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Dynamic analysis of traffic noise across various land uses based on real-time data

Keywords: noise mapping, traffic, land use, real-time data

Introduction

One type of environmental pollution that significantly affects people's health and quality of life in big cities is traffic noise. The distribution of noise tends to vary depending on land use factors, such as residential, commercial, and industrial areas. At present, noise has become a serious environmental issue that must be taken into account in sustainable development policies (Othman et al., 2024). Therefore, understanding the distribution of noise across various types of land use is crucial for designing more effective environmental management policies. According to Lakawa et al. (2023), physical road characteristics, traffic volume, and roadside environmental conditions are some of the elements that can be used as indications of what causes traffic noise in metropolitan settings.

Traffic noise has become one of the strategic transportation issues in urban areas due to the increasing growth of motor vehicles (Graziuso et al., 2022; Meller et al., 2023). This condition is also observed in Kendari City. According to data,

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the growth rate of motor vehicles in Kendari City averages 9.3% per year (BPS – Statistics Kendari Municipality, 2024). Traffic activity resulting from this growth inevitably triggers traffic noise. The volume of heavy vehicles is the main variable affecting noise levels (Khedaywi et al., 2021).

Previous studies on several road segments in Kendari City found that noise levels had reached 70.5 dB (Lakawa et al., 2023). This figure has already exceeded the environmental noise threshold applicable in Indonesia (Keputusan KEP-48/MENLH/11/1996). At certain intensities, noise not only disrupts hearing but can also affect the physical and psychological health of residents and road users themselves (Sonaviya & Tandel, 2019; Dewi et al., 2023). High noise levels not only endanger human hearing but can also affect safety and work productivity (Starke et al., 2024). Therefore, it is necessary to predict traffic noise levels in the event of land use development (Alam et al., 2020).

Studies integrating real-time data with noise mapping across various land uses are still very limited. In general, research on traffic noise tends not to provide a comprehensive picture and does not take into account the dynamic relationship between noise and land use characteristics. The distribution of traffic noise across various land uses in Kendari City has never been comprehensively mapped, especially using technology based on real-time data. With technological advancements, real-time traffic noise data collection has become more feasible. The use of noise sensors can help accurately map noise distribution. The results of this study are expected to serve as a reference for the Kendari City Government in designing more environmentally friendly and sustainable transportation and spatial planning policies, particularly in noise control.

Materials and methods

Literature review

The noise characteristics of each road segment will naturally differ. This variation is influenced by numerous factors, such as differences in the types of motor vehicles, the proportion of heavy vehicles, vehicle speed, road conditions, and the surrounding environment. The effect of road service level on traffic noise is 31.1% (Lakawa et al., 2024). Therefore, further investigation is needed to identify the patterns of noise distribution across various land uses. According to Adza et al. (2022), traffic control and engineering systems are strategies that can be applied to reduce noise levels. These strategies include imposing vehicle speed limits, providing pedestrian-only zones, and installing traffic lights.

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Numerous large cities worldwide have undertaken studies on traffic noise. However, there is still a dearth of research, especially in small and medium--sized cities, that examines the distribution of noise across different land uses by combining real-time data with GIS-based mapping. Some related studies include mapping noise based on volunteered geographic information and Web mapping technology. Noise data were collected from residents using mobile devices to obtain subjective perceptions of noise in the community (Sofianopoulos et al., 2024).

Ibili et al. (2021) developed a model for interpreting traffic noise, including variations in assumptions. They discovered that the source, the line of sound transmission, and the noise receivers should all be the focus of efficient traffic noise control. Lee et al. (2022) mapped noise across all road types, where computational time efficiency was measured using grid methods and receiver height. Helal et al. (2019) performed real-time 3D noise mapping using 900 autonomous noise sensors, which measured all surrounding noise types such as vehicle sounds, sirens, and human conversations. This approach proved highly effective in improving strategies and policies to reduce urban environmental noise.

Zambon et al. (2018) investigated noise using the Dynamap method, which was developed to predict traffic noise in large urban areas. This system provided an accurate depiction of road traffic noise. Liu et al. (2025) combined geographical models and multi-source data to model noise utilizing IoT technologies. This approach combines a number of data sets, including ADS-B, meteorological, and noise data. The analysis results showed that the noise monitoring method used could effectively interpret noise distribution patterns.

