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Noise mapping due to motor vehicle activities in the by-pass ring road area of the city of Kendari

Keywords: traffic, noise exposure, mapping, ring road

Introduction

The issue of traffic noise constitutes a critical concern and a pervasive transportation challenge in urban areas, primarily driven by the rapid growth of motorized vehicles. This is also stated by Shvetsov (2021) that the noise level in modern cities continues to increase every year, primarily attributed to motor vehicles on highways. At certain intensities, this auditory intrusion can detrimentally affect the well-being and comfort of people in settlements, as well as road users themselves. Recent data indicates an annualized growth rate of 3% in motorized vehicles over the past three years in Indonesia (Kepolisian Republik Indonesia, 2021). Paradoxically, this surge in vehicles is not proportionately matched by the development of the road infrastructure, with the road growth rate languishing at a mere 0.6% per annum (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2021).

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This lopsided growth dynamic creates problems that permeate the transportation system's comfort, notably manifesting as traffic congestion. Simultaneously, the escalating prevalence of motorized vehicles contributes to the degradation of environmental quality, with noise pollution emerging as a prominent byproduct. In the urban milieu, evading traffic noise has become a challenging feat (Kim et al., 2012). Despite the numerical preponderance of two-wheeled vehicles, it is the light vehicles that emerge as the principal contributors to noise pollution in urban areas, even when their numerical representation is dwarfed by that of two-wheeled vehicles in Indian urban settings (Agarwal & Swami, 2011).

As the capital of Southeast Sulawesi Province and a major city in Indonesia, the city of Kendari is poised to grapple with noise phenomena similar to developed countries and other major urban centers. Prior research in control locations has discerned noise levels reaching 75 dB (Lakawa, Sufrianto & Jusrin, 2021). This aligns with preliminary observations at various points in the by-pass ring road area of the city of Kendari, identifying noise levels peaking at 73 dB, surpassing the noise threshold stipulated in Indonesia (KEP-48/MENLH/11/1996).

Thus far, information on traffic noise distribution on highways has predominantly relied on numerical data, portraying trend descriptions that might not be readily comprehensible to the wider public. Moreover, the delineation of noise distribution across various land uses, particularly in the city of Kendari, remains an unexplored territory. This study seeks to address these gaps by presenting traffic noise variables as vector data, translating points of noise elevation into digitized representations. This approach aims to visually articulate information on traffic noise exposure.

The by-pass ring road in the city of Kendari connects the city center with the developing hinterland areas on the outskirts. Sections of this ring road include Edi Sabara Street, M. Joenoes, MT. Haryono, AH. Nasution, Malaka, ZA Sugianto, and Tapak Kuda. These road segments experience heavy motor vehicle traffic, leading to occasional congestion at specific hours. This situation has the potential to escalate traffic noise levels on the highways. The key question is the extent of traffic noise intensity and its distribution in the by-pass ring road area. In light of these considerations, a study was conducted in the by-pass ring road area of the city of Kendari. The research aims to determine roadside noise levels, predict noise exposure in land use, and map the distribution of noise.

Material and methods

Transportation challenges in urban areas encompass a spectrum of issues, including traffic congestion, parking, public transportation, pollution, and traffic order. While considerable attention is often directed toward mitigating traffic congestion, an equally crucial concern stems from the noise generated by motorized vehicles on highways, known as traffic noise. Existing prediction models for traffic noise on collector roads incorporate independent variables such as vehicle volume, motorcycle speed, light vehicle speed, heavy vehicle speed, and noise measurement distance (Wedagama, 2012).

Numerous international studies highlight that highways constitute the primary source of noise in urban areas. This prevalence arises from the extensive use of motorized vehicles, including two-wheelers, four-wheelers, and those with more than four wheels. Notably, heavy vehicles (trucks, buses) and passenger cars emerge as the primary contributors to road noise, with motorcycles dominating at 60% (Mondal, 2013).

