



Analysis of Air Particulate Quality and Respiratory Health Impact in Aceh Border 2025

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Abstract

Air pollution is the leading cause of environment-related deaths globally, with 8.3 million fatalities in 2017. Indonesia, as one of the largest contributors to air pollution, faces challenges in managing air quality, particularly in industrial and high-traffic areas. This study analyzes air quality at the border of Nagan Raya and West Aceh Regencies and its impact on community respiratory health. A mixed-method approach was used, including PM_{2.5} and PM₁₀ measurements at eight strategic locations and in-depth interviews with residents and stakeholders.

The results indicate that PM_{2.5} and PM₁₀ concentrations are mostly within safe limits according to WHO and national air quality standards. However, some locations in West Aceh exceed the threshold, particularly within 100–300 meters of pollution sources. Transportation and industry are the main contributors, with greater health impacts observed during the dry season. Acute Respiratory Infections (ARI) are the most prevalent diseases, with higher cases in Nagan Raya despite lower pollution levels, suggesting other influencing factors such as population density and environmental sanitation.

In conclusion, although air quality is generally within safe limits, significant health risks remain. Mitigation efforts such as tree planting, road spraying, and intensive air quality monitoring are necessary.

INTRODUCTION

Globally, air pollution has become the leading environmental cause of death, with 8.3 million deaths recorded in 2017 (Nicky, 2019). Among various types of pollution, air pollution poses the greatest threat, causing nearly 7 million premature deaths annually. Currently, approximately 70-75% of the world's population is exposed to air quality exceeding the safe annual threshold of $10 \mu\text{g}/\text{m}^3$, as recommended by the World Health Organization (IQAir, 2022). WHO also recorded in 2020 that Acute Respiratory Infections (ARI) are the leading cause of morbidity and mortality due to infectious diseases worldwide, with an estimated 4.25 million deaths per year (Fadila & Siyam, 2022; Garmini & Purwana, 2020; Gobel et al., 2021; Martahan et al., 2020; Sarinah Basri K. et al, 2022).

According to a report from BBC News, the Air Quality Life Index (AQLI) identifies Indonesia as one of the six countries that contribute the most to global air pollution. In the latest AQLI report published by BBC News, Indonesia ranks among the top six largest contributors to global air pollution, alongside China, India, Pakistan, Bangladesh, and Nigeria. Together, these countries account for approximately 75% of the total global air pollution burden, driven by high pollution levels and large populations (BBC Indonesia, 2023). The average Indonesian is estimated to lose 2.5 years of life expectancy due to current air pollution levels, which do not meet WHO's safe threshold for fine particulate matter (PM_{2.5}).

Over the past two decades, Indonesia's average air pollution levels have been three times higher than the WHO-recommended threshold (Lee & Greenstone, 2021). Professor Dr. Agus Dwi Susanto, SpP(K), a pulmonology expert from the Faculty of Medicine, University of Indonesia (FKUI), stated that more than 123,000 people die annually in Indonesia due to air pollution (Dewi, 2023). A study by FKM UI revealed that air pollution ranks fifth among the highest risk factors for death in Indonesia, following hypertension, high blood sugar, smoking, and obesity (Anggie Meidyana, 2023).

Air pollution in Indonesia is primarily caused by human activities in the industrial and transportation sectors (Jakarta Rendah Emisi, 2021). Industrial activities, such as manufacturing plants, processing factories, and fossil fuel power plants, release harmful gas emissions, including sulfur dioxide (SO₂), nitrogen oxides (NO_x), and fine particulate matter (PM_{2.5} and PM₁₀), which are widely dispersed in the atmosphere (Fathori, 2023). Additionally, with 148,261,817 motor vehicles recorded in 2022, the transportation sector significantly impacts air quality (Badan Pusat Statistik Indonesia, 2022).

Pollutants from the industrial and transportation sectors are the primary contributors to air pollution, leading to a decline in quality of life and an increased health risk for the Indonesian population. Research by Setyaningsih et al. (2023) states that exposure to high dust concentrations can cause lung function disorders. The accumulation of dust in the lungs reduces their ability to inhale and exhale air, limiting the volume of air that can be breathed in. Prolonged dust accumulation in lung tissue can cause inflammation and thickening of the tissue, ultimately deteriorating overall lung capacity (Abidin et al., 2021; Yulaekah et al., 2007). The decline in lung function due to excessive dust exposure poses a serious health risk, particularly for individuals exposed to high-dust environments, such as workplaces or areas with severe dust pollution (Abidin et al., 2021).

