

Original Research Articles

Impact of Speed Bump on Vehicle Noise: Motorcycle and Light Vehicle

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Highlights:

- Speed bump height significantly influences vehicle noise levels in residential areas.
- Motorcycles generate higher noise levels than light vehicles over speed bumps.
- Speed bump width has a smaller impact on noise levels compared to height.
- Average noise levels for motorcycles are 65.8 dBA, 69.3 dBA, and 70.5 dBA in areas 1, 2, and 3.
- Speed bumps reduce vehicle speed and increase noise levels in areas 2 and 3.

Abstract: Installing speed control devices, or speed bumps, in residential areas has positive and negative impacts. The positive impact is that it functions to control vehicle speed, while the negative impact is noise and discomfort for residents. This research aims to determine the effect of installing speed bumps on noise levels and vehicle speed and explore the relationship between speed bump dimensions, speed reduction, and noise levels. Linear regression analysis was conducted using SPSS software, employing stepwise and enter methods. The results show that the noise level produced by vehicles is higher when passing over speed bumps in area 2 and after passing them in area 3 compared to before encountering the speed bumps in area 1. The average noise levels for motorcycles (MC) are 65.8 dBA in area 1, 69.3 dBA in area 2, and 70.5 dBA in area 3. The average noise levels for light vehicles (LV) are 64.7 dBA in area 1, 68.2 dBA in area 2, and 69.3 dBA in area 3. Additionally, the study found that motorbike noise levels are higher than those of light vehicles. Furthermore, the analysis showed that speed bump width has a lower correlation with increased noise compared to speed bump height and speed reduction. This study reveals that while the height of speed bumps can significantly influence noise levels, the width of speed bumps and speed reduction have a smaller impact.

Keywords: Noise, resident area, speed, speed bump

1. Introduction

Population growth and rapid technological advances have significantly increased transportation needs in Indonesia [1]. However, existing infrastructure often lags, leading to frequent traffic jams. Drivers often use residential roads as alternative routes to avoid congestion and save time, frequently exceeding the speed limit by 25-30 km/h. This behavior can lead to traffic accidents and endanger road users. Traffic calming measures are commonplace in modern society. These physical design techniques encourage or force drivers to maintain a slow and constant speed, preventing speeding and improving overall road safety [2][3]. Calming traffic also makes roads more accessible and livable for other users, such as pedestrians, cyclists, and residents. Traffic calming primarily aims to reduce speed and create a safer traffic environment. Although traffic calming measures by installing speed bumps effectively reduce the number of accidents, these measures can also have undesirable impacts, especially in generating noise. The noise produced by speed bumps, resulting from vehicles braking and accelerating as they pass over the obstacles, is a significant concern. This noise can disturb and endanger human health, causing various physiological and communication problems. Understanding the relationship between vehicle type, speed bump design, and noise levels is critical for developing effective noise mitigation strategies.

This study aims to determine the difference in the impact of speed bumps on noise levels between motorcycles (MC) and light vehicles (LV). By analyzing how vehicle type influences noise generation and exploring the role of speed bump dimensions, this research seeks to provide insights into optimizing speed bump design. The potential positive outcomes of this research, such as reduced noise pollution and improved road safety, may inspire and motivate urban planners

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and policymakers to consider and implement the findings. This paper is organized as follows: Section 2 reviews previous studies on speed bumps on vehicle noise. Section 3 explains how the data was collected and a general explanation of the regression analysis. The results and comparison of noise generated by speed bumps are described in section 4. Finally, section 5 is the conclusion.

