Analysis of Traffic Noise Levels in Heterogeneous Traffic at the Five-Way Intersection Underpass

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ABSTRACT

The increasing number of motor vehicles has resulted in higher road noise levels, contributing to environmental issues beyond traffic congestion, such as noise pollution. Noise is a physical factor that can negatively impact health and safety. This study aims to analyze the current noise levels generated by heterogeneous traffic at the Simpang Lima Underpass, Sultan Hasanuddin Airport, and predict noise levels for the next 10 years. Data was collected using a sound level meter (SLM) to measure traffic noise. Based on calculations of the annual growth rate of motor vehicles, the predicted noise level for the next 10 years at Jl. Underpass Makassar-Maros is 89.97 dB(A), exceeding acceptable limits and requiring mitigation measures. According to the Instruction of the Ministry of Public Works No. 1 (2003) on Road Environmental Capacity Calculations, the measured and predicted LAeq values using the GIS RLS 90 model surpass the allowable thresholds, highlighting the urgent need for noise control strategies.

Keywords: Traffic Volume, Noise, Underpass

1. Introduction

Rapid urbanization, population growth, and the expansion of socioeconomic activities have led to significant transformations in urban infrastructure, particularly in the transportation sector. The increasing volume of motor vehicles has introduced numerous challenges to urban living, including heightened traffic congestion and environmental degradation. One of the most critical environmental concerns associated with transportation is noise pollution, which has been increasingly recognized as a major public health issue (Kumaat, 2013). Noise, defined as unwanted or disruptive sound, can have far-reaching consequences on human health and well-being, ranging from mild discomfort to severe auditory and psychological impairments. According to the Decree of the Minister of Health of the Republic of Indonesia, noise originating from production or transportation activities can, at certain levels, lead to hearing disturbances and other health-related issues (Anizar, 2009). Given the increasing number of vehicles on urban roads, noise pollution is no longer a secondary concern but rather a primary environmental issue that requires immediate attention and comprehensive management strategies. In Indonesia, the rapid growth in motor vehicle ownership has far outpaced the expansion of road infrastructure, exacerbating noise-related problems. According to the Central Bureau of Statistics, between 2013 and 2014, the number of motor vehicles increased by 5% to 10% annually, while the expansion of national toll roads was limited to only 1%. This imbalance has resulted in heightened traffic congestion and prolonged exposure to high noise levels, particularly in urban centers such as Makassar. In this city alone, vehicle growth reached 8% to 12% during the same period, and data from subsequent years indicate a continued upward trend. As urban populations continue to rise, noise pollution is expected to worsen, potentially leading to significant health and environmental repercussions if not adequately addressed.

Extensive research has been conducted on the impacts of traffic noise, highlighting its negative effects on both human health and environmental quality. Noise pollution in urban environments has been linked to various health problems, including communication difficulties, cognitive impairments, cardiovascular issues, and sleep disturbances (Ministry of Health, Republic of Indonesia, 1996). Studies by Ismail (2011) and Mahmud (2017) have emphasized that prolonged exposure to high noise levels can lead to both temporary and permanent hearing loss, with occupational and residential areas being particularly vulnerable. Psychological impacts such as increased stress levels, reduced concentration, and disturbances in daily activities have also been documented. Furthermore, research suggests that noise pollution can influence social behavior, productivity, and overall quality of life, underscoring the urgent need for effective noise management policies. Despite the growing body of literature on traffic noise and its associated health effects, many studies have primarily focused on measuring noise levels in general urban settings without considering the unique characteristics of specific high-traffic areas. For instance, the Five-Way Intersection (Simpang Lima) Underpass near Sultan Hasanuddin Airport serves as a crucial transportation hub where vehicles from multiple directions converge, often resulting in prolonged traffic congestion and increased noise emissions. Previous studies have provided limited insights into the specific noise dynamics at such complex intersections, where the combination of heavy traffic flow, infrastructure limitations, and driver behaviors may significantly contribute to noise pollution beyond acceptable limits. Additionally, existing research lacks predictive analyses that estimate future noise levels based on traffic growth projections, making it difficult for policymakers to implement proactive noise control measures.

While previous studies have examined the health impacts and regulatory frameworks related to noise pollution in Indonesia, there remains a substantial gap in understanding the long-term implications of noise exposure at strategic traffic points such as the Five-Way Intersection Underpass. Most prior research has been descriptive, focusing on short-term noise assessments without considering the evolving nature of urban traffic patterns and their potential future impact. This study offers a novel approach by not only assessing the current noise levels at this critical location but also employing predictive modeling to estimate noise trends over the next decade. By incorporating traffic growth projections, infrastructure developments, and regulatory compliance considerations, this research aims to provide a comprehensive analysis that extends beyond static noise measurements. Another key contribution of this study lies in its focus on the behavioral and environmental factors that influence noise pollution levels at congested intersections. Traffic congestion often leads to irregular driving patterns, such as frequent acceleration and braking, honking, and engine idling, all of which contribute to fluctuating noise levels. Understanding these behavioral aspects in relation to noise generation will provide deeper insights into the underlying causes of noise pollution and inform the development of targeted mitigation strategies.

