.201	14–987	289.39–621.87
Temperature	36.50	35.38	1.734	33.83–38.70	35.85–37.15
Humidity	45.93	45.45	3.480	39.90–50.35	44.63–47.23

The measurement of environmental value (temperature and humidity) which is measured at the 5 points which are close to the PM<sub>2.5</sub> measurement obtains a result which is shown in Table 3. It is found that the average temperature at 5 location points in limestone mining location is 36.50°C (95% CI: 35.85–37.15). From 95% interval analysis, it is believed that the average temperature is from 35.85 to 37.15°C with deviation standard of 1.734 and median of 35.38°C. The lowest temperature in the limestone mining location is 33.83°C and the highest is 38.70°C. Meanwhile, it is found that the average humidity at the 5 location points is 45.93 (95% CI: 44.63–47.23). From 95% interval analysis, it is believed that the average humidity is from 44.63 to 47.23 with deviation standard of 3.480 and median of 45.45. The lowest humidity in the limestone mining location is 39.90 and the highest is 50.35 (Table 4).

**Case study of decreased pulmonary function**

In Table 5, it can be seen that analysis test result from two variable data between age and impaired pulmonary function shows that the result in Table 2 × 2 does not meet the Chi-square test requirement because there is expected value that is lower than five. The alternative analysis used by the researcher is Fisher's Exact Test. Statistical analysis result shows that there are 5 (45.5%) workers with age ≤35 years old have impaired pulmonary function and 11 (57.9%) workers with age >35 years old have impaired pulmonary function with p = 0.078 which means that there is no correlation between age and impaired pulmonary function.

Based on the workers nutritional status, workers with abnormal nutritional status who have impaired pulmonary function is 5 workers (71.4%) and workers with normal nutritional status who have impaired pulmonary function is 11 workers (71.4) with  $p = 0.399$  which means that there is no correlation between nutritional status with impaired pulmonary status on mining workers at Karang Dawa Village in Tegal Regency 2019.

Limestone mining workers who have disease history and experience impaired pulmonary function is 11 workers (33.3%) and workers who has no disease history and experience impaired pulmonary function is 15 workers (55.6%). Statistical result gets  $p = 0.586$  which means that there is no correlation between disease history with impaired pulmonary function on mining workers at Karang Dawa Village in Tegal Regency.

The result from smoking habit data analysis with impaired pulmonary function shows that there are 16 workers (57.1%) who actively smoke also experience impaired pulmonary function and 0 workers (0%) who do not smoke and experience impaired pulmonary function. Statistical test result shows that  $p = 0.209$  which means that there is no correlation between smoking habit with impaired pulmonary function on mining workers at Karang Dawa Village in Tegal Regency.

PPE usage data analysis with impaired pulmonary function on the mining's workers shows that there are 10 workers (52.6%) who do not wear PPE when working experiencing impaired pulmonary function and there are 6 workers (54.5%) who wear PPE when working experiencing impaired pulmonary function. Statistics shows that  $p = 0.000$  which means that there is a correlation between the usage of PPE with impaired pulmonary function on the limestone mining workers.

The length of working hours' data analysis with impaired pulmonary function on the mining's workers shows that there are 0 workers (0%) whose working hours is 8 h experiencing impaired pulmonary function. Meanwhile, there are 16 workers (55.2%) whose working hours is >8 h experiencing impaired pulmonary function. Statistics shows that  $p = 0.467$  which means that there is no correlation between the length of working hours with impaired pulmonary function on the limestone mining workers at Karang Dawa Village Tegal Regency (Table 5).

### **The correlation between $PM_{2.5}$ concentration with impaired pulmonary function**

The analysis result between  $PM_{2.5}$  concentrations with impaired pulmonary function shows that there is 0 worker (0.0%) experiencing impaired pulmonary function with  $PM_{2.5}$  concentrations under the threshold value. Meanwhile, there are 16 workers

