

Spatial Mapping of Air Quality and Respiratory Health Around the Babelan Coal-Fired Power Plant Using the Air Pollutant Standard Index (ISPU)

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Abstract

Air pollution from coal-fired power plants (PLTU) poses a critical environmental challenge that directly impacts public health, particularly in densely populated areas such as Babelan District, Bekasi Regency. This study aims to: (1) analyze air quality conditions around the Babelan PLTU using the Air Pollutant Standard Index (ISPU); (2) identify spatial distribution patterns of respiratory diseases; and (3) examine the influence of air quality on residents' respiratory health within a 1–3 km radius of the power plant. A quantitative approach was employed, combining secondary data from the Environmental Agency and local health centers with primary survey data from 175 households selected through disproportional stratified random sampling. Data were analyzed using ISPU calculation, spatial mapping with Geographic Information Systems (GIS), and multivariate regression across dry and rainy seasons. The findings show that $PM_{2.5}$ is the dominant pollutant, categorized as “Unhealthy” within a 1 km radius during the dry season. The highest incidence of respiratory symptoms such as cough and runny nose occurred within this radius, with decreasing prevalence at 2–3 km. Regression analysis confirms that $PM_{2.5}$ significantly affects respiratory symptoms ($p < 0.05$), with the highest R^2 value (0.68) at the 1 km radius, while the effect declines notably during the rainy season and at greater distances. These results highlight the substantial health risks of $PM_{2.5}$ exposure for communities living near coal-fired power plants, underscoring the urgent need for emission control measures and targeted public health interventions.

Keywords: Air Quality, ISPU, $PM_{2.5}$, Respiratory Diseases, PLTU Babelan

DOI: [10.20527/jpg.v12i2.23305](https://doi.org/10.20527/jpg.v12i2.23305)

Received: 20 July 2025; **Accepted:** 25 September 2025; **Published:** 28 September 2025

How to cite: Rahmawati, A. D., Juhadi. (2025). Spatial Mapping of Air Quality and Respiratory Health Around the Babelan Coal-Fired Power Plant Using the Air Pollutant Standard Index (ISPU). *JPG (Jurnal Pendidikan Geografi)*, Vol. 12 No. 2.

<http://dx.doi.org/10.20527/jpg.v12i2.23305>

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1. Introduction

Issues related to air pollution have become a global and national concern due to its significant impact on human health, ecosystems and environmental quality (Ananda et

al., 2021). Pollution is also caused by waste activities caused by human activities to meet their needs, both from the construction sector and the transportation sector (Budiyono & Aji, 2015). Air pollution will affect air quality in an area. Air quality is the level of pollution or cleanliness in a particular area that can be measured and determined by the amount of pollutants (Sabrina & Ridho, 2022). In Indonesia, one of the causes of air pollution is the activity of Steam Power Plants (PLTU) because coal-fired power plants burn coal, which causes pollutants to be released into the atmosphere from piles called “exhaust gases.”

These pollutants include gases (NOX, SOX, and mercury gas) and suspended particles (PM_{2.5}) (Wicaksana & Rachman, 2018). Including the Babelan PLTU which started operating in 2017 with a production capacity of 280 MW located in Babelan District, North Bekasi (Listrindo, 2024). The reason for constructing the Babelan PLTU was to meet industrial needs and supply electricity consumed by companies in industrial areas, specifically to meet the electricity needs of five industrial areas, including Jababeka District, Lippo Cikarang District, EJIP District, MM2100 District, and Hyundai District (Khamdi, 2024). However, the PLTU is very close to residential areas such as Muarabakti, Bunibakti, Samudrajaya, Sukatenang, Sukamekar, Kedung Pengawas, and Kedungjaya Villages, all of which are within a radius of 1-3 km from the PLTU area.

This condition causes negative impacts felt by residents related to air quality and its impact on health. Some of the complaints that arise include coughing, runny nose, shortness of breath, and sore throat, itching which mainly appears during the dry season and at night when thick yellow smoke is observed coming out of the PLTU chimney (Arumningtyas, 2020). This situation is relevant for further study, especially considering the incompatibility of the PLTU location with Regional Regulation Number 11 of 2011 related to the Bekasi RTRW (Bupati Bekasi, 2013). And Law Number 40 of 2016 concerning Technical Guidelines for Industrial Estates which stipulates a minimum distance of 2 km between industrial estates and settlements (Menteri Perindustrian RI, 2016).

A literature review shows that air pollution caused by PLTU activities contains pollutants such as NO₂, SO₂, and PM_{2.5}, PM₁₀ (Hildayani & Nadir, 2024). These substances have concentration thresholds that should not be exceeded. Nitrogen Dioxide (NO₂) is a toxic gas that can cause disturbances in the human respiratory system, especially the lungs with a threshold of 100 µg/m³ (Izzati et al., 2021). Sulfur Dioxide (SO₂) in the air can cause respiratory tract irritation and increase mucosal secretions with a threshold of 75 µg/m³ (Jumadil, 2023). Particulate Matter (PM₁₀ and PM_{2.5}), which are particles with a diameter of less than 10 µm which are usually referred to as PM₁₀, with the threshold for Particulate Matter (PM₁₀) is 75 µg/m³ and for Particulate Matter (PM_{2.5}) is 55 µg/m³, if you exceed the threshold you will experience respiratory problems such as coughing, difficulty breathing and asthma (Septiyana et al., 2023).

ISPU stands for Air Pollutant Standard Index, which is a number that has no unit and can define ambient air quality conditions in a place (Septiyana et al., 2023). This definition aligns with Government Regulation of the Republic of Indonesia No. 41 of 1999, which defines it as a dimensionless number that can describe the ambient air quality conditions at a specific location, based on its impact on human health, aesthetic value, and other living organisms (Pemerintah, 1999). The ISPU value will be displayed in

public or public places in the form of LED screens in the form of ISPU health levels, namely good, healthy, unhealthy and very unhealthy (Wangintan & Sofyan, 2019).