Air quality conditions in Indonesia vary across regions, with some areas experiencing alarming pollution levels. However, Indonesia has shown an improving trend in air quality in recent years. According to data from BMKG and IQAir, PM_{2.5} concentrations in Indonesia have started to decline, reflecting efforts by both the government and society to reduce air pollution (National meteorological and geophysical service of Indonesia, 2024). In 2018, the annual average PM_{2.5} concentration was $42 \mu\text{g}/\text{m}^3$, rising to $51.7 \mu\text{g}/\text{m}^3$ in 2019, but recent years have shown a declining trend. Factors contributing to this decline include emission controls, increased use of public transportation, and forest fire management (BMKG, 2023).

Air pollution in the border areas of Nagan Raya and Aceh Barat Regencies is mainly caused by transportation, such as motor vehicles, and manufacturing activities operating in the vicinity. Emissions from motor vehicles and local industries contribute hazardous pollutants, including fine particulate matter (PM_{2.5} and PM₁₀), carbon monoxide (CO), and nitrogen oxides (NO_x), which pose health risks to residents (Ananda et al., 2021; Anandari et al., 2024; Mardili, 2024).

The border region between Nagan Raya and Aceh Barat Regencies is of significant concern regarding air quality due to the high exposure to dust and pollution originating from industrial and transportation activities. Its strategic location as a major inter-regional route increases vehicle traffic intensity, significantly contributing to air pollution. Furthermore, the limited availability of public transportation in the region exacerbates the problem, as most people rely on private vehicles. Therefore, the assumption of this study is that transportation and industrial activities in this border region are the primary factors influencing air quality, necessitating further research to assess their environmental and public health impacts.

One of the main challenges in reducing air pollution in Indonesia is the limited access to public transportation in certain areas (Syahputri, 2023). People in Nagan Raya and Aceh Barat Regencies still heavily depend on private vehicles for daily mobility. This reliance contributes to increased emissions of air pollutants, such as dust, carbon monoxide (CO), and nitrogen oxides (NO_x), negatively impacting air quality in the region. Additionally, manufacturing activities in the area are also a significant source of air pollution. This condition underscores the need for further research to examine the impact of air pollution on respiratory health in the border region.

This study aims to analyze air quality in the border region between Nagan Raya and Aceh Barat Regencies and evaluate its impact on respiratory health using an observational quantitative method. Measurements were conducted using a digital dust measuring instrument, specifically the Particle Counter HT-9600, to identify particulate matter

concentrations of PM_{2.5} and PM₁₀, providing an objective overview of air quality in the region. Furthermore, this study incorporates a qualitative approach to understand public perceptions of air pollution and its perceived impact on daily life.

The novelty of this research lies in its specific focus on the border area between Nagan Raya and Aceh Barat Regencies, a high-mobility inter-regional route that has not previously been studied in terms of particulate air quality analysis. Additionally, the use of the HT-9600 instrument, which provides precise and real-time air quality measurements, adds methodological strength compared to previous studies.

METHOD

This study employs a mixed-methods approach, combining both quantitative and qualitative methods to gain a comprehensive understanding of the impact of air pollution on respiratory health in border areas between West Aceh Regency and Nagan Raya Regency. The quantitative approach involves field experiments to measure particulate matter concentrations (PM_{2.5} and PM₁₀) using a Digital Particle Counter HT-9600 at eight strategically selected measurement points. These locations were chosen based on the intensity of air pollution from transportation and industrial activities.

Quantitative data collection was conducted from January to February 2024 through air quality measurements at predetermined locations. Primary data sources include air quality measurement results from the device (HT-9600), while secondary data is derived from Environmental Agency reports on air quality in the region and previous research on respiratory health.

Quantitative data analysis follows a univariate approach to assess pollutant concentrations at various points. Ethical considerations were maintained by ensuring procedural safety and adherence to research standards during field measurements.

RESULT AND DISCUSSION

A. Research Location Overview

This study was conducted in the border area between West Aceh Regency and Nagan Raya Regency, which serves as a major transportation route in Sumatra with high vehicle activity, including both private and heavy-duty vehicles. The limited availability of public transportation has led to a heavy reliance on private vehicles, especially during peak hours. Additionally, this area contains two large industrial zones that further contribute to air pollution. Air quality measurements were conducted at several strategic locations, selected based on activity levels and their distance from the "Welcome to Nagan Raya Regency" gate, to provide a comprehensive overview of air quality conditions in both regencies.