**Table 5: Correlation of covariate variables with impaired pulmonary function**

	Impaired pulmonary function		Total	%	p value		
	No impairment	With impairment					
	n	%	n	%	n		
Age							
≤35 years old	6	54.5	5	45.5	11	100	0.078
>35 years old	8	42.1	11	57.9	19	100	
Nutritional status							
Normal	12	52.2	11	47.8	23	100	0.399
Abnormal	2	28.6	5	71.4	7	100	
Disease history							
Yes	12	44.4	15	55.6	27	100	0.586
No	2	66.7	1	33.3	3	100	
Smoking habit							
Active	2	100	0	0	2	100	0.209
Non-active	12	42.9	16	57.1	28	100	
The use of protecting tools							
No	9	47.4	10	52.6	19	100	0.000
Yes	5	45.5	6	54.5	11	100	
Working hours							
8 h	1	100	0	0.0	1	100	0.467
>8 h	13	44.8	16	55.2	29	100	
Working period							
>5 years	11	47.8	12	52.5	23	100	0.000
≤5 years	3	42.9	4	57.1	7	100	

(69.6%) with  $PM_{2.5}$  concentrations more than the threshold value experiencing impaired pulmonary function. Chi-square test result shows that  $p = 0.002$  which means that there are proportion differences of impaired pulmonary function on the workers with  $PM_{2.5}$  concentrations. Statistically, there is correlation between  $PM_{2.5}$  concentrations with impaired pulmonary function on the workers (Table 6).

**Table 6: Correlation between exposure of limestone dust concentration ( $PM_{2.5}$ ) with impaired pulmonary function on limestone mining workers at Karang Dawa Village Tegal Regency**

	Impaired pulmonary function		Total	%	p value		
	No impairment	With impairment					
	n	%	n	%	n		
$PM_{2.5}$							
Under threshold value	7	100.0	0	0.0	7	100	0.002
More than threshold value	7	30.4	16	69.6	23	100	

### **Analysis of environmental factors with $PM_{2.5}$ concentration**

Based on Table 7, the result of environmental factors data is obtained. In the correlation of temperature and  $PM_{2.5}$  concentrations,  $p = 0.233$ , which shows that the correlation between temperature and  $PM_{2.5}$  concentrations is meaningless because  $p > 0.01$ . The value of spearman correlation is 0.225 shows negative correlation which means it has weak power.

**Table 7: Environmental factors analysis (temperature and humidity) and  $PM_{2.5}$  concentration**

$PM_{2.5}$ concentration	
Temperature	$r = -0.225$ $p = 0.233$ $n = 30$
Humidity	$r = 0.087$ $p = 0.648$ $n = 30$

Meanwhile, on the humidity with  $PM_{2.5}$  data analysis result, it is obtained that  $p = 0.648$  which shows that the correlation between humidity and  $PM_{2.5}$  concentrations is meaningless because  $p > 0.01$ . However, spearman correlation value which is 0.087 shows a positive correlation which means that it has strong power.

## Discussion

### **Individual characteristic**

Analysis result of correlation between age and impaired pulmonary function obtains that there are 5 workers whose age are  $\leq 35$  experiencing impaired pulmonary function (45.5%) and 11 workers whose age are  $>35$  are experiencing impaired pulmonary function (57.9%). That result shows that  $p = 0.078$  which means that there is no correlation between age and impaired pulmonary function on the limestone mining workers. This research matches with the one conducted in cement factory which declares that workers whose age are  $>35$  and above have risks of experiencing impaired pulmonary function compared to workers whose age are less than or same with 35 years old [8]. Based on theory, lungs will experience a decrease in function after someone is above 35 years old. It is because when someone is above 35 years old there will be changes on the physical form such as the changes in muscles and bones, changes of lungs' tissue, and changes of nerve system [9].

In the analysis of nutritional status with impaired pulmonary function,  $p = 0.399$  which means that there is no correlation between nutritional status with impaired pulmonary function. There are 11 workers (47.8%) with normal nutritional status who are experiencing impaired pulmonary function. Meanwhile, there are 5 workers (71.4%) with abnormal nutritional status who are experiencing impaired pulmonary function. This matches with the research conducted at cement industry in 2017 which shows that there is no meaningful correlation statistically [10]. Another matched research with this research is the one conducted by Riski, the research which was conducted in Tanjung Priok Harbor shows  $p = 0.48$  with  $OR = 1.5$  ( $95\% CI = 0.5-0.46$ ). It means that there is no significant correlation between workers' nutritional status with the chronic obstructive pulmonary disease (COPD) experienced by workers in Tanjung Priok Harbor, and the workers with abnormal nutritional state have 1.5 times higher risk to get COPD than those who have normal nutritional state [11].