The World Health Organization defines health as a state of complete physical, mental, and social well-being and the absence of disease or infirmity (Najah, 2022). Schindel's definition of health in the journal (Lasso, 2023) is a state of integrity of the body to carry out individually meaningful tasks and the ability to manage stress, psychological, biological, and physical. Physical health has a definition if all organs and bodies are in good condition then it is considered healthy (Amelia et al., 2021). From this definition, this research will discuss more about physical health, especially in villagers who live within a radius of 1-3 km from the PLTU. The main focus of the research is disease symptoms such as cough, runny nose, sore throat, and shortness of breath.

Based on research (Ananda et al., 2021), (Hutauruk et al., 2021) and (Berliandaldo & Hendrix, 2022) that discuss the relationship between air quality and population health, it is found that there is a correlation between PLTU activity and a decrease in the level of health in the population. However, the study did not use ISPU calculations as the basis for measuring air quality and was not equipped with a spatial analysis of disease distribution. Other relevant research (Cropper et al., 2021) in India also shows that PLTU activities are closely related to a decrease in population health. However, in this study, it has a wide scale, namely the country in analyzing and not equipped with mapping.

This research is important because air quality and its impact on the health of residents around PLTU have not been systematically studied using ISPU calculations. As well as, specifically examining parameters such as nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and particulates (PM₁₀ and PM_{2.5}) because their concentrations are most commonly found in the air around PLTU and have a direct impact on the health of residents such as cough and runny nose, sore throat and shortness of breath.

The main objectives of this study are: (1) analyzing the condition of air quality in the Babelan PLTU area using the ISPU calculation, (2) identify the distribution pattern of respiratory diseases in the Babelan PLTU area, (3) examine the effect of air quality on the physical health of residents who live within a radius of 1-3 km from the PLTU. This research is geographically limited to the 7 villages and focuses on physical health aspects.

By linking air quality data with ISPU calculations, population health questionnaire results, puskesmas data and disease distribution maps, this study is expected to provide a comprehensive picture of the impact of air pollution from the Babelan PLTU on the health of the surrounding population. The results of this study are expected to be not only theoretically useful in the development of environmental health studies, but also practically as input for environmental and spatial policies in dense industrial areas such as Bekasi Regency.

2. Method

A. Research Location

The research will be conducted in villages directly affected by the Babelan PLTU in April 2024-May 2025. There are 7 villages that are directly affected, namely Muarabakti Village, Bunibakti Village, Samudrajaya Village, Sukatenang Village, Sukamekar Village, Kedung Pengawas Village, and Kedungjaya Village. These areas are within a radius of 1 km, 2 km, and 3 km from the PLTU and were chosen because they have the potential to be directly exposed to air pollution from PLTU activities which will be displayed in Figure 1, below.

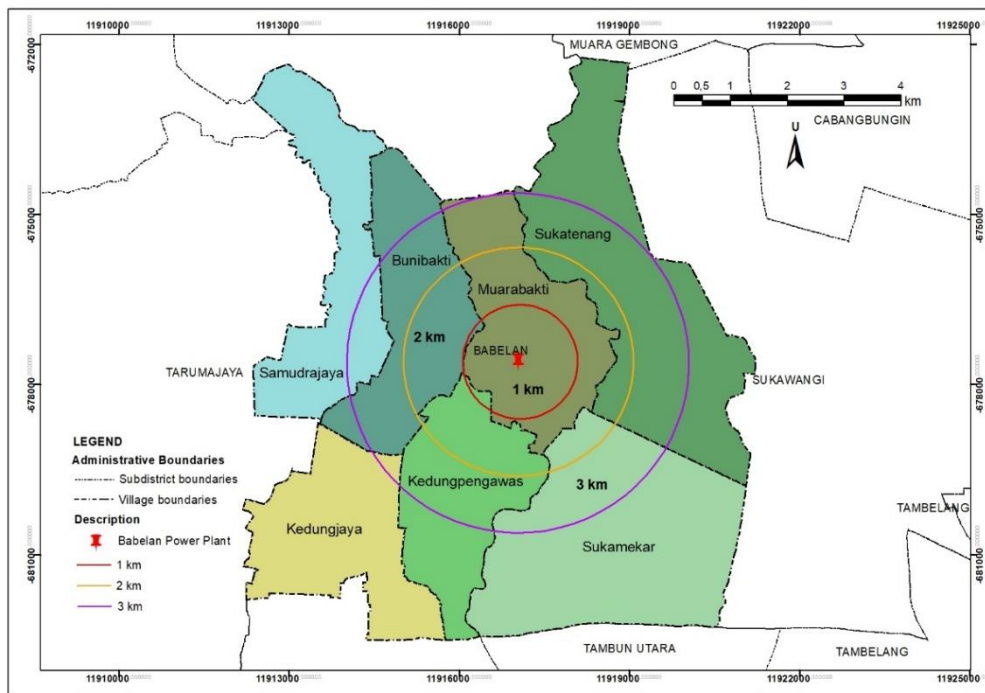


Figure 1. Research Location Map

B. Types, Sources and Data Collection Techniques

The type of data used in this research is quantitative data which is secondary and primary. For secondary data comes from data from the Bekasi Regency Environmental Service (DLH) in the form of air pollution concentration data, namely NO_2 , SO_2 , and $\text{PM}_{2.5}$, PM_{10} in April-March, and Puskesmas data including the number of coughs, runny nose, sore throats and shortness of breath in April-March. Primary data was obtained through the distribution of questionnaires with indicators of respiratory disease symptoms, namely cough, runny nose, sore throat, and shortness of breath. These indicators were adapted from research (Hutauruk et al., 2021) and reinforced by data from the Community Health Center (Puskesmas) showing that these diseases are the most common among residents living near the power plant. The questionnaires will be distributed to heads of households (KK) within a 1 km, 2 km, and 3 km radius because they are directly affected by the Babelan PLTU. The area covers seven villages that are directly affected, namely Muarabakti, Bunibakti, Samudrajaya, Sukatenang, Sukamekar, Kedungpengawas, and Kedungjaya.