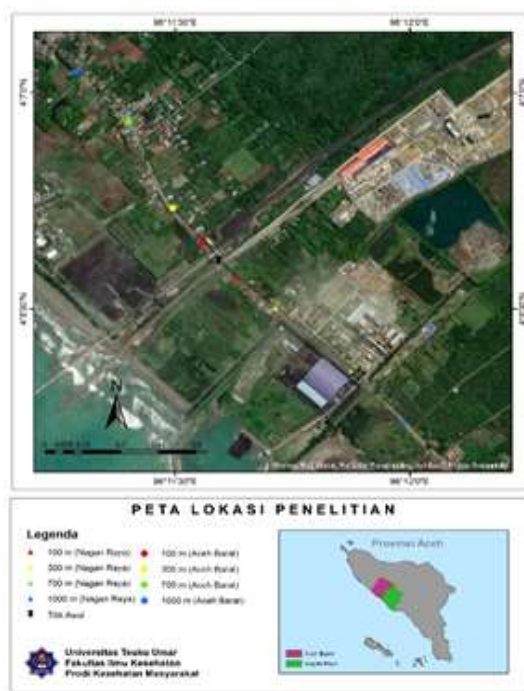


Figure 1 Research location map



Figure 2. Main research locations

B. Measurement Locations at 8 Points

The research was conducted at several points in Nagan Raya Regency and Aceh Barat Regency, representing areas with different characteristics in terms of vehicle activity and proximity to industrial zones. In Nagan Raya Regency, Point A (100 meters) is located near the border gate, with a high intensity of sand transport trucks and street vendor activities, causing air pollution in the form of dust. Point B (300 meters) is at the entrance of Industrial Zone B, where heavy vehicle traffic and a high density of workers contribute to a higher concentration of pollutants. Point C (700 meters) is farther from the main road but still affected by heavy vehicle activity heading to the industry, generating dust and exhaust gas pollution. Point D (1000 meters) is in a residential area with several restaurants; although air pollution is lower, parked private vehicles still contribute to the impact. Meanwhile, in Aceh Barat Regency, Point A1 (100 meters) is near the entrance of Industrial Zone A, where heavy vehicles and dusty roads result in high air pollution. Point B1 (300 meters) is around the worker's dormitory, where pollution from private vehicles and industrial operations is lower than at Point A1 but still has an impact. Point C1 (700 meters) is near a residential area, with private vehicles stopping at nearby restaurants, adding to pollution. Lastly, Point D1 (1000 meters) is in a residential zone, where air pollution levels are lower, although vehicle activity heading to the industrial area continues to have an effect.

Table 1. Measurement point conditions

Time	Location	Temp. (°C)	Humidity (%)
09:34	A	32.2	76.5

10:06	B	33.8	64
10:35	C	36.2	58.8
11:02	D	36.70	57.3
12:36	A1	33.22	69.6
13:00	B1	36.51	61.7
13:20	C1	36.75	59.1
13:42	D1	36.20	60.6

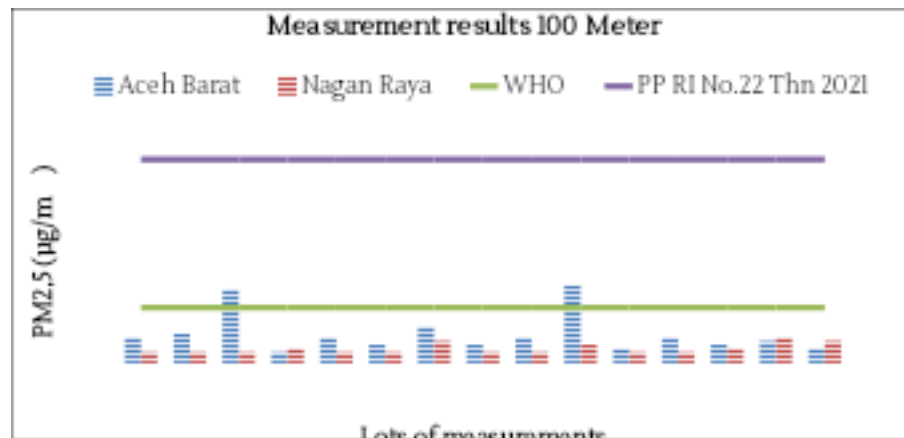
Table 2. Air quality index by AQI (US)

Number Range ($\mu\text{g}/\text{m}^3$)	Information
0 – 12	Very good
12,4 – 35	Good/Moderate
35,4 – 55	Unhealthy for sensitive groups
55,4 – 150	Unhealthy
150,4 – 250	Very unhealthy
≥ 250	Hazardous

