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Analysis of PM2.5 and PM10 Levels in the Area Around the Celukan Bawang Coal Fried Steam Power Plant (CFSPP) Using an Air Quality Detector

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Abstract: The Celukan Bawang (CFSPP) in Buleleng, Bali, utilizes coal as its primary fuel source, potentially impacting surrounding air quality and public health. This study aimed to analyze the concentrations of fine and coarse particulate matter ($PM_{2.5}$ and PM_{10}) and to assess their environmental and health implications based on temporal and meteorological variations. The research was conducted from September to October 2025 using a quantitative descriptive method. Air quality measurements were taken at three sampling locations SP1 (east), SP2 (west), and SP3 (south) using an Air Quality Detector equipped with an optical light-scattering sensor and GPS. Data were analyzed using Microsoft Excel and compared to Indonesia's ambient air quality standards (Government Regulation No. 22 of 2021). The results showed that $PM_{2.5}$ concentrations ranged from 12.5–22.3 µg/m³ and PM_{10} from 8.0–11.0 µg/m³, all below national thresholds (55 µg/m³ for $PM_{2.5}$; 75 µg/m³ for PM_{10}). However, according to WHO (2021), guidelines, the $PM_{2.5}$ value at SP1 (22.3 µg/m³) exceeded the daily exposure limit (15 µg/m³), indicating potential long-term risks such as respiratory and cardiovascular diseases. Overall, the air quality around CFSPP remains within national safety limits, although continuous monitoring and emission control are recommended to safeguard community health in downwind areas.

Keywords: Air pollution; Air quality; PM2,5; PM10; Power plant

Introduction

The Coal-Fired Steam Power Plants (CFSPPs) are a major source of air pollution, primarily due to emissions of fine particulate matter such as $PM_{2.5}$ and PM_{10}, which are produced from coal combustion. These particulates have the potential to cause health problems, such as respiratory and cardiovascular diseases, and even premature death (Amster, 2019).

The Celukan Bawang CFSPP in Buleleng Regency, Bali, which began operating in 2015 with a capacity of 3x142 MW, is the only coal-fired power plant on the island. In recent years, public complaints have emerged regarding increased black dust, shortness of breath, and persistent coughing in the surrounding area, particularly in Celukan Bawang Village, Tinga-Tinga Village, and Pungkukan Hamlet, which are less than one kilometer from the power plant complex (Greenpeace Indonesia, 2018). An investigation by Greenpeace Indonesia (2018) indicated that approximately 170,000 people living near the Celukan Bawang CFSPP are potentially exposed to air pollutants from power plant activities.

Daily air quality monitoring also indicates that $PM_{2.5}$ concentrations frequently exceed 50 µg/m³ in the morning, twice the WHO guideline limit (25 µg/m³)

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(Myllyvirta, 2021). This situation highlights the urgent need for field-based scientific research to assess the extent to which ambient air quality around the Celukan Bawang Coal-fired Power Plant remains within safe limits and its impact on local public health.

The novelty of this research lies in its approach, which combines direct measurements of $PM_{2.5}$ and PM_{10} concentrations in residential areas around the Celukan Bawang coal-fired power plant with descriptive analysis of their impacts on health and the environment. Similar research in other regions of Indonesia has generally focused on densely populated industrial areas such as the Suralaya coal-fired power plant or the Paiton coal-fired power plant, while research in Bali, particularly in coastal and tourism areas like Celukan Bawang, is still very limited (Ismaya & Wafi, 2023).

Furthermore, the location of this coal-fired power plant is unique because it is adjacent to fishing communities, coconut groves, and coastal ecosystems that are sensitive to changes in air quality. Therefore, this study not only fills a gap in local scientific data but also contributes to environmental management in tourist areas that depend on clean air quality.

Globally, research on particulate matter pollution from coal-fired power plants has shown a strong association between exposure to $PM_{2.5}$ and PM_{10} and an increased risk of chronic respiratory disease (Singh et al., 2025), decreased lung function (Cummiskey et al., 2019), and immune system disorders (Du, 2023). A study in South Africa also showed that areas with high coal-fired power plant density had average $PM_{2.5}$ levels exceeding 60 $\mu g/m^3$, significantly contributing to increased cases of asthma and bronchitis (Ngamlana et al., 2025).