2. Literature Review

The study area this section reviews the literature on the impact of speed bumps on vehicle noise. Numerous studies have explored how installing speed bumps affects noise and speed [4][3]. The extensive research on speed bump installation highlights their potential to reduce vehicle noise levels significantly. For instance, Kokowski et al. (2006), [5] modeled the effects of speed bumps on light vehicle noise during the deceleration and acceleration phases, demonstrating a notable reduction in noise emissions. Their findings underscore the effectiveness of speed bumps in mitigating noise pollution associated with vehicular traffic. Bachok et al. (2017), [6] found that road bumps typically reduce passenger car noise levels by 0.4 to 5 dB, though this reduction is inconsistent across all scenarios. Some studies indicate that speed bumps can increase noise levels under certain conditions. The design of speed bumps plays a crucial role in their acoustic impact. A study evaluating the impact of vehicle interior noise caused by speed bumps found that the geometry of the bumps significantly influences the noise produced. This suggests that careful consideration of speed bump design is essential to minimize undesirable noise effects. Our research aims to provide more detailed insights into the impact of speed bumps on vehicle noise, focusing specifically on motorbikes and light vehicles.

3. Material and Method

3.1. Material

The research focuses on residential roads with speed bumps, covering five locations. The primary data used in this study was obtained through observation surveys and direct field measurements, including:

- 1) Speed bump: Height, width, installation distance between speed bump and manufacturing material.
- 2) Road section: type of pavement and road width.
- 3) Noise and speed data: MC and LC in area 1, area 2, and area 3.

In this research, noise data analysis for each type of vehicle is calculated based on the type of vehicle. Meanwhile, the results of calculating the noise level for each vehicle can be known by collecting the sound level meter (SLM). This sound level meter measures the pressure difference, and the output from this tool is in decibels (dB) using a basic equation [Eq. (1)] [7]. This noise data was used to compare the noise levels before and after the vehicle crossed the speed bump. These comparisons are one of the variables in determining the relationship between noise, speed, and speed bump dimensions.

$$SPL = 10 \log \left(\frac{p}{p_{ref}} \right) \quad (1)$$

where SPL is noise pressure level (dB), p is sound pressure (N/m²), and p_{ref} is reference sound pressure (2x10⁻⁵ N/m²). The noise threshold value (NTV) regulates the average noise pressure or noise level based on the duration of noise exposure. It represents the condition where almost all workers are exposed to noise repeatedly without causing hearing problems or difficulty understanding everyday speech. The NTV of noise for 8 hours of daily work is 85 dBA.

Speed observations were conducted over 30-minute periods based on the distance traveled. Vehicle speed was calculated after recording and compiling all data for each type of vehicle during the observation period [Eq. (2)]. Speed calculations are used to obtain the space mean speed (SMS) [Eq. (3)] [8]. The average speed in this space is one of the variables used to explore the relationship between the dimensions of the speed bumps (height and width), road width, the distance at which the speed bumps are installed, and the relationship between noise and speed.

$$v = \frac{S}{t} \quad (2)$$

$$\bar{\mu}\text{SMS} = \frac{l}{\sum_{t=1}^n t_i / n} = \frac{l}{1/n \sum_{t=1}^n t_i} \quad (3)$$

where v is the speed of the vehicle (km/hour), s is the distance between two-speed bumps (m), and t is vehicle speed time (second). Meanwhile, $\bar{\mu}\text{SMS}$ is space average speed (km/h), l is distance of road section (km), n is number of vehicles, and $t-1$ vehicle travel time (hours).

3.2. Method

This research analyzed the relationship between noise levels, vehicle speed, and speed bump dimensions using regression analysis. Analysis was conducted using SPSS software, the enter method, and the stepwise method. Regression analysis measures the relationship between two or more variables expressed as a function or equation. To determine this relationship, it is crucial to distinguish between the independent variable (X) and the dependent variable (Y). Typically, these variables have a causal relationship, where changes in X influence Y . Thus, regression defines a specific function where Y is expressed as $f(X)$. The form of the regression depends on the underlying function or equation that models the relationship. Regression analysis is used to predict how far the value of the dependent variable will change if the value of the independent variable is manipulated, increased, or decreased. Regression analysis's benefit is determining whether changes in the dependent variable can be effectively managed by adjusting the independent variable [9] [10].