This research uses disproportional stratified random sampling technique. Determination of the number of samples taken using the Slovin formula with an error limit of 7.5% and obtained a sample size in this study of 175 samples of Family Heads (KK). The sample details taken from 7 villages were 74 samples from Muarabakti Village, 60 from Bunibakti Village, 14 each from Kedungpengawas and Sukatenang Villages, 9 from Sukamekar Village, and 2 each from Kedungjaya and Samudrajaya Villages. The reason this technique was chosen was because it could reduce sample bias by ensuring that groups with high or low risk were not missed and to find out more about health quality factors based on the closest distance to the PLTU.

C. Analysis Technique

Using Descriptive analysis, namely calculating the value of the Air Pollution Standard Index (ISPU) based on data on the concentration of NO₂, SO₂, and PM_{2.5}, PM₁₀ obtained from the Environmental Service Data (DLH). This calculation uses a standard formula in accordance with the Decree of the Head of Bapedal No. Kep-107/KABAPEDAL/11/1997 with the formula calculation using the standard formula in accordance with the Decree of the Head of Bapedal No. Kep-107/KABAPEDAL/11/1997 (Winatama, Derystanto, 2023).

$$I = \frac{(I_a - I_b)}{(X_a - X_b)} (X_x - X_b) + I_b$$

Where:

I = Air Pollutant Standard Index (ISPU)

I_a = ISPU upper limit value

I_b = ISPU lower limit value

X_a = oncentration upper limit corresponding to I_a

X_b = concentration lower limit corresponding to I_b

X_x = concentration of the pollutant measured

This formula is applied to calculate the ISPU value for each pollutant (NO₂, SO₂, PM_{2.5}, and PM₁₀) based on the concentration data obtained from DLH. The resulting ISPU values are then classified into categories (Table 1) to interpret the level of air quality and its potential health impacts.

The results will be categorized based on the provisions of the Minister of Environment and Forestry (Kehutanan, 2020). It also has a value index scale of 0 to 500, where the higher the ISPU value, the worse the local air quality and the more detrimental it is to human health (Putra & Rismawan, 2023). The Air Pollutant Standard Index (ISPU) numbers and categories are shown in Table 1.

Table 1. Air Pollutant Standard Index (ISPU) Numbers and Categories

ISPU Value	Health Level
0 – 50	Good
51 – 100	Moderate
101 – 199	Unhealthy
200 – 299	Very Unhealthy
300 – 500	Hazardous

This index has a scale of 0 to 500. The higher the ISPU value, the worse the local air quality and the more detrimental it is to human health (Putra & Rismawan, 2023).

Then, spatial analysis is used to map the distribution of air quality and disease distribution based on a radius of 1-3 km from the PLTU. Mapping is done with the help of ArcGis application 10.8. And, multivariate regression analysis to test the effect of air quality such as pollutants NO₂, SO₂, and PM_{2.5}, PM₁₀ with health in the form of cough, runny nose, sore throat and shortness of breath. Analyses were conducted separately to determine differences in air quality and health impacts based on the dry and wet seasons.

3. Result and Discussion

A. Air Quality Conditions

The air quality condition around PLTU Babelan was analyzed based on air pollutant concentration data obtained from the Bekasi Regency Environmental Agency in April 2024-March 2025. The data is then converted into an Air Pollutant Standard Index (ISPU). The ISPU value will be used to determine the level of air pollution and health risks that will be caused, with 5 categories, namely, Good, Moderate, Unhealthy, Very Unhealthy and Hazardous.

1) Seasonal Contrast

In the dry season, namely April–September 2024, the conditions around the PLTU tend to be dry due to low rainfall, so that the concentration of pollutants in the air will gather in the PLTU area which makes the surrounding area feel hotter than other areas. The monitoring points refer to the air quality monitoring locations established by the Environmental Agency (DLH) at distances of 1 km, 2 km, and 3 km from the PLTU. To facilitate spatial analysis, these points were used as the center for creating buffer zones representing each radius. The analysis will be carried out using 3 monitoring points representing a radius of 1 km, 2 km and 3 km outside the PLTU boundary fence. The results of pollutant monitoring will be shown in Table 2, and are complemented by the results of the calculation of the ISPU value.

Table 2. Dry Season Concentration and ISPU Values

Radius	Parameter	Concentration ($\mu\text{g}/\text{m}^3$)	ISPU value	Category
1 km	PM _{2.5}	57.91	103	Unhealthy
	PM ₁₀	54.97	52	Moderate
	SO ₂	40.19	39	Good
	NO ₂	15.58	23	Good
2 km	PM _{2.5}	52.18	96	Moderate
	PM ₁₀	49.53	50	Good
	SO ₂	36.17	35	Good
	NO ₂	14.05	23	Good
3 km	PM _{2.5}	46.97	89	Moderate
	PM ₁₀	44.57	45	Good
	SO ₂	32.56	31	Good
	NO ₂	12.65	22	Good

Source: Environmental Agency (DLH), 2024

Based on Table 2, the highest ISPU value at a radius of 1 km for the parameter PM_{2.5} is 103 with the category "Unhealthy". The ISPU values for other parameters at the 1 km radius are in the "Moderate" (PM₁₀) and "Good" (NO₂ and SO₂) categories. At 2 km and 3 km radius, all parameters will experience a decrease in the ISPU value, with PM_{2.5} in the "Moderate" category and other parameters in the "Good" category. This shows that PM_{2.5} is the dominant parameter. In order to clarify the comparison of ISPU values between each parameter within a 1-3 km radius, the data will be depicted in the form of a bar graph in Figure 2, below.

