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Systematic Review: The Impact of Particulate Matter 2.5 ($PM_{2.5}$) Exposure on Public Health Around Coal Mines

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Abstract

Air pollution is one of the major public health challenges in Indonesia. Coal mining areas are air polluted and vulnerable to air pollution, especially $PM_{2.5}$ dust particles. Air pollution in coal mining areas if not managed can cause degradation of the atmospheric environment. The impact of unmanaged $PM_{2.5}$ can cause harm to humans, especially respiratory health problems and even death. This article aimed to summarize several relevant scientific articles on the description of the impact of $PM_{2.5}$ exposure on public health that occurs due to coal mining. This article used the systematic review method. The literature search used two scientific databases, namely Google Scholar and Science Direct published in the range of 2016-2024. There were 1133 articles retrieved in the initial selection, and at the end there were 10 articles included in the systematic review. Based on the review conducted on the selected articles, the results show that coal mining can have several negative impacts on the health of the surrounding community, which can cause various acute respiratory infections, asthma, coughing, Chronic Obstructive Pulmonary Disease (COPD), digestive disorders, cardiovascular disorders, and accumulation of $PM_{2.5}$ that exceeds the threshold and in a long time can cause death.

Keywords: *Air Pollution, Coal Mines, Particulate Matter 2.5, Public Health.*

INTRODUCTION

Indonesia is one of the countries with the largest coal reserves in the world and is heavily dependent on coal-fired power plants (PLTU) as its main source of energy. (Rahma et al., 2021). Coal in Indonesia is estimated at 36 billion tons, which is spread across several islands in Indonesia. Indonesia is one of the countries that relies heavily on coal-fired power plants, thus it can be said that the increase in coal combustion process per day is very high (Juniah et al., 2013). Combustion in PLTU activities will produce residual ash, which consists of 20% bottom ash collected at the bottom of the furnace and 80% fly ash. If 80% of fly ash does not go through a filtering process, it will have a negative impact on life, especially for the surrounding community and workers, namely a high risk of respiratory disease (Agustiyaningsih et al., 2022).

Coal-fired power plants are a major source of fine particulate air pollution ($PM_{2.5}$). Exposure to $PM_{2.5}$ is associated with an increased risk of mortality. To assess the success of air quality improvement efforts, it is necessary to estimate the health impacts, including mortality, associated with specific air pollution sources (Corda et al., 2024). Previous

attempts to estimate such impacts assumed that $PM_{2.5}$ from all sources is equally toxic. However, $PM_{2.5}$ from coal is rich in sulfur dioxide, black carbon and metals. Recent evidence suggests that such emissions may be more deadly than $PM_{2.5}$ from other sources (Krittanawong et al., 2023).

Coal mining areas are recognized as one of the main sources of $PM_{2.5}$ emissions worldwide. The mining process, from excavation to transportation of coal, produces fine particles that are dispersed in the air. Studies in India show that coal burning activities also contribute significantly to air pollution, based on the air quality index released through the AQI in New Delhi City the PM level is 2,553 micrograms per cubic meter on average. AQI is a public safety standard related to air pollution level standards used by several major countries, especially India (Trianisa et al., 2020). This suggests that coal mining areas, especially in densely populated areas, have great potential to increase air pollution that can affect the quality of life of local residents (Ostro et al., 2024).

Not only in terms of air pollution, $PM_{2.5}$ particles also have long-term effects on public health. Based on previous research, long-term exposure to $PM_{2.5}$ from mining sources can increase the risk of respiratory disease, cardiovascular disease, and even premature death (Rahmasari & Budiono, 2016) This study also revealed that the health risks due to $PM_{2.5}$ are higher in populations living around mining areas, who are daily exposed to emissions from various activities at the mine. This condition is further exacerbated by the lack of effective emissions management at some mine sites, especially in developing countries (Xie et al., 2022).

Furthermore, meteorological factors such as wind and rainfall also play an important role in dispersing and concentrating $PM_{2.5}$ in mining areas. In a study by Ostro *et al* (2024), $PM_{2.5}$ air pollution from uncovered coal trains had an impact on mortality, increased hospitalizations due to cardiovascular and respiratory diseases and asthma (Ostro et al., 2024). Simulation studies show that in areas with high wind speeds, $PM_{2.5}$ emissions from mines can spread further, increasing the risk of pollution over a wider area (Zahirah & Santoso, 2025). This shows the importance of considering geographical and meteorological factors in pollution management in mining areas, especially for areas with dominant winds that can accelerate the dispersion of fine particles (Trianisa et al., 2020).

