ORIGINAL ARTICLE

Risk Assessment Of Ambient Air Pollution PM2.5 Exposure To Communities In The Cement Industrial Area, Pangkep Regency, Indonesia

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ABSTRACT

Introduction: $PM_{2.5}$ particles are significant problem and the most significant environmental health risk causing premature death. The study aims to assess the health risk analysis of $PM_{2.5}$ exposure in the residential areas around the cement industry. Material and Methods: the study used a cross sectional study with an environmental health risk analysis approach. The population of the study were 827 households. The study applied inclusion criteria involving the selecting only one respondent from the same family, so there were 297 respondents from population target. The sample selection was calculated by Lemeshow formula and resulted 98 samples. The measurement $PM_{2.5}$ located at intervals of 0-5 km from the source of primary pollution areas. The measurement of $PM_{2.5}$ used HazDust Epam. Guideline standards from the Environmental Protection Agency were used to assess the risk of exposure to pollutants. Results: the average concentration of the southern zone is 60 μg/m^3 , the northern zone is 40 μg/m^3, the eastern zone is 21.67 μg/m^3, and the western zone is 46.67 μg/m^3. The Risk Level (RQ) of Real-time $PM_{2.5}$ intake is relatively safe with RQ<1; and intake lifetime risk is RQ>1; except for the eastern zone RQ<1. Conclusion: the result indicates that $PM_{2.5}$ exceed the environmental quality standard according to WHO, which is > 10 μg/m^3 from the pollution source. Risk Management recommends a safe concentration in the risk zone, proper environmental management and control efforts to reduce health risks in the affected resident.
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INTRODUCTION

The massive use of fossil fuels highly contribute to air pollution and recently (1-3 years), the issue globally got much attention. Around one million premature death occur over the world as the result of air pollution. One of the air pollutants becoming an important factor is exposure to particles with a diameter of less than 2.5 ($PM_{2.5}$). Lelyevld et al (2015) in the Global Burden of Disease Database, found that there were approximately 3.15 million deaths every year in 2010, 1.61-4.81 million deaths every year with a 95% confidence interval, cerebrovascular disease (CEV) accounted for 42% of all premature deaths, and 34% (1.08 million) due to coronary heart disease (IHD) associated with $PM_{2.5}$ (4). The study also shows that the contribution of air pollution to premature death will increase to 6.6 million in 2050 (5) .

Air pollution is one of the main problem indicators for global public health in the 21st century. There is a significant correlation among air pollution, mortality, and morbidity in various risk groups (6). Seven million deaths occur every year due to air pollution worldwide. Among various kinds of air pollutants, particulate matter is one the most harmful which is released from various biogenic and anthropogenic sources or formed in the atmosphere as a result of secondary reactions. (7–9). The physicochemical properties of $PM_{2.5}$ and PM_{10} are different. PM2.5 ratio of good particles to coarse particles can provide more information about particle sources, generation processes and human health effects. (10–12). PM_{10} can be the respiratory tract causing respiratory diseases, However, the small size of $PM_{2.5}$ can pass through the respiratory tract and accumulate in the lungs causing various more severe respiratory diseases and lung cancer (11,13–15).

The increase of morbidity and mortality in the European Union population is associated with the increase concentrations of $PM_{2.5}$ reducing the average life span by up to 8.6 months (16). Furthermore, according to the results of different studies, a decrease in the concentration level of $PM_{2.5}$ by 10 μg/m^3 enable to increase the life time by 0.61 years (17,18). $PM_{2.5}$ has a higher toxicity than PM10 and it can induce inflammation and oxidative stress. The particulate of $PM_{2.5}$ is particularly concerned because it is able to penetrate deep into the alveoli where it can be stored and absorbed. These good particles are thought to have more aggressive health effects than larger particles. $PM_{2.5}$ can lead to various health problems, including respiratory diseases such as asthma, bronchitis, and upper respiratory tract infections (19).

Air pollution is sourced from the cement industry which is characterized by high energy intensity and the production of several hazardous air pollutants (HAPs). Some common air pollutants include sulfur dioxide (SO2), nitrogen oxides (NOX), carbon monoxide (CO), and particulate matter (PM) (20). In Tiongkok, the cement industry is the largest contributor to particulate emissions, accounting for approximately 20-30% of national emissions and 40% of industrial emissions (21).