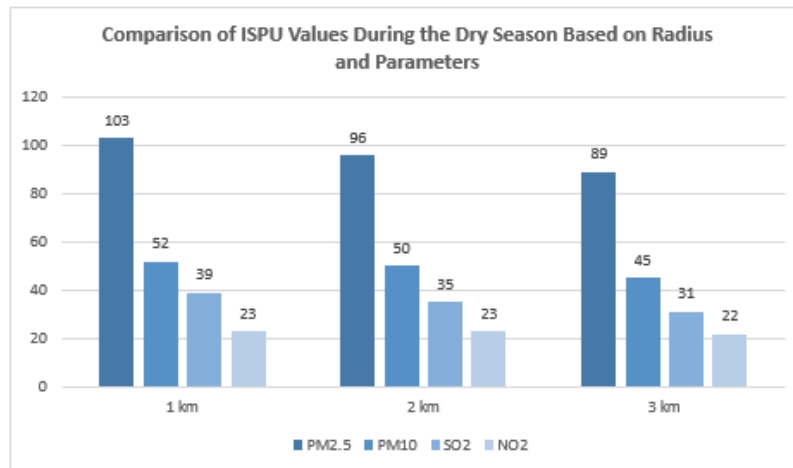


Figure 2. Comparison Chart of ISPU Values for Dry Season

The bar graph in Figure 2, shows that the highest ISPU value is at a radius of 1 km, especially the $PM_{2.5}$ parameter reaching a value of 103 with the "Unhealthy" category. If the further away from the PLTU area the ISPU value will gradually decrease. In addition, the results of data obtained from the Environmental Agency (DLH) for the dry season will be displayed spatially in Figure 3, which aims to determine areas with high ISPU categories.

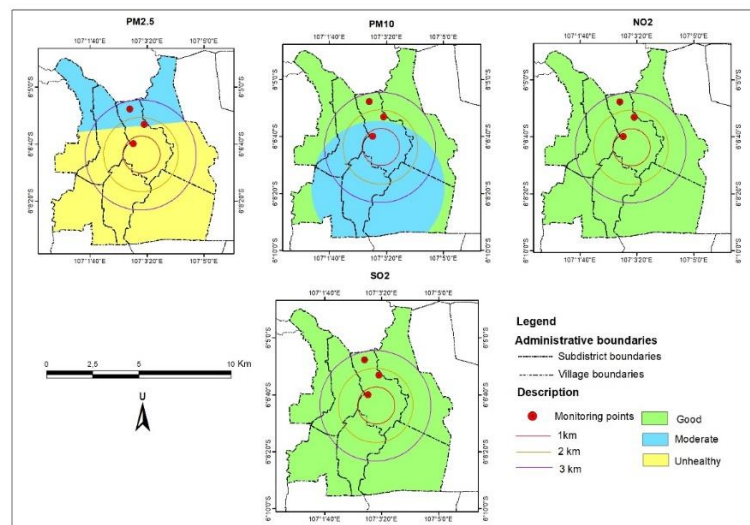


Figure 3. Air Quality Map in Dry Season

Based on the mapping results in Figure 3, it shows the spatial distribution of air quality based on 4 pollutant parameters namely NO_2 , SO_2 , $PM_{2.5}$ and PM_{10} . For the $PM_{2.5}$ parameter, the "Unhealthy" category is dominated in all areas within a radius of 1 km, which means that the concentration of fine particulates is quite high in the area near the PLTU and the "Moderate" category in the area within a radius of 2-3 km. For PM_{10} , the "Moderate" category is dominated at a radius of 1 km and the "Good" category at a radius of 2-3 km, which indicates that there is a concentration of matter particles around the PLTU and will decrease with increasing distance from the PLTU. As well as, for SO_2 and NO_2 shows the "Good" category at a radius of 1-3 km, which means that the concentration of pollutants is relatively low.

The mapping results show that the worst air quality is at a radius of 1 km from the PLTU, especially for PM_{2.5} and PM₁₀ pollutant concentrations. While the 2-3 km area shows that air quality is starting to improve with the "Good" category. The distribution is related to dry season conditions and low rainfall, which allows pollutants to settle and spread limitedly in the area around the PLTU.

In the rainy season (October 2024-March 2025) the concentration of air pollutants, namely NO₂, SO₂, PM_{2.5} and PM₁₀ tends to decrease in concentration, due to high rainfall and an increase in air humidity around the PLTU area. This makes pollutant particles from coal combustion easier to precipitate, thus affecting the condition of air quality around the PLTU. To find out the distribution and level of air pollution will be shown in Table 3, below.

Table 3. Rainy Season Concentration and ISPU Values

Radius	Parameter	Concentration ($\mu\text{g}/\text{m}^3$)	ISPU value	Category
1 km	PM _{2.5}	36.61	80	Moderate
	PM ₁₀	33.28	42	Good
	SO ₂	17.99	37	Good
	NO ₂	13.76	22	Good
2 km	PM _{2.5}	33.04	72	Moderate
	PM ₁₀	30.03	40	Good
	SO ₂	16.28	36	Good
	NO ₂	12.39	22	Good
3 km	PM _{2.5}	29.73	68	Moderate
	PM ₁₀	27.03	39	Good
	SO ₂	14.65	35	Good
	NO ₂	11.15	21	Good

Source: Environmental Agency (DLH), 2024-2025

Based on the results of Table 3, all parameters in the rainy season have decreased compared to the dry season, which is in the "Moderate" and "Good" categories. The PM_{2.5} parameter shows an ISPU value of 80 at a radius of 1 km with a category of "Moderate" and will decrease the ISPU value at a radius of 2 km and 3 km. while the PM₁₀, NO₂ and SO₂ parameters from a radius of 1-3 km are in the "Good" category. To clarify the changes in the ISPU value within a radius of 1-3 km, a bar graph will be drawn in Figure 4, below.

