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Study of Road Environmental Capacity in the School Area in Banda Aceh City

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ABSTRACT

This study investigates the environmental capacity of roads with regard to noise and air pollution caused by traffic near a school area in T. Panglima Nyak Makam, Banda Aceh. The levels of noise and air pollution are influenced by the road's geometry, vehicle volume, and speed. The average traffic volume is 486.8 pcu/hour in each direction, with an average vehicle speed of 33.19 km/h. The road's capacity is 1455.3 pcu/hour. Noise levels (Leq) measured between 72.8 dB(A) and 78.2 dB(A), with an average of 76.00 dB(A), indicating noise pollution that exceeds the school area standard of 55 dB(A), although it remains below the highway threshold of 85 dB(A). Regarding air quality, CO (LV) levels were 1,301 ppm, CO (HV) 0.016 ppm, NOX 0.096 ppm, and HC 0.063 ppm. These values are within acceptable limits based on urban road standards, meaning the road can still accommodate traffic without exceeding air pollution limits, despite the noise levels posing a concern for school areas.

Keywords: air pollution, noise, road environmental

1. Introduction

Congestion in the city of Banda Aceh has become a significant urban problem, with a traffic ratio of 0.98 or LOS D, indicating unstable traffic conditions with frequent stop-and-go, which impacts both the physical road capacity and environmental aspects such as noise and air pollution [1] [2]. The rapid increase in traffic correlates with economic growth of 2.22% in 2019, which has raised population mobility and living standards, thereby increasing pollution caused by vehicle emissions [2] [3]. These pollutants include CO, CO2, SO2, NO, HC, and particulate matter such as smoke, dust, and harmful substances influenced by traffic volume on secondary arterial roads, especially near educational areas [1] [4].

This study examines the relationship between road capacity and environmental pollution, specifically noise and air pollution, caused by traffic volume on Type 6/2 D roads in front of educational zones, which significantly contributes to environmental degradation as population and mobility increase [1] [4]. The urban development pattern of Banda Aceh (Figure 1) follows a Multi-Nuclei Model, which shapes the city's spatial structure with multiple activity centers influencing traffic flow and causing congestion and pollution challenges [5] [6].

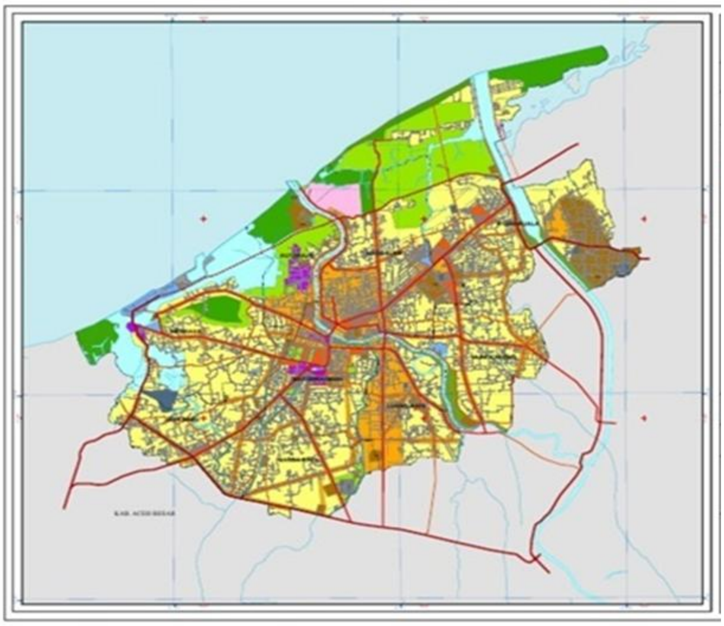

Figure 1. Spatial pattern of Banda Aceh city

(Source: Banda Aceh city RTRW 2020) [6]

This Multi-Nuclei Model results in a city structure composed of several activity centers such as commercial hubs, educational zones, and residential areas connected by road networks, but traffic distribution becomes uneven, causing congestion on main arteries [7]. Linear growth happens along the main road network, which serves as the backbone of the city's transport infrastructure, linking various urban centers and increasing traffic concentration on these major roads [6]. Secondary roads, intended to distribute traffic, are often underutilized or poorly maintained, failing to relieve pressure on main routes [8].