Air pollution occurs when various compounds, such as dust particles (PM2.5 and PM10), mix in the atmosphere. At certain concentrations, this condition can cause respiratory problems, eye irritation, and allergic skin reactions (Nugroho et al., 2023). Indoor air pollution can also have direct and indirect impacts on human health. Decreased air quality is generally caused by the presence of chemical, physical, and biological pollutants (Rumampuk et al., 2021). Particulate Matter (PM) is a type of air pollutant consisting of a mixture of solid and liquid particles suspended in the air. The size, composition, and source of these particles vary widely, and their presence can pose health risks (Rosidin & Dirgawati, 2023).

Air pollutants in the form of $PM_{2.5}$ and PM_{10} are often found in urban areas with high levels of activity and population density. One of the most dangerous types of particles to health is very small, fine dust known as Particulate Matter 2.5 (Anjelicha et al., 2022). PM2.5 is a mixture of solid particles and liquid droplets in the air with a diameter of less than 2.5 micrometers (Wulan et al., 2024), while PM10 includes airborne particles up to 10 micrometers in size and consists of smoke, dust, soot, salts, acids, and metals (Naimah et al., 2024).

Therefore, even though the Celukan Bawang coal-fired power plant operates with modern combustion technology, its air pollution risks still require scientific and ongoing evaluation. This research is important because local data on air quality in North Bali is still very limited, while public complaints and potential health impacts have been widely reported. Furthermore, the study area is densely populated, with many children and the elderly being more vulnerable to the effects of particulate pollutants (Amster, 2019; Mukaddas, 2025).

The results of this study are expected to provide a scientific basis for evaluating emission control policies at coal-fired power plants (CFSPP), strengthen community-based air quality monitoring systems, and inform the planning of corporate social responsibility and environmental management programs.

The research problem formulation focuses on two main issues: the ambient air quality, based on $PM_{2.5}$ and PM_{10} parameters, in residential areas around the Celukan Bawang CFSPP, and the impact of this air quality on public health and the environment. Unlike studies at other CFSPPs, which tend to assess only the technical aspects of emissions or air dispersion models (Zigler et al., 2020), this study combines technical aspects with the socio-environmental context of the coastal communities of North Bali.

Thus, this research has high novelty and scientific significance. The purpose of this study was to determine ambient air quality in residential areas around the Celukan Bawang CFSPP based on $PM_{2.5}$ and PM_{10} parameters and to analyze their impact on public health and the environment. It is hoped that the results of this study can inform policymaking regarding air quality management and public health protection in the coastal areas of North Bali.

Method

This research was conducted during September and October 2025 to capture representative dry-season air quality conditions in the vicinity of the Celukan Bawang Coal-Fired Steam Power Plant (CFSPP), located in Gerokgak District, Buleleng Regency, Bali Province. The primary data consisted of measurements of fine particulate matter ($PM_{2.5}$) and inhalable particulate matter (PM_{10}), which were collected from three designated sampling points (SP1–SP3) strategically positioned around residential areas near the CFSPP to represent different wind directions and distances from the emission source (Figure 1).

Measurements were conducted using Air Visual Pro (IQAir, USA), a laser light scattering optical sensor with an accuracy of ±10 µg/m³ for PM2.5 and ±15 µg/m³ for PM10, which was calibrated prior to sampling and verified with the local Environmental Laboratory reference instrument. In its application, the use of AirVisual Pro (IQAir, USA) was accompanied by an external calibration procedure and adequate humidity correction. A study by Hagan & Kroll (2020) showed that the influence of humidity can be minimized by local calibration, while Le et al. (2025) demonstrated that a humidity-based calibration model can improve accuracy up to R^2 0.92. Data collection was carried out continuously for 24 hours at three sampling points representing different residential exposure zones: SP1 (east of the coal-fired power plant, 600 m), SP2 (west of the coal-fired power plant, 1 km), and SP3 (south of the coal-fired power plant, 400 m). Several air monitoring studies around coal-fired power plants have shown that the distribution of air pollutants generally decreases sharply after passing a distance of 1–2 km from the main emission source, so a 1-km radius is the optimal boundary for delineating the directly affected area (Wang et al., 2021; Hardiyan & Zulistyawan, 2023; Pertiwi et al., 2024; Wellid et al., 2024). Each location was georeferenced using GPS, and meteorological parameters such as wind speed and direction were simultaneously recorded using a portable weather station to evaluate their effect on particulate dispersion. All data were processed using Microsoft Excel 2021 for descriptive and statistical analysis, including mean, minimum, and maximum values. The tested parameters were then compared with the ambient air quality standards stipulated in Government Regulation of the Republic of Indonesia Number 22 of 2021 concerning the Implementation of Environmental Protection and Management, Appendix VII on Ambient Air Quality Standards ($PM_{2.5}$ = 55 µg/m³; PM_{10} = 75 µg/m³).