This research aims to bridge the gap between theoretical noise assessment frameworks and practical, location-specific noise management solutions, making it a valuable addition to existing literature. This research aims to comprehensively assess the noise pollution levels at the Five-Way Intersection Underpass near Sultan Hasanuddin Airport and to evaluate whether they comply with the established regulatory standards set by the Decree of the Minister of Environment No. 48 of 1996. Additionally, the study aims to project future noise levels over the next 10 years, considering the ongoing growth in traffic volume and urban expansion. The findings will provide valuable insights for urban planners, policymakers, and public health officials to develop effective noise mitigation strategies and ensure a safer and more sustainable urban environment.

2. Material And Methods

2.1 Time and Location

This study was conducted over a period of two months, from May to July, encompassing several phases, including document review, preliminary investigations, and data collection and processing. Field data collection took place over one month, from Monday to Friday, between 06:00 and 18:00, with measurements performed hourly at intervals ranging from 15 to 60 minutes. The research site was the Simpang Lima Underpass near Sultan Hasanuddin Airport, a critical traffic node with high vehicle density and varied land use. Three measurement points were strategically selected based on land-use characteristics such as commercial, residential, and office areas to ensure a comprehensive assessment of noise levels. The calculation steps to obtain the daily equivalent noise level (LAeq,day) can be seen in Figure 1.

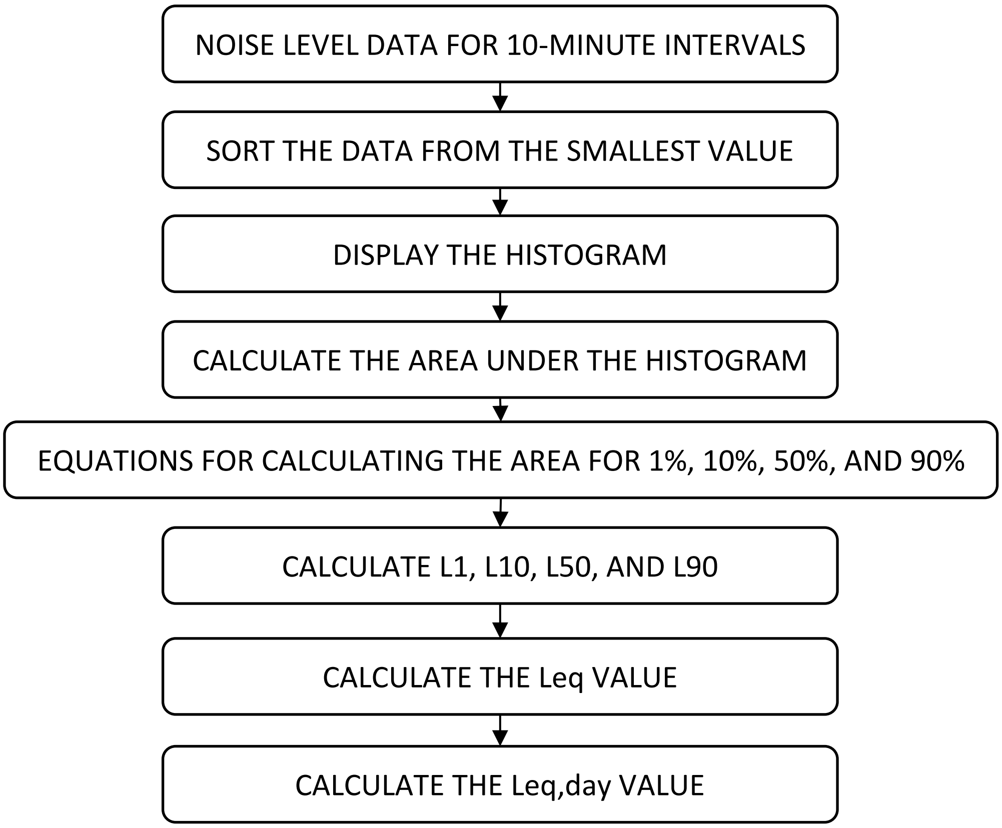

Figure 1. Noise Level Data Processing Flowchart

2.2. Data Collection

Both primary and secondary data were utilized to obtain a comprehensive understanding of noise pollution at the study site. Primary data were collected through direct field measurements, including noise levels, traffic volume, vehicle speed, and horn usage. Noise levels were measured using a Sound Level Meter (SLM) to ensure accuracy and reliability in capturing environmental noise conditions. Traffic volume was recorded manually by categorizing vehicles into motorcycles, light vehicles, and heavy vehicles to analyze the distribution and density of traffic flow. Vehicle speed was measured using a speed gun, which allowed for the assessment of movement patterns and speed variations across different vehicle types. Additionally, horn usage was documented by counting the frequency and duration of horn sounds, providing valuable insights into driver behavior and traffic congestion.

Secondary data were obtained from various sources, including previous research studies, government reports, and supporting documents such as road network maps and traffic statistics from the Central Bureau of Statistics. These secondary sources provided contextual insights and historical trends that complemented the primary observations, allowing for a more comprehensive analysis of noise pollution at the study site.