Environmental health risk analysis is a method that can be used to evaluate the increased risk of health problems in individuals who are exposed to high concentrations of particulate matter. PM concentrations and chemical composition from one region to another show significant variations, mainly depending on geographic position, particular climatic conditions, anthropogenic activities, and pollutant sources (22,23).

Pangkep is one of regencies in South Sulawesi Province. It is one of the rapidly developing agricultural, fishing, and industrial regions in Indonesia. It becomes home for several national-scale cement industries supporting the national cement demand. Therefore, it is essential for the researchers to study the health risks of $PM_{2.5}$ exposure in the residential areas. Although the studies on heavy metal concentrations in $PM_{2.5}$ in Indonesia have been conducted, they are limited due to data scarcity. Understanding the level of particulate matter in the air has significant consequences for public health, given the increasing trend to air pollution. This study aims to assess the human health risk of $PM_{2.5}$ exposure from anthropogenic sources in Pangkep.

MATERIALS AND METHODS

Research Design

The method of the study was Environmental Health Risk Analysis (EHRA) calculating the estimated risk of exposure to a risk agent in a population at risk by considering the agent's characteristics and the population.

Study Area

$PM_{2.5}$ samples were collected at the location of the cement industry in Pangkep. The distribution of research locations was divided into some zones (regions) according to cardinal points, namely the north zone (NZ), east zone (EZ), south zone (SZ), and west zone (WZ). $PM_{2.5}$ measurements were conducted based on Indonesian National Standard No. 1971-19.62005. The measurements were taken within every 5 km radius of the pollution source, with measurements every 1.5 km corresponding to residents around cement factories. The research locations were selected based on population density and proximity to cement factories. Specific data collection was conducted in the Bungoro District of Pangkep. Sampling of $PM_{2.5}$ were conducted at 12 points within a 5-km radius of the pollutant source. One point was taken for every 1.5 km radius, resulting in a total of 3 points in each zone (north, east, south, and west). This was based on Decision of the Head of the Environmental Control Agency No. 205 of 1996 about Technical Guidelines for Non-Stationary Source Air Pollution Control that there are minimum of 2 sampling points from the pollutant source required. $PM_{2.5}$ measurements were carried out during the day and night, namely from 07.00-20.00 with the consideration that emission activity is higher than during the day. Lower air temperature, air pressure and wind speed cause $PM_{2.5}$ to be closer to the ground surface. There are more residents at the research location at night, so potential exposure to $PM_{2.5}$ occurs more easily. $PM_{2.5}$ measurements are taken using a HazDust EPAM 5000 device with pre-calibration, ensuring the quality of the measurement data remains valid. $PM_{2.5}$ sampling was carried out by using the grab sampling technique, namely instantaneous measurements with the consideration that this method is one of the standard methods and suits the characteristics of the research area. Samples were taken at 12 sampling points and measured for 15 minutes. Each sampling point of $PM_{2.5}$ was measured 3 times to get the average daily $PM_{2.5}$ value. Sampling for each measurement was carried out 3 times and for 15 minutes. The first measurement was taken at 09.00 to represent the morning, the second measurement at 17.00 to represent the afternoon and the third measurement at 20.00 to represent the evening. This is done with the consideration that it can represent one day and that the measurement time is the highest daily exposure concentration.To determine $PM_{2.5}$ concentration levels, the researcher used the gravimetric method, namely quantitative analysis based on measuring the weight of a particular element or compound which is usually used to determine the total minerals (as ash) in the material.

Population and Sample

Sample selection was based on zones: north, east, south, and west. The zones located within 5 km radius from the central cement factory. There were initially 827 households in these zones. Inclusion and exclusion criteria were applied to obtain a homogeneous sample. Inclusion criteria included respondents not living in the same family and residing in the research area for two consecutive years. The characteristic of respondents were adult between 17-65 years; required to work;

and having no cancer. After applying these criteria, the target population for inclusion and exclusion criteria was 297 respondents. The sample size was calculated by using cross-sectional research proportions using the Lemeshow formula and considering that the population was known, resulting in a sample size of 98.

Research Instrument

$PM_{2.5}$ measurement used a pre-calibrated HazDust EPAM 5000 digital direct reading device. This device uses a laser analysis method to measure particles. Particle measurement are read directly from the device screen. The examination of vital lung capacity by spirometry (Spiro Analyzer ST75 series 72/21157). Then, the spirometry test results were compared with predetermined average values to obtain the percent predicted value. Moreover, the analytical method referred to the American Thoracic Society (ATS), with the rapid test method. Then, the individual characteristics questionnaire referred to the Environmental Protection Agency on Environmental Health Risk Analysis questionnaire.