Factors contributing to high congestion include population growth, economic development that concentrates commercial activities along main roads, the presence of educational institutions in key city areas, and insufficient road infrastructure unable to accommodate the growing vehicle volume [4] [6] [7] [9]. The resulting congestion increases emissions of harmful pollutants such as CO, NOx, and fine particulates that degrade air quality and public health, as well as traffic noise in sensitive areas like schools and hospitals [2][3].

In summary, the Multi-Nuclei urban growth model in Banda Aceh has led to concentrated congestion on major roads, worsening air and noise pollution due to rising demand on limited infrastructure. Therefore, addressing congestion and environmental protection must be central in future urban planning and infrastructure development in Banda Aceh [4] [5] [6].

Service Level Analysis (Road Capacity)

Capacity is stated in passenger car units (SMP). The equation for determining capacity is as follows [1].

$$C = CO \text{ x } FCW \text{ x } FCSP\text{x } FCSF\text{x } FCCS \quad (1)$$

Information:

C = Capacity (junior high / hour)

C0 = Basic capacity (junior high / hour)

FCw = Adjustment factor for the width of the traffic lane

FCsp = Directional separator adjustment factor

FCsf = Adjustment factor of side and shoulder obstacles

FCcs = City size adjustment factor

Road Environment Capacity

Road environment capacity refers to the maximum number of vehicles permitted to pass through a road segment without exceeding environmental quality standards, specifically regarding noise and air pollution levels. Unlike conventional road capacity, which focuses solely on physical traffic flow, road environment capacity integrates environmental factors to ensure sustainable road operation while protecting public health and comfort [10] [11].

Assessment of road environment capacity involves a multi-factor approach that accounts for various environmental impacts generated by traffic, such as pollutant gas emissions (CO, NOx, HC) and noise pollution levels. In this method, the traffic volume capacity is constrained not only by the physical infrastructure capacity but also by environmental quality limits set by relevant standards. [12] [13] [14]

In the case study documented for Banda Aceh, the road environment capacity calculation integrates predictions of traffic-induced air pollution and noise using models like the General Motor Model for pollutant dispersion and sound level measurement for noise impact. For instance, noise levels (Leq) measured ranged between 72.8 dB(A) to 78.2 dB(A), exceeding the typical environmental noise standard for sensitive areas like schools but still below highway thresholds. Air pollution concentrations are assessed through estimation of pollutant emissions per vehicle volume, comparing the results against national and international air quality standards.

The capacity is quantified in passenger car units per hour (pcu/hour), incorporating adjustment factors such as lane width, directional separation, side obstacles, and urban size. The evaluation shows that roads in the study area can still accommodate traffic volumes without surpassing harmful pollution thresholds, but with noise levels approaching critical limits. This integrated capacity evaluation ensures that traffic management strategies not only improve flow efficiency but also minimize environmental harm, enabling urban road networks to support growth while safeguarding environmental quality and public health.

Prediction of Air Pollution

In the analysis of air pollution prediction based on the uploaded document, the study utilizes a model to predict air pollution that links pollutant concentrations with various environmental factors. One of the equations used to predict pollutant concentration (ppm) is the model developed by Boubel (1994). This model involves variables such as the average vehicle emission rate (g/km), effective wind speed (m/s), building height along the road (h0), and the vertical dispersion parameter (σz). With this model, the air pollution levels produced by vehicle volume passing through an area can be estimated, aiming to ensure that pollutants remain within safe limits.

Table 1 in the document presents air quality standards from various organizations, such as WHO and AHRMC. These standards include various pollutants like carbon monoxide (CO), nitrogen dioxide (NO2), and particulate matter suspended in the air. For example, for CO, WHO sets a limit of 87 ppm for a maximum 15-minute exposure and 9 ppm for an 8-hour exposure. In this context, the predicted air pollution can be compared with these established limits to assess whether the pollutant concentrations exceed the set standards.