2.3. Noise Measurement and Analysis Procedures

To ensure consistency and accuracy, noise measurements followed standardized procedures involving several sequential steps, as illustrated in Figure 1. Noise sampling was conducted by recording sound levels at three selected locations over specified time intervals, adhering to regulatory guidelines and best practices for environmental noise assessment. The collected noise level data were processed by sorting them from the smallest to the largest values, followed by the generation of histograms to visualize the frequency distribution. The calculation of the Equivalent Continuous Sound Level (LAeq) involved determining statistical noise levels, including L1, L10, L50, and L90, which represent the noise exceedance levels at 1%, 10%, 50%, and 90% of the measurement time, respectively. The equivalent continuous noise level (Leq) and the daily noise level (LAeq,day) were then estimated by incorporating time-weighted averages to assess daily exposure levels comprehensively.

In addition to noise measurements, traffic volume and speed data were collected to establish correlations between traffic density and noise pollution levels. Traffic volume for motorcycles (MC), light vehicles (LV), and heavy vehicles (HV) was recorded hourly, revealing that motorcycles constituted the highest proportion of traffic, while heavy vehicles were the least. Vehicle speed data were obtained using a speed gun, with 30 vehicles of each type measured at each observation point, and average speeds calculated to assess their contributions to noise levels. A predictive analysis of future noise levels was conducted using historical traffic data from the Central Bureau of Statistics (2015–2020) and recent survey data (2021). Linear regression models were applied to analyze vehicle growth trends, while the Exponential Growth Method was employed to estimate future noise levels over the next 10 years, considering projected traffic growth and infrastructure developments. Statistical and computational methods, including the Generalized Additive Model (GAM) and the GIS-based RLS 90 model, were used to analyze spatial and temporal noise distributions. Compliance with Indonesian noise regulations, specifically the Decree of the Minister of Environment No. 48 of 1996, was evaluated, and potential mitigation strategies were recommended. To ensure data reliability and validity, several quality assurance measures were implemented, such as calibration of the sound level meter before each measurement session, adherence to standardized measurement procedures aligned with international guidelines, and replication of measurements at different times of the day to account for variability in traffic patterns and environmental conditions. These methodological approaches provide a robust foundation for assessing traffic noise pollution at the Simpang Lima Underpass and support the development of evidence-based noise mitigation strategies.

3. Results

3.1 Objective Conditions

The research was conducted at three designated locations along the underpass road at the Simpang Lima Intersection, Sultan Hasanuddin Airport, which features a 4/2 D road configuration. This configuration consists of four lanes, with two lanes in the center dedicated to through traffic, designed to facilitate smoother traffic flow and reduce congestion in the primary movement corridor. The study locations were selected based on variations in land use surrounding the underpass, including commercial, residential, and office areas. Each type of land use significantly influences traffic volume, vehicle composition, and resultant noise levels. For instance, commercial areas are characterized by high activity and vehicular density throughout the day, residential areas exhibit peak traffic volumes during morning and evening commute hours, and office zones experience increased activity during standard working hours. Measurements were conducted along the roadside, adhering to established environmental assessment guidelines and ensuring that observation points were situated to accurately represent local conditions. The placement of observation points was guided by factors such as the proximity of the road to noise-reflective surfaces (e.g., walls and buildings), intersection configurations, and pedestrian activity. The selection process aimed to minimize sampling bias while accounting for diverse environmental and traffic dynamics. To ensure the reliability and consistency of the data, meteorological conditions—such as temperature, humidity, and wind speed—were monitored during the measurement period. These factors were carefully considered because they can influence the propagation of sound waves and, consequently, the accuracy of noise level readings. Measurements were taken systematically under similar conditions across all observation points to allow for meaningful comparisons between the locations. Preliminary observations revealed that the Simpang Lima Intersection functions as a critical traffic node, accommodating a heterogeneous mix of vehicles, including motorcycles, light vehicles, heavy vehicles, and public transportation. This diverse traffic composition contributes significantly to noise pollution, as the different vehicle types produce varying levels and frequencies of sound. The central lanes of the underpass were primarily utilized by faster-moving vehicles, while the outer lanes experienced frequent stops and starts due to pedestrian crossings and access to adjacent land-use areas. These factors compounded the complexity of noise generation, necessitating a robust methodological approach to capture the full spectrum of noise pollution.