4. Results and Discussion

The research was conducted at five spots in residential areas. Generally, the speed bumps were semicircular with varying heights, base widths, road widths, and distances between bumps. They were made from either asphalt or rubber. Table 1 provides a summary of the speed bump sizes.

Table 1. A Summary Speed Bump Different Area

Spot	High (cm)	Wide (cm)	Width Road (m)	Speed Bump	Area
1	6	50	5	concrete	residential
2	4.8	70	7	concrete	residential
3	5	50	6	concrete	residential
4	7	65	8	concrete	residential
5	6.3	43	5	concrete	residential

4.1. Vehicle Noise and Speed

The vehicle noise and speed levels at each spot vary. The same calculation procedure was applied to ensure consistency, and the number of samples at each spot was controlled. The calculation of the data adequacy test, based on motorcycle noise at location 1. The minimum required sample size was 30 data points for measuring noise increase. To enhance the quality of the survey data, the study set the sample requirement to 40 data points for noise increase at each location. In total, 200 samples of noise increase data were collected for motorbikes and cars across the five spots studied.

Installing speed bumps of various sizes has different effects on reducing vehicle speed. The road section studied is divided into three areas:

- Area 1: To determine normal speed.
- Area 2: To determine speed when passing a speed bump.
- Area 3: To determine vehicle speed between speed bumps.

4.2. Comparison of Vehicle Speed Different Area

The speed characteristics vary across the studied locations. Therefore, sample number control is conducted at each site based on speed data to ensure consistency. The primary vehicle types observed on the studied road sections are motorcycles and light vehicles. Table 2. presents the calculation of the data adequacy test based on motorcycle speed at area 1. Table 3 illustrates

that in area 1 (normal speed), the average maximum speed of motorbikes passing through the five locations studied in residential areas is 33.177 km/h. In contrast, the average maximum speed for light vehicles is 29.689 km/h. These speeds are dangerous, especially in densely populated residential areas where children play and pedestrians are present. Residents have installed speed bumps to reduce vehicle speeds and mitigate this risk. In area 2 (speed over the speed bump), vehicle speeds are significantly reduced due to the speed bumps installed by the community. The average maximum speed over the speed bumps in the five road sections studied is 5.163 km/h for motorbikes and 3.766 km/h for light vehicles. In area 3 (speed after the speed bump), vehicle speeds increase but remain lower than in area 1. The average maximum speed for motorbikes is 18.672 km/h, and for light vehicles, it is 19.435 km/h. The speed of vehicles on roads with speed bumps generally follows the same trend: a decrease in speed when entering area 2 and an increase in speed after passing through area 3. The extent of the speed reduction in area 2 varies, depending on the size of the speed bump, as does the subsequent speed increase in area 3. This trend of speed variation is depicted in Figure 1.

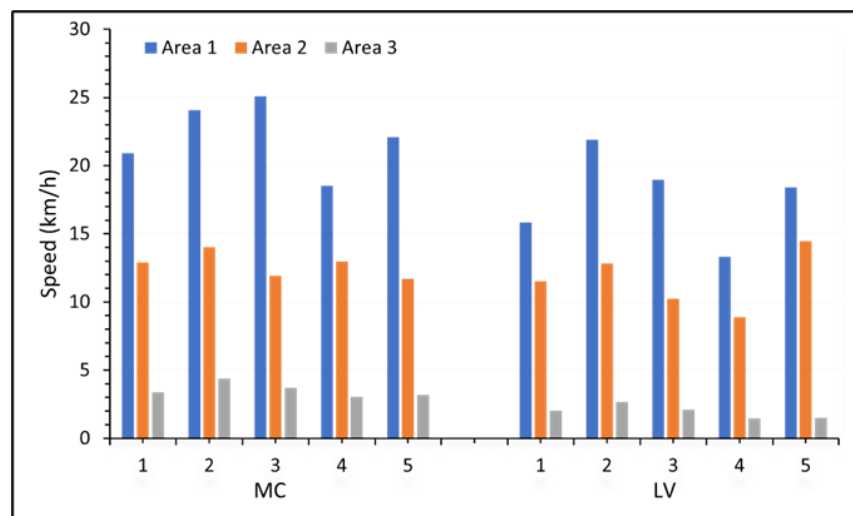
Table 2. Summary MC Speed Data (km/hour) and Control Number of Samples