Health Risk Assessment and Evaluation

The health risk assessment was based on the guidelines for human health assessment proposed by the EPA. It is organized for various age groups: newborns (0 - 1 years), children (1 -12 years), adolescents (12 - 8 years) and adults (18 - 70 years). There are three routes of exposure which serve as measurement indicators namely: inhalation, ingestion and dermal through the skin. The health risk assessment considers the average concentrations of individuals over the sampling period, assuming that they are representative of the area's annual pollutant concentrations under consideration.

The risk assessment of exposure to non-carcinogenic chemicals was based on a comparison of exposure estimates such as average daily dose (ADDi) and reference dose (RfDi), expressed in mg/kg/day, airborne exposure expressed in inhalation concentrations (RfCi) expressed in mg/kg/day.. This ratio is called the hazard ratio (HQi) and calculated by using a single formula in Eq (24.25).

Use the formula to estimate the health risk of exposure to $PM_{2.5}$ particles in the community:

$$I_{inh}: \frac{C \text{ x I inhR x LE x EF x ED}}{\text{Wb x t Avg}}$$

Where I_{inh} is the exposure dose µg/m^3, I inhale is the average daily dose for inhalation, and C is the exposure concentration $PM_{2.5}$ µg/m^3, which is the concentration of a pollutant in the environment through ingestion or inhalation; LE is length of exposure (days/year), EF is frequency of exposure (days/year) ED is duration of exposure (years), Wb is body weight, t Mean time, days, and this value for a non-carcinogen equals 30 Ч 365 days and for carcinogens equal 70 years (lifetime) Ч 365 days.

Risk Characteristics

The risk level (RQ) is calculated by dividing the non-carcinogenic intake (intake) of each risk agent by the RfC or RfD.

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

RQ is the risk level of $PM_{2.5}$ µg/m^3, I am the exposure dose (intake $PM_{2.5}$) /I_{inh} ,and Rfc is the $PM_{2.5}$ reference dose (mg/kg/day) of 2.42 mg/kg/day. In EHRA, the greater the RQ value (RQ>1), the more likely the risk will occur, and vice versa. If the RQ value is smaller (RQ<1) then the possibility of risk will be smaller.

Ethical Clearance

This research has received approval from the Health Research Ethics Committee (KEPK), polytechnic of the ministry of health Makassar No. 0304/KEPK-PTKMKS/V/2021, polytechnic Of The Ministry Of Health Makassar No. 0304/KEPK-PTKMKS/V/2021

RESULTS

Description of Research Locations

The results of the study indicate an increase of $PM_{2.5}$ pollutant concentrations in Pangkep due to its status as a cement-producing region with many cement industries. $PM_{2.5}$ concentration measurements in the atmosphere exceeded the environmental quality standard set by the Indonesian government, which is 15 µg/m^3. The concentrations for each zone were as follows: North Zone 40 µg/m^3, East Zone 21.67 µg/m^3, South Zone 60 µg/m^3, and West Zone 46.67 µg/m^3.

Table I shows the exposure classification of the measurement process and refers to the time when people are exposed to substances in the environment or estimates of future exposure. The values of all parameters are included in the health risk assessment (HRA). Table 1 presents the health risk analysis of exposure to $PM_{2.5}$, where the average age of respondents in the western zone is 37 years; in the eastern zone is 45 years; in the southern zone is 44 years; and in the northern zone is 40 years. For the respondents' body weight from all zones, it falls in the range of 50-59 kg; with exposure levels of 11-12 years; exposure frequency of 37-45 years; exposure duration of 26-37 years; and inhalation rate of 14 mg3/day.

Table II presents the characteristics of individual respondents and their activity patterns based on the research zones, which will be used to calculate inhalation intake in the health risk assessment of those exposed to $PM_{2.5}$ from the cement industry in four research zones.
Real-time and lifetime intake values for each zones were calculated as follows: South Zone 2.30 mg/kg/day and