C. Concentration Measurement Results PM_{2.5}

1. Distance 100 Meters

At the primary measurement point (100 meters), the results showed that the PM_{2.5} concentration in Nagan Raya Regency had a minimum value of 3 $\mu\text{g}/\text{m}^3$ and a maximum of 7 $\mu\text{g}/\text{m}^3$, with an average of 3.93 $\mu\text{g}/\text{m}^3$. In Aceh Barat Regency, the lowest concentration was also recorded at 3 $\mu\text{g}/\text{m}^3$, but the highest value reached 21 $\mu\text{g}/\text{m}^3$, with an average of 7.93 $\mu\text{g}/\text{m}^3$. While the average concentrations and most values in both regencies complied with both Indonesian national standards and WHO guidelines (daily threshold of 15 $\mu\text{g}/\text{m}^3$), the peak value of 21 $\mu\text{g}/\text{m}^3$ in Aceh Barat exceeded the strict WHO 24-hour guideline, although it remained well below the Indonesian national standard (55 $\mu\text{g}/\text{m}^3$).

**Figure 3.** Measurement results 100 meters

2. Distance 300 Meters

At a distance of 300 meters, the PM_{2.5} concentration in Nagan Raya Regency recorded a minimum of 3 $\mu\text{g}/\text{m}^3$ and a maximum of 10 $\mu\text{g}/\text{m}^3$, with an average of 5.47 $\mu\text{g}/\text{m}^3$. Meanwhile, in Aceh Barat Regency, the lowest concentration was 2 $\mu\text{g}/\text{m}^3$, while the highest reached 68 $\mu\text{g}/\text{m}^3$, with an average of 11.47 $\mu\text{g}/\text{m}^3$. The peak value in

Aceh Barat (68 $\mu\text{g}/\text{m}^3$) exceeded both the WHO guideline (15 $\mu\text{g}/\text{m}^3$) and the Indonesian national standard (55 $\mu\text{g}/\text{m}^3$), indicating significant local pollution sources at this point. However, the average concentrations in both regencies remained compliant with national environmental standards.

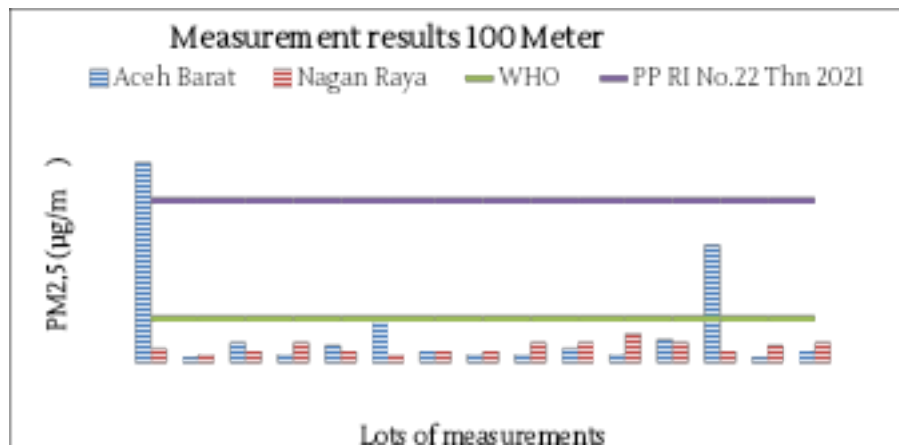


Figure 4. Measurement results 300 meters

3. Distance 700 Meters

At a distance of 700 meters, the PM2.5 concentration in Aceh Barat Regency recorded a minimum of 1 $\mu\text{g}/\text{m}^3$ and a maximum of 26 $\mu\text{g}/\text{m}^3$, with an average of 4.67 $\mu\text{g}/\text{m}^3$. In Nagan Raya Regency, the lowest concentration was 3 $\mu\text{g}/\text{m}^3$, while the highest reached 8 $\mu\text{g}/\text{m}^3$, with an average of 4.4

$\mu\text{g}/\text{m}^3$. While the average concentrations in both regencies remained below all established standards, the peak value in Aceh Barat (26 $\mu\text{g}/\text{m}^3$) exceeded the WHO 24-hour guideline (15 $\mu\text{g}/\text{m}^3$), though it stayed safe under Indonesian national regulations (55 $\mu\text{g}/\text{m}^3$).