n	Speed decrease (x) (km/h)	$(\bar{X} - x)$	$(\bar{X} - x)^2$
1	-24.560	4.975	24.750
2	-19.763	0.178	0.032
3	-18.676	-0.909	0.826
4	-17.340	-2.245	5.040
5	-16.890	-2.695	7.263
6	-19.343	-0.242	0.059
7	-24.456	4.871	23.726
8	-18.940	-0.645	0.416
9	-25.346	5.761	33.189
10	-18.890	-0.695	0.483
11	-17.340	-2.245	5.040
12	-16.972	-2.613	6.828
13	-19.480	-0.105	0.011
14	-18.340	-1.245	1.550
15	-17.450	-2.135	4.558
16	-18.342	-1.243	1.545
17	-25.770	6.185	38.254
18	-19.370	-0.215	0.046
19	-19.450	-0.135	0.018
20	-20.693	1.108	1.228
21	-20.350	0.765	0.585
22	-26.360	6.775	45.900
23	-22.347	2.762	7.628
24	-15.530	-4.055	16.443
25	-16.786	-2.799	7.835
26	-16.789	-2.796	7.818
27	-15.380	-4.205	17.682
28	-19.343	-0.242	0.059
29	-18.355	-1.230	1.513
30	-18.900	-0.685	0.469
Total	-587.551		260.796
Average	-19.585		8.693

Table 3. Comparison of MC and LV Speeds in Each Area

Spot	MC average			LV average		
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
L1	29,032	5,722	18,947	25,000	5,491	17,734
L2	40,724	6,245	19,459	35,019	6,120	19,355
L3	33,582	5,567	20,339	30,717	2,700	17,910
L4	32,143	3,028	17,308	28,846	2,092	16,822
L5	30,405	5,253	17,308	28,846	2,428	25,352
Average	33,177	5,163	18,672	29,686	3,766	19,435

Table 4. presents the speed variations of motorcycles and light vehicles from areas 1, 2, and 3 as they traverse a speed bump. Additionally, Table 5. displays the results of the Significance Test (Independent T-Test) for all areas.

**Figure 1.** Different Speed MC and LV Each Location**Table 4.** Speed of MC and LV Area 1-2, and 1-3

Spot	MC (area 1-2)		MC (area 1-3)		LV (area 1-2)		LV (area 1-3)	
	Area 1	Area 2	Area 1	Area 3	Area 1	Area 2	Area 1	Area 3
L1	20.898	3.362	20.898	12.908	15.814	2.006	15.814	11.504
L2	24.051	4.368	24.051	14.034	21.894	2.663	21.894	12.814
L3	25.070	3.703	25.070	11.923	18.977	2.099	18.977	10.245
L4	18.502	3.028	18.502	12.961	13.318	1.472	13.318	8.892
L5	22.091	3.198	22.091	11.692	18.389	1.512	18.389	14.461

Table 5. Output T-Test Values MC and LV

Pair	Paired differences								
	Type	Mean	Std. dev.	Std. error mean	95% Confidence interval of the difference		t	df	Sig (2-talled)
					Lower	Upper			
Area 1-2	MC	18.590	2.225	0.995	15.826	21.354	18.676	4	0.000
Area 1-3	MC	9.418	2.841	1.270	5.890	12.947	7.412	4	0.002
Area 1-2	LV	15.728	2.901	1.297	12.125	19.330	12.122	4	0.000
Area 1-3	LV	6.095	2.575	1.151	2.897	9.293	5.292	4	0.006