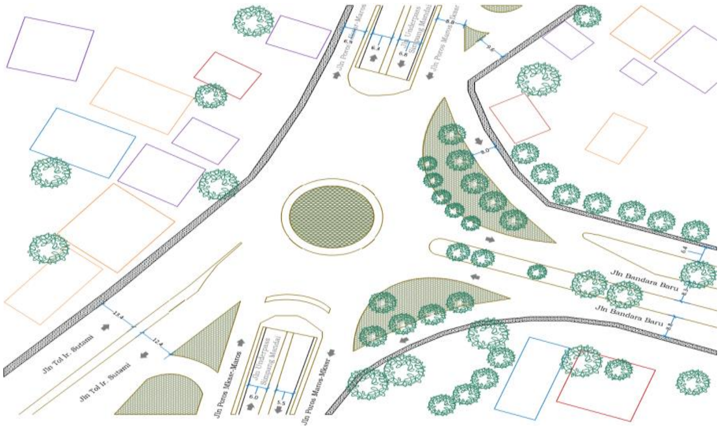

Figure 2. Visualization of Sultan Hasanuddin Intersection

3.2 Noise Level Measurement Results

3.2.1 Traffic Volume

Traffic volume measurements were conducted concurrently with noise measurements. The measurement results, which include motorcycles, light vehicles, and heavy vehicles, are presented in Table 1. The traffic volume measurements for the entire 4/2 D road section can be seen in Figures 3 and 4 below. For traffic volume measurements representing each hour for each road segment, refer to the appendix. In Table 1 and Figure 3 below, it can be observed that the highest total vehicle volume is for motorcycles (MC), while the lowest is for heavy vehicles (HV).

Table 1. Traffic Volume Measurement Results

Road Section Code	LAeqDay	Traffic Volume/hour			Volume (%)		
	(dBAA)	MC	LV	HV	MC	LV	HV
R1	76,31	406	317	24	31,82	28,79	30,00
R2	72,59	180	283	36	14,11	25,70	45,00
R3	78,15	690	501	20	54,08	45,50	25,00

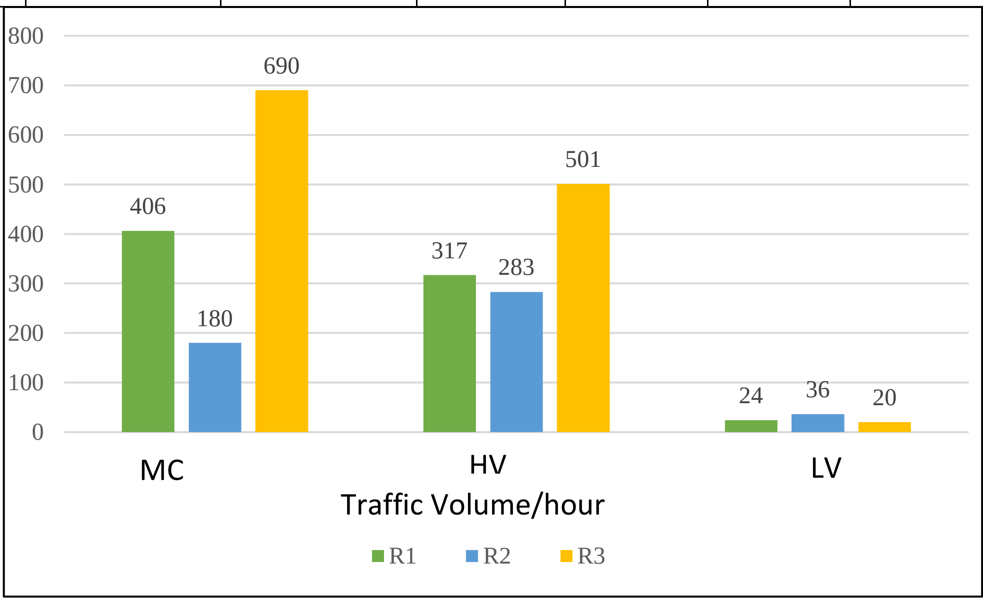

Figure 3. Motorcycle, Light Vehicle, and Heavy Vehicle Traffic Volume in Vehicles Per Hour (vph)

Note:

R1 = New Airport Main Road

R2 = Makassar-Maros Main Road

R3 = Makassar-Maros Underpass Road

In Figure 3 above, it can be observed that the traffic volume for each road section is based only on peak hour traffic, as follows: for R1, the peak hour occurs from 08:00 to 09:00 WITA, for R2, the peak hour is from 13:00 to 14:00 WITA, and for R3, the peak hour is from 17:00 to 18:00 WITA. The maximum motorcycle (MC) traffic volume is recorded at the R3 observation point, which is the Makassar-Maros Underpass Road, with a total of 690 vehicles per hour. This is due to the fact that this road section is located in an area with commercial, hotel, and residential land use. The minimum motorcycle (MC) traffic volume is found at the R2 observation point, the Makassar-Maros Main Road, with a total of 180 vehicles per hour. The low motorcycle traffic on this road is attributed to the residential land use, which makes the road less congested compared to other sections. Meanwhile, the maximum light vehicle (LV) traffic volume is recorded at the R3 observation point, Makassar-Maros Underpass Road, with 501 vehicles per hour. The minimum light vehicle traffic volume is found at the R2 observation point, Makassar-Maros Main Road, with 283 vehicles per hour.