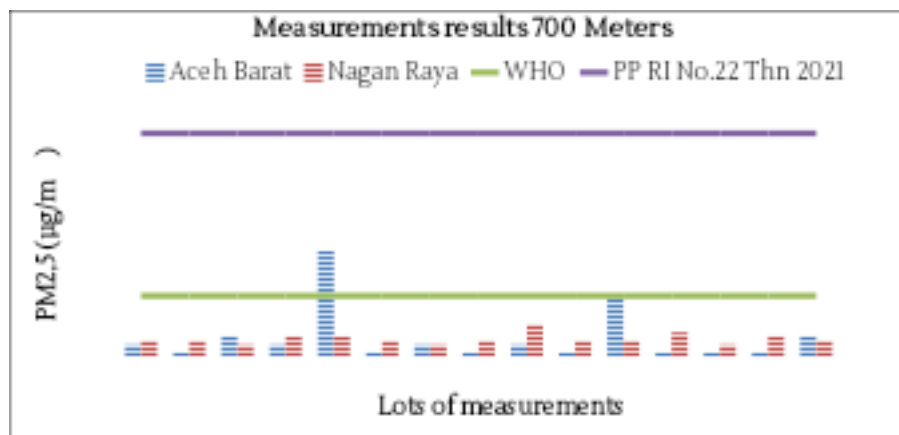


Figure 5. Measurement results 700 meters

4. Distance 1000 Meter

At a distance of 1000 meters, the PM2.5 concentration in Aceh Barat Regency recorded a minimum of 1 $\mu\text{g}/\text{m}^3$ and a maximum of 6 $\mu\text{g}/\text{m}^3$, with an average of 2 $\mu\text{g}/\text{m}^3$. Meanwhile, in Nagan Raya Regency, the lowest concentration was recorded at 2

$\mu\text{g}/\text{m}^3$, with a maximum of 7 $\mu\text{g}/\text{m}^3$ and an average of 4 $\mu\text{g}/\text{m}^3$. At this distance, both regencies demonstrated excellent air quality, with all PM2.5 concentrations well below both the Indonesian national standard and WHO guidelines, indicating no significant health risks at the time of measurement.

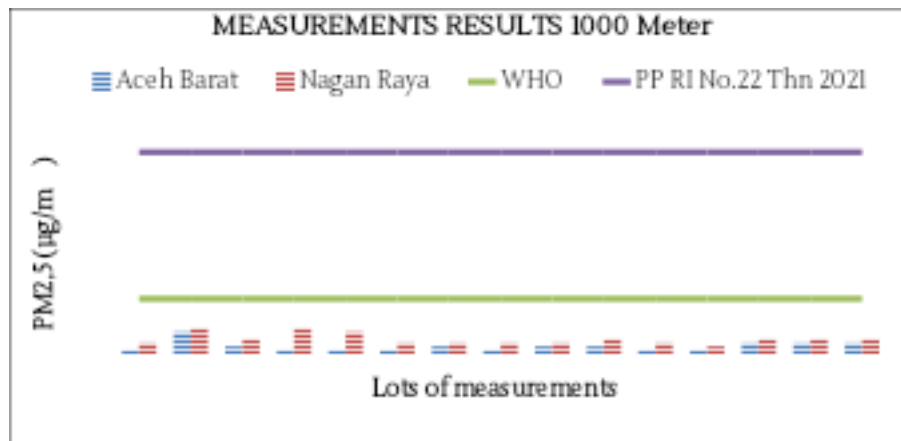


Figure 6. Measurement results 1000 meters

D. Concentration Measurement Results PM₁₀

1. Distance 100 Meters

At a distance of 100 meters, measurement results showed a significant difference between the two regencies. In Nagan Raya Regency, the lowest recorded PM₁₀ concentration was 4 µg/m³, while the highest was 34 µg/m³, with an average of 11.93 µg/m³. Meanwhile, in Aceh Barat Regency, the lowest concentration was recorded at 8

µg/m³, with the highest reaching 224 µg/m³ and an average of 62.27 µg/m³. The peak value in Aceh Barat exceeded both Indonesia's daily threshold (75 µg/m³) and the WHO guideline (45 µg/m³), indicating a significant potential health risk, especially if prolonged exposure to these high concentrations occurs. Although the average values in both regencies remain within the safe category, the high concentrations in Aceh Barat require serious attention.