Although a number of studies have identified the dangers of $PM_{2.5}$ in general, particles originating from coal combustion have different chemical characteristics and are thought to be more toxic than those from other sources. However, there has been no systematic review specifically compiling and evaluating evidence on the health impacts of $PM_{2.5}$ from coal combustion. In other words, there is a gap in the literature that limits scientific understanding and evidence-based policy-making, particularly in countries with high dependence on coal such as Indonesia.

Therefore, this systematic review aimed to fill this gap by consolidating and evaluating existing scientific evidence related to the health impacts of exposure to $PM_{2.5}$ from coal combustion, both from epidemiological and toxicological studies. This review is expected to provide a strong scientific basis to support emission control policies and public health protection.

METHODOLOGY

This research used a systematic review method using the flow. The source of scientific articles used in this study was published from 2016 to 2024. Searching for articles in the database was carried out using the keywords Particulate Matter 2.5 ($PM_{2.5}$) air pollution, public health, air pollution due to coal mining through the Science Direct and Google Scholar platforms. Furthermore, the title and abstract of each article were

reviewed in accordance with the topic under study, namely the impact of $PM_{2.5}$ exposure on public health around coal mining.

In this study, Google Scholar and Science Direct were selected as the main databases because they both provide broad access to scientific literature from various disciplines, including environmental health, toxicology, and energy. The use of both databases aims to balance depth (from Science Direct) and breadth (from Google Scholar). Other databases were not included due to limited full access, resource constraints, and considerations of time efficiency and the adequacy of the literature already available from the two sources used.

We applied several study selection criteria as follows. First, only articles with free full-text access were selected so that the entire content of the article could be accessed completely and transparently, allowing for a more in-depth assessment of quality and data without the constraints of paid access. Second, the publication period was limited to between 2016 and 2024 to ensure that the results analyzed reflect the latest evidence and are relevant to the conditions of coal combustion technology, emission regulations, and emerging exposure patterns and health risks during that period. This period also helps maintain the focus and feasibility of the review given the large amount of available literature. Third, the studies included were those published in Indonesian and English, the two main languages in scientific literature relevant to the context of this research. This language restriction was imposed to minimize the risk of misinterpretation and ensure the quality of the literature review in line with the researchers' language proficiency. Fourth, the research design chosen was observational studies with a cross-sectional and case-control approach. This design is considered most appropriate for examining the relationship between $PM_{2.5}$ exposure from coal and health impacts, as cross-sectional studies provide an overview of the prevalence of health effects in exposed populations, while case-control studies allow for retrospective analysis of the association between exposure and disease incidence. The selection of this design also took into account the availability of sufficient studies and the consistency of the types of data analyzed in this review.

After the initial search, the articles found were collected and duplicates were removed using reference management software Zotero and manual checks. Next, researchers independently selected titles and abstracts based on inclusion and exclusion criteria. Articles that were deemed irrelevant were excluded.