4.3. Comparison of Vehicle Noise in Different Areas

The installation of speed bumps, a common practice in residential areas, significantly impacts the noise levels caused by vehicles. Our research has identified three key areas of noise measurement: area 1, which captures the noise at normal speed or before crossing a speed bump; area 2, which measures the noise when a vehicle crosses a speed bump; and area 3, which records the noise when a vehicle accelerates. These findings provide a comprehensive understanding of the noise dynamics in areas with speed bumps. Table 6 shows that in area 1 (noise before passing a speed bump), the average maximum noise of motorbikes passing at the 5 locations studied on roads in residential areas is 68.8 dBA. In contrast, the average noise for LV, the maximum number of vehicles passing through the 5 locations studied in residential areas was 70.6 dBA. This indicates that the noise levels exceed the statutory limit of 55 dBA set for residential areas.. In area 2, the noise generated by vehicles increases quite a lot when over speed bumps. The maximum average noise for vehicles passing over speed bumps on the 5 road sections studied was 73.1 dBA for MC and 74.3 dBA for LV. In area 3 (noise between speed bumps), vehicle noise experienced a not-too-significant increase in noise. For MC, the maximum average noise is 74.0 dBA; for light vehicle noise, it is 75.7 dBA. The noise from vehicles passing on roads where speed bumps are installed generally shows the same trend: increasing noise when entering Area 2 and increasing noise when passing through area 3. The increase in vehicle noise in area 2 is quite varied, the magnitude of the increase in noise depending on the size of the speed bump installed on the road section in question as well as the additional noise of vehicles when passing through area 3 depending on the installation distance between the speed bumps. The trend of decreasing noise can be seen in Figure 2.

Table 6. Comparison of MC and LV Noise in Each Area (dBA)

	MC average			LV average		
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
L1	69,7	74,4	74,8	70,6	73,5	74,5
L2	68,6	71,9	72,6	68,6	72,3	74,1
L3	67,7	71,4	74,5	71,2	75,0	76,5
L4	67,7	73,9	74,8	71,2	75,4	76,6
L5	70,3	74,1	74,9	71,3	75,2	76,9
Average	68,8	73,1	74,0	70,6	74,3	75,7