Predicting traffic noise extends beyond vehicle-related variables, encompassing traffic parameters, road characteristics, environmental conditions, weather variables, and residential parameters. Noise prediction involves not only vehicle volume and the percentage of heavy vehicles, but also factors like average vehicle speed and road conditions such as height, width, and gradient (Tripathi, Mittal & Ruwali, 2012). The level of traffic noise is further influenced by the distance between the noise source and the receiver, with an average reduction of 1.3 dB as the distance increases (Handayani, Rahadi & Hadiani, 2016). According to Lakawa, Hujiyanto and Haryono (2023), the parameters triggering urban traffic noise include traffic factors such as vehicle volume, speed, density, and vehicle composition. Physical road factors encompass superelevation, gradient, road width, road type, and road surface conditions. Environmental road factors include building density, tree density, leaf volume, ground surface type, and air temperature. However, from a different perspective, Kuehnel, Moeckel and Ziemke (2021) argue that responses to noise exposure differ between high and low-income households.

Despite the prevalence of road noise, comprehensive studies addressing its multifaceted nature have been limited. The intricacies lie in the diverse sources contributing to road noise, with heavy vehicles, constituting 4%, playing a crucial role on arterial roads but demonstrating lesser significance on collector roads, where their composition is 3%. In these settings, noise is more prominently influenced by motorcycles and light vehicles (Lakawa, Samang, Selintung & Hustim, 2015). The dispersion of noise exposure on highways occurs in all directions, involving absorption, transmission, and reflection.

International studies have leveraged advanced technologies to predict and address traffic noise. In Korea, a study utilized SoundPLAN software to predict noise distribution and facilitate noise reduction initiatives during and after road construction projects. The results revealed that increased traffic volume due to industrial area development had a more substantial impact on the surrounding area than on the industrial zone itself (Jeong, Din, Otsuru & Kim, 2010). Sotiropoulou, Karagiannis, Vougioukas, Ballis and Bouki (2020) conducted measurements and predictions of traffic noise in front of high-rise buildings in Athens using the calculation of road-traffic noise (CRTN) method. They found a high consistency between the predicted and measured noise levels. This model is suitable for predicting traffic noise in front of tall buildings during the planning and design phases.

Similarly in Surat, India, traffic noise mapping was conducted using the RLS-90 computer simulation model, integrating noise data, road inventory, geometric features, vehicle volume, speed, and meteorological data. The approach allowed for the incorporation of horn correction values to assess heterogeneous traffic conditions (Sonaviya & Tandel, 2020).

Novel methods, such as utilizing Google API for traffic flow data, have been employed to predict noise levels in Rome and Pisa. The BPR model estimated traffic volume, and the resulting noise mapping generated conventionally and from big data, offered valuable insights (Licitra, Moro, Teti & Del Pizzo, 2021). In the Delhi region, India, digital maps generated through optimization techniques illustrated horizontal and vertical noise level profiles with variations in measurement distances (Akhtar, Ahmad & Gangopadhyay, 2012).

A road traffic noise model developed using a graph theory approach, incorporating variables like vehicle speed, traffic volume, road width, the number of heavy vehicles, and horn sound, has demonstrated satisfactory performance. Despite slightly elevated results, this method proves effective in predicting future noise levels (Gilani & Mir, 2021).

Based on the research objectives of obtaining roadside noise levels, predicting noise exposure in land use, and mapping the distribution of noise in the area, the data collection activities are systematically conducted following survey procedures. Stage 1 involves the identification and analysis of traffic data. The survey is carried out at 11 points in the by-pass ring road area of the city of Kendari (Fig. 1), with observation times of 10 $\text{min}\cdot\text{h}^{-1}$. The observation time is set at 10 min based on the noise survey procedures (KEP-48/MENLH/11/1996). Location selection is varied to represent various land use types along the road, such as settlements, commercial, services, and school areas.

