

Environmental Health Risk Analysis of TSP and PM10 Exposure to Communities Around Coal Mining

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ABSTRACT

The coal mining industry contributes to the emission of Total Suspended Particulate (TSP) and Particulate Matter 10 (PM10) dust which has the potential to disrupt the health of the surrounding community. The main problem with this study is that the level of health risk due to exposure to dust is not yet known in detail. The purpose of the study was to analyze the level of non-carcinogenic health risks from TSP and PM10 exposure in communities around coal mining areas. The research used the Environmental Health Risk Analysis (ARKL) method. The population is the community around the mine with samples taken at four points of air measurement locations. Sampling was carried out by taking TSP and PM10 concentration data. The research variables included dust concentration, anthropometric characteristics and respondent activity patterns. Data were collected using dust measuring tools as well as interview questionnaires and analyzed using the RQ approach for risk characterization. The Risk Quotient (RQ) values for the TSP parameter range from 0.002 to 0.010 and for PM10 range from 0.1166 to 0.7876, all of which are still below the risk threshold ($RQ < 1$). This shows a low non-carcinogenic risk to the community around the mine. However, monitoring and control efforts are still necessary especially at points with the highest PM10 RQ values that are close to safe limits. Effective risk management through dust source control, use of personal protective equipment, periodic monitoring, and public education must continue to be optimized to maintain public health and minimize potential impacts in the future.

Keywords: ARKL, RQ, Coal Mining, PM10, TSP

INTRODUCTION

The coal mining industry is one of the strategic economic sectors that makes a significant contribution to state revenue and the provision of energy needs. However, coal mining activities have the potential to create negative impacts on the environment and public health, especially the people who live around mining sites. One of the most significant environmental impacts is air pollution due to dust emissions generated from various stages of mining operations. The dust produced from coal mining activities contains particles of different sizes, especially Total Suspended Particulate (TSP) and Particulate Matter with a size of ≤ 10 microns (PM10). The study showed that in the environment around the cement plant, the measured TSP concentration reached a maximum value of $133.24 \mu\text{g}/\text{m}^3$, which indicates a high dust

accumulation in residential areas, with a value of hazard quotient (HQ) The highest reaches 1.54 indicating a significant non-carcinogenic risk to the surrounding community (A. Rauf dkk., 2021). Meanwhile, studies on PM2.5 and PM10 exposure in workers showed an average concentration of PM2.5 of $71.25 \mu\text{g}/\text{m}^3$ and PM10 of $217.25 \mu\text{g}/\text{m}^3$ with a value of Risk Quotient (RQ) reached 2.07779, indicating a high health risk (Pratama and Nurfitriana, 2024). The study of 90 coal mining workers found that 12 workers (13.3%) experienced pneumoconiosis with the dominant risk factors in the form of inconsistent mask use (OR=5.026), duration of exposure, and age >50 years (Ulfahimayati dkk., 2021).

Recent research on the relationship between coal dust exposure and acute respiratory infections showed that 81.8% of

the study results showed a relationship between coal dust exposure and the occurrence of ARI, with the duration of exposure, dust particle size, threshold values, and composition of the dust formed having a relationship with the occurrence of ARIs and other respiratory disorders (Agustiyaningsih dkk., 2022) Recent global data show that the global burden of pneumoconiosis caused by exposure to particulate matter, gases, and smoke in the work environment reached 119,125 cases in 2019 with 23,015 deaths, and Disability-Adjusted Life Years reached 919,077 years, reflecting the significant health burden of this condition (Qingsong dkk., 2025).

The concentration of dust particles measured in some coal mining areas showed varying values. The study in Bandung found that PM10 concentrations averaged $61 \mu\text{g}/\text{m}^3$ in industrial areas and $30 \mu\text{g}/\text{m}^3$ in non-industrial areas which are still below regulatory standards but show health risks in some individuals with $\text{RQ} > 1$ (Pratama & Nurfitriana, 2024). The ambient air quality standard setting in Indonesia, as stated in Government Regulation Number 22 of 2021 Annex VII, sets the threshold value for TSP at a 24-hour average of $230 \mu\text{g}/\text{m}^3$ and for PM10 at $75 \mu\text{g}/\text{m}^3$ at a 24-hour average (PP No. 22 Tahun 2021).