Theoretically, lack of nutrition on someone causes low weight, where a low weight can cause a decrease on respiratory muscle's power and the increase of mortality. If someone is overweight, it can decrease lungs' vital capacity so it causes heavy lung's impairment. Overweight can cause chronic diseases, meanwhile improper body weight can affect the function of respiratory bones and muscles [12].

In this research, disease history does not have any correlation with impaired pulmonary function. The result of this research matches with the research conducted by Zikri at a cement factory in Bogor which stated that history of respiratory disease does not have any correlation with impaired pulmonary function [10]. However, it has 2 OR value, which means that workers who

have history of respiratory disease have 2 times higher risk of getting impaired pulmonary function than those who do not. Based on theory, there are several diseases which can cause pulmonary function impairment such as tuberculosis, bronchitis, emphysema, pneumonia, shortness of breath due to allergies, asthma, and sinusitis which can cause abnormal result of pulmonary function measurement [13].

### **Workers behavior characteristics**

This research found that there is no correlation between smoking habits with impaired pulmonary function on the limestone mining workers. A parallel research was done by Putra *et al.* to parking officers in Pandanaran Street Semarang. Using the spearman correlation test, it gets a conclusion that there is no significant correlation between smoking habits with KVP value. This is not in sync with the theory which mentions that smoking can cause pulmonary function's impairment [14]. The WHO also stated that smoking is the highest cause of death which is preventable. Smoking can add the risk of getting heart disease to 2–4 times higher compare to those who are not active smokers. Smoking can also increase the risk of death because of lungs cancer. Those incompatibilities are affected by the lack of data's accuration about the amount of cigarettes consumed in a day [3].

Meanwhile, the use of PPE has a significant correlation with impaired pulmonary function. The result of this research matches with the research conducted by Afiani which stated that there are correlations between the used of PPE with the existence of pulmonary function impairment [15]. It can be understood by the fact that there are 18.2% workers who wear masks still experience impaired pulmonary function. Several factors which cause the use of PPE to be less maximum such as the unsuitable masks to wear, wrong way to use the masks, broken masks, and no sanction for workers who do not wear PPE so that many of them take it lightly [16].

### **Job's characteristics**

The result of statistical test of working period with impaired pulmonary function found that  $p = 0.46$  which means that there is no correlation between working period with impaired pulmonary function. Workers in limestone industry have different working period, if it is compared to the Act number 13 Year 2003, the workers of limestone mining with working period and days are above the threshold standard.

Working period is a period of time when someone starts their job for the 1<sup>st</sup> time until the time when the research is conducted [17]. The analysis result of the correlation between working period and impaired pulmonary function in the limestone mining workers shows that workers whose working period is more than 5 years have higher risk to experience

impaired pulmonary function than those whose working period is <5 years. Based on Kusnopranto's theory (1990) states that the longer someone is working, the higher risk of them getting diseases due to their jobs.

### **PM<sub>2.5</sub> concentration in limestone mining location**

PM<sub>2.5</sub> is a particle that has diameter  $\leq 2.5 \mu\text{m}$ . PM<sub>2.5</sub> cannot be seen with bare eyes; the size of this particle is said to be 3% of a human's hair size [18]. The source of PM<sub>2.5</sub> on this research comes from the burning and processing activity of limestone which uses the mix of hazardous and toxic waste. The measurement of PM<sub>2.5</sub> in limestone mining location was conducted at morning and evening. The measurement of PM<sub>2.5</sub> was conducted in 5 limestone mining location points with 60 min each. Every second of sample taking can represent burning sites or chimneys for limestone burning. The measurement of PM<sub>2.5</sub> concentrations was conducted when the weather is good and not raining.

Based on the measurement of PM<sub>2.5</sub> in the limestone mining location, it is found that the average of PM<sub>2.5</sub> concentrations is  $455.6 \mu\text{g}/\text{m}^3$ . The highest PM<sub>2.5</sub> concentrations are  $987 \mu\text{g}/\text{m}^3$  which is found in point 2 which is located between burning sites or chimneys 4, 5, 6, 7, and 8. Meanwhile, the lowest PM<sub>2.5</sub> concentrations are found in point 4 which are located in the resident's area that is close to the burning site. There are 3 measurement points for PM<sub>2.5</sub> that pass over the threshold limit value which is stated by Act of Republic Indonesia number 41 Year 1999 about the Air Pollution Control which is  $65 \mu\text{g}/\text{m}^3$  within 24 h. The high and low of PM<sub>2.5</sub> concentrations are affected by environmental factors such as temperature, humidity, wind speed, and wind direction.