Table I: Health Risk Assesment Exposure $PM_{2.5}$

Factor	Unit	Mean	Median	SD	Min	Max
Age						
North Zone	Year	37.16	60.00	9.326	20	64
East Zone		45.29	47.50	10.901	26	58
South Zone		44.72	43.00	13.777	19	64
West Zone		40.00	37.50	11.909	23	64
Weight (WB)						
North Zone	Kg	58.88	60.00	13.878	34	84
East Zone		52.83	51.50	9.370	37	72
South Zone		57.84	59.00	10.688	30	73
West Zone		51.17	50.50	11.750	30	74
Long Exposure (LE)						
North Zone	Year	11.84	12.00	2.08	8	15.00
East Zone		11.04	11.00	1.90	8	14.00
South Zone		12.16	12.00	2.61	8	18.00
West Zone		12.00	12.00	1.87	9	16.00
Exposure Frecuency (EF)						
North Zone	Days/ Year	37.16	60.00	9.326	20	58
East Zone		45.29	47.50	10.901	26	64
South Zone		44.72	43.00	13.777	19	64
West Zone		40.00	37.50	11.909	23	
Exposure Duration (ED)						
North Zone	Year	26.56	25.00	9.09	11	45
East Zone		36.58	36.50	14.42	15	64
South Zone		34.60	31.00	17.37	5	65
West Zone		29.88	28.00	13.06	12	56
Inhalation Rate (I_{inh})						
North Zone	m^3/day	14.55	14.05	1.30	11.79	16.58
East Zone		14.05	13.99	0.95	12.24	15.77
South Zone		14.50	14.71	1.12	11.13	15.84
West Zone		13.81	13.89	1.29	11.13	15.91

Average Lifetime (t avg). days. Dt x 365 x 70 (Carsinogenic). Dt x 365 x 30 (Non Carsinogenic)

4.66 mg/kg/day; West Zone 1.49 mg/kg/day and 3.48 mg/kg/day; East Zone 0.88 mg/kg/day and 1.68 mg/kg/day; and North Zone 0.11 mg/kg/day and 2.92 mg/kg/day, as shown in Table III.

Table IV presents the environmental health risk assessment for real-time and lifetime risks. In the real-time risk group, all zones were considered not at risk. However, in the lifetime risk group, only the East Zone had no risk, while the other three zones had carcinogenic risks due to RQ values >1. Risk assessment was based on the risk characterization guidelines from the Environmental Protection Agency (EPA), using the calculated reference dose (RfD) and reference concentration (RfC) obtained from existing literature (accessible at www.epa.gov/iris). Risk levels were considered safe when intake ≤ RfD or RfC, indicated by RQ ≤ 1. Risk levels were considered unsafe when intake > RfD or RfC, as indicated by RQ > 1.

Table II: Individual Characteristics and Activity Patterns of Respondents by Zone

Zone Characteristics	Zone			
	North Zone (NZ)	East Zone (EZ)	South Zone (SZ)	West Zone (WZ)
Weight (WB) Kg	58.88	52.83	57.84	51.17
Long Exposure (LE) hour/day	11.84	11.04	12.16	12.00
Exposure Frecuency (EF) Day/year	316	321.50	321	276.54
Exposure Duration (DT) Year	26.56	35.58	34.6	29.88
Inhalation Rate(IR) m^3/hour	14.55	14.05	14.71	13.81

Table III: Realtime Intake And Lifetime Intake Of Respondents By Zone

No	Zone	Realtime Intake (mg/kg/day)	Lifetime Intake (mg/kg/day)
1.	North Zone	0.11	2.92
2.	East Zone	0.88	1.68
3.	South Zone	2.30	4.66
4.	West Zone	1.49	3.48

Pulmonary vital capacity examinations were conducted to gather additional data to assess the real impact of $PM_{2.5}$ exposure on health. Spirometry was used to measure forced expiratory volume and airflow velocity to estimate total lung capacity. The results show that most respondents experienced restrictive lung disorders in all zones (north, east, south, and west), and only two respondents had normal lung capacity, as shown in Table V.

DISCUSSION

The research location is in Pangkep which is about 55 km from the city of Makassar. The cement industry rapidly increasing in Pangkep, particularly located in Biring Ere Village, Bungoro District. The area is partly surrounded by limestone-mountains which are the raw material for cement. The roofs of resident house are visible plant leaves covered with cement dust. The air circulation inside the houses is not optimal, as well as environmental infrastructure highly disrupting the mobility of the local resident. Then, Biomass burning

Table IV: Realtime And Lifetime Risk Levels Of Respondents By Zone

No.	Zone		Risk Level (RQ)				Risk Level (RQ)		
			n	RQ	Condition		n	RQ	Condition
1.	North Zone	Realtime RIsk	25	0.46	no risk	Lifetime Risk	25	1.21	Risk
2.	East Zone		24	0.36	no risk		24	0.69	No Risk
3.	South Zone		25	0.95	no risk		25	1.93	Risk
4.	West Zone		24	0.61	no risk		24	1.44	Risk