Figure 1. Map of research locations and seawater quality sampling

Result and Discussion

Table 1. Results of laboratory analysis of sea water quality around Celukan Bawang CFSPP

Parameter	Unit	Limit	Sampling Area		
			SP1	SP2	SP3
September 2025					
PM2,5	µg/m³	55	17.60	12.30	13.25
PM10	µg/m³	75	9.71	8.65	8.25
October 2025					
PM2,5	µg/m³	55	22.65	10.35	17.66
PM10	µg/m³	75	10.90	6.50	6.78

Table 2. Results of wind speed and direction measurements during sampling in September 2025 and October 2025

Sampling Area	Parameters in September 2025		Parameters in October 2025	
	Wind Speed (m/s)	Wind Direction	Wind Speed (m/s)	Wind Direction
SP1	4.3	Southeast	4.7	East
SP2	3.5	Southwest	4	South
SP3	5.2	South	5.5	South

PM2.5 and PM10 Concentrations in September 2025

This study was conducted to measure $PM_{2.5}$ and PM_{10} concentrations at three observation points located around the Celukan Bawang CFSPP during September 2025. The measurement results were then compared with ambient air quality standards stipulated in Government Regulation of the Republic of Indonesia Number 22 of 2021. The field measurement data for $PM_{2.5}$ and PM_{10} levels in September 2025 are presented in Figure 1.

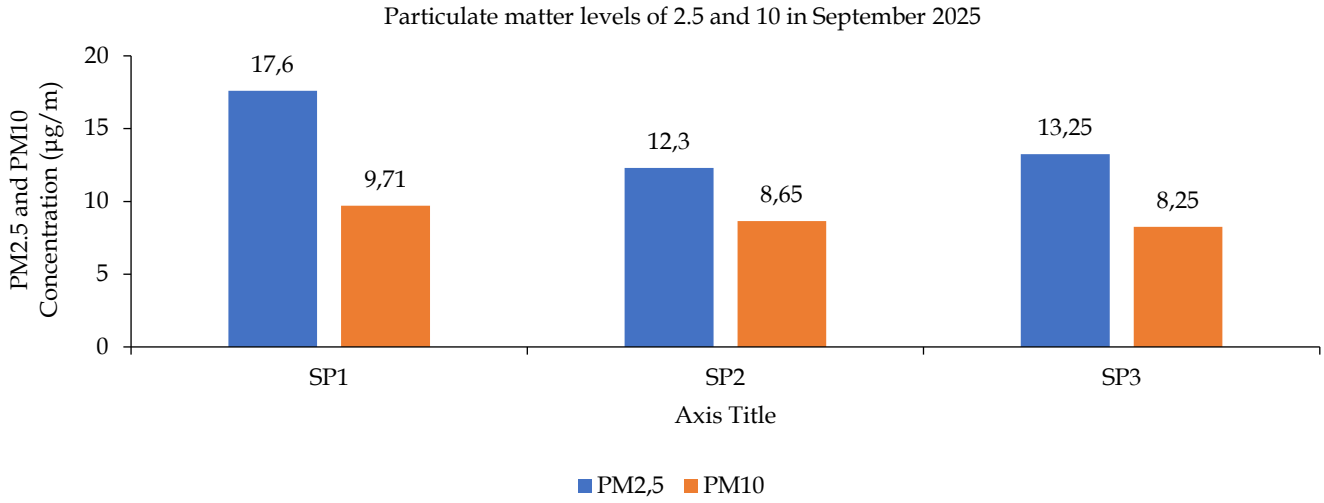

Figure 2. Comparison of PM2.5 and PM10 levels at each observation location in September 2025