The biggest factor affecting noise intensity is traffic density, which is followed by vehicle volume and speed (Lakawa et al., 2023). Increases in the number of motor vehicles on the road will lead to higher noise levels. Similarly, vehicle speed affects noise intensity-the faster the vehicle, the higher the noise level (Subramani et al., 2012). However, in cities with heterogeneous traffic characteristics, a phenomenon occurs where low vehicle speeds and traffic congestion actually increase traffic noise levels due to the common practice of drivers honking their horns (Lakawa et al., 2015).

Data collection and analysis

In general, the investigation and data analysis process is divided into three stages: data collection, data input/coding, and analysis with discussion. Traffic surveys (vehicle volume and speed) were conducted during peak hours in the morning (06:00–09:00), midday (11:00–14:00), and afternoon (16:00–19:00). Simultaneously, real-time noise measurements were conducted across various land uses using a sound level meter (SLM) integrated with computer software. At each sampling point, two noise measurement units were placed: one at 1 m and the other at 10 m from the roadside. The SLM was installed at a height of 1.2 m above ground level. Subsequently, the coordinates for each noise point were digitized using GPS (Fig. 1). At a certain distance, noise intensity decreases with increasing distance from the roadside (Lakawa et al., 2022).

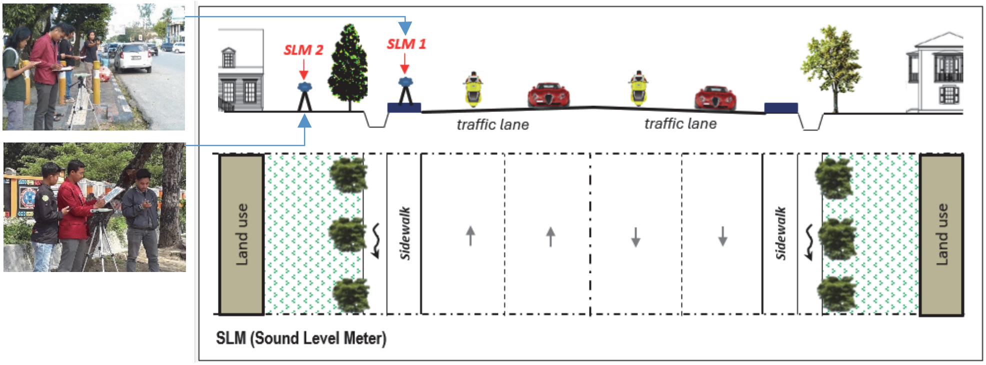

FIGURE 1. Schematic placement of SLM microphones for traffic noise measurement (SLM_1 at 1 m from the roadside, SLM_2 at 10 m from the roadside)
Source: own work.

A mathematical formula is used to determine the equivalent noise level (L_{eq}) based on field data:

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

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

An overlay was then performed according to the coordinate points to identify critical noise distribution. The validation stage involved comparing the analysis results with the noise quality standards set by Decree KEP-48/MENLH/11/1996 of the Minister of State for the Environment of the Republic of Indonesia (Table 1).

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TABLE 1. Noise level standards

Type of land use	Noise level [dB]
Land use designation	
Housing and settlements	55
Trade and services	70
Office and commerce	65
Green open space	50
Industry	70
Government and public facilities	60
Recreation	70
Special	
airport[a]	
railway station[a]	
seaport	70
cultural heritage	60
Surrounding activity	
Hospital or the like	55
School or the like	55
Place of prayer or the like	55

[a]Adjusted to the provisions of the Minister of Transportation.

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

The highest amount of noise that can be released into the atmosphere without endangering public health or environmental comfort is known as the noise threshold value. The average sound pressure level during a certain time period can be expressed using the concept of equivalent noise level (L_{eq}). The sound generated by numerous vibrations dispersed in all directions is known as motor vehicle noise on roadways (Fig. 2).