Table V: Distribution of Respondents to Impaired Lung Function Based on Study Zone

Lung Function Dissorders	Zone							
	North (ZN)		East (ZE)		South (ZS)		West (ZW)	
	n	%	n	%	n	%	n	%
Normal	0	0	0	0	0	0	2	8.33
Obstructive	7	28	3	12.50	2	8	3	12.50
Restrictive	18	72	21	87.50	23	92	19	79.17
Total	25	100	24	100	25	100	24	100

is the main source of $PM_{2.5}$ mass concentration in residential areas. For example, the problem of factory smoke during the sample period occurs during the dry season and is affected by the northeast monsoon. The average $PM_{2.5}$ concentration of all sampling locations exceeded the WHO indicator, which should not exceed 25 µg/m3 (26,27).

Most $PM_{2.5}$ sources in Southeast Asia come from automobile exhaust, industrial pollution and secondary aerosols as the main sources (28). Vehicle activity, industrial by-products, and re-suspension of crustal soils are the main anthropogenically driven drivers of the release of particulate pollutants into the environment (29–31). It is known that Pangkep is a cement industry area whose production activities emit pollutant materials. One of $PM_{2.5}$ so exposure will increase health risks and increase pollutant concentrations above environmental quality standards. The results of the research show that the concentration of $PM_{2.5}$ pollutants is above environmental quality standards. It causes health problems such as impaired lung function. It is similar to the result of research by Rachmawati et al (2020) which states that pollutant matter causes impaired lung function (41).

The measurement of ambient air $PM_{2.5}$ around cement factories was conducted during daylight hours with a duration of 30 minutes. The purpose of this measurement was to determine the impact of $PM_{2.5}$ on the lung capacity of traders, expressed in daily exposure doses. Calculations using the reference dose formula (RfC) resulted in 0.18 mg/kg/day. Subsequently, the individual $PM_{2.5}$ intake was compared to the reference dose value. From direct measurements at several sampling points in each zones, it was found that the $PM_{2.5}$ concentration far exceeds the quality standard set by the WHO, which is 10 µg/m^3.

The maximum value of $PM_{2.5}$ exposure was found in the southern zone at 60 µg/m^3, while the minimum value was in the eastern zone at 21.67 µg/m^3. Based on observations at the measurement location, it was affected by the topography of the region. In the southern region which is a mountainous area, the $PM_{2.5}$ particles tended to accumulate in the specific area with some areas surrounded by limestone-mountains. Then, the particles of size ≤ 2.5 were carried by the wind in all directions. Moreover, the turbulence primarily occurred in the southern part (southern zone) of the cement factory location, so the $PM_{2.5}$ concentrations is higher in the southern region than other zones. It is a line with research by Lelieveld and Zhang that $PM_{2.5}$ concentrations were very high from anthropogenic activities, especially from the cement industry.

The Pangkep karst area is surrounded by karst quarries, cement and marble factories operating for the last two decades. The majority of industries involves dry processes and high temperatures in their production activities. In cement factories, particulates produced piles that can be carried by toxic particulates such as PAHs, heavy metals and organic materials which are harmful to the environment around the population. (42,43). In addition, the use of coal in industry releases heavy metal ions involving high temperatures which is likely to increase risks to human health.During the study period, the average concentration of $PM_{2.5}$ was higher than the acceptable annual limits set by the WHO Air Quality Standards. The increased concentration especially during the dry season at the time of research showed that climate, weather, and wind direction influence the increasing of pollutant concentrations compared to the rainy season. It is the same results of research by Bodor et al, Liu et al, Meng et al, dan Xiao et al that the $PM_{2.5}$ concentrations were higher in the dry season because it was supported by the direction and speed of wind; and hotter weather. (30,32–34). It indicates that the higher the mass of particulates produced from industrial chimneys, the possibility of high accumulation of toxic elements in other media such as soil and water bodies will increase (35).