Based on the graph of $PM_{2.5}$ and PM_{10} particulate levels in September 2025, $PM_{2.5}$ concentrations were generally higher than PM_{10} at all observation points. Point SP1 showed the highest values for both parameters, which were around 17.5 µg/m³ for $PM_{2.5}$ and 9.5 µg/m³ for PM_{10}. At SP2 and SP3, $PM_{2.5}$ concentrations decreased to 12.5 µg/m³ and 13.5 µg/m³, respectively, while PM_{10} was in the range of 8.5 µg/m³ and 8.0 µg/m³. This difference illustrates that the distribution of fine particulate matter ($PM_{2.5}$) is more dominant than coarse particulate matter (PM_{10}), especially at SP1 which is located on the east side of the Celukan Bawang CFSPP. This condition correlates with the dominant wind direction from the southeast which carries combustion emissions towards the eastern region, thus causing an increase in concentration at that point. Meanwhile, at SP2 and SP3 the particulate matter concentration is lower because the direction and speed of the wind in the southwest and south regions tend to push the dispersion of pollutants away from the main emission source. Overall, the graph shows that although there are variations between points, all $PM_{2.5}$ and PM_{10} values are still below the ambient air quality standard threshold stipulated in Government Regulation No. 22 of 2021, so that the air quality around the CFSPP can be categorized as safe. The results of the measurement of $PM_{2.5}$ and PM_{10} particulates, which are still below the quality standard threshold, indicate that the ambient air quality is still in the safe category and does not pose a significant health risk to the surrounding population. $PM_{2.5}$ and PM_{10} are fine particles that can enter the human respiratory system. $PM_{2.5}$ is very small (≤ 2.5 µm) so it can penetrate to the alveoli of the lungs, while PM_{10} can reach the upper respiratory tract. If the concentration is high, these two types of particles can cause disorders such as chronic coughing, shortness of breath, eye irritation, and even cardiovascular disease (WHO, 2021). However, based on measurements around the coal-fired power plant, $PM_{2.5}$ values ranged from 12.5–17.5 µg/m³ and PM_{10} values between 8.0–9.5 µg/m³ still well below national standards (55 µg/m³ for $PM_{2.5}$ and 75 µg/m³ for PM_{10}). Air quality can be maintained within safe limits if emission control is carried out consistently (Mirawati et al., 2016).

Therefore, the current public health impact is minimal, as particulate exposure levels are not high enough to cause acute or chronic effects. However, long-term exposure remains a concern. Routine monitoring,

sustainable emissions management, and the implementation of an effective environmental management system remain crucial to prevent future increases in particulate levels and protect public health in the areas surrounding the CFSPP. Even though particulate levels are still within safe limits, long-term exposure remains a risk to public health (Adilasari et al., 2025). In addition, vegetation around residential areas plays a very effective role in improving local air quality, particularly in reducing the concentration of fine particles $PM_{2.5}$ and PM_{10} (Jupri, 2022). Through the surface of its leaves and stems, vegetation can capture and retain dust particles floating in the air. Furthermore, vegetation helps lower temperatures and increase air humidity, which encourages suspended particles to settle to the ground surface. Thus, vegetation functions as a natural filter capable of reducing $PM_{2.5}$ and PM_{10} levels in the surrounding environment.

PM2,5 and PM10 Concentrations in Oktober 2025

To complement the analysis of particulate matter in the air, $PM_{2.5}$ and PM_{10} levels were also measured at the same location and during a different period, namely in October 2025. The measurement results were then compared with ambient air quality standards stipulated in Government Regulation of the Republic of Indonesia Number 22 of 2021. The field measurement data for $PM_{2.5}$ and PM_{10} levels in September 2025 are presented in Figure 2.

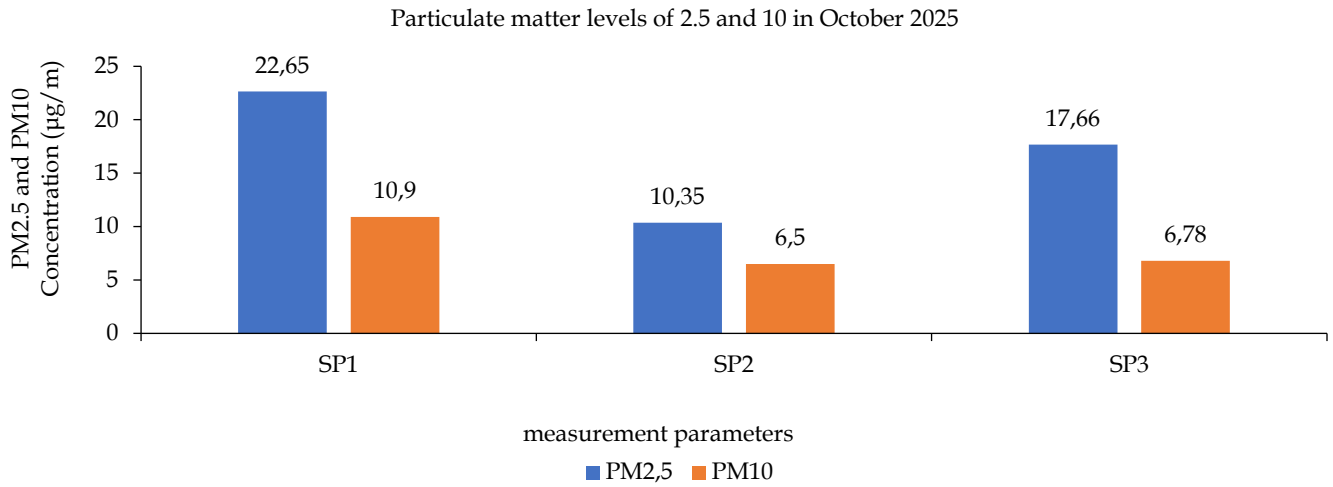

Figure 3. Comparison of PM2.5 and PM10 levels at each observation location in October 2025.