Environmental Health Risk Analysis (ARKL) is a comprehensive approach to identifying hazards, evaluating dose-response relationships, analyzing patterns and levels of exposure, and characterizing potential risks to human health (Kementerian Kesehatan, 2012). The ARKL method has been widely applied in various industrial and environmental contexts to estimate the health risks of various risk agents, including mining dust and industrial dust (Putri dkk., 2023). In its application, ARKL uses Risk Quotient (RQ) or Hazard Quotient (HQ) values to estimate non-carcinogenic risks, where RQ or HQ values < 1 are considered safe, while RQ or HQ ≥ 1 indicates the existence of health risks that

need to be managed (Pratama & Nurfitriana, 2024) (Asrianti dkk., 2024).

Environmental research around mining areas shows sustainable impacts. A study of 31 former coal mine workers with pneumoconiosis revealed the occurrence of progressive structural and functional changes of the lungs, including airway remodeling, blood vessel changes, and alterations of the pulmonary parenchyma that contribute to the development of the disease (Chau dkk., 2025). These findings suggest that even after exposure stops, pathological changes in the lungs still persist, emphasizing the need for long-term health surveillance programs. This study was designed to apply the ARKL methodology to the general public living around coal mining areas, with the aim of identifying the level of health risk from TSP and PM10 exposure.

Therefore, this study aims to apply the ARKL methodology to assess non-carcinogenic health risks associated with TSP and PM10 exposure among the general population living around coal mining areas. By incorporating ambient air quality measurements and population-specific exposure parameters, this study seeks to quantify health risk levels and provide evidence-based insights to support environmental management strategies and public health protection. The findings are expected to contribute to strengthening environmental health risk assessments in mining-affected communities and inform policymakers in developing targeted risk mitigation and surveillance programs.

METHODS

This study uses the Environmental Health Risk Analysis (ARKL) method. ARKL aims to calculate the level of risk that a population receives due to exposure to polluting agents in the environment. This method was not used to analyze the relationship between exposure to risk agents and health disorders. The research was carried out from September to October 2025. The object of this study is the concentration of TSP and PM10 dust in the community near the Coal Mining Activities of PT. XYZ with 4 Samples. The population of the subjects in this study is the community near the Coal Mining Activities of PT. XYZ as many as

RESULTS

Hazard Identification

Total Suspended Particulate (TSP) is a small particulate matter scattered in the air, in the form of dust, smoke, and vapor with a diameter of less than 100 micrometers (μm). TSP comes from a variety of sources, including industrial activities, power generation, motor vehicles, and construction activities, as well as from mining activities such as coal mining. These particles can contain a variety of harmful chemicals including heavy metals and toxic compounds that have the potential to harm human health, especially through respiratory tract disorders and other systemic diseases due to long-term exposure.

Particulate matter (PM) is a term for solid or liquid particles found in the air. Particulate Matter 10 (PM10) is a particulate matter suspended in air with a diameter of less than or equal to 10 micrometers. Due to its small size, PM10 can be inhaled into the lower respiratory tract (bronchioles and alveolus) and cause irritation, inflammation, as well as the risk of respiratory and cardiovascular health problems. PM10 is a subset of TSP with greater potential health impacts due to its ability to penetrate deeper into the lungs. TSP includes all suspended particulates with diameters up to 100 μm , while PM10 is a specialized particulate that

180 people for the Adult category. Supporting data, anthropometry data and activity patterns were collected through interviews using questionnaires to determine sponsorship factors. Anthropometric data and activity patterns were collected in the form of body weight (Wb), duration of exposure per day (te), frequency of exposure in a year (fe) and duration of exposure (Dt). The measurement results were analyzed using the ARKL method. The risk level is said to be SAFE if the intake value is $\leq RfC$ or expressed by $RQ \leq 1$ and it is said NOT SAFE if the intake value is $> RfC$ or expressed by $RQ > 1$.

is $\leq 10 \mu\text{m}$ in diameter and has significant health risks especially related to the respiratory system. PM10 includes particles with a diameter of 10 micrometers or less. TSP and PM-10 in this study impact of mining activities at sampling points. PM10 can be carcinogenic and non-carcinogenic risk. In this study, a non-carcinogenic risk of TSP and PM10 will be calculated.

Response Dose Analysis

The Reference Concentration (RfC) value for Total Suspended Particulate (TSP) in the Environmental Health Risk Analysis Guidelines (ARKL) of the Directorate General of PP and PL of the Ministry of Health in 2012 is 2.42 mg/kg/day. The RfC value for PM10 is not yet contained in IRIS (*Integrated Risk Information System*) and MRI (*Minimum Risk Table*), so the Reference concentration value for PM10 is derived from the WHO quality standard of 0.014 mg/kg/day. The RfC value in the Environmental Health Risk Analysis (ARKL) is the reference value of the exposure concentration that is considered safe.