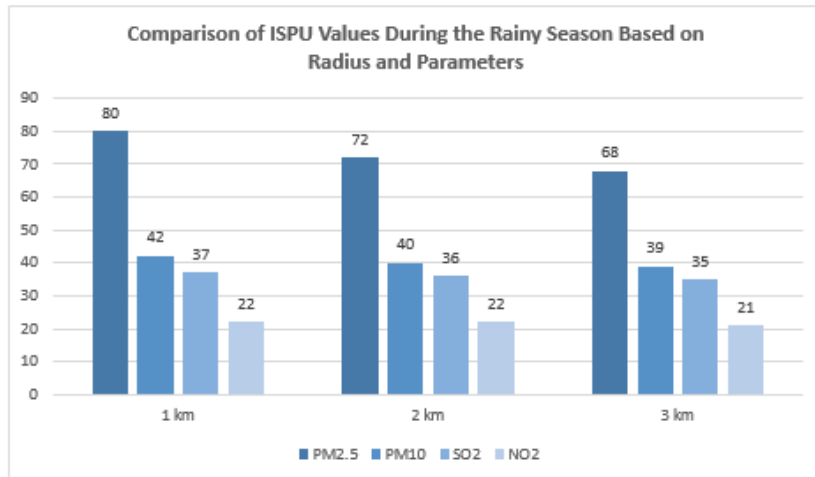


Figure 4. Comparison Chart of ISPU Values Rainy Season

From Figure 4, it can be seen that all parameters experience a decrease in ISPU values in the rainy season. The most dominant decrease is the concentration of PM_{2.5} from the "Unhealthy" category in the dry season, to "moderate" in the rainy season. This shows that pollutants will affect meteorological conditions such as rain. In addition, spatial analysis was also carried out through a map of air conditions in the rainy season in Figure 5, to show a more detailed picture of air quality conditions around the PLTU.

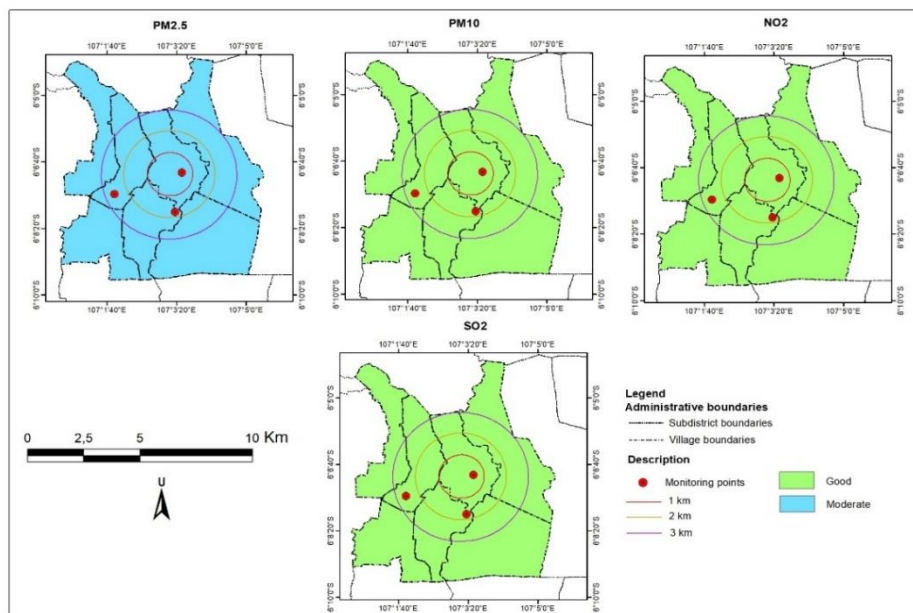


Figure 5. Air Quality Map in the Rainy Season

(Aisyah Dian, 2025)

The map in Figure 5, illustrates the spatial distribution of air quality based on the parameters PM_{2.5}, PM₁₀, SO₂, and NO₂ across the 3 monitoring radius. Green color dominates almost all areas, indicating that air quality is generally in the "Good" to "Moderate" category. However, the PM_{2.5} parameter shows ISPU values in the "Moderate" category in all areas within a 1-3 km radius, while the PM₁₀, SO₂, and NO₂

parameters are all in the "Good" category. This shows that rainfall can significantly reduce pollutant concentrations, but the $PM_{2.5}$ parameter can still be influential, especially in the immediate area of the PLTU.

When compared to the dry season, the rainy season shows an improvement in air quality in all parameters, especially the $PM_{2.5}$ parameter. However, the area within a radius of 1 km from the PLTU still shows a higher level of pollution than the radius of 2 km and 3 km, which indicates that pollutants from burning coal are still influential around the PLTU area even though in general the air quality has improved.

Air quality conditions as reflected by ISPU values provide an overview of the level of exposure to pollutants that residents may experience. Elevated concentrations of pollutants, particularly $PM_{2.5}$ and SO_2 , are closely associated with respiratory health risks. Therefore, after analyzing the air quality conditions, this study further examines the spatial distribution of respiratory diseases in the surrounding communities to understand how variations in air quality correspond with reported health outcomes.

B. Disease Distribution Pattern

The pattern of disease distribution in the Babelan PLTU area was analyzed based on the results of a questionnaire that had been distributed to each Head of Family (KK) within a radius of 1-3 km from the PLTU point. The questionnaire includes questions related to respiratory disease symptoms such as cough, runny nose, sore throat, and shortness of breath.

The data that has been collected is then summarized and presented in the form of Table 2, which shows the number of symptoms of each type of disease based on the radius where the respondent lives. This presentation has the purpose of being able to identify areas with the highest number of disease complaints.

Table 4. Number of Respiratory Disease Symptoms

Radius	Cough	Runny Nose	Sore Throat	Shortness Of Breath	Total
1 km	55	44	23	18	140
2 km	39	21	17	9	86
3 km	10	6	8	1	25
Total	104	71	48	28	251

Source: Questionnaire Results, 2025

Based on the data in Table 4, it can be seen that the number of symptoms of respiratory diseases such as cough, runny nose, sore throat and shortness of breath is highest at a radius of 1 km from PLTU Babelan. Then, at a radius of 2 km and 3 km the number of symptoms complained of by respondents will gradually decrease. This shows that the proximity of residential locations from the PLTU location can affect the amount of exposure to air pollution that affects the respiratory health of residents.