Based on the results of measurements of $PM_{2.5}$ and PM_{10} particulate concentrations in October 2025, as well as wind direction and speed data, $PM_{2.5}$ concentrations were generally higher than PM_{10} at all observation points. The highest value was found at SP1 at 22.3 µg/m³, while at SP2 and SP3 they were recorded at 10.2 µg/m³ and 17.6 µg/m³, respectively. The difference in concentration between these points indicates the influence of meteorological conditions, especially wind direction and speed, on the distribution of particulates in the air. Based on the table, the dominant wind direction in October 2025 came from the east and south with speeds ranging from 4.0 to 5.5 m/s. The wind direction from the east at SP1 with a speed of 4.7 m/s likely carried particulate emissions from the combustion area towards residential areas on the west side of the CFSPP, thus causing an increase in concentrations at that point. In contrast, at SP2 and SP3, which have southerly winds, relatively high wind speeds facilitate pollutant dispersion, resulting in lower particulate concentrations in the air. Although there are differences between locations, all measurement results are still below the ambient air quality standard threshold according to Government Regulation No. 22 of 2021 ($PM_{2.5} \leq 55$ µg/m³ and $PM_{10} \leq 75$ µg/m³), so the air conditions around the Celukan Bawang CFSPP are still considered safe for public health. However, the relatively high $PM_{2.5}$ values at SP1 require caution because these small fine particles can penetrate lung tissue and cause health impacts if exposure continues over the long term. Green open spaces act as natural filters for air pollutants (Husna et al., 2024). particularly fine particles such as $PM_{2.5}$ and PM_{10}. Through the presence of trees, shrubs, and ground cover vegetation, green open spaces can capture and retain dust particles on the surface of leaves and stems. Furthermore, vegetation in green open spaces also helps lower temperatures and increase air humidity, thereby accelerating the settling process of suspended particles. Thus, green open spaces play a significant role in maintaining air quality and creating a healthier environment for the community.

Conclusion

Based on the results of particulate concentration measurements in September and October 2025, it can be concluded that the air quality around the Celukan Bawang CFSPP is still below the national quality standard threshold, as stipulated in Government Regulation No. 22 of 2021, with $PM_{2.5}$ values not exceeding 55 μg/m³ and PM_{10} below 75 μg/m³. In September, the highest $PM_{2.5}$ concentration was in SP1 at 17.5 μg/m³, while the highest PM_{10} was at 9.5 μg/m³. Meanwhile, in October, the $PM_{2.5}$ value increased in SP1 to 22.3 μg/m³, while PM_{10} also increased slightly to 11 μg/m³. This increase was influenced by the dominant wind direction from the east and south, as well as average wind speeds between 4.0 and 5.5 m/s, which carried particles from the combustion area toward residential areas on the west side of the CFSPP. Although the measurement results were still within the safe range according to national standards, $PM_{2.5}$ values at SP1 in October exceeded the WHO-recommended daily limit (15 μg/m³). Long-term exposure to $PM_{2.5}$ above this threshold can increase the risk of respiratory disorders, asthma, chronic bronchitis, and even cardiovascular disease, especially for vulnerable groups such as children, the elderly, and people with lung disease. Therefore, these results demonstrate the need for continuous monitoring and consistent emission control, particularly in residential areas east and west of the CFSPP, which are located along the dominant wind direction. Overall, air quality around the Celukan Bawang CFSPP during the September–October 2025 period was still under control and met national quality standards; however, there were indications that exposure to fine particulate matter ($PM_{2.5}$) at several points had the potential to cause long-term health impacts according to WHO standards. This emphasizes the importance of regular evaluation of the environmental management system, increasing the efficiency of emission control, and involving the community in monitoring air quality as a preventive effort to maintain health and environmental sustainability in the area around the CFSPP. Although emission performance is still safe, routine monitoring is required, especially for particulates.

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Conceptualization, formal analysis, investigation, resources, writing original draft, project administration, L.I.C.; methodology, writing review and editing, funding acquisition, L.I.C. and I.M.G.; visualization, supervision, I.M.G. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest
Authors declare that there is no conflict of interest in this publication.

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