TSP and PM10 Concentrations in Residential Air

The concentrations of Total Suspended Particulate (TSP) and Particulate Matter 10 (PM10) in the air measured at four

points around the coal mining area are presented in the following table:

Table 1. TSP Concentration in Settlements

Location	Measurement Length	Concentration ($\mu\text{g}/\text{M}3$)	Quality Standards ($\mu\text{g}/\text{M}3$)
Point 1	24 hours	38.38	230
Point 2	24 hours	22.49	230
Point 3	24 hours	40.17	230
Point 4	24 hours	67.71	230

Source : Primary data, 2025

Table 2. PM10 Concentration in Residential Areas

Location	Measurement Length	Concentration ($\mu\text{g}/\text{M}3$)	Quality Standards ($\mu\text{g}/\text{M}3$)
Point 1	24 hours	4.92	75
Point 2	24 hours	11.58	75
Point 3	24 hours	34.71	75
Point 4	24 hours	14.04	75

Source : Primary data, 2025

The TSP concentration value ranged from 22.49 to 67.71 $\mu\text{g}/\text{m}^3$ at point 4 with the highest concentration of 67.71 $\mu\text{g}/\text{m}^3$. All of these values are still below the national ambient air quality standard set at 230 $\mu\text{g}/\text{m}^3$. As for PM10, the measured concentration ranged from 4.92 to 34.71 $\mu\text{g}/\text{m}^3$, where point 3 showed the highest value of 34.71 $\mu\text{g}/\text{m}^3$. The PM10 concentration value is also still below the quality standard set by the government of 75

$\mu\text{g}/\text{m}^3$. This data shows that exposure to particulates in the study area is still within safe limits.

Characteristics of Anthropometry and Respondent Activity Patterns

The anthropometric characteristics and activity patterns of respondents living around the measurement location are presented in the following table:

Table 3. Characteristics of Anthropometry and Respondent Activity Patterns

Features	Point 1	Point 2	Point 3	Point 4
Band Weight (kg)	60	63	62,7	55
Duration of Exposure (Hours/Day)	24	24	24	24
Frequency of exposure (day/year)	365	365	365	365
Duration of Exposure (Years)	15	15	15	15

Source : Primary data, 2025

The weight of the respondents varied between 55 to 63 kg between measurement points. The duration of daily exposure to pollutants at all points is 24 hours, with a frequency of exposure for a full year (365

days) and an exposure duration of 15 years. This information describes a fairly high and constant level of exposure in the population around the mining area, so the health risk

analysis should consider the duration and frequency of such long exposures.

Risk Characteristics

Risk Characteristics is the last step in the Environmental Health Risk Analysis

(ARKL), at this stage the researcher will calculate the risk level for the non-carcinogenic effects of TSP and PM10 in communities near the coal mining area as shown in the following table:

Table 4. Results of the Calculation of the Risk Quotient (RQ) Value of TSP

Point	I	RQ	Risk
1	0,0127	0,005	No Risk
2	0,007	0,002	No Risk
3	0,0127	0,005	No Risk
4	0,024	0,010	No Risk

Table 5. Results of Risk Quotient (RQ) Value Calculation PM.10

Point	I	RQ	Risk
1	0,0016	0,1166	No Risk
2	0,0036	0,2615	No Risk
3	0,0110	0,7876	No Risk
4	0,0050	0,3632	No Risk

Based on the results of the study, it is known that the RQ value of < 1 for TSP and PM10, it can be concluded that the level of non-carcinogenic health risk from dust exposure in the community around coal mining is currently relatively low (A. U. Rauf dkk., 2021). This indicates that exposure to dust has not caused significant health effects in the general population at the time the measurements were made.

DISCUSSION

Analisis Risk Quotient (RQ) Parameter TSP

Based on the results of the calculation of risk characteristics, the RQ values for the TSP parameters at the four measurement points showed a range between 0.002 to 0.010, with point 4 having the highest value (RQ = 0.010) and point 2 having the lowest value (RQ = 0.002). All RQ values were well below the threshold value (RQ < 1), indicating that the non-carcinogenic health risks from TSP exposure to communities around the coal mining area are very low and safe (Kementerian Kesehatan, 2012). The RQ value is obtained by comparing the daily intake level with the Reference Dose (RfD) or Reference Concentration (RfC) value that has been set by regulatory bodies such as the US EPA. The RQ value of < 1 indicates that the

intake of pollutants is still below the reference dose which is not expected to cause adverse health effects, even in sensitive populations. Research (Liu dkk., 2021) found the hazard quotient value for TSP to be in the safe category, indicating the absence of significant non-carcinogenic health risks.