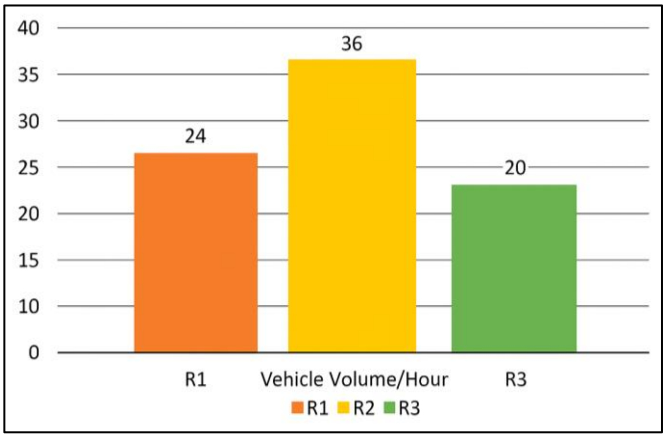

Figure 4. Heavy Vehicle Traffic Volume in Vehicles/hour (vph)

In Figure 4, it can be seen that the maximum heavy vehicle (HV) traffic volume is recorded at the R2 observation point, the Makassar-Maros Main Road, with 36 vehicles per hour. The minimum volume is recorded at the R3 observation point, the Makassar-Maros Underpass Road, with 20 vehicles per hour.

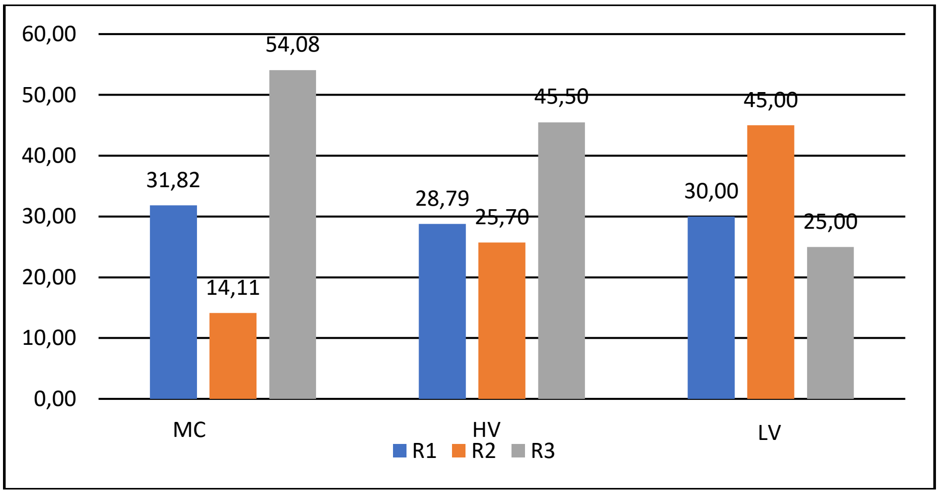

Figure 5. Percentage of Heavy Vehicle Traffic Volume in Vehicles/hour (vph)

As shown in Figure 5, the average percentage of motorcycles (MC) is 31.82%, with a maximum value of 54.08% observed at the R3 observation point, and a minimum value of 14.11% at the R2 observation point. For light vehicles (LV), the average percentage is 28.79%, with a maximum value of 45.50% observed at the R3 observation point, and a minimum value of 25.70% at the R2 observation point. For heavy vehicles (HV), the average percentage is 30.00%, with a maximum value of 45% at the R2 observation point, and a minimum value of 25.00% at the R3 observation point. From these results, it can be concluded that motorcycles (MC) constitute the majority of vehicles, while heavy vehicles (HV) are in the minority. The observation point with the greatest disparity in the percentage of MC, LV, and HV is the R3 observation point, located at the Makassar-Maros Underpass Road, where the percentage of motorcycles (MC) is 54.08%, light vehicles (LV) is 45.50%, and heavy vehicles (HV) is 25.00%. This can be attributed to the fact that the Makassar-Maros Underpass Road runs through residential areas, shopping centers, and hotels, which results in a higher usage of motorcycles to avoid traffic congestion. Traffic volume tends to increase during peak hours, such as in the morning, afternoon, and evening, which correspond to the beginning and end of commercial activities, office hours, and other events.

3.2.2 Speed data

Speed measurements were conducted concurrently with noise and traffic volume assessments to establish correlations between vehicle speeds and noise levels. A speed gun was used to measure the velocity of 30 vehicles for each vehicle type—motorcycles (MC), light vehicles (LV), and heavy vehicles (HV)—at each measurement point along the designated road segments. The results of the average speed measurements for each road segment are presented in Table 2.