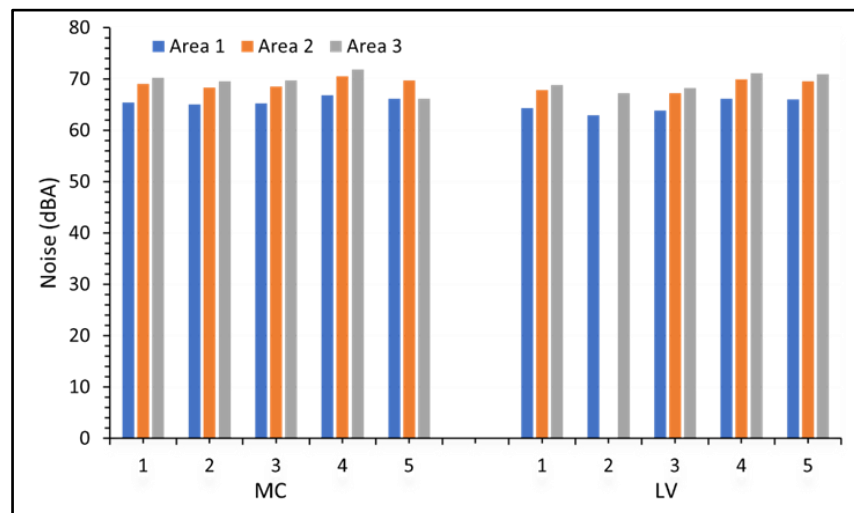


Figure 2. Differences Noise MC and LV Each Location

Table 7. Noise of MC and LV Area 1-2, and 1-3

Spot	MC (area 1-2)		MC (area 1-3)		LV (area 1-2)		LV (area 1-3)	
	Area 1	Area 2	Area 1	Area 3	Area 1	Area 2	Area 1	Area 3
L1	65.5	69.1	65.5	70.3	64.4	67.9	64.4	68.9
L2	65.1	68.4	65.1	69.6	63.0	66.2	63.0	67.3
L3	65.3	68.6	65.3	69.8	63.9	67.3	63.9	68.4
L4	66.9	70.6	66.9	71.8	66.2	70.0	66.2	71.1
L5	66.2	69.8	66.2	71.1	66.1	69.6	66.1	71.0

Table 8. Output T-Test Values MC and LV

Pair	Paired differences							Sig (2- talled)	
	Type	Mean	Std. dev.	Std. error mean	95% Confidence interval of the difference		t		df
					Lower	Upper			
Area 2-1	MC	3.500	0.187	0.083	3.267	3.732	41.833	4	0.000
Area 3-1	MC	4.720	0.204	0.091	4.465	4.974	51.499	4	0.000
Area 2-1	LV	3.480	0.216	0.069	3.210	3.749	35.893	4	0.000
Area 3-1	LV	4.620	0.268	0.120	4.286	4.953	38.500	4	0.000

To determine changes in noise levels for motorbikes and light vehicles in each area, a significance test was conducted across the five locations studied, as shown in Table 7. The results of this significance test are detailed in Table 8.

4.4. Relationship Between Noise, Speed, and Dimensions of Speed Bump

The relationship between increasing noise, decreasing speed, and speed bump dimensions for MC is calculated using multiple linear regression analysis, which includes dependent and independent variables. This analysis aims to determine the effect of the independent variables on the dependent variable. Based on the correlation results, it shows that the independent variables with correlation values greater than 0.5, which indicate a strong correlation with the dependent variable, are speed bump height (X1) and road width (X3), with correlation values of 0.976 and 0.884, respectively. In contrast, the speed bump width variable (X2) has a correlation value of – 0.200, indicating it does not significantly influence the dependent variable.

The relationship between increased noise, decreased speed, and speed bump dimensions is significant for LV. The independent variables with a strong correlation (correlation value of more than 0.5) with the dependent variable are speed bump height (X1) and speed (X3), with correlation values of 0.952 and 0.819, respectively. The speed bump width variable (X2) has a correlation value of 0.359, suggesting it does not significantly influence the dependent variable. This indicates multicollinearity between the independent variables. According Gregorich et. Al (2021) [11], a good regression model should not have a high correlation between independent variables. One highly correlated independent variable should be removed from the regression model to address this issue. In this case, the speed bump width variable (X2) is expressly excluded from the multiple linear regression model, a methodological approach to address multicollinearity.

Based on the stepwise method shown in Table 9, the mathematical model $Y = 2.342 + 0.199X_1$ with $R^2 = 0.952$ best meets the statistical test requirements. This model shows that the increase in motorcycle noise (Y) is significantly influenced by the height of the speed bump (X1). R^2 value shows a strong relationship. Similar results are observed in the mathematical models for motorcycle noise levels in Area 3 and light vehicle noise levels in Areas 2 and 3 (Tables 10-12). This research revealed that although the height of speed bumps can significantly influence noise levels, the width of speed bumps and speed reduction have a more negligible effect. Specifically, the R^2 value is 0.952 in area 2 and 0.907 in area 3 for MC noise. For LV noise, the R^2 value is 0.906 in area 2 and 0.884 in area 3. R^2 value indicates that other variables, apart from the dimensions and speed of the speed bump, also contribute to the increase in noise levels.