In addition, the results of the questionnaire are displayed spatially in Figure 6, namely the disease distribution map. The Geographic Information System (GIS) application is used in making disease distribution mapping. Each point on the map represents the number of symptoms experienced. The colors and symbols on the map correspond to the type of disease complained about.

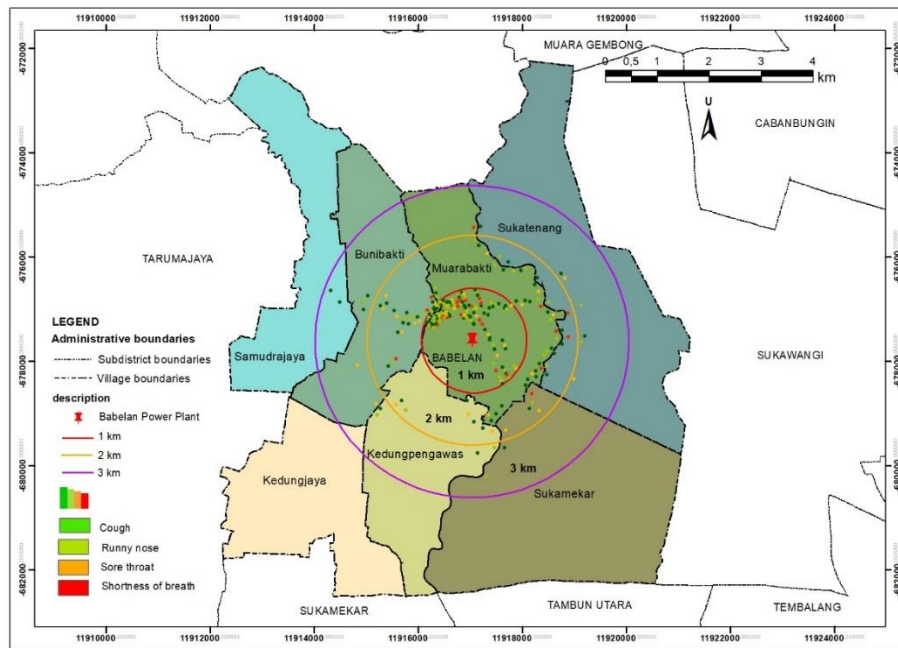


Figure 6. Map of Disease Distribution in the PLTU Area, 2025

Source: Questionnaire and GIS Analysis, 2025

Based on the mapping results in Figure 6, shows the distribution of respiratory disease symptoms based on the results of questionnaires that have been collected from residents who live within a radius of 1-3 km from PLTU Babelan. There are 4 types of symptoms that are mapped and represented with dot symbols and different colors, namely symptoms of cough (dark green), runny nose (light green), sore throat (orange) and shortness of breath (red).

The map shows that disease symptoms are mostly concentrated in areas within a radius of 1 km from the PLTU, especially in Muarabakti Village and partly in Bunibakti Village. Also, the further away the disease is from the PLTU location, the more the symptoms of the disease will decrease and spread.

This finding is also relevant to the provisions of Law Number 40 of 2016 concerning Technical Guidelines for Industrial Estates, which states that the minimum distance between industrial estates and settlements is 2 km. In this case, settlements located within a radius of 1 km are at high risk of being directly affected by the respiratory health of residents (Menteri Perindustrian RI, 2016).

C. Health Case Pattern

1) Dry Season

In addition to primary data obtained from the results of questionnaires that have been distributed. Official reports from the Babelan II Health Center, Babelan District, are also a source of secondary data used in this study. The data will display the number of cases of respiratory disorders, namely coughs, runny nose, sore throats and shortness of breath within a 1-3 km radius. Recorded between April-September 2024, during the dry season. To make it easier to identify disease cases at each radius, the data will be presented in Table 5, below.

Table 5. Number of Respiratory Disease Cases in the Dry Season

Radius	Cough	Runny nose	Sore Throat	Shortness of Breath	Total
1 km	278	169	78	13	538
2 km	216	130	57	8	411
3 km	164	97	41	3	305
Total	658	396	176	24	1,254

Source: Health center data, 2024

Table 5 shows that the number of cases of respiratory disease is highest at a radius of 1 km from the PLTU, and gradually decreases at a radius of 2 km and 3 km. Cough symptoms are the most complained symptoms in the three radii, followed by runny nose and sore throats. Cases of shortness of breath are relatively few but still show a decrease as the distance increases. The results of the data from the Babelan II Health Center can strengthen the results of the questionnaire data, namely that the closer the residents live to the PLTU, the higher the number of respiratory disease complaints experienced. This shows that exposure to air pollution from PLTU activities does have an impact on the health of the population, especially during the dry season. In this season, the concentration of pollutants such as PM_{2.5}, PM₁₀, SO₂, and NO₂ tends to be higher due to low rainfall, so that pollutant particles from coal combustion are not evenly distributed, but rather settle around the PLTU area.

2) Rainy Season

Complementing the findings of the dry season, secondary data was also collected from the official report of Puskesmas Babelan II for the rainy season period, October 2024-March 2025, to compare cases of respiratory problems per season. This data includes the number of cases of coughs, runny nose, sore throats and shortness of breath which will be categorized based on the radius distance of the population's residence from the PLTU, namely a radius of 1 km, 2 km, and 3 km.

The data will be presented in table 6, which aims to facilitate the identification of disease cases based on radius during the rainy season and will be compared with data in the dry season.

Table 6. Number of Respiratory Disease Cases in the Rainy Season

Radius	Cough	Runny nose	Sore Throat	Shortness of Breath	Total
1 km	131	100	39	2	272
2 km	103	74	28	1	206
3 km	79	54	18	0	151
Total	313	228	85	3	629

Source: Health center data, 2024

Based on the results in Table 6, most respiratory diseases occur within a radius of 1 km from the PLTU, with cough and runny nose symptoms as the most dominant complaints. The farther away from the PLTU area the cases of disease symptoms will decrease as in the radius of 2 km and 3 km. Although the symptoms of shortness of breath are fairly low, the further away from the PLTU location the complaints related to these symptoms will decrease. Compared to the dry season, the number of overall respiratory

disease symptoms in the rainy season has decreased. This is due to the high rainfall factor, which indirectly removes pollutants such as PM_{2.5}, PM₁₀, SO₂, and NO₂ from the air. However, the pattern of distribution of respiratory disease cases is higher in areas close to the PLTU, which shows that the distance factor does have an effect.