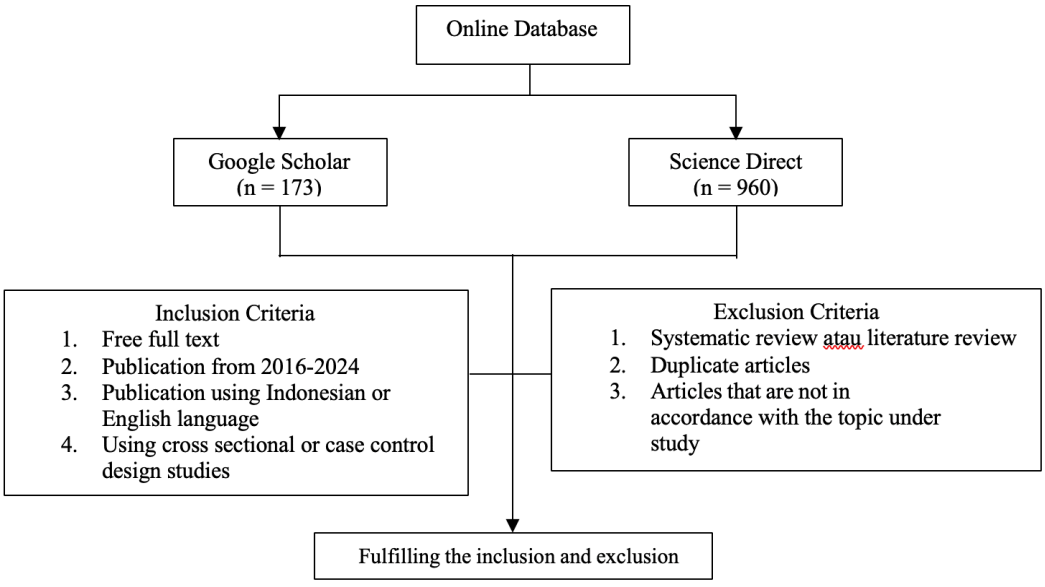

Figure 1. Flowchart of Systematic Review

RESULT

After screening the articles, 10 articles were obtained that met the inclusion and exclusion criteria. further reviewed by researchers and then summarized in table 1 below:

Tabel 1. Research Results

No.	Authors/Years	Article Title	Design Study	Sample	Result
1.	(Ostro et al., 2024)	Health Impact Assessment of $PM_{2.5}$ from Uncovered Coal Trains in the San Francisco Bay Area: Implications for Global Exposures	Cross sectional	The study area covers cities in the East Bay region of the San Francisco Bay Area, California, approximately 12 miles east of San Francisco	This study shows that open coal trains increase $PM_{2.5}$ exposure in residential areas, although it is still below the national air quality threshold. This exposure has a significant impact on health, including an increased risk of premature death, heart disease, respiratory disease, and asthma, especially among vulnerable groups such as children and low-income communities. These findings underscore that the negative impacts of coal begin during transportation, not just during combustion, and represent a global public health and environmental justice issue.
2.	(Fauziah et al., 2020)	Subjective Complaints of Respiratory Disorders Among Workers in the Jambi Coal Stockpile Area	Cross sectional	36 workers in the coal stockpile area	This study aims to identify subjective complaints of respiratory disorders among workers exposed to coal dust in the Jambi coal stockpile area. Using a quantitative descriptive approach involving 36 workers, the study found that the majority of respondents experienced respiratory complaints, such as coughing (50.0%), excessive phlegm (36.1%), and

					shortness of breath (16.7%). These findings suggest that without proper risk management, workers in this sector will continue to experience health issues that could have long-term effects on their productivity and quality of life.
3.	(Sugiharti & Sondari, 2016)	Overview of Chronic Obstructive Pulmonary Disease (COPD) in Coal Mining Areas, Muara Enim Regency, South Sumatra Province	Cross sectional	The sample size was 469 household members in designated areas and 504 household members in non-designated areas	The results showed that the incidence of COPD based on symptoms was higher in designated areas (1.07%) than in non-designated areas (0.20%). Similarly, symptoms/diagnoses were higher in designated areas (2.35%). This study found that the prevalence of Chronic Obstructive Pulmonary Disease (COPD) is higher among communities living in areas near coal mines compared to those living in areas far from mines. Air quality, both indoors and outdoors, shows higher concentrations of pollutants (SO_2, NO_2, PM_{10}, and $PM_{2.5}$) in areas near mines. Additionally, the higher prevalence of smoking in these areas exacerbates the risk of developing COPD. These findings confirm that the combination of exposure to coal dust and behavioral factors such as smoking directly contributes to the increased incidence of chronic respiratory disorders in mining environments.

4.	(Arba, 2019)	Concentration of Respirable Particulate Matter ($PM_{2.5}$) and Health Disorders in Communities Living Near Coal-Fired Power Plants	Cross sectional	Sample size 30 respondents in the exposed group and 30 respondents in the unexposed group	The results of this study show that the concentration of $PM_{2.5}$ in ambient air in the exposed group was 26.77 μg/m3, while in the unexposed group it was 17.22 μg/m3. Health issues in the exposed group included coughing (70%) and eye irritation (47%), while in the unexposed group, health issues included coughing and rashes (10%). There was a significance value of 0.05 ($p < 0.05$), with Exp (B) = 1.174. This study concludes that there is a significant influence between $PM_{2.5}$ concentration in ambient air and health issues.
5.	(Gultom et al., 2020)	Analysis of the Impact of the Coal Stockpile Industry on the Environment and Public Health	Cross sectional	100 respondents	This study found that coal stockpiling activities in Tarahan Village, Bandar Lampung, have a significant impact on the quality of the environment and the health of the surrounding community. Measurements showed that dust and $PM_{2.5}$ levels exceeded thresholds in several residential areas. Residents reported health issues such as coughing, respiratory problems, and skin irritation. While the company's environmental impact outreach efforts were deemed adequate, overall environmental impact management was still considered