The identification and analysis of noise levels aims to obtain existing traffic noise values at the roadside. The noise survey is carried out simultaneously with the traffic survey, utilizing a sound level meter (SLM) for noise measurement (Fig. 2). Additionally, field coordinates are digitized during this stage. The existing noise data are then analyzed using mathematical equations. The final stage involves mapping the noise distribution using an overlay approach in ArcGIS. In the mapping process, noise values are treated as elevation points, and colors are assigned based on noise interval levels. This method provides a visual representation of noise levels across the area.

Lakawa, I., Syamsuddin, Hujiyanto, Ilham, V. A. (2023). Noise mapping due to motor vehicle activities in the by-pass ring road area of the city of Kendari. *Sci. Rev. Eng. Env. Sci.*, *32* (4), 392–406. DOI 10.22630/srees.5550

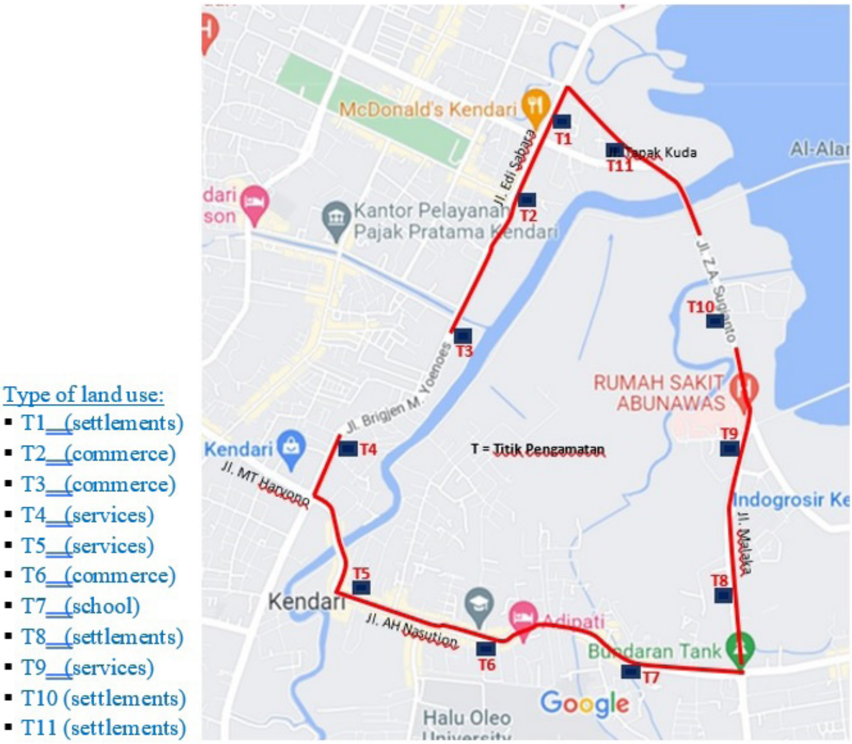

FIGURE 1. Observation point locations

Source: own work.

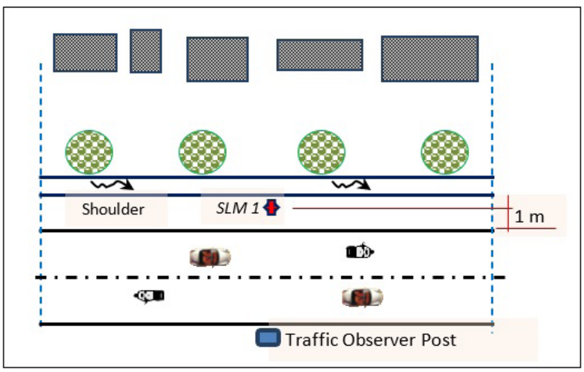

FIGURE 2. Noise measurement scheme

Source: own work.