This, the results in the dry season and rainy season show the same pattern, namely, the closer the location of residents' settlements to the PLTU, the higher the number of complaints of illness experienced.

D. Effect of Air Quality on Population Health

The effect of air quality on population health will use multivariate regression with independent variables (X) namely the concentration of air pollution PM_{2.5}, PM₁₀, SO₂, and NO₂ and for the dependent variable (Y) namely symptoms of respiratory diseases such as cough, runny nose, sore throat and shortness of breath. The analysis will be carried out separately based on the dry season and the rainy season, and will consider the distance of residence within a radius of 1-3 km from the PLTU.

1) Dry Season

The thing that is done before doing multivariate regression for the effect of air quality on population health in the dry season is to test classical assumptions. The classical assumption tests carried out are normality test (Mardia's test), multicollinearity (VIF test), heteroscedasticity (Breusch-pagan test), autocorrelation (Durbin-watson test) and linearity (RESET test). The results of the classical assumption test will be presented in table 7, below.

Table 7. Dry season classical assumption test results

Radius	Mardia's test	VIF test maks	(BP test)	(DW test)	RESET test
1 km	0,124	2,36	0,43	1,94	0,668
2 km	0,097	1,93	0,33	1,88	0,553
3 km	0,131	2,33	0,29	1,96	0,322
Results	Fulfilled	Fulfilled	Fulfilled	Fulfilled	Fulfilled

Source: Analysis Results, 2025

Based on the classical assumption test, the normality test for the 1-3 km radius has a $p > 0.05$ value, indicating that the residual data is normally distributed. The multicollinearity test shows a maximum VIF < 10 , indicating that there is no high correlation between independent variables. The heteroscedasticity test results show that the significant value is > 0.05 for the entire radius, which means there is no pattern of unvaried variance distribution. The autocorrelation test with Durbin-watson test values ranged from 1.88-1.96 which is close to 2, indicating no recurring pattern in the model prediction error. Then, the linearity test results showed $p > 0.05$, meaning that the relationship between independent and dependent variables is linear. Thus, multivariate regression analysis can be performed because all classical assumption tests are met. The multivariate regression results are presented in Table 8, below.

Table 8. Multivariate Regression Test Results Dry Season

Radius	PM _{2.5} (β)	PM ₁₀ (β)	SO ₂ (β)	NO ₂ (β)	R ²	Significant Symptoms
1 km	Y1=6,6907 + 0,5106X1 + 0,1596X2 – 0,0640X3 – 0,0332X4					Cough, Runy nose (p<0.05)
	0,5106	0,1596	–0,0640	–0,0332	0,68	
	Y2=6,3446 + 0,4842X1 + 0,11282X2 – 0,0595X3 – 0,0104X4					
	0,4842	0,11282	–0,0595	–0,0104	0,60	
2 km	Y1=4,5986 + 0,3968X1 + 0,1079X2 – 0,0336X3 – 0,0061X4					Cough (p<0.05)
	0,3968	0,1079	– 0,0336	– 0,0061	0,53	
	Y2=4,7582 + 0,4058X1 + 0,0637X2 – 0,0104X3 – 0,0003X4					
3 km	0,4058	0,0637	–0,0104	– 0,0003	0,12	Not significant (p>0.05)

Source: Analysis Results, 2025

At each radius (1 km, 2 km, and 3 km) in the dry season, a multivariate regression analysis was conducted on 4 dependent variables representing respiratory disease symptoms, namely cough, runny nose, sore throat, and shortness of breath. In total, 4 regression models were generated for each radius. However, only one regression model from each radius will be presented, which is the model with symptoms that have a significant influence on the pollutant concentration variable. The model shown is considered to represent the pattern of the relationship between pollutant concentrations and their impact on the health of residents at that radius.

The concentration of pollutants has a significant effect on the health of the population, as evidenced by the multivariate regression results in Table 8, which show that PM_{2.5} concentration has a significant effect on cough and runny nose symptoms within a 1 km radius of the PLTU with a p value <0.05 and R² of 0.68 and 0.60 respectively. With an R² value of 0.53, the impact of PM_{2.5} on cough symptoms is still quite large within a 2 km radius. With an R² value of 0.12, there is no significant relationship between pollutant concentration parameters and disease symptoms within a 3 km radius. This indicates that the farther the distance of residence from the PLTU, the lower the concentration of pollutants will be.

2) Rainy Season

In the rainy season, the classical assumption test is also carried out as a condition for conducting multivariate regression analysis in determining the effect of air quality on population health. The types of tests carried out are normality test (Mardia's test), multicollinearity (VIF test), heteroscedasticity (Breusch-pagan test), autocorrelation (Durbin-watson test) and linearity (RESET test). The results of the classical assumption test will be presented in table 9, below.

Table 9. Rainy Season Classical Assumption Test Results

Radius	Mardia's test	VIF test maks	(BP test)	(DW test)	RESET test
1 km	0,117	3,23	0,25	2,12	0,836
2 km	0,074	2,37	0,17	2,01	0,691
3 km	0,109	3,10	0,18	2,05	0,494

Results	Fulfilled	Fulfilled	Fulfilled	Fulfilled	Fulfilled
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Source: Analysis Results, 2025

Based on the classical assumption test, it shows that all tests that have been carried out are fulfilled, such as the normality test has a $p > 0.05$ value, that the residual data is normally distributed. The multicollinearity test shows the maximum VIF < 10 , indicating that there is no high correlation between independent variables. The heteroscedasticity test results that the significant value is > 0.05 for the entire radius, which means that the distribution pattern is diverse. The autocorrelation test with Durbin- watson test values ranged from 2.01-2.12, meaning there was no recurring pattern in the model's prediction error. Then, the linearity test results showed $p > 0.05$, meaning that the relationship between the independent and dependent variables was linear. Thus, multivariate regression analysis can be performed to determine the effect of air quality on population health in the rainy season. The multivariate regression results are presented in Table 10, below.