					insufficient. Additionally, air pollution and disturbances to peace and quiet caused by stockpiling activities were also complained about by residents. These findings underscore the importance of stricter environmental oversight and the need for efforts to protect the health of communities living near coal stockpile areas.
6.	(Sari & Sunarti, 2023)	The Relationship Between Mask Use and Respiratory Tract Infections Among Coal Mine Workers at PT.X	Cross sectional	Sample of 94 workers	From the results of research related to mask usage behavior and respiratory tract infections among coal mine workers at PT.X, 54 coal mine workers at PT.X were found to have respiratory tract infections, with a percentage of 57.4%.
7.	(Bahri, 2018)	Health and Environmental Impacts of Dust Emissions from the Karangkandri Cilacap Coal-Fired Power Plant	Life Cycle Assessment study based on ISO 14040 of 2006	Karangkandri Cilacap 600 MWe Power Plant	The impact assessment results show that the loading and unloading route through Tanjung Intan Port has a greater impact (both on health and the environment) than the loading and unloading route through the PLTU Pier, with the difference in impact between the two as follows: (1) Non-carcinogenic impact of 2.28×10^{-5} DALY, (2) carcinogenic impact of 2.13×10^{-6} DALY, (3) impact on respiratory disorders of 3.67×10^{-3} DALY.
8.	(Rahman et al., 2020)	Coal Dust and Acute Respiratory Infections in South Kalimantan	Case control	20 case groups in the boiler unit and 20 case groups	This study shows a significant relationship between exposure to coal dust and the incidence of acute respiratory infections

		PT 'X' Coal Mining Workers		in the filling unit	(ARI) among coal miners. Measurements of dust levels in the boiler unit exceeded the established threshold, and 65% of workers in this unit reported experiencing ARI. In contrast, in the filling unit, where dust levels were lower, only 25% of workers experienced ARI. Statistical tests confirm that exposure to coal dust directly increases the risk of acute respiratory disorders. These findings emphasize that working conditions with high dust levels significantly contribute to the deterioration of miners' respiratory health.
9.	(Agustan et al., 2024)	The Relationship between $PM_{2.5}$ and PM_{10} in Ambient Air and Acute Respiratory Infections (Case Study of Tanjung Jambu Village, East Merapi District, Lahat Regency)	Cross sectional	376 respondents	This study shows that although $PM_{2.5}$ and PM_{10} levels in ambient air are still below environmental quality standards, the prevalence of ARI in the productive age group is quite high, at 25.5%. However, statistically, no significant relationship was found between $PM_{2.5}$/PM_{10} levels and the incidence of ARI. Behavioral factors, especially smoking habits, were found to have a significant relationship with an increased risk of ARI. These findings indicate that, in addition to air quality, lifestyle factors also play an important role in influencing respiratory health in the community.

10.	(Rahmasari & Budiono, 2016)	The Relationship between Dust Levels at the Karangkandri Coal-Fired Power Plant and Incidences of Respiratory Tract Infections in Karangkandri Village, Kesugihan Subdistrict, Cilacap Regency in 2016	Cross sectional	48 respondents	This study found that $PM_{2.5}$ levels in the vicinity of the coal stockpile in Karangkandri Village exceeded the daily threshold of 89.33 µg/m³. Most respondents living near the site experienced respiratory complaints, particularly coughing and shortness of breath. Statistical tests showed a significant correlation between $PM_{2.5}$ levels and respiratory complaints. These findings confirm that coal stockpile activities contribute to air pollution and have a direct impact on the health of the surrounding community.