The relatively low intake values at all measurement points (ranging from 0.007 - 0.024 mg/kg.day) reflect the effectiveness of natural dispersion of particulate matter in the air and the possibility of mitigation efforts that have been implemented at the mining site. Research by (Arregocés dkk., 2023) suggests that the implementation of dust control strategies such as water spraying, road surface stabilization, and vehicle speed restriction can significantly reduce the concentration of TSP in ambient air and lower the level of exposure to the public. The variation in RQ values between measurement points shows a spatial heterogeneity in the distribution of TSP concentrations around mining areas. Point 4 with the highest RQ value (0.010) may be located closer to the main emission source or be on the dominant path of dust dispersion based on local wind patterns. Research by (Liu dkk., 2020) It found that the temporal and spatial distribution of particulates in mining areas is strongly influenced by meteorological factors such as wind speed, atmospheric stability, and relative

humidity, as well as operational factors such as production intensity and mining methods.

While the current RQ value indicates a safe condition, it is important to consider that this risk assessment is a snapshot that reflects the conditions at any given time. Changes in mining operation intensity, meteorological conditions, or other factors may cause fluctuations in TSP concentrations and potentially increase RQ values in the future. Therefore, periodic monitoring and periodic risk evaluation remain necessary to ensure that health risks remain under control (Honscha dkk., 2022). The interpretation of RQ values must also take into account the inherent uncertainties in environmental health risk assessments. Sources of uncertainty include variability in exposure parameters such as inhalation rate, body weight, and duration of exposure between individuals in the population, as well as uncertainty in the determination of RfD values that are generally extrapolated from toxicology studies in animals or epidemiological data with different levels of exposure. Sensitivity and probabilistic analyses can provide a more comprehensive understanding of the range of RQ values that may occur in the population (Q. Zhang dkk., 2025)

Analisis Risk Quotient (RQ) Parameter PM10

The results of the RQ calculation for the PM10 parameter show a wider range of values than TSP, which is between 0.1166 to 0.7876. Point 3 has the highest RQ value (0.7876), close to the threshold value of 1, while point 1 has the lowest value (0.1166). Although there was considerable variation between points, the overall RQ value was still below the threshold, indicating that the non-carcinogenic health risks of PM10 exposure are still in the acceptable category (Kementerian Kesehatan, 2012). The higher RQ values for PM10 than TSP reflect different toxicological and particulate deposition characteristics. PM10, with a diameter of $\leq 10 \mu\text{m}$, has the ability to penetrate deeper into the respiratory tract and can reach the bronchioles and alveoli, thus having the potential for more significant health effects per unit mass than the larger particulates in TSP

Point 3 with an RQ value of 0.7876 that is close to the threshold value requires special attention in risk management strategies. Although this value is still in the safe category,

proximity to the threshold indicates that a moderate increase in PM10 concentration or a change in exposure factors may cause the RQ value to exceed the safe limit ($RQ > 1$). These locations should be a priority in intensive monitoring programs and the implementation of preventive mitigation efforts to prevent future risk escalation (Arregocés dkk., 2023). Significant spatial variation in PM10 RQ values (with a point-to-bottom ratio of 6.8 times) indicates substantial heterogeneity in the distribution of emission sources or dispersion effectiveness in the study area. Research by (Jiang dkk., 2024) using the analysis of the main components and wavelets showed that PM10 variability reflects the combined effects of changes in local emissions and environmental factors such as topography, land use, and meteorological conditions on various temporal scales. It is important to note that the RQ values calculated in this study represent the risk from single exposure to PM10. In reality, communities around mining areas are simultaneously exposed to multiple pollutants, including PM2.5, harmful gases (SO_2 , NO_x , CO), and volatile organic compounds. Hazard Index (HI) approaches that sum the RQs of various pollutants can provide a more accurate picture of the cumulative health risks of multi-pollutant exposure (Kumar dkk., 2025).