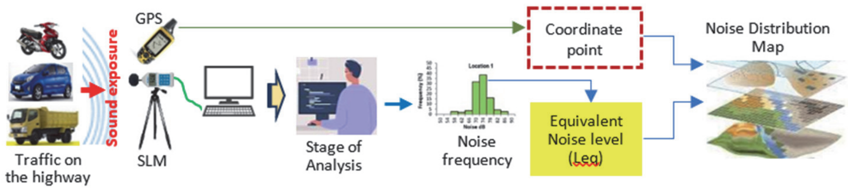

FIGURE 2. Flowchart of the noise monitoring and data analysis process

Source: own work.

Results and discussion

Traffic noise in Kendari City is considerably significant, with most areas exceeding the permissible threshold. Careful attention is required in spatial planning and traffic management to mitigate the impact of noise. Policy implementation is necessary in regulating traffic flow, operational hours for heavy vehicles, and the application of noise-reducing technologies on major roads as potential solutions to reduce noise impacts. This analysis compares noise levels at the roadside and within building yards. Noise levels tend to vary depending on the type of land use.

Figure 3 illustrates the probability distribution of noise levels for various land uses, both at the roadside and within building yards. These values vary according to the type of land use. A probability plot was used to assess whether the noise distribution data follow a normal distribution. The analysis's findings demonstrate that the data are normally distributed since the p-value is higher than 0.05.

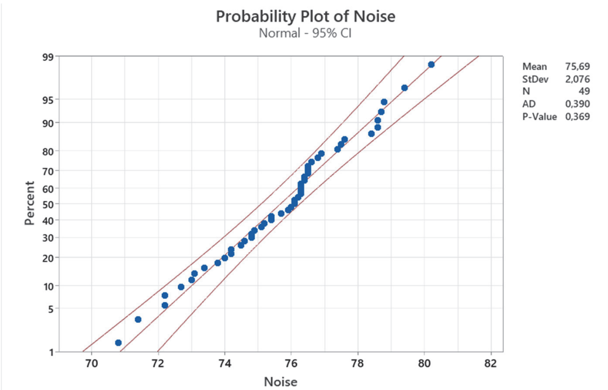

FIGURE 3. Probability of noise levels across various land uses
Source: own work.

Traffic noise was measured using the equivalent noise level (L_{eq}), which serves as a metric for assessing environmental noise caused by road traffic. Statistical analysis of noise levels at each sampling point across various land uses yielded L_{eq} values at the roadside (1 m from the roadside) and within yards (10 m from the roadside).

Traffic noise levels in Kendari City have exceeded the environmental noise thresholds for residential areas, schools, commercial areas, service areas, and public facilities. The average noise level at the roadside was 75.4 dB, while

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at 10 m from the roadside (yard) it was 71.1 dB. The difference in noise intensity between the roadside and the yard was 4.3 dB (Fig. 4). These levels are classified as high and may cause disturbances if exposure is continuous. Service, commercial, and office areas, which function as social activity centers, showed higher noise levels compared to residential areas, schools, and public facilities.

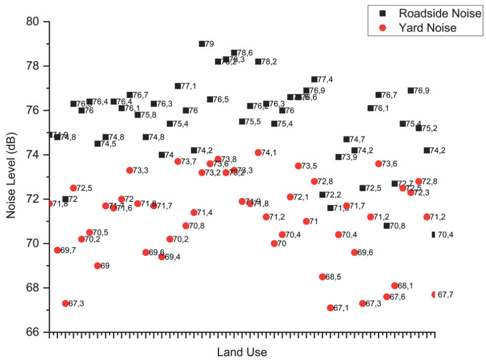

FIGURE 4. Results of the noise level analysis by land use (roadside and yard)
Source: own work.

Nearly all categories of land use in Kendari City are subject to traffic noise levels surpassing the limits established by Decree KEP-48/MENLH/11/1996 of the Minister of State for the Environment of the Republic of Indonesia. This indicates that traffic noise exposure is an aspect that must be taken seriously in spatial planning and transportation system management. Traffic management considerations should include measures such as one-way traffic systems and restrictions on heavy vehicles on certain roads.

Figure 5 illustrates the dynamic relationship between noise, speed, and traffic volume. The graph explains the interaction between traffic factors and noise levels on major roads in Kendari City. The fluctuation of variable values provides insight into how changes in traffic volume and vehicle speed contribute to noise intensity. This dynamic behavior indicates that the higher the traffic volume on a given road, the higher the resulting noise level. This is due to the greater number of vehicles moving along the road, which increases noise generated from vehicle engines, tire-road friction, and horn use. At the same time, vehicle speed tends to decrease due to traffic congestion. This is a logical outcome, as higher traffic volumes and congestion naturally result in reduced speeds. Land uses located along main roads with high traffic volumes will experience higher noise intensities compared to those situated farther from the roadside.