Table 9. Motorcycle Noise Levels (Area 2)

Model	R ²	T-test	F test
Method Stepwise: $Y = 2.342 + 0.199X_1$	0.952	significant	significant
Method Enter: $Y = 4.492 + 0.067X_1 - 0.006X_2 + 0.058X_3$	0.995	not significant	not significant
$Y = 2.771 + 0.174X_1 + 0.012X_3$	0.978	not significant	significant
$Y = 2.342 + 0.199X_1$	0.952	significant	significant
$Y = 4.881 - 0.074X_3$	0.781	significant	not significant

Table 10. Motorcycle Noise Levels (Area 3)

Model	R ²	T-test	F test
Method Stepwise: $Y = 3.283 + 0.243X_1$	0.907	significant	significant
Method Enter: $Y = 4.359 + 0.175X_1 - 0.009X_2 + 0.022X_3$	0.994	not significant	not significant
$Y = 2.738 + 0.299X_1 + 0.002X_3$	0.940	not significant	not significant
$Y = 3.283 + 0.243X_1$	0.907	significant	significant
$Y = 5.180 + 0.051X_3$	0.382	not significant	not significant

Table 11. Light Vehicle Noise Levels (Area 2)

Model	R ²	T-test	F test
Method Stepwise: $Y = 2.319 + 0.200X_1$	0.906	significant	significant
Method Enter: $Y = 2.901 + 0.166X_1 - 0.004X_2 + 0.01X_3$	0.963	not significant	not significant
$Y = 2.482 + 0.186X_1 + 0.005X_3$	0.908	not significant	not significant
$Y = 2.319 + 0.2X_1$	0.906	significant	significant
$Y = 4.334 + 0.054X_3$	0.670	significant	not significant

Table 12. Light Vehicle Noise Levels (Area 3)

Model	R ²	T-test	F test
Method Stepwise: $Y = 3.283 + 0.243X_1$	0.884	significant	significant
Method Enter: $Y = 4.359 + 0.175X_1 - 0.009X_2 + 0.022X_3$	0.917	not significant	not significant
$Y = 2.738 + 0.299X_1 + 0.002X_3$	0.887	not significant	not significant
$Y = 3.283 + 0.243X_1$	0.884	significant	significant
$Y = 5.180 + 0.051X_3$	0.763	not significant	not significant

5. Conclusion

It is important to emphasize that this research utilized the linear regression method with the SPSS tool, employing both enter and stepwise methods. The study focused on speed bumps installed on residential roads, which are traversed by all types of vehicles:

- 1) The research results show that the noise level generated by vehicles when passing speed bumps (Area 2) and after passing speed bumps (area 3) is higher than the noise level before the vehicle passes speed bumps (area 1). The average noise level for motorbikes is 65.8 dBA in Area 1, 69.3 dBA in Area 2, and 70.5 dBA in Area 3. Meanwhile, the light vehicles' noise level is 64.7 dBA in Area 1, 68.2 dBA in Area 2, and 69.3 dBA in Area 3. Another finding from this research is that the noise level of motorcycles is greater than that of light vehicles.
- 2) The linear regression analysis results underscore the research's practical implications. They show that speed bump width has a lower correlation to increased noise compared to speed bump height and reduced speed. The statistical tests that best meet the requirements reveal a

significant relationship between increased noise and the dimensions of speed bumps and the decrease in speed caused by vehicles when crossing them. This research revealed that while the height of speed bumps can significantly influence noise levels, the width of speed bumps and speed reduction have a smaller effect. These findings can guide urban planners and policymakers in making informed decisions about traffic noise mitigation strategies.

Author Contributions:

Ina Monica Br Tarigan: conceptualization, methodology, data collection, and curation, writing – original draft; Zulfhazli Abdullah: supervision, review and editing, funding acquisition; Muhammad Fauzan: supervision, review and editing; Yulius Rief Alkhaly: methodology, data collection, and curation, review and editing; Muhammad Fikry: visualization, writing – review and editing; Muhammad Basyir: visualization, writing – review and editing; Thierry Yerema Coulibaly: conceptualization, visualization; Herman Fithra: review and editing.