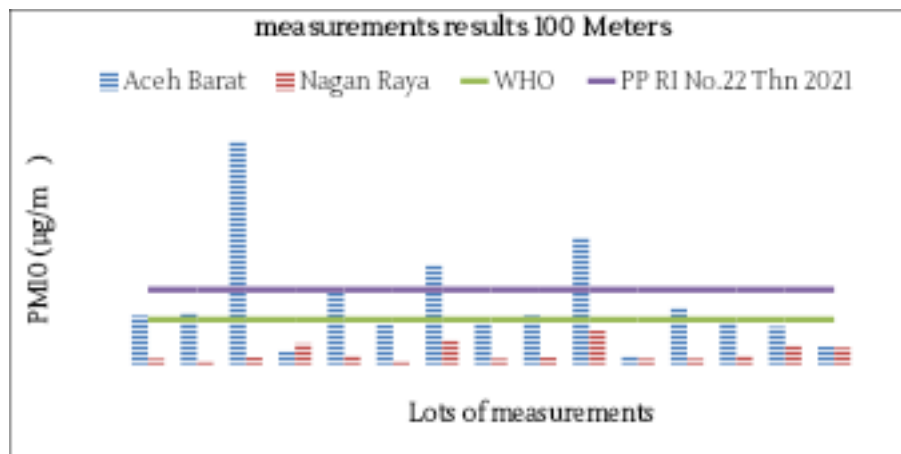


Figure 7. Measurements results 100 meters

2. Jarak 300 Meter

At a distance of 300 meters, the recorded PM₁₀ concentration in Nagan Raya Regency ranged from a minimum of 6 µg/m³ to a maximum of 51 µg/m³, with an average of 24.87 µg/m³. Meanwhile, in Aceh Barat Regency, the lowest recorded concentration was 9 µg/m³, while the highest reached 195

µg/m³, with an average of 47.13 µg/m³. These results indicate that the highest PM₁₀ concentration in Aceh Barat has exceeded the safe limits set by WHO and AQI (US), potentially increasing health risks, especially for vulnerable groups such as children and the elderly.

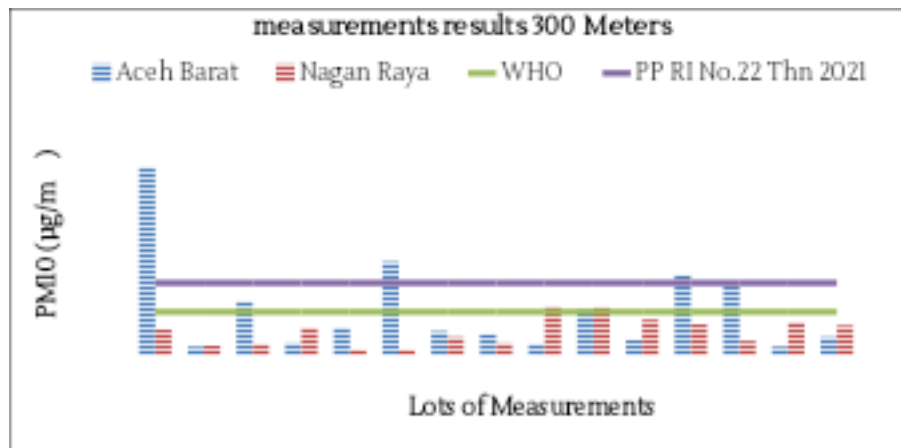


Figure 8. Measurements results 300 meters

3. Distance 700 Meters

At a distance of 700 meters, the PM10 concentration in Nagan Raya Regency ranged from a minimum of 7 $\mu\text{g}/\text{m}^3$ to a maximum of 42 $\mu\text{g}/\text{m}^3$, with an average of 16.6 $\mu\text{g}/\text{m}^3$. In Aceh Barat Regency, the lowest recorded concentration was 1 $\mu\text{g}/\text{m}^3$, while the highest reached 70 $\mu\text{g}/\text{m}^3$, with an average of 13.4

$\mu\text{g}/\text{m}^3$. These measurements are still within the safe category according to the standards set by Indonesia, WHO, and AQI. However, the peak value of 70 $\mu\text{g}/\text{m}^3$ in Aceh Barat suggests potential health impacts if prolonged exposure occurs. Therefore, efforts to manage pollutant emissions in this area should be enhanced.