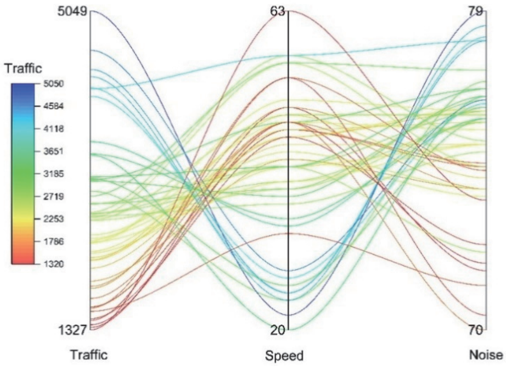

FIGURE 5. Dynamic behavior of traffic characteristics and noise levels
Source: own work.

Figure 6 depicts the critical noise exposure areas in Kendari City as a result of land development. These areas indicate zones that are likely to be affected by traffic noise exceeding environmental thresholds. Critical noise exposure generally occurs in areas with high traffic volumes. Infrastructure development, such as the expansion of commercial areas, can exacerbate this condition. Increased human activity in land use areas that is not balanced with adequate transportation management will result in heightened noise impacts.

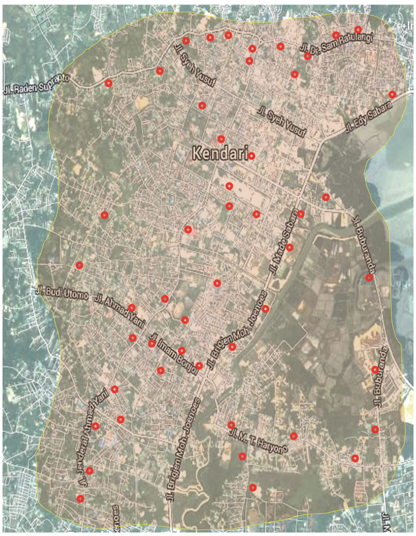

FIGURE 6. Critical noise exposure areas due to land development
Source: own work.

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Several areas experiencing critical noise exposure are strategic points connecting various community activity centers. Land development that fails to consider noise aspects can worsen environmental quality and create high-risk zones for residents, especially those living in residential areas close to main roads. Air pollution and noise constitute significant challenges in urban planning. Industrial zones and highways constitute the principal sources of air and environmental noise pollution (Govea et al., 2024). Wise transportation management policies are urgently needed to mitigate the negative impacts of noise in the future.

The highest noise exposure was recorded in service areas at 76.9 dB, followed by commercial areas at 76.1 dB, office areas at 75.8 dB, school areas at 75.4 dB, residential areas at 74.6 dB, and the lowest in public facility areas at 73.4 dB. High noise exposure in each land use type is influenced by the high trip generation rate of community activities. Additionally, location plays a role – these land uses are strategically situated along roads connecting several nearby community activity centers (Figs. 7 and 8).

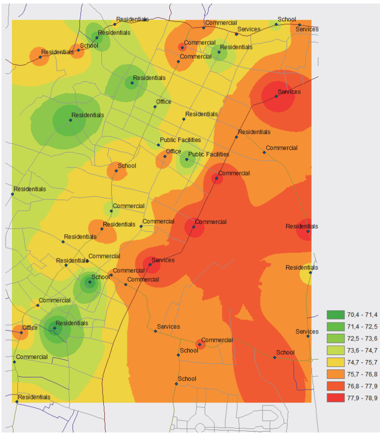

FIGURE 7. Distribution of traffic noise across various land uses

Source: own work.

The findings indicate that noise distribution is influenced not only by traffic volume and vehicle speed but also by the location of land near community activity centers. This phenomenon demonstrates that high-activity areas, such as service, commercial, and office zones, experience higher noise exposure compared to other areas. There is a significant relationship between land use, activity, and noise sources in urban areas (Margaritis et al., 2020). The influence of land use on noise levels is often considered secondary compared to traffic volume and other noise sources. However, the results of this study reveal that the type and location of land use contribute to trip generation, which in turn triggers surrounding traffic noise. Commercial and densely serviced areas are the most affected by extreme noise levels.