DISCUSSION

Based on research reports obtained from the last 9 years, there are several health impacts for workers and the community arising from $PM_{2.5}$ exposure from coal mining activities:

Causing Acute Respiratory Infections (ARI)

Exposure to fine particles such as $PM_{2.5}$ originating from coal mining activities has been proven to have a significant impact on the respiratory health of the community and mine workers. A number of studies show that $PM_{2.5}$ concentrations around mining areas, stockpiles, and settlements near mines often exceed the established safety thresholds. For example, $PM_{2.5}$ levels in Palangka Raya were recorded at 89.33 µg/m³, far above the daily quality standard, and were statistically associated with respiratory complaints such as coughing and shortness of breath (Sari & Sunarti, 2023). In South Kalimantan and Muara Enim, research shows that increased $PM_{2.5}$ levels correlate with a rise in the prevalence of Acute Respiratory Infections (ARI), even among the productive age population. Additionally, based on the research from Rahman et al (2020), mining workers directly exposed to coal dust without protective gear such as masks have a significantly higher risk of ARI. A study at PT.X revealed that 87.2% of workers who did not wear masks experienced ARI, compared to only 27.7% of workers who consistently used masks.

Overall, findings from various locations and study methods confirm that PM2.5 from coal mines poses a real threat to the respiratory system. The effects are exacerbated by low compliance with workplace safety protocols and inadequate management of environmental impacts. Mitigation efforts such as the use of personal protective equipment, emission control, and workplace health education are crucial to reducing the health impacts of PM2.5 exposure in the coal mining sector.

Acute respiratory infection (ARI) is an environmentally-based disease because it is spread through the air. This disease is caused by transmission of viruses or bacteria carried on droplets and inhaled by healthy people. Air pollution from smoke/gas is a risk factor for ARI because the particles contained in the air are polluted (Ningsih & Rahayu, 2025). Based on a survey conducted by Sari & Sunarti (2023), 57.4% of coal mine workers suffer from ARI (Sari & Sunarti, 2023)

After pollutants enter the atmosphere, they undergo physical and chemical changes before reaching receptors. Large-scale surface mining has the potential to contribute significantly to air pollution, especially in the operation stage. All activities during the various stages of ore extraction, processing, handling, and transportation rely on equipment, generators, processes, and materials that produce hazardous air pollutants, such as particulates, heavy metals, carbon monoxide, sulfur, phur dioxide, and nitrogen oxides. Mobile air pollution sources include heavy vehicles and cars operating on uneven roads (Juniah et al., 2013).

In line with the research of Ostro et al (2024), open pit mining activities can release $N_{(2)}O$, CO, SO_2, and dust particles or so-called coal particulate matter into the air, where these gases can cause ARI. If particles of these gases are inhaled by the surrounding community, it will disturb their respiratory tract. For dust, inhalable particles are around 0.1-<10 μm. Dust between 1-3 μm in size is referred to as respirable dust. Respirable dust is the most dangerous because it can be retained and deposited from the bronchioles terminalis to the alveoli. This can cause ARI and even black lungs (Ostro et al., 2024). The onset of ARI disease in the community can be caused by the inactivity of mining companies to encourage the community to be more sensitive to health (Zahirah & Santoso, 2025).

Several stages of mining operations cause air emissions. This often occurs during the exploration, development, construction and operational stages of mining (Luo et al., 2021). Mining operations can mobilize large amounts of material and waste piles containing small particles that are easily dispersed by the wind. The main sources of air pollution in mining operations typically include, particulate matter transported by wind, wind erosion, exhaust emissions from mobile sources such as trucks increasing particulate pollution levels, and emissions from fuel combustion at stationary and mobile sources, explosions, and mineral processing (Munawer, 2018).

If residents continue to inhale dirty pollution from the burning of PLTU coal, residents will be very likely to suffer from respiratory diseases such as shortness of breath, lung cancer, asthma, cough, and other health problems (Arba, 2019). This will be very detrimental to residents because they will experience various health problems caused by breathing dirty air continuously and this is also related to their economy again, where health is the number one thing if someone has to carry out activities to find their source of livelihood.

Chronic Obstructive Pulmonary Disease

There are three articles stating that there is an impact of $PM_{2.5}$ exposure on cases of Chronic Obstructive Pulmonary Disease (COPD). Based on a review of the three articles from Ostro et al (2024), Sugiharti & Sondari (2016), and Trianisa et al (2020), there is an explicit relationship between exposure to fine particles ($PM_{2.5}$) and an increase in cases of Chronic Obstructive Pulmonary Disease (COPD). The article by Ostro et al. (2024) shows that coal transportation using open-top trains in the San Francisco Bay Area results in a significant increase in $PM_{2.5}$ concentrations along the train routes, particularly in densely populated and low-income areas. This increase has been quantitatively proven to elevate morbidity and mortality rates due to respiratory and cardiovascular diseases.