In the study results presented, there is a relationship between vehicle volume, road capacity, and the level of air pollution produced. For instance, on Wednesday, January 29, 2020, with a vehicle volume of 19,846 vehicles per hour and a traffic volume of 558,245 PCU per hour, the predicted CO (LV) concentration was 1.301 ppm, which is still well below the WHO standard of 25 ppm for CO over 15 minutes. However, in the following observation on Monday, February 3, 2020, with a higher vehicle volume (23,713 vehicles), the CO (LV) concentration increased to 1.607 ppm, showing an increase in air pollution as vehicle volume rose.

Based on the available data, although in some observations, air pollution concentrations remain within safe limits, it is evident that air pollution tends to increase as vehicle volume rises. Therefore, it is crucial to monitor and control vehicle volume, as well as consider other factors such as the use of environmentally friendly vehicle technologies, to ensure that pollutant concentrations remain within the standards established by relevant authorities. To further understand how air pollution can be accurately predicted, we must first consider the method used for this prediction. The model employed in this study is based on the General Motor Model, which provides a robust equation for estimating pollutant concentrations. The equation, developed by Boubel in 1994, incorporates various factors such as the average emission levels of vehicles, wind speed, and the dispersion characteristics of the area.

The method for predicting air pollution is the model of the general motor, while the general motors model equation is as follows (Boubel, 1994):

$$C = \frac{Q}{\sqrt{2\pi U\sigma z}}\left\{exp\left[-\frac{1}{2}\left(\frac{z+h0}{\sigma z}\right)2\right] + \exp\left[-\frac{1}{2}\left(\frac{z-h0}{\sigma z}\right)2\right]\right\} \tag{2}$$

Information :

C = pollutant concentration (ppm)

Q = estimated average emission level (g / km)

U = effective wind speed (m / sec)

ho = building height at distance x from road (m)

σz = vertical dispersion parameter

Table 1. Air quality standards

Pollutant	Limitation	Institutions
Suspended matter	40 µg/m3 (*annual mean*)	*WHO*
Total suspended particulates	90 µg/m3 (*annual mean*)	*AHRMC*
	0,26 µg/m3 (24 *hour max*)	Indonesia
Particulate Matter < 10 µm	50 µg/m3 (*annual mean*)	*US EPA*
	150 µg/m3 (24 *hour max*)	
Lead	µm (90 *day average*)	*AHRMC*
Carbon monoxide	87 ppm (15 *minuttes max*)	*WHO*
	25 ppm (1 *hour max*)	*WHO*
	9 ppm (8 *hour max*)	*AHRMC*
	8 ppm (8 *hour*)	Indonesia
Nitrogen dioxide	16 ppm (1 *hour max*)	*AHRMC*
	5 ppm (*annual mean*)	*US EPA*
	92,5 µm/m3 (3 hr)	Indonesia
Non methane	160 µm/m3 (3 hr *max/year*)	*US EPA*
Hydro carbons	0,25 ppm (3 hr)	Indonesia
Ozone	12 pphm (1 *hour max*)	*AHRMC*

(Source: Murwono, 1999) [7]

Minister of the Environment Decree No. 48 of 1996 concerning Standard Noise Levels carried out every 10 seconds for 10 minutes. The next noise level is determined by the equation:

$$\text{Leq} = 10 \text{ Logs } \{1\ T\ [(t1x100.1L1) + (t2\ x100.1L2) + \ldots.\ (tnx100.1Ln]\} \tag{3}$$

Information:

Leq = continuous sound pressure level is equivalent

L1 = sound pressure level in period t1

Ln = sound pressure level in the period tn

T = total measurement time (t1 + t2 + ... + tn)

Traffic Noise

Traffic noise is a significant environmental concern, primarily originating from motorized vehicles. It stems from various sources, including the sound produced by vehicle engines, exhaust systems, and the interaction between the vehicle's wheels and the road surface. These noises contribute to an elevated noise level in urban areas, particularly in regions with high traffic volumes, such as roads near commercial, industrial, and residential zones.