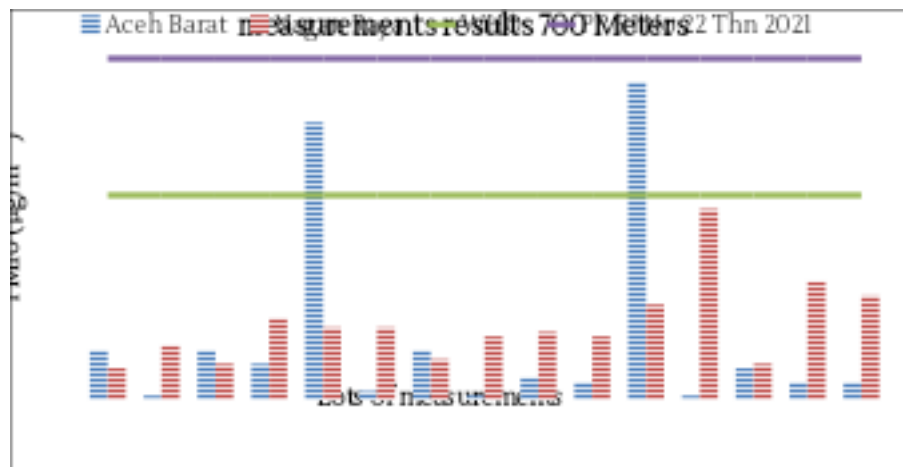


Figure 9. Measurements results 700 meters

4. Jarak 1000 Meter

At a distance of 1000 meters, the PM10 concentration in Nagan Raya Regency recorded a minimum of 1 $\mu\text{g}/\text{m}^3$ and a maximum of 35 $\mu\text{g}/\text{m}^3$, with an average of 14.67 $\mu\text{g}/\text{m}^3$. In Aceh Barat Regency, the lowest concentration was recorded at 4 $\mu\text{g}/\text{m}^3$, with a maximum of 21 $\mu\text{g}/\text{m}^3$ and an

average of 8.2 $\mu\text{g}/\text{m}^3$. Both regencies exhibited good air quality at this distance, with PM10 concentrations well below the daily threshold limits. However, continuous monitoring is necessary to maintain air quality, especially in areas closer to pollution sources.

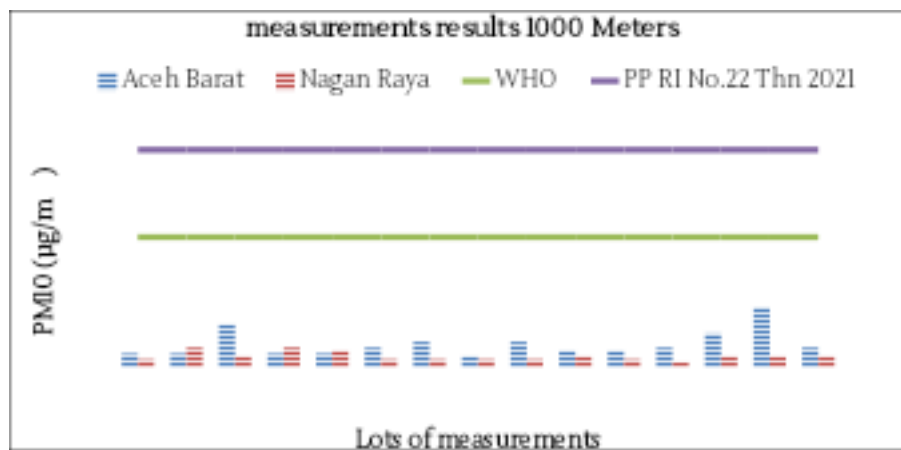


Figure 10. Measurements results 1000 meters

E. Comparison of Concentrations $PM_{2.5}$ and PM_{10}

Overall, although the concentrations of $PM_{2.5}$ and PM_{10} in Nagan Raya and Aceh Barat Regencies are mostly within the safe category according to national air quality standards regulated by Government Regulation No. 22 of 2021 (Republik Indonesia, 2021), and the Air Quality Index (AQI) guidelines by the WHO (Geneva: World Health Organization, 2021), several measurement points in Aceh Barat exceed the WHO and AQI thresholds, particularly at distances of 100 to 300 meters from the arrival gate. Based on WHO standards, the recorded concentrations of $PM_{2.5}$ and PM_{10} at certain points in Aceh Barat, such as the 100-meter distance where PM_{10} reached $224 \mu\text{g}/\text{m}^3$, surpass the WHO thresholds ($45 \mu\text{g}/\text{m}^3$ for PM_{10} and $15 \mu\text{g}/\text{m}^3$ for $PM_{2.5}$). This indicates significant local pollution with potential health risks. Meanwhile, according to national air quality standards (PP No. 22 Tahun 2021), although the average concentrations of PM_{10} and $PM_{2.5}$ in both regencies remain within safe limits, the highest recorded values in Aceh Barat, particularly at 100 meters and 300 meters, far exceed the national daily threshold for PM_{10} ($75 \mu\text{g}/\text{m}^3$). This highlights potential adverse effects, especially for vulnerable groups such as children, the elderly, and individuals with respiratory conditions.

According to the AQI, PM_{10} concentrations recorded at several points in Aceh Barat fall into the Unhealthy and Very

Unhealthy categories, indicating serious health risks for the entire population if exposure occurs over an extended period. Therefore, it is crucial to implement effective mitigation efforts to identify pollution sources, reduce emissions, and ensure air quality remains controlled to protect public health and prevent the long-term impacts of air pollution exposure.