$PM_{2.5}$, in theory, results from anthropogenic sources, both residential, transportation, and industrial activities. The results of our study bring out that there is an increase in the concentration of $PM_{2.5}$ pollutants in Pangkep because it is a cement-producing area. The measurement of $PM_{2.5}$ is committed based on the guidelines of the Indonesian National Standard 1971-19.62005 regarding the measurement of $PM_{2.5}$ and Decision of the Head of the Environmental Control Agency No. 205 of 1996 on the Technical Guidelines for Air Pollution Control from Non-Mobile Sources. The Decision of the Head of the Environmental Control Agency is a regulation or policy issued by the head of that agency to govern various aspects related to environmental impact control and environmental protection. The content of the decision can vary, such as technical guidelines, environmental standards, pollution control procedures, or provisions related to environmental permits. The Decision of the Head of the Environmental Control Agency typically has legal consequences and is binding on parties involved in environmental matters governed by the decision. The regulation explains the method for sampling $PM_{2.5}$ in environments where the source of pollution originates from non-mobile source emissions (specifically in the research, and the non-mobile source is the smokestack emissions from the cement industry). The sampling equipment is positioned at a height of 10 meters, and the equipment shelter has a height of 2.5 meters. Align with the guidelines in the regulation, ensuring that the data from $PM_{2.5}$ measurements are pollutants originating from the cement industry. Additionally, the geographical conditions of the measurement area do not include public roads used for motor vehicle transportation.

Environmental Risk Assessment

Most of $PM_{2.5}$ comes from anthropogenic sources. Therefore, variations in the contribution of exposure frequency sources must be influenced by meteorological factors and environmental conditions. Thus, this study's human health risk assessment analysis focuses on $PM_{2.5}$ exposure. The findings of the study were based on sources of human activity, especially cement industry waste. However, the most important control measures must be considered, especially the air quality where people live in or around the sampling area (5,30,35).

Environmental health risk assessment of $PM_{2.5}$ Exposure

In the study, $PM_{2.5}$ and its health risk implications were assessed. Risk quotes are calculated to estimate the toxicological risk that an average dose of $PM_{2.5}$ was released. The results bring out that the highest ratio of $PM_{2.5}$ exposure was in areas with a large industrial background, namely the cement industry. It indicated an increase in the contribution of $PM_{2.5}$ from the industry. Furthermore, the relative risk calculation represents a positive risk for impaired lung function due to $PM_{2.5}$ exposure. These results indicate that the health risks posed by exposure to ambient $PM_{2.5}$ air around industrial areas are below USEPA standards.

The risk to human health in the industrial zone from exposure to $PM_{2.5}$ requires investigation and monitoring. Furthermore, Table 4 describes the lifetime health risk showing the entire non-carcinogenic risk exceeding safe levels and the risk of chronic health effects in society. Following research, heavy metals bound to $PM_{2.5}$ reported total heavy metals entering through the ingestion exposure route, followed by skin contact and inhalation (36,37). Sakunkoo's research said that the main source of exposure was through the inhalation route, followed by ingestion and skin contact. It gets along with our research. Therefore, it is important to implement a long-term plan to reduce $PM_{2.5}$ levels (26). Potential health risks are higher in adulthood due to higher health vulnerabilities such as elderly people or disease sufferers, who have a higher risk of adverse health impacts (42).

Based on the results of a health risk assessment, it is evident that $PM_{2.5}$ exposure can significantly affect environmental and carcinogenic risks based on RQ > 1. Sakunkoo et al in Thailand pointed out that $PM_{2.5}$ exposure resulted in non-carcinogenic and carcinogenic risks in children and adults. It is interesting because this study also indicates that the risk occurs higher in children than adults (26). The mayority of respondents experienced impaired lung function. It is get matched with the previous study, Suryadi el al, Manuel and Sexton that $PM_{2.5}$ gives impact to the function of lung. When $PM_{2.5}$ enters the body, especially through the respiratory system, they will push and cause health problems. People exposed to $PM_{2.5}$ for a long time can cause a decrease in life expectancy, with many deaths from lung cancer. Particulates that enter the lungs, stick to the lining of the bronchi which can then cause a bodily reaction in the form of coughing (38,39,40).

CONCLUSION

$PM_{2.5}$ concentrations in the study area exceed the WHO standard. The risk assessment results indicate the potential carcinogenic and non-carcinogenic effects on the research respondents potentially affecting both children and adults. The effective strategies can include self-protection from inhalation exposure, such as using personal protective equipment (masks) and reducing exposure concentration, duration, and frequency. In the industry, pollution control is carried out through periodic air quality monitoring and the use of pollution control technologies such as electrostatic precipitators to reduce pollutants.

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