To understand the impact of traffic noise, it's crucial to compare the observed noise levels against established standards, which serve as thresholds for acceptable noise in different environments. Table 2: Standard Noise Levels provides noise level limits for various types of areas and activities, as determined by regulations such as the Minister of Environment Decree No. 48 of 1996. These standards help assess whether the noise levels exceed what is considered safe or comfortable for the surrounding population. For example, in residential areas, the acceptable noise level is set at 55 dB(A), while for trade and service areas, it can reach up to 70 dB(A). These thresholds indicate that residential zones are more sensitive to noise pollution, with lower limits applied to ensure the comfort and well-being of the inhabitants. Conversely, areas like industrial zones or offices may tolerate higher noise levels without significant adverse effects on health or productivity.

When analyzing traffic noise using these standards, we can determine if the noise produced by vehicles, especially in areas with high traffic volumes, exceeds the limits set for the relevant land use. If traffic noise levels surpass the permissible limits, it may lead to health problems such as stress, sleep disturbance, and hearing impairment among residents or workers in the affected areas. Furthermore, prolonged exposure to high levels of traffic noise can contribute to more severe long-term effects, including cardiovascular diseases and a general decline in quality of life. In this context, monitoring and mitigating traffic noise becomes crucial. Traffic management measures, such as controlling vehicle speed, implementing noise barriers, or encouraging the use of quieter vehicles, can help reduce the noise pollution generated by road traffic. Regular assessments of noise levels, compared against the standards in Table 2, allow authorities to determine whether existing noise mitigation strategies are effective or if further actions are required to maintain environmental quality and public health.

Table 2. Standard Noise Levels

	Allotment of Area / Environment Activities	**Noise level dB (A)**
1.	Allotment of Regions	
a.	Housing and Settlements	55
b.	Trade and Service	70
c.	Office and Trade	65
d.	Green open space	50
e.	Industry	70
f.	Government and Public Facilities	60
g.	Recreation	70
2.	Activity Environment	
a.	Hospital or the like	55
b.	School or the like	55
c.	Place of Worship or the like	55

(Source: Decree of the minister of environment No. 48 of 1996 concerning) [9]

2. Method

The research methodology employed in this study is designed to assess the relationship between road capacity, traffic volume, and environmental quality, particularly focusing on air and noise pollution caused by traffic in urban areas. This approach combines both theoretical models and empirical data collection to predict pollution levels and evaluate whether these exceed the prescribed environmental standards.

Data for this study is collected through field observations at various locations within the study area. Key parameters such as vehicle volume, traffic speed, and road capacity are recorded. Additionally, noise levels and air pollution concentrations are measured at specified intervals. Traffic data is obtained using traffic flow monitors, and air and noise pollution levels are measured using portable sensors placed at selected points along the study route. To predict air pollution, the study applies the General Motor Model, which uses a formula developed by Boubel (1994) [15][16]. This model calculates the concentration of pollutants based on vehicle emissions, wind speed, building height, and dispersion parameters. The following formula is used to predict pollutant concentrations:

$$C = \frac{Q}{U \times h_0 \times \sigma_z}$$

Where:

- C = pollutant concentration (ppm)
- Q = estimated average emission level (g/km)
- U = effective wind speed (m/s)
- h_o = building height at distance x from the road (m)
- σz = vertical dispersion parameter

The predicted concentrations are then compared with the air quality standards outlined in Table 1 to evaluate the level of pollution against regulatory limits.

For noise pollution, the study uses the Leq (Equivalent Continuous Sound Pressure Level) formula to determine the average sound level over a specified period. The formula used for calculating Leq is:

$$Leq = 10 \log_{10} \left(\frac{1}{T} \sum_{i=1}^{n} (t_i \times 10^{(L_i / 10)}) \right)$$

Where:

- Leq = continuous sound pressure level is equivalent
- $L_1, L_2, \ldots L_n$ = sound pressure levels during each time period
- T = total measurement time ($t_1 + t_2 + \ldots + t_n$)

Noise levels are measured in different zones (residential, commercial, industrial) along the study route and compared against the standard noise levels set forth in Table 2 to assess whether the noise exceeds acceptable thresholds.