Integral to this investigation is the establishment of a threshold value for noise levels. This value represents the maximum allowable noise limit to be emitted into the environment without causing health disturbances for humans and environmental discomfort. The calculation of the equivalent noise level (L_{eq}) was conducted using the following equation:

$$L_{eq} = L_{50} + 0.43(L_1 - L_{50}), \quad (1)$$

where: L_{eq} is the equivalent noise level [dB], L_{50} is the 50% noise percentile [dB], and L_1 is the 1% noise percentile [dB].

The values of L_{50} and L_1 are obtained from the readings of the SLM during the survey, according to the following equation:

$$L_{eq2} = L_{eq1} - 10\log(r_2/r_1), \quad (2)$$

where: L_{eq2} is the noise level at r_2 distance from the center of the road noise source [dB], L_{eq1} is the noise level at r_1 distance from the center of the road noise source [dB], r_1 is the distance from the noise source to the SLM measuring position [m], and r_2 is the distance from the noise source to the building wall [m].

The threshold value for noise levels represents the maximum permissible limit of noise released into the environment, aiming to prevent health risks and ensure environmental comfort. Table 1 outlines the noise standards in Indonesia, referring to the Minister of State for the Environment of the Republic of Indonesia's decree KEP-48/MENLH/11/1996.

TABLE 1. Noise level quality standard

Type of land use	Noise level standards [dB]
1. Appropriation of region	
a) housing and settlements	55
b) trade and services	70
c) office and commerce	65
d) green open space	50
e) industry	70
f) government and public facilities	60
g) recreation	70

TABLE 1 (cont.)

h) specifically – airport* – railway station* – harbor – cultural heritage	 70 60
2. Surrounding activity	
a) hospital or the like	55
b) school or the like	55
c) worship place or the like	55

*In accordance with the regulations of the Minister of Transportation PM 62/2021 and PM 175/2015.

Source: Minister of State for the Environment of the Republic of Indonesia's decree KEP-48/ /MENLH/11/1996.

Results and discussion

The study focuses on traffic volume, particularly the number of motorized vehicles traversing the by-pass ring road area, serving as a vital connection to developing suburban regions (Fig. 3). Calculations are based on observed vehicle counts at various locations during the study period, converted into passenger car units per hour [$pcu \cdot h^{-1}$].

Notably, the highest vehicle volume is recorded on ZA Sugianto Street at 2,734 $pcu \cdot h^{-1}$, followed by MT. Haryono Street (1,937 $pcu \cdot h^{-1}$), M. Joenoes Street (1,868 $pcu \cdot h^{-1}$), Edi Sabara Street (1,630 $pcu \cdot h^{-1}$), Malaka Street (1,375 $pcu \cdot h^{-1}$), Tapak Kuda Street (1,300 $pcu \cdot h^{-1}$), and the lowest on AH Nasution Street (1,229 $pcu \cdot h^{-1}$). Motorcycles dominate the composition at 68%, followed by light vehicles at 27%, and heavy vehicles at 5%. Peak traffic hours vary; MT Haryono and AH Nasution streets peak in the morning, Edi Sabara and Brigjen M. Joenoes streets peak during the day, while Malaka, ZA Sugianto, and Tapak Kuda streets peak in the evening. Notably, motorcycle compositions in medium and large cities typically range from 60–70%. Survey results include the coordinates of each location (refer to Table 2), while L_{eq} noise values are obtained using Equation (1).

Figure 4 illustrates that traffic noise levels along the by-pass ring road surpass the environmental noise threshold outlined in the Minister of State for the Environment of the Republic of Indonesia's decree (KEP-48/MENLH/11/1996) for settlements/ /school, office, and commerce/service areas. The average noise level on the highways is 76 dB, with the level reaching the receiver at 67 dB, indicating an average noise reduction of 9 dB. The average distance from the receiver to the noisy road source is 14 m, resulting in a noise reduction of 2 dB·m^{-1}. Noise levels are influenced by land use, with the commerce area exhibiting the highest noise levels, followed by service and school areas, and the lowest in front of settlement areas. These variations are intricately linked to the activities associated with each land use (Table 3).