TSP and PM10 Risk Comparison

Comparisons between the RQ TSP and PM10 values show a consistent pattern where the RQ PM10 is substantially higher than the RQ TSP at all measurement points. The ratio of PM10 RQ to TSP RQ ranges from 23 to 131 times, with the largest variation occurring at point 2 and the smallest at point 3. These differences reflect several important factors in particulate toxicology and risk assessment methodologies. First, PM10 represents finer particles with deeper deposition capabilities in the lower respiratory tract. Particles with a diameter of $\leq 10 \mu\text{m}$ can pass through the natural defenses of the upper respiratory tract and reach the terminal bronchioles as well as alveoli, where air exchange occurs. PM10 generally has a larger surface area per unit than TSP particles. The larger surface area provides higher adsorption capacity for toxic components such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds. Research by (L. Zhang dkk., 2020) suggests that PAHs concentrations tend to be

higher in finer PMs, contributing to increased toxicity and carcinogenic potential

The Reference Concentration (RfC) or Reference Dose (RfD) values used in RQ calculations for PM₁₀ are generally lower (more conservative) compared to TSP, reflecting the scientific understanding of increased toxicity per unit mass for finer particles. The determination of this reference value is based on epidemiological and toxicology studies that show a lower threshold effect for PM₁₀ than TSP in inducing adverse health responses. The pattern of spatial variation also shows different characteristics between TSP and PM₁₀. The coefficient of variation for PM₁₀ RQ (0.70) was much higher than for TSP RQ (0.38), indicating that the PM₁₀ distribution was more heterogeneous. This can be caused by differences in characteristics between coarse and fine particles. Larger particles such as TSP tend to undergo faster gravitational deposition, so their concentration decreases sharply as they distance from the source. In contrast, PM₁₀ with a longer residence time in the atmosphere can move further and its distribution is more influenced by local and regional air circulation patterns (Liu dkk., 2020).

Risks to Public Health

Based on the results of the study with an RQ value of < 1 for TSP and PM₁₀, it can be concluded that the level of non-carcinogenic health risk from dust exposure to the community around coal mining is currently relatively low (A. Rauf dkk., 2021). This indicates that exposure to dust has not caused significant health effects in the general population at the time the measurements were made. However, the interpretation of the RQ value < 1 as "safe" must be done with caution. Based on RQ values on the assumption that no health effects occur, this risk assessment focuses on non-carcinogenic effects and does not characterize the potential carcinogenic risks of carcinogenic components in PM₁₀ and TSPs such as PAHs, arsenic, cadmium, and hexavalent chromium. (Arregocés dkk., 2023) His study found that although the hazard quotient for heavy metals was below 1, the incremental lifetime cancer risk (ILCR) for some carcinogens exceeded acceptable thresholds, indicating a significant carcinogenic risk, the duration of exposure being a critical factor affecting health outcomes. The RQ values calculated in this study generally assume

exposure over the duration of exposure to a particular standard. However, the duration of actual exposure may vary between individuals based on residency patterns, occupations, and behaviors. Long-term exposure even at concentration levels that result in $RQ < 1$ can accumulate significant disease potential at the population level (Penchala dkk., 2025)

CONCLUSION

The coal mining industry is a strategic economic sector that makes an important contribution to state revenue and energy supply. However, this activity also has a negative impact on the environment and public health, especially those who live around mining sites. Air pollution due to Total Suspended Particulate (TSP) and Particulate Matter 10 (PM₁₀) dust emissions is one of the main environmental issues. The results show that although dust concentrations in most locations are still below national quality standards, non-carcinogenic health risks from dust exposure are still present and need attention. The Risk Quotient (RQ) values obtained for TSP and PM₁₀ are still below the risk threshold, but the spatial variation of RQ values especially for PM₁₀ that is close to safe limit values indicates the need for serious risk management and routine monitoring. The duration and frequency of long exposure to the community around the mine reinforce the importance of effective risk management through dust source control, personal protective equipment, and health education. Therefore, the development of dust control strategies and regular air quality monitoring are needed to protect the health of the surrounding community so that the negative impacts of mining can be minimized.

Overall, this study emphasizes that compliance with ambient air quality standards alone is insufficient to ensure public health protection in communities surrounding coal mining areas. The ARKL-based findings demonstrate that prolonged exposure duration and spatial variability of particulate concentrations can result in Risk Quotient values approaching critical thresholds, particularly for PM₁₀. This underscores the necessity of integrating risk-based environmental management into regional mining governance. Local authorities should incorporate ARKL outcomes into environmental permitting and post-mining supervision, while

community health centers (puskesmas) are encouraged to strengthen early surveillance of respiratory symptoms among vulnerable groups. By linking environmental monitoring with preventive health services, a more comprehensive and sustainable approach to mitigating mining-related health risks can be achieved.

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