Table 2. Traffic Volume Measurement Results

Kode Ruas	**LAeqDay**	**Kecepatan Rata-rata (km/jam)**		
	(dBA)	**MC**	**LV**	**HV**
R1	73,31	49	35	33
R2	74,83	26	24	14
R3	76,31	44	29	28

The analysis of speed data reveals variations in average speeds across different road segments. As illustrated in Figure 6, the overall average speeds recorded were 35 km/h for motorcycles, 30 km/h for light vehicles, and 29 km/h for heavy vehicles. Among the observed road segments, Jl. Poros Bandara Baru exhibited the highest average speeds. This can be attributed to the relatively wider road width and two-way traffic flow, which allows drivers to maintain higher speeds with minimal interruptions. Conversely, lower speeds were observed on road segments characterized by higher traffic density, road narrowing, and frequent intersections. The results indicate that variations in vehicle speeds are influenced by several factors, including road geometry, traffic density, and land use characteristics. For instance, the highest speeds were recorded in areas with commercial and residential functions, where traffic tends to flow more freely outside peak hours. Meanwhile, road segments with higher traffic congestion, such as R2, demonstrated significantly lower vehicle speeds, particularly for heavy vehicles, which were recorded at an average of 14 km/h, due to the presence of frequent stop-and-go traffic conditions. The findings of this study align with previous research on traffic flow and noise pollution relationships. For example, a study by Alimuddin (2016) on urban roads in Makassar demonstrated that higher vehicle speeds were associated with increased noise levels, particularly in areas with high heavy vehicle concentrations. Similarly, research by Ismail (2011) found that road segments with lower vehicle speeds tend to produce lower peak noise levels due to reduced engine acceleration and braking activities. The results from the present study corroborate these findings, highlighting that road design and vehicle composition play critical roles in determining both speed and noise characteristics. Furthermore, the study by Fadillah (2016) indicated that traffic speeds on major urban roads in Indonesia typically range from 20 to 50 km/h, depending on road conditions and congestion levels, which aligns with the speed data obtained in this study. However, it is worth noting that the speeds recorded in this research are slightly lower for heavy vehicles compared to previous studies, likely due to the specific characteristics of the Simpang Lima Underpass, which include traffic merging points and frequent bottlenecks. As shown in Figure 6, the average speed for motorcycles is 35 km/h, for light vehicles is 30 km/h, and for heavy vehicles is 29 km/h. The Jl. Poros Bandara Baru road segment has a relatively high average speed, which is due to several observation points on this road being two-way with a wide road width, allowing drivers to increase their vehicle speed.

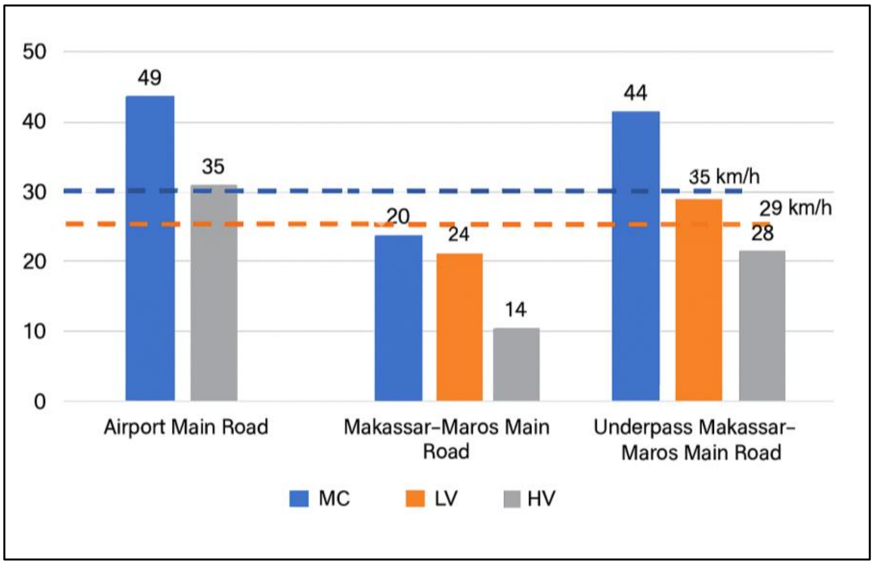

Figure 6. Percentage of Heavy Vehicle Traffic Volume in Vehicles/hour (vph)

3.2.3 Horn count

Horn usage data were collected to analyze the frequency and patterns of horn honking across different vehicle types, considering the duration and intensity of horn sounds. The measurements were conducted at various observation points to capture variations in traffic conditions and driver behavior. The results of the horn count measurements for motorcycles (MC), light vehicles (LV), and heavy vehicles (HV) at each road segment are presented in Table 3. The data presented in Table 3 indicate significant differences in horn usage across vehicle types and road segments. Motorcycles exhibited the highest horn usage, ranging from 218 to 343 honks per hour, with the highest frequency observed at the R3 segment. Light vehicles followed, with horn counts varying between 109 and 164 honks per hour, whereas heavy vehicles recorded the lowest horn usage, ranging from 19 to 25 honks per hour. The high horn usage by motorcycles can be attributed to their maneuverability and tendency to weave through traffic, often requiring frequent horn use to alert other road users. In contrast, light vehicles demonstrated moderate horn usage, primarily in congested conditions and at intersections. Heavy vehicles, due to their slower movement and larger size, used horns less frequently, likely relying more on passive road presence to signal their intentions. The findings of this study are consistent with previous research on urban traffic noise and driver behavior. A study conducted by Alimuddin (2016) in Makassar found that motorcycles were the predominant contributors to horn noise in urban traffic due to their high maneuverability and frequent interactions with other vehicles. Similarly, research by Fadillah (2016) highlighted that horn usage tends to increase in areas with high traffic density and complex intersection configurations, which aligns with the high counts observed in the R3 segment of the present study. Furthermore, the study by Wulandari (2007) on traffic noise pollution emphasized that horn honking is often influenced by road design and traffic congestion levels. The results of the current study support this observation, as segments with wider roads and smoother traffic flow (such as R1) recorded lower horn counts compared to the more congested R3 segment, where frequent stop-and-go conditions prevail.