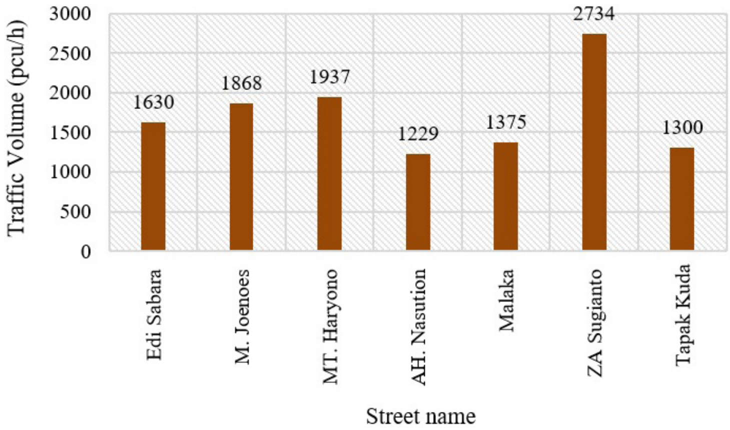

FIGURE 3. Volume traffic on seven regional roads traversing the by-pass
Source: own work.

TABLE 2. Point coordinates and noise values

Street name	Location code	Point 1 (1 m from the roadside)			Noise level [dB]		
		coordinate	east longitude	south latitude	L_1	L_{50}	L_{eq}
Jl. Edi Sabara	T.1	1183	122° 31' 30.54" E	3° 58' 29.60" S	81.9	71.7	75.7
Jl. M. Joenoes	T.2	1185	122° 31' 21.90" E	3° 58' 47.43" S	84.4	73.1	78.0
Jl. M. Joenoes	T.3	1187	122° 31' 11.91" E	3° 59' 8.55" S	88.4	72.6	79.4
Jl. M. Joenoes	T.4	1189	122° 30' 53.22" E	3° 59' 25.00" S	85.2	72.2	77.8
Jl. MT. Haryono	T.5	1191	122° 30' 55.52" E	3° 59' 53.91" S	83.6	71.6	76.8
Jl. AH. Nasution	T.6	1197	122° 31' 14.57" E	3° 59' 59.69" S	83.8	69.3	75.5
Jl. AH. Nasution	T.7	1199	122° 31' 46.97" E	4° 0' 5.17" S	87.6	68.2	76.5
Jl. Malaka	T.8	1203	122° 32' 2.49" E	3° 59' 28.33" S	83.6	69.7	75.7
Jl. Malaka	T.9	1201	122° 32' 1.27" E	3° 59' 56.09" S	81.7	70.2	75.1
Jl. ZA Sugianto	T.10	1205	122° 32' 1.26" E	3° 59' 10.50" S	85.6	71.9	77.8
Jl. Tapak Kuda	T.11	1207	122° 31' 42.54" E	3° 58' 36.36" S	81.8	70.7	75.5

Source: own work.

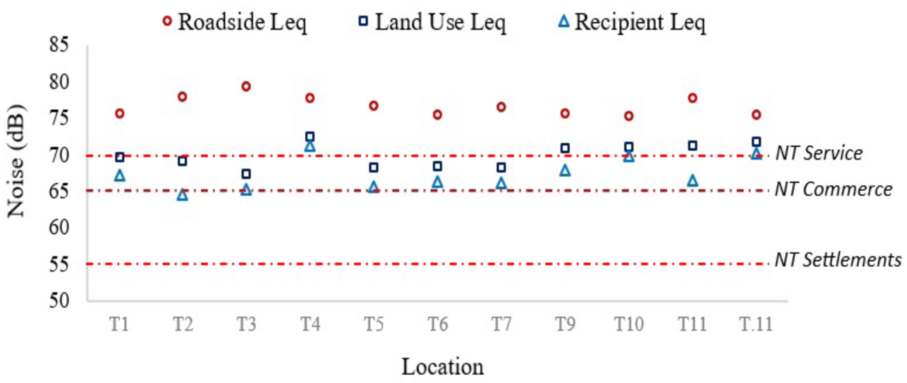

FIGURE 4. Traffic noise level on the highway, NT Settlements 55 dB, NT Commerce 65 dB, and NT Service 70 dB

Source: own work.