F. Number of Respiratory Health Cases

Air pollution is one of the major risk factors that can directly impact public health, particularly in causing respiratory disorders (Puspitasari, R. D. dan Fauziah, 2023). Both short-term and long-term exposure to air pollutants, such as $PM_{2.5}$ and PM_{10} , can increase the risk of various respiratory diseases, including acute respiratory infections (ARI), bronchitis, asthma, and chronic obstructive pulmonary disease (COPD) (Laksono & Afyani, 2023).

Previous studies have shown that air pollution has a significant impact on respiratory health, especially among vulnerable groups such as children, the elderly, and individuals with pre-existing medical conditions. A study by Enda Silvia Putri and Susy Sriwahyuni revealed that long-term exposure to air pollutants like $PM_{2.5}$ and PM_{10} increases the prevalence of chronic respiratory disorders, including asthma and COPD. Furthermore, the study highlighted the correlation between the rise in ARI cases and increased pollutant

concentrations during the dry season, when dust and pollutant particles accumulate more easily due to the lack of rain to cleanse the air (Putri & Sriwahyuni, 2022).

In Indonesia, this situation is exacerbated by poor air quality management in certain regions (Kementrian Lingkungan Hidup dan Kehutanan, 2022). Air pollution from motor vehicle emissions and industrial activities is a leading cause of respiratory diseases in developing countries (Yusrianti, 2018). According to a report from the World Health Organization (WHO), air pollution significantly contributes to the increase in ARI cases, particularly among populations living near industrial areas and high-traffic transportation routes (World Health Organization, 2024). This leads to increased hospital admissions and a greater burden of disease, affecting both productivity and overall quality of life.

Although PM2.5 and PM10 concentrations in Aceh Barat Regency tend to be higher than in Nagan Raya Regency at several measurement points—particularly within 100 to 700 meters from the arrival gate—the number of ARI cases is higher in Nagan Raya. This difference suggests that, in addition to air pollution exposure, other factors influence the high ARI incidence, such as population density, smoking habits, environmental sanitation, and public awareness of respiratory health. A study by the Environmental Health Research Center also found that air pollution exposure in major cities across Indonesia significantly contributes to the rise in ARI cases, especially among populations living near industrial zones and busy transportation routes.

The difference in ARI case numbers may also reflect variations in case recording and reporting systems at local health centers. Nagan Raya Regency may have a more active case registration system or broader healthcare coverage, leading to higher ARI detection rates compared to Aceh Barat Regency. Socioeconomic factors also influence vulnerability to air pollution. The 2018 Basic Health Research (Riskesdas) report stated that lower socioeconomic groups are more susceptible to the health effects of air pollution, as they tend to live in more polluted environments and have limited

access to technologies or treatments that could mitigate health risks associated with air pollution.

CONCLUSION

Based on the research findings on air quality and its impact on respiratory health in Nagan Raya and Aceh Barat Regencies, several key conclusions can be drawn:

1. Air Quality in Both Regencies shows significant variation at each measurement point (100 m, 300 m, 700 m, and 1000 m) from the arrival gate. The measurement results of PM2.5 and PM10 concentrations indicate that while most levels remain within the limits set by the Indonesian government and the WHO, some points exceed these thresholds. In Aceh Barat Regency, particularly at distances of 100–300 meters, PM10 and PM2.5 concentrations recorded high values, with maximum levels surpassing both WHO and national air quality standards. This suggests a significant potential for localized pollution, primarily caused by heavy traffic activities, such as motor vehicles passing through the area.
2. The data on respiratory health cases provides additional context on disease incidence in the region, alongside air quality conditions. At Padang Rubek Health Center in Nagan Raya Regency, the number of Acute Respiratory Infection (ARI) cases reached 76 in May 2020. Meanwhile, at Meureubo Health Center in Aceh Barat Regency, the figures recorded 3,998 cases in August and 3,400 cases in September. Although direct statistical correlation cannot be drawn due to differences in temporal periods between the historical health records and the 2024 particulate measurements—as well as the univariate scope of this analysis—these high figures indicate that historical disease burdens remain a concern in certain locations. Furthermore, the 2024 particulate measurements reveal that pollutant concentrations in specific areas,

particularly in Aceh Barat, still pose potential health risks that require ongoing attention.

Transportation Activities are the main contributors to air pollution in both regencies, with motor vehicles significantly impacting PM_{2.5} and PM₁₀ concentrations in high-traffic areas. The geographical conditions, which are prone to dust accumulation during the dry season, further deteriorate air quality, directly affecting the respiratory health of the local population.

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