Specifically, hospitalizations due to chronic lung diseases such as COPD increased by 7.3% for every 1 μg/m³ increase in $PM_{2.5}$, alongside increases in asthma symptoms, strokes, and heart attacks.

Similar conditions were reported by Sugiharti and Sondari (2016) in Muara Enim District, Indonesia, an area with intensive coal mining activities. The study showed that the prevalence of COPD based on symptoms and medical diagnosis was higher in areas near mines (2.35%) compared to areas further away (1.19%). This increase aligns with findings that air quality in mining areas, particularly indoor $PM_{2.5}$ concentrations, is far higher than the safe limits recommended by the WHO. This indicates that chronic exposure to $PM_{2.5}$ from mining activities directly worsens the lung health of the surrounding community.

These findings are reinforced by a study in India by Trianisa et al. (2020), which shows that coal as the primary energy source contributes significantly to the air pollution crisis in that country. High $PM_{2.5}$ concentrations resulting from coal combustion in power plants and mining activities cause various respiratory disorders in the community, such as chronic bronchitis, bronchial asthma, and COPD. The study highlights that most residents in mining areas like Odisha suffer from serious lung disorders, directly linked to poor air quality due to massive coal use.

Thus, the three articles consistently show that exposure to $PM_{2.5}$ from various stages of the coal cycle—including transportation, mining, and combustion—has a significant impact on the increase in COPD cases among exposed populations. This underscores the importance of controlling fine particle emissions to protect public health, particularly in areas with high coal activity.

Chronic Obstructive Pulmonary Disease (COPD) is a pare disease that can be caused by exposure to coal dust that results in the onset of the disease (Fernández et al., 2024). There are two diseases, chronic bronchitis and emphysema. The symptoms that arise in this disease are a decrease in the restrictive number during a pare examination and intermittent and short breath. Decreased pare function occurs when there is an increase in the amount of coal dust exposure in the body coupled with smoking and several other factors (Saha et al., 2021). COPD is a worldwide cause of morbidity, mortality and health care. COPD is a global health problem, where smoking is a major risk factor in addition to other factors such as exposure to indoor and outdoor pollution. The burden of COPD will continue to increase in the coming years (Gasparotto & Martinello, 2021).

Coal dust contains chemicals that can cause lung disease. The disease occurs when people who are in coal mining locations, or in coal transportation traffic areas, inhale coal dust continuously, and the most at risk are coal mining workers themselves (Trianisa et al., 2020). The lungs are one of the most important organs exposed to materials in the environment. Continuous exposure to industrial gases and chemicals is another risk factor for COPD. Air pollution can cause a variety of diseases and disorders of body functions, including pulmonary disorders. Air pollution also increases the incidence of bronchial asthma in the community (Trianisa et al., 2020). Chronic coal dust exposure can cause several part diseases including pneumoconiosis, chronic bronchitis and emphysema (Sugiharti & Sondari, 2016). In addition to pneumoconiosis (black lung), coal mining also causes various other diseases, such as tuberculosis, asthma and lung cancer. Therefore, communities around mining are expected to be aware of the symptoms that arise due to the rampant mining and transportation of coal (Saha et al., 2021).

Digestive Disorders

Air pollution causes a huge burden of disease worldwide. Recent evidence suggests that $PM_{2.5}$ contributes to intestinal diseases (Gultom et al., 2020). Fine particulate matter measuring less than 2.5 microns, or $PM_{2.5}$ has long been associated with various health effects, particularly on the respiratory and cardiovascular systems. However, recent research also shows that $PM_{2.5}$ can have a significant impact on the digestive system, both directly and indirectly.

Generally, $PM_{2.5}$ enters the body through inhalation (breathing), with some particles being trapped by the mucus in the upper respiratory tract and then swallowed, entering the gastrointestinal system. Additionally, $PM_{2.5}$ can also enter the body through the consumption of contaminated food or water, especially in areas near emission sources such as power plants or mining areas (Xie et al., 2022).