TABLE 3. Types of land use and exposure distance

Street name	Location code	Type of land use	Exposure distance [m]	
			source-SLM (r_1)	source-land use (r_2)
Jl. Edi Sabara	T1	settlements	9	18
Jl. M. Joenoes	T2	commerce	9	36
Jl. M. Joenoes	T3	commerce	9	26
Jl. M. Joenoes	T4	services	9	16
Jl. MT Haryono	T5	services	7	19
Jl. AH Nasution	T6	commerce	8	19
Jl. AH Nasution	T7	school	8	21
Jl. Malaka	T8	settlements	9	20
Jl. Malaka	T9	services	9	18
Jl. ZA Sugianto	T10	settlements	7	32
Jl. Tapak Kuda	T11	settlements	5	13

Source: own work.

Based on the roadside noise level (L_{eq}) values in Table 2 and the r_1 and r_2 exposure distances, the predicted results of noise distribution in land use are obtained using Equation (2), as seen in Figure 5.

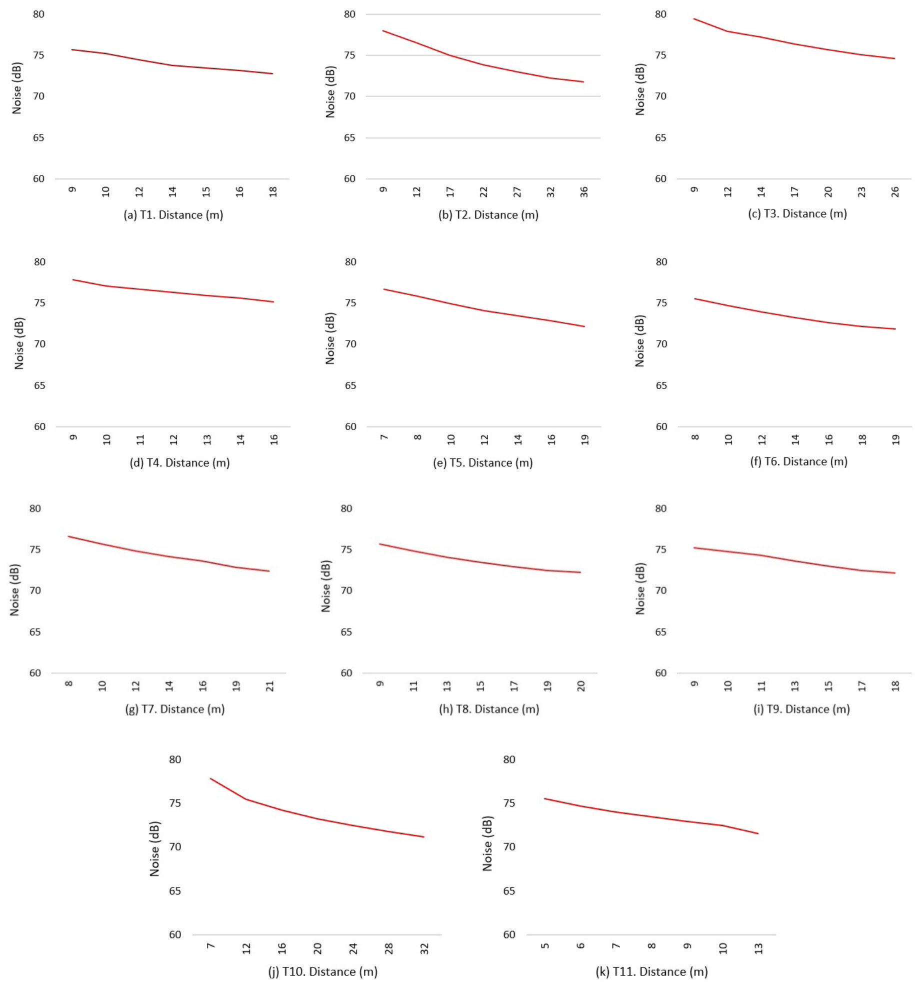

FIGURE 5. Prediction of noise exposure in land use based on the distance from the roadside
Source: own work.