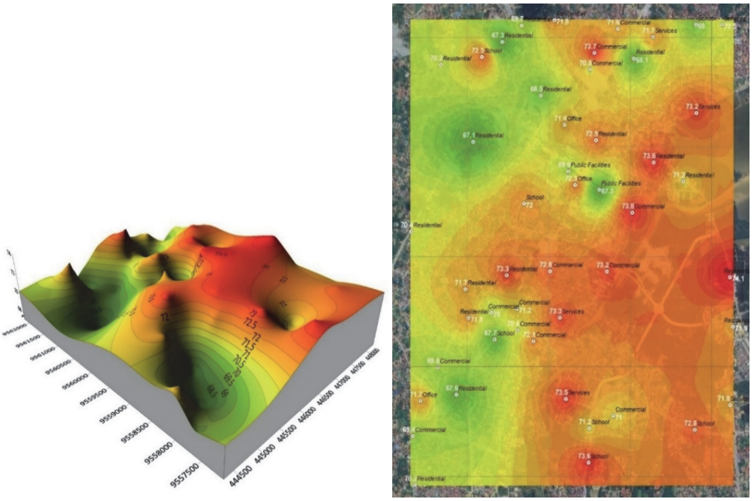

FIGURE 8. Traffic noise exposure at 10 m from the roadside
Source: own work.

Having noise maps facilitates the investigation and identification of problematic locations for urban residents (Lezhneva et al., 2019). Effective spatial planning and transportation system management should be considered to reduce traffic noise, especially in areas with high noise levels. Land use characteristics and traffic patterns inevitably differ between small and large cities. The use of real-time data enables dynamic noise monitoring, allowing changes in traffic conditions and external factors to be accounted for. This study not only measures noise based on traffic zones but also considers various land use types that influence noise levels holistically.

Conclusions

Traffic noise levels in Kendari City have exceeded the thresholds set by the Ministry of Environment of the Republic of Indonesia. The average noise level at the roadside reached 75.4 dB, while at 10 m from the roadside (yard) it was

71.1 dB. The main factors contributing to high noise levels are vehicle volume and the location of land used close to social activity centers. Noise levels vary depending on the type of land use. Office, service, and commercial areas have higher noise levels compared to residential areas, schools, and public facilities. The dynamic noise behavior observed shows that the higher the traffic volume, the greater the noise level produced.

The increase in noise intensity can endanger the health and comfort of residents living near roads. To mitigate noise impacts, integrated spatial policies are required in conjunction with transportation planning and management, such as regulating traffic circulation patterns and implementing green zones along roads. The Kendari City Government must take noise aspects into account in spatial planning, paying attention to the arrangement of green zones in accordance with noise potential. The implementation of green zones along roads, using natural barriers, can help reduce exposure to traffic noise.

The novelty of this research lies in the real-time data integration approach to map the distribution of traffic noise by land use types. This study not only measures noise levels statistically, but also considers the dynamic relationship between traffic volume, vehicle speed, and land use characteristics.

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Summary

Dynamic analysis of traffic noise across various land uses based on real-time data. Traffic noise is one of the most significant forms of environmental pollution in urban areas. It can have negative impacts on both road users and residents living near highways. The high growth rate of motor vehicles from year to year in Kendari City has triggered an increase in traffic noise levels. This study aims to analyze the distribution of traffic noise across various land uses by utilizing real-time data. Noise measurements were conducted using a sound level meter (SLM) at several sampling points representing residential, commercial, service, office, school, and public facility areas. The SLM was positioned 1 m and 10 m away from the edge of the road. According to the findings of the analysis, Kendari City's traffic noise levels have exceeded the environmental noise threshold. The study found that the main factors contributing to high noise levels are traffic volume and low vehicle speed. Areas with high traffic volumes, such as service, commercial, and office zones, produce higher noise exposure compared to other land use types. Land uses located near social activity centers are significantly impacted by noise exposure. Real-time data-based noise mapping is highly effective in designing sustainable urban transportation and spatial planning policies in cities with heterogeneous traffic categories.