Table 10. Multivariate Regression Test Results Rainy Season

Radius	PM _{2.5} (β)	PM ₁₀ (β)	SO ₂ (β)	NO ₂ (β)	R ²	Significant Symptoms
1 km	Y1=2,1290 + 0,3707X1 + 0,0137X2 + 0,0092X3 – 0,0062X4					Cough, Runy nose (p<0.05)
	0,3707	0,0137	0,0092	– 0,0062	0,47	
	Y2=2,0446 + 0,2664X1 + 0,0118X2 – 0,0054X3 – 0,0076X4					
	0,2664	0,0118	– 0,0054	– 0,0076	0,45	
2 km	Y1=1,4520 + 0,1443X1 + 0,0111X2 – 0,0032X3 + 0,0053X4					Cough (p<0.05)
	0,1443	0,0111	– 0,0032	0,0053	0,33	
	Y1=0,2868 + 0,0477X1 + 0,0129X2 – 0,1025X3 + 0,1002X4					
3 km	0,0477	0,0129	– 0,1025	0,1002	0,21	Not significant (p>0.05)

Source: Analysis Results, 2025

Based on the rainy season regression results, at a radius of 1 km, PM_{2.5} had a significant effect on cough and runny nose symptoms with R² values of 0.47 and 0.45, indicating that almost half of the variation in symptoms was caused by the pollutant. At a radius of 2 km, PM_{2.5} remained significant for cough with an R² of 0.33, although its effect decreased compared to that at a radius of 1 km. While at a radius of 3 km, all pollutant variables were insignificant with an R² of 0.21, indicating a weak relationship between pollutants and respiratory symptoms in areas farther from the PLTU. This shows that the farther the distance and radius of the residence from the PLTU, the lower and lower the concentration of pollutants.

The results of the multivariate regression during the dry and rainy seasons show differences in the effects of pollutants on the health of residents living near coal-fired power plants. In the dry season, atmospheric conditions with low rainfall and weak wind speeds allow pollutants to accumulate, resulting in higher PM_{2.5} exposure and a significant impact on respiratory symptoms, especially within a radius of 1–2 km from the emission source. Conversely, in the rainy season, high rainfall helps reduce pollutant concentrations in the air through the process of rain scavenging, thereby lowering the

health risks posed by pollutants. These findings are consistent with air pollution theory, which states that $PM_{2.5}$ with a threshold of $55 \mu g/m^3$ can trigger coughing, asthma, and other respiratory disorders when concentrations exceed the standard, as well as with the ISPU framework, which categorizes air quality into health levels (good, moderate, unhealthy, hazardous).

In response to these conditions, the government and the Babelan PLTU have undertaken several measures to control pollution, such as the mandatory use of scrubber technology to reduce SO_2 and particulate emissions, the introduction of a biomass substitution program to reduce coal consumption, the installation of a Continuous Emission Monitoring System (CEMS) integrated with SISPEK to ensure emissions meet quality standards, and reforestation initiatives through the planting of trees and mangroves. These efforts align with environmental health theory, which emphasizes the importance of keeping pollutant levels below established thresholds in order to minimize negative impacts on public health. Thus, although this study shows that $PM_{2.5}$ still has a significant impact on health during the dry season, these government policies and interventions represent important mitigation measures to reduce health risks for communities living near the power plant.

4. Conclusion

Based on the results and discussion described above, the air quality around the Babelan Power Plant is dominated by $PM_{2.5}$ pollutants, with an “unhealthy” rating within a 1 km radius during the dry season. Pollutant concentrations decrease with increasing distance and rainfall, so that during the rainy season air quality is relatively better, although $PM_{2.5}$ remains in the “moderate” category. The distribution pattern of respiratory diseases—cough, runny nose, sore throat, and shortness of breath—shows the highest prevalence within a 1 km radius, decreasing at distances of 2–3 km. Multivariate regression results confirm that $PM_{2.5}$ has a significant effect on respiratory symptoms, particularly cough and runny nose, with the strongest effect during the dry season and at the closest distance to the power plant. Conversely, during the rainy season and at greater distances, the effect of pollutants tends to decrease. These findings are consistent with air pollution, ISPU, and environmental health theories, which confirm that exposure to pollutants above the threshold can increase the risk of respiratory disorders. Mitigation efforts undertaken by the government and the power plant, such as the use of scrubber technology, biomass substitution, installation of a Continuous Emission Monitoring System (CEMS) integrated with SISPEK, and reforestation, represent important steps to reduce emissions, mitigate health risks, and maintain air quality in the areas surrounding the power plant.

This study is limited to a one-year observation period and focuses only on a 1–3 km radius from the power plant, which may not fully capture the long-term impacts or the effects on wider areas. Moreover, the analysis considered only four pollutant parameters ($PM_{2.5}$, PM_{10} , SO_2 , and NO_2), excluding other pollutants such as CO, O_3 , and heavy metals that also have the potential to affect human health.

Further research is recommended to extend the observation period to allow for the analysis of long-term trends and to expand the study area beyond a 3 km radius. In addition, incorporating other relevant pollutant parameters and meteorological factors (such as temperature, humidity, wind direction, and wind speed) would provide a more

comprehensive analysis.

7. Acknowledgment

The authors would like to express their sincere gratitude to the Academic Advisor from the Department of Geography, Semarang State University, for the guidance and support provided during the research process. Thanks are also extended to the residents around the Babelan Power Plant, as well as to the Head of the Bekasi Regency Environment Agency (DLH) and the Head of the Babelan II Community Health Center for granting permission for this research and providing the data necessary for this study.

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