Figure 5 illustrates the varying noise exposure across different land uses in the research area. The service area at Point T4 exhibits the highest noise level at 75.2 dB, succeeded by the commerce area at Point T3 with a measurement of 74.6 dB. Other notable levels include the settlements area at Point T1 (72.8 dB), school area at Point T7 (72.4 dB), service area at Point T5 (72.2 dB), settlements area at Point T8 (72.2 dB), service area at Point T9 (72.2 dB), commerce area at Point T6 (71.8 dB), settlements area at Point T11 (71.5 dB), and the lowest in the settlements area at Point T10 (71.2 dB).

The analysis emphasizes that noise intensity diminishes with increased distance from the noise source to the receiver. According to Lakawa, Hujiyanto, Sulaiman and Haryono (2022), a reduction in noise levels within an area may occur due to increased distance, resulting in an average decrease of 1.3 dB. Consequently, the determination of noise exposure hinges on the intensity within a specific area and the duration of exposure. Disparities in noise reduction among the eleven areas stem from both the augmented distance and the magnitude of the roadside noise level. Additionally, variations are influenced by the type of land surface transitioning from the roadside to land use, along with the extent and density of greenery or tree planting along the roadside.

The mapping results indicate that the noise intensity in the by-pass ring road area is best understood by observing the color intervals of contour lines. Yellow and red colors signify a moderate level of noise (Fig. 6). Furthermore, the noise exposure reaching land use planning exceeds the noise threshold set in Indonesia. This potential overstep poses a threat to the health and comfort of both road users and residents living along the road. For instance, hearing impairment can be temporary or permanent, depending on the duration and frequency of exposure to noise.

a b

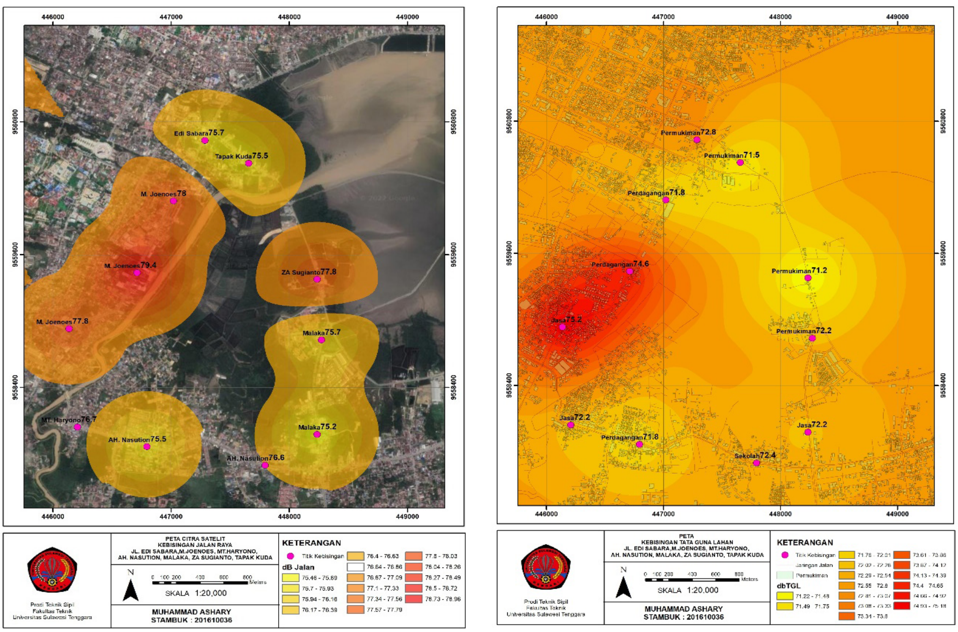

FIGURE 6. Noise distribution map: a – noise distribution at the roadside; b – noise exposure that reaches land use

Source: own work.