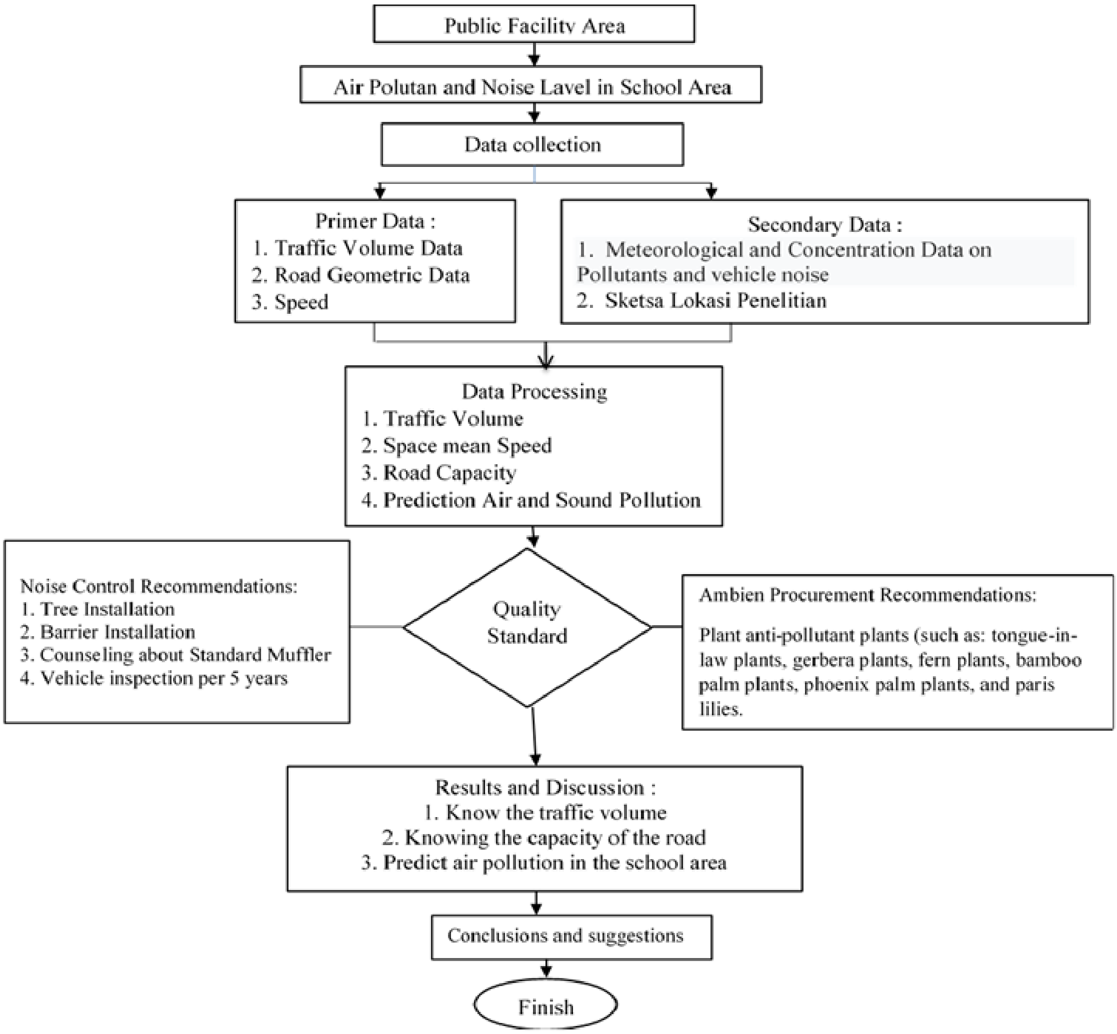

Figure 2. Research methodology

The research follows a systematic methodology that includes several key stages. First, data on traffic volume, vehicle speed, and road capacity are collected. Second, the air pollution prediction model and noise level measurements are used to estimate pollution levels. Next, the predicted values are compared against the established air quality and noise standards. Finally, the results are analyzed to assess the impact of traffic volume on environmental quality, specifically air and noise pollution, and conclusions are drawn based on this analysis. Recommendations for mitigation strategies are made where necessary. This structured approach provides a comprehensive understanding of the environmental impacts of traffic and offers a basis for decision-making regarding traffic management and pollution mitigation strategies in urban areas. The methodology flowchart, depicted in Figure 2, illustrates the step-by-step process of data collection, pollution prediction, analysis, and comparison with environmental standards, serving as a guide to understanding how each element of the methodology contributes to the overall assessment of traffic-related pollution.