Table 3. Horn Count Measurement Results

Kode Ruas	Jumlah Klakson (kali/jam)		
	MC	LV	HV
R1	218	136	19
R2	235	164	23
R3	343	109	25

In the table, it can be seen that the horn count for motorcycles at each road segment ranges from 218 to 343 times per hour, for light vehicles from 109 to 164 times per hour, and for heavy vehicles from 19 to 25 times per hour.

4. Discussion

4.1 Objective Conditions

Noise measurements on the roadway were conducted using a sound level meter for 12 hours, resulting in 600 data points each hour, totaling 7,200 data points over the 12-hour period. However, the noise level (L) is not the equivalent average noise level (LAeq) representing the 10-minute measurement interval, so several calculation steps were performed to obtain the LAeq value. In general, the calculation steps for LAeq begin with sorting the 1-minute noise level data per hour from smallest to largest, followed by frequency distribution calculations as shown in equations 2.5 to 2.17. After the data is distributed, it is presented in the form of a histogram, as shown in Figure 7.

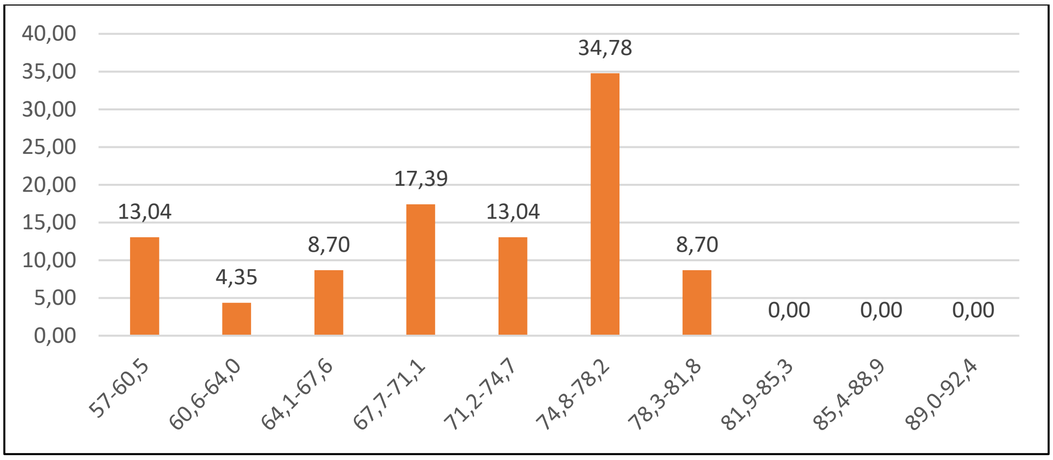

Figure 7. Traffic Noise Levels on Underpass Road Makassar-Maros

Next, the values of L1, L10, L50, and L90 are calculated as shown in Equations 2.5 to 2.17, and a graph is created for L10, L50, L90, and LAeq. As an example, this can be seen in Figure 8, which is the noise level graph for traffic on the Makassar-Maros Underpass Road. The graphs for all observation points can be found in the appendix.

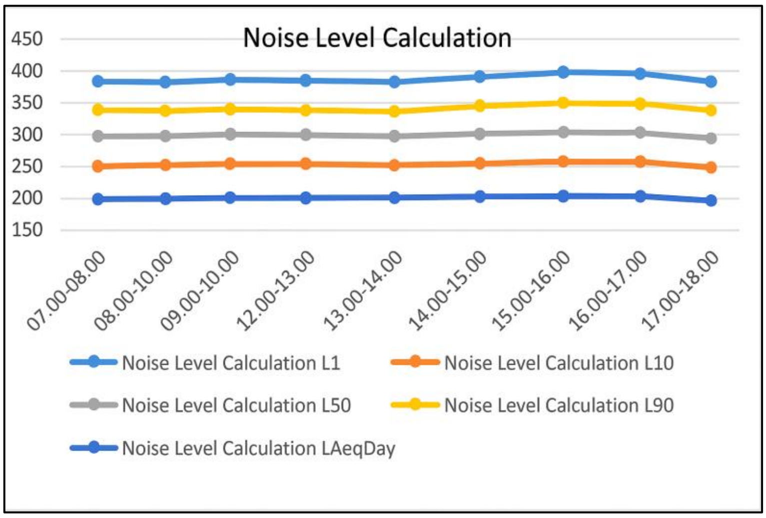

Figure 8. Peak Traffic Noise Levels on Underpass Road Makassar-Maros

4.1.1 Prediction of Noise Levels for the Next 10 Years

The prediction of vehicle volume on the Makassar-Maros Underpass Road is based on vehicle data from the Central Bureau of Statistics for the years 2015–2020, along with the results from the most recent vehicle survey in 2021. Based on the vehicle data for the Makassar-Maros Underpass Road, a vehicle growth trend model for the city of Makassar can be developed using linear regression analysis. For predicting vehicle growth on the Metro Tanjung Bunga road segment in the 10th year, the Exponential