In a comparative context, noise level mapping was conducted in Rome during the COVID-19 pandemic, focusing on strategies to control the virus. The mapping generated a noise emission map, exploring scenarios of restricting private vehicle travel and scenarios of easing private vehicle use (Aletta et al., 2020). Notably, this mapping exercise did not explicitly depict noise level limits. Similarly, noise mapping was undertaken to evaluate noise disturbances stemming from the operations of Athens International Airport. The analysis revealed that the community experienced noise levels surpassing 70 dB. The mapping exercise involved a comparative analysis of strategic noise maps between 2017 and 2019, considering daytime and nighttime noise indices. Furthermore, this study formulated an action plan for Athens International Airport, commencing in 2007 (Vogiatzis, Dimitriou & Gerolymatou, 2019). Similarly, noise measurements were conducted in Tehran using the FHWA TNM software. This model considers barrier parameters, trees, sidewalks, and slopes. The research produced a traffic noise map based on a combination of modeling and field measurement results. The study's findings highlighted that a significant number of trucks in Tehran are outdated, contributing to elevated noise levels (Mohamady, Noorpoor & Bayatian, 2021).

Distinctively, the present research has successfully generated a traffic noise map for the highway, delineating its distribution across various land uses and receivers. This distribution encompasses commerce areas, services, schools, and settlements areas. The mapping results provide a visual indication of areas where noise levels surpass the regulatory limits set forth in Indonesia.

Conclusions

The vehicle composition along the by-pass ring road is dominated by motorcycles at 68%, followed by light vehicles at 27%, and heavy vehicles at 5%. The average noise level on the highway is 76 dB, with land use patterns significantly influencing noise fluctuations on the road. The highest noise levels occur in the commerce area, followed by service and school areas, while the lowest levels are observed in front of residential areas. This correlation is closely related to the movement patterns associated with each land use. Notably, the trend is consistent: the farther the distance from the noise source to the receiver, the lower the intensity of the noise. This highlights the crucial role of spatial distance in determining noise exposure levels.

To mitigate traffic noise in the by-pass ring road area of the city of Kendari, it is recommended to implement green landscaping, specifically by planting trees along the road. This strategic tree planting approach can effectively reduce traffic noise. Additionally, combining tree planting with creeping plants can further enhance the noise reduction efforts.

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Summary

Noise mapping due to motor vehicle activities in the by-pass ring road area of the city of Kendari. The by-pass ring road in Kendari serves as a crucial artery, facilitating accessibility and mobility between the city center and the expanding outskirts. However, heightened traffic has led to a notable upswing in noise along the highway. This study aims to systematically map the distribution of this noise across various land uses in the vicinity. To accomplish this, measurements were taken at eleven specific points along the road, utilizing a sound level meter (SLM). The collected data, encompassing noise levels on the highway and its impact on different land uses, underwent a thorough analysis through mathematical equations. Subsequently, mapping was executed using the overlay method based on coordinate points. The findings reveal a vehicular composition predominantly comprised of motorcycles (68%), followed by light vehicles (27%), and heavy vehicles (5%). Notably, although heavy vehicles constitute a mere 5%, they significantly influence the elevation of noise levels. The highest noise intensity impacting land use is observed in service areas, succeeded by commercial and school zones, with the lowest levels recorded in settlement areas. The mapped results depict a noise exposure of 67 dB reaching receptors, coupled with an average noise reduction of 9 dB. Remarkably, as the average distance from the noise source on the highway to the receptors increases (averaging 14 m), there is a discernible reduction in noise intensity. This visually apparent trend is corroborated by the noise mapping results.