3. Result and Discussion

This section presents the findings of the study related to road capacity, traffic volume, and their impact on environmental factors such as noise and air pollution. The results are based on field observations and data collected on T. Panglima Nyak Makam Street in Banda Aceh, focusing on road capacity, noise levels, and air pollution predictions. The analysis compares the observed data with established environmental standards to evaluate the road's suitability for the surrounding community.

The road capacity and degree of saturation (DS) for T. Panglima Nyak Makam Street were analyzed based on traffic data collected on different observation days. Table 3, which summarizes the data for January 29, February 2, and February 3, 2020, shows the total number of vehicles (PCU/hour) and traffic volume, with the DS for each day calculated. On January 29, 2020, the total traffic volume was 558,245 PCU/hour, with a DS of 0.38. On February 2, 2020, the traffic volume decreased to 235,904 PCU/hour, and the DS dropped to 0.16. On February 3, 2020, the traffic volume increased to 666,034 PCU/hour, and the DS increased to 0.46. These variations indicate the impact of traffic volume on road capacity and congestion, with a higher DS suggesting that the road is operating closer to its capacity, leading to increased congestion and higher pollution levels.

Table 3. Road Capacity recapitulation (6/2 D) and degree of saturation

Observation Day	Total Vehicle (PCU/Hour)	Total Traffic Volume (PCU/Hour)	Capacity PCU/Hour	DS
Wednesday 29-01-2020	19846	558,245	1455,3	0,38
Sunday 02-02-2020	11925	235,904	1455,3	0,16
Monday 03-02-2020	23713	666,034	1455,3	0,46

Table 4 shows the relationship between traffic volume, noise levels, and road capacity. On January 29, 2020, the vehicle noise level was measured at 76.1 dB(A), which exceeded the environmental noise standard of 55 dB(A) for school areas, indicating a significant noise impact on the surrounding community. On February 2, 2020, the noise level was lower at 74.7 dB(A), but still exceeded the standard. On February 3, 2020, the noise level increased to 77.2 dB(A), indicating that higher traffic volumes lead to higher noise pollution levels. The relationship between traffic volume and noise levels suggests that as the number of vehicles increases, noise pollution also rises, due to the combined effects of vehicle engines, exhaust systems, and interactions between the wheels and the road surface. This highlights the need for noise management strategies, especially in sensitive areas like schools, where noise levels should not exceed 55 dB(A) to ensure a healthy learning environment.

Table 4. Recapitulation of the relationship between noise, number of vehicles, traffic volume, road capacity and degree

Day.Date	Vehicle Noise dB(A)	Number of vehicles	Traffic Volume (PCU/Hour)	Road Capacity (PCU/Hour)	Degree of Saturation (DS)
Wed, 29 January 2020	76,1	19846	558,245	1455,3	0,38
Environmental Standard Standards	55,0	14343	403,462	1051,8	0,27
Sun, 2 February 2020	74,7	11925	235,904	1455,3	0,16
Environmental Standard Standards	55,0	8780	173,689	1071,5	0,11
Mon, 3 February 2020	77,2	23713	666,034	1455,3	0,46
Environmental Standard Standards	55,0	16894	474,506	1036,8	0,33

(Source: Research Results, 2020)

Table 5 presents the predicted air pollution levels based on the observed traffic volumes and road capacity for each day. On January 29, 2020, the CO (LV) concentration was 1.301 ppm, CO (HV) was 0.016 ppm, NOx was 0.096 ppm, and HC was 0.063 ppm. These values were compared to air pollution standards, such as 25 ppm for CO (LV) and 16 ppm for NOx, as established by organizations like WHO and AHRMC. The predicted concentrations were well within the acceptable limits, indicating that despite the high traffic volume, the air quality remained within safe limits on that day. On February 2, 2020, with a lower traffic volume, the CO (LV) concentration dropped to 0.324 ppm, CO (HV) to 0.007 ppm, NOx to 0.026 ppm, and HC to 0.016 ppm, all remaining well below the standards. Similarly, on February 3, 2020, the CO (LV) concentration increased to

1.133 ppm, but it was still below the 25 ppm threshold. These findings suggest that while traffic volume plays a significant role in air pollution levels, the concentrations of key pollutants remained within safe limits, indicating that the road environment was still capable of accommodating the traffic volume without exceeding the air quality standards.