Declaration of Competing Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. M. Haseeb, G. Zandi, N. H. Hartani, M. H. Pahi, and S. Nadeem, "Environmental analysis of the effect of population growth rate on supply chain performance and economic growth of Indonesia," *Ekoloji*, vol. 28, no. 107, pp. 417–426, 2019.
https://www.researchgate.net/publication/340598135_Environmental_Analysis_of_the_Effect_of_Population_Growth_Rate_on_Supply_Chain_Performance_and_Economic_Growth_of_Indonesia
2. A. T. Moreno and A. García, "Use of speed profile as surrogate measure: Effect of traffic calming devices on crosstown road safety performance," *Accid. Anal. Prev.*, vol. 61, pp. 23–32, 2013,
<https://doi.org/10.1016/j.aap.2012.10.013>
3. T. A. O. Salau, A. O. Adeyefa, and S. A. Oke, "Vehicle speed control using road bumps," *Transport*, vol. 19, no. 3, pp. 130–136, 2004, <https://www.tandfonline.com/doi/abs/10.1080/16484142.2004.9637965>
4. A. Jaganaputra and T. B. Joewono, "Pengaruh Penggunaan Speed Humps Terhadap Tingkat Kebisingan," *J. Transp.*, vol. 11, no. 1, pp. 19–28, 2011.
<https://journal.unpar.ac.id/index.php/journaltransportasi/article/view/439>
5. P. Kokowski and R. Makarewicz, "Predicted effects of a speed bump on light vehicle noise," *Appl. Acoust.*, vol. 67, no. 6, pp. 570–579, 2006, <https://doi.org/10.1016/j.apacoust.2005.10.001>
6. K. S. Radhiah Bachok, A. A. Kadar Hamsa, M. Z. Bin Mohamed, and M. Ibrahim, "A theoretical overview of road hump effects on traffic noise in improving residential well-being," *Transp. Res. Procedia*, vol. 25, pp. 3383–3397, 2017, <https://doi.org/10.1016/j.trpro.2017.05.224>
7. F. Soriguera and F. Robusté, "Estimation of traffic stream space mean speed from time aggregations of double loop detector data," *Transp. Res. Part C Emerg. Technol.*, vol. 19, no. 1, pp. 115–129, 2011,
<https://doi.org/10.1016/j.trc.2010.04.004>
8. R. Burkard, "Sound pressure level measurement and spectral analysis of brief acoustic transients," *Electroencephalography and clinical Neurophysiology*, vol. 57, no. 1, pp. 83–91, 1984,
[https://doi.org/10.1016/0013-4694\(84\)90010-5](https://doi.org/10.1016/0013-4694(84)90010-5)
9. A. Wald, "A Note on Regression Analysis Author (s): Abraham Wald Source: The Annals of Mathematical Statistics, Vol. 18, No. 4 (Dec., 1947), pp. 586–589 Published by: Institute of Mathematical Statistics Stable URL: <http://www.jstor.org/stable/2236237>," vol. 18, no. 4, pp. 586–589, 1947, [Online]. Available: <https://www.jstor.org/stable/2236237>
10. W. T. Bhirawa, "Proses Pengolahan Data Dari Model Persamaan Regresi Dengan Menggunakan Statistical Product and Service Solution (SPSS)," *Statistika*, pp. 71–83, 2020, [Online]. Available: <http://journal.universitassuryadarma.ac.id/index.php/jmm/article/download/528/494>
11. M. Gregorich, S. Strohmaier, D. Dunker, G. Heinze, "Regression with Highly Correlated Predictors: Variable Omission Is Not the Solution" *Int. J. Environ. Res. Public Health* 2021, 18(8), 4259; <https://doi.org/10.3390/ijerph18084259>