Exposure to $PM_{2.5}$ not only affects the respiratory system but also has the potential to cause digestive system disorders. $PM_{2.5}$ containing heavy metals and toxic compounds can trigger intestinal inflammation, damage epithelial function, and increase the risk of diseases such as gastritis and IBD. Additionally, $PM_{2.5}$ can cause an imbalance in gut microbiota (dysbiosis), reduce nutrient absorption, and increase the risk of gastrointestinal cancer. These particles can also affect liver function, worsening conditions like non-alcoholic fatty liver disease (Ostro et al., 2024). Therefore, $PM_{2.5}$ poses a serious threat to digestive health, especially with long-term exposure.

Cardiovascular Disorders

The pathogenicity of particulate matter to the cardiorvascular system is determined by its physical properties, such as size, composition, and solubility. It is also influenced by the origin of particulate matter, whether natural and/or man-made, which distinguishes chemical properties such as water-soluble ions and inorganic and organic compounds (Mahiyuddin et al., 2023). Furthermore, their ability to produce reactive oxygen will trigger inflammation in cardiovascular and other target organs. Particulate matter with an aerodynamic diameter smaller than 10µm (PM_{10}) can be inhaled through the lungs and impact human health. However, fine $PM_{2.5}$, with a relatively smaller diameter than PM_{10}, can bypass upper respiratory filtration, allowing particles to reach the lower respiratory tract (Krittanawong et al., 2023). $PM_{2.5}$ also has a larger surface area per concentration to carry toxic substances. It will then accumulate and diffuse in the alveolus and can be distributed to other parts of the body through air exchange and cause systemic damage (Krittanawong et al., 2023).

Many epidemiological studies in different geographical areas of the world, including multicity studies, have shown a significant association between air pollution and adverse effects on human health, particularly affecting the cardiovascular and respiratory systems. Human exposure to particulate matter air pollutants induces alveolus inflammation, contributes to metabolic diseases, and increases the risk of cardiovascular diseases (Mahiyuddin et al., 2023). Furthermore, exposure to air pollutants will worsen conditions for those with pre-existing chronic cardiovascular and respiratory diseases and make them more susceptible to respiratory infections. Both short- and long-term human exposure to $PM_{2.5}$ increases the risk of cardiovascular and respiratory diseases and death (Corda et al., 2024).

This systematic review has several key limitations. The majority of studies used cross-sectional designs, which cannot establish a causal relationship between $PM_{2.5}$ exposure and health outcomes. Small sample sizes and geographically limited study locations, such as specific industrial or mining areas, restrict the generalizability of findings to broader populations. Additionally, differences in exposure measurement

methods and the lack of control for confounding factors such as smoking or socioeconomic status increase the risk of bias. To ensure that the limitations of the systematic review do not undermine the validity and generalizability of the findings, it is important to rigorously screen studies by assessing methodological quality, apply sensitivity and subgroup analyses to identify consistent patterns, and present results cautiously and transparently without claiming causality when evidence remains observational. Additionally, reviewers should encourage further research with stronger designs. The results of this systematic review serve as an initial indication or foundation for further research with stronger methodological designs, larger sample sizes, and broader geographical coverage. With these steps, existing limitations can still be controlled, and the review's findings remain relevant as a basis for decision-making and further research.

CONCLUSION AND ADVICE

Based on the results of the literature study that has been conducted on 10 research articles related to the impact of $PM_{2.5}$ exposure on health due to coal mining activities, it is taken that sytematic literature review is the process of identifying, reviewing, evaluating, and interpreting all available research on the topic area of interest phenomena with certain relevant research questions. So from the results discussed by the researcher, it is concluded that coal mining produces $PM_{2.5}$ which can have several negative impacts on the health of both workers in coal mines and the surrounding community, namely causing various acute respiratory infections, coughing stones, asthma or shortness of breath, Chronic Obstructive Pulmonary Disease (COPD), digestive disorders, cardiovascular disorders, until the accumulation of $PM_{2.5}$ which exceeds the threshold and for a long time can cause death.

There is a need for regulation and supervision that is carried out in a sustainable manner by considering the impact caused by coal mining so that it can prevent more severe damage both to health and to the environment around the mine. In addition, it is necessary to design a special route for coal distribution by limiting the time of distribution.

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