Method formula is used. The predicted noise level for the Makassar-Maros Underpass Road in the 10th year, calculated using the Exponential Method and the trend prediction from linear regression analysis, can be seen in the following graph:

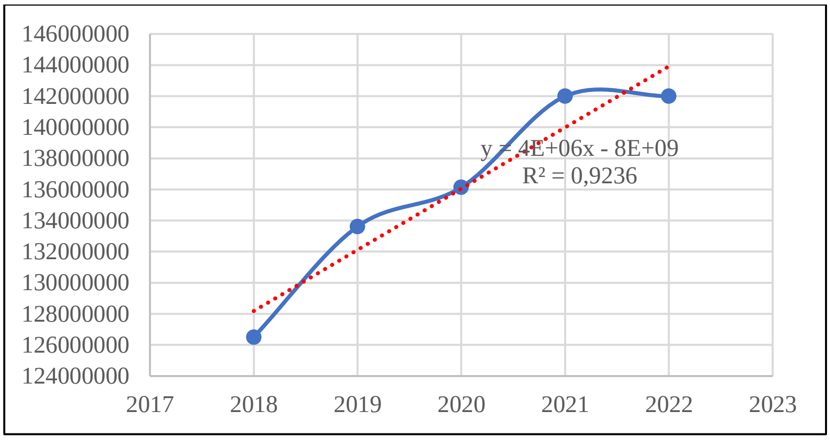

Figure 9. Trend Analysis of Vehicle Count (Y) on Underpass Road Makassar-Maros Over Time (X)

The graph shows the predicted traffic noise levels based on the forecasted vehicle volume in the future. The predicted vehicle volume for the city of Makassar is calculated using annual motor vehicle data from the Central Bureau of Statistics of Makassar City and data from the One-Stop Integrated Administration System (SAMSAT) of Makassar City. Based on the modeling analysis, a linear regression trend equation for motor vehicles was obtained as follows: (Y) = 4E+06x - 8E+09 (X) with R2 = 0.9236.

It is assumed that the vehicle growth follows the growth trend model for the Makassar-Maros Underpass road segment. The next step involves calculating the predicted noise level (n = 10 years) for the Makassar-Maros Underpass road segment using the best noise level model equation derived from linear regression analysis.

The predicted future noise levels can be seen in the following graph:

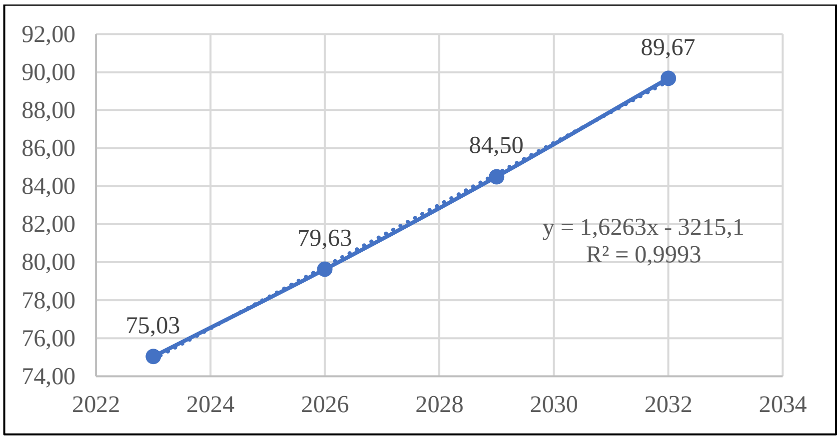

Figure 10. Trend Analysis of Vehicle Noise (Y) on Underpass Road Makassar-Maros Over Time (X)

By calculating the average annual growth rate of motor vehicles, the predicted traffic noise level at the study location, the Makassar-Maros Underpass Road, for the year 2032 is 89.67 dBA (A), indicating the need for noise mitigation measures. Based on the linear regression trend graph, the predicted noise level for 2021 is 75.03 dBA (A). A projection for the future, based on the average vehicle growth rate of 7.6% in Makassar, indicates a projected noise level of 90.67 dBA (A) for the year 2030.

5. Conclusion

The research indicates that the predicted traffic noise level at the Makassar-Maros Underpass Road for the next 10 years is 89.97 dB(A), based on the average annual growth rate of motor vehicles, highlighting the need for noise mitigation measures. Additionally, the LAeq day values derived from both measurements and GIS model predictions (RLS 90) exceed the required threshold set by the Ministry of Public Works (No. 13, 2003), signaling the importance of addressing noise pollution at the study site. These findings confirm the necessity for intervention in managing traffic noise and provide a basis for future research and policy recommendations aimed at improving environmental quality and public health in urban transportation corridors.

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