Table 5. Ideal data on average Air pollution per day

Observation Day	Air Pollution Standards	Air pollution (C)		Total vehicle (Veh/jam)	Traffic Volume (PCU/Hour)	Capacity (PCU/Hour)	DS
Wednesday 29-01-2020	25 ppm	CO (LV)	1,301	19846	558,245	1455,3	0,38
		CO (HV)	0,016				
	16 ppm	Nox	0,096				
	0,25ppm	HC	0,063				
	Ideal	CO (LV)	1,879	21132	822,277	1100	0,75
		CO (HV)	0,035				
		Nox	0,141				
		HC	0,091				
Sunday 02-02-2020	25 ppm	CO (LV)	0,324	11925	235,245	1455,3	0,16
		CO (HV)	0,007				
	16 ppm	Nox	0,026				
	0,25ppm	HC	0,016				
	Ideal	CO (LV)	0,720	13211	499,277	1100	0,45
		CO (HV)	0,013				
		Nox	0,056				
		HC	0,035				
Monday 03-02-2020	25 ppm	CO (LV)	1,133	23713	666,034	1455,3	0,46
		CO (HV)	0,021				
	16 ppm	Nox	0,084				
	0,25ppm	HC	0,055				
	Ideal	CO (LV)	1,607	24999	930,066	1100	0,85
		CO (HV)	0,030				
		Nox	0,117				
		HC	0,078				

The results show a clear relationship between traffic volume, road capacity, noise, and air pollution. As traffic volume increases, both noise levels and air pollution tend to rise. However, when traffic volume decreases, pollution levels are reduced. This highlights the importance of maintaining optimal road capacity to minimize congestion and its associated environmental impacts. The data also indicates that while the air pollution concentrations were within acceptable limits, the noise levels exceeded the recommended thresholds for school areas. The study suggests that the road is still suitable for handling the traffic volume under the given conditions, as the predicted air pollution levels remained within safe limits. However, noise levels in certain areas, particularly near schools, exceeded the recommended levels, indicating a need for mitigation measures to reduce noise pollution, such as traffic flow management, noise barriers, or the use of quieter vehicles. In conclusion, the findings underscore the importance of managing road capacity, traffic volume, and pollution to ensure that urban areas remain livable and sustainable. By addressing the issues of noise and air pollution through targeted interventions, the quality of life for residents, especially in sensitive areas like schools, can be improved.

4. Conclusions

The study reveals that noise pollution levels on T. Panglima Nyak Makam Street in Banda Aceh have surpassed the acceptable limits due to high traffic volumes and the diverse composition of the vehicles on the road. These factors have resulted in noise levels that exceed the community threshold of 70 dB(A), which has prompted a reaction from the local residents. However, these noise levels have not yet surpassed the maximum allowable highway noise level of 85 dB(A). In terms of air pollution, the analysis of road capacity and traffic volume shows that with a Degree of Saturation (DS) of 0.85, the road can accommodate a traffic volume of 930,066 PCU/hour while maintaining an air quality within safe limits. The concentrations of pollutants such as CO for light vehicles (1.607 ppm), CO for heavy vehicles (0.030 ppm), NOx (0.117 ppm), and HC (0.078 ppm) all remain below the established air quality standards. These pollutant concentrations are classified as safe, indicating that even with a high traffic volume, the air quality remains within the acceptable limits as per environmental standards. Thus, while the road can still accommodate the traffic volume without exceeding air quality standards, the noise levels in certain areas, particularly near schools, are of concern and may require mitigation measures to ensure they fall within acceptable limits for residential and educational environments.

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6. Conflict of Interest

The authors affirm that there are no conflicts of interest associated with the publication of this study. The research was carried out independently, with no external financial or personal influences affecting the results or interpretations presented in the paper.

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