### **Environmental factors (temperature and humidity)**

In the research's result, environmental factors (temperature and humidity) show different correlation. In temperature with PM<sub>2.5</sub> concentrations, it shows negative correlation. Meanwhile, in humidity with PM<sub>2.5</sub> concentrations, it shows positive correlation so that statistically there is no meaningful correlation between environmental factors and PM<sub>2.5</sub> concentration.

Temperature has negative correlation with PM<sub>2.5</sub> concentrations ( $r = -0.225$ ) which means that it has weak correlation power. It is caused by when the temperature rises then PM<sub>2.5</sub> concentrations will go down. It matches with the research conducted by Fathamaulida which stated that temperature and PM<sub>2.5</sub> concentrations because it can be affected by wind turbulence factor [19]. Wind can lower a quite high temperature so that it can minimize PM<sub>2.5</sub> concentrations ( $r = 0.087$ ) meaning that there is a strong power. It matches with the research conducted by Yao *et al.*

which shows that humidity relatively will be followed by the increase of PM<sub>2.5</sub> concentrations [20].

### **The correlation of PM<sub>2.5</sub> with impaired pulmonary function**

Impaired pulmonary function on the workers can be known from the result of pulmonary function measurement using spirometry. Spirometry becomes an alternative to know someone's lungs condition because it is said to be easy, practical, and accurate. The measurement result of spirometry will produce Forced Vital Capacity (FVC) and Force Expiratory Volume (FEV<sub>1</sub>) value. If the comparison of FEV<sub>1</sub> value and FVC value is <70%, then it can be categorized that one has impaired pulmonary function. Meanwhile, if the comparison is  $\geq 70\%$  so it can be categorized as normal or there is no impaired pulmonary function.

In this research, it is obtained that the value of  $p = 0.002$ , which means that there is correlation between PM<sub>2.5</sub> with impaired pulmonary function on the limestone mining workers. This research shows meaningful correlation between PM<sub>2.5</sub> correlations with impaired pulmonary function on adults at industrial sites in Pulogadung, East Jakarta. Another research conducted in limestone industrial site in Grobogan shows that workers who are exposed to impaired pulmonary function are those who have dust exposure above the threshold limit value [21].

## **Conclusions**

Based on the result obtained from this research, it can be concluded that:

1. The average PM<sub>2.5</sub> concentrations which is measured in 5 limestone mining location points in Karang Dawa Village Tegal Regency are  $455.63 \mu\text{g}/\text{m}^3$ . The highest PM<sub>2.5</sub> concentrations are  $987 \mu\text{g}/\text{m}^3$  and the lowest PM<sub>2.5</sub> concentrations are  $14 \mu\text{g}/\text{m}^3$ .
2. The average PM<sub>2.5</sub> concentration value is over threshold limit value which is based on Act of Republic Indonesia Number 41 Year 1999 about Air Pollution Control which is  $65 \mu\text{g}/\text{m}^3$ . There are 16 workers (53.3%) who experience impaired pulmonary function, meanwhile there are 14 workers (46.7%) who are not experiencing impaired pulmonary function.
3. There is significant correlation between the use of self-protecting tools with impaired pulmonary function ( $p = 0.000$ ). There is significant correlation between working period with impaired pulmonary function on limestone mining workers ( $p = 0.000$ ) and there is no correlation between factors (age, nutritional

- status, disease history, smoking habit, working frequency, temperature, and humidity).
- There is a significant correlation between PM<sub>2.5</sub> concentrations with impaired pulmonary function ( $p = 0.002$ ).

## Author Contributions

Conceptualization, SWU and ZH; methodology, SWU and AA; software, ZH; validation, SWU and ZH; formal analysis, SWU and AA; investigation, SWU and ZH; resources, SWU; data curation, SWU and ZH; writing-original draft preparation, SWU; writing-review and editing, ZH and AA; visualization, SWU; supervision, SWU; project administration, ZH; funding acquisition, SWU. All authors have read and agreed to the published version of the manuscript.

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