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TIRE-PAVEMENT NOISE ANALYSIS ON THE LOJA-MALACATOS ROAD: A CASE STUDY

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A B S T R A C T

This study analyzes the noise generated by tire-pavement interaction on the Loja-Malacatos road, a 34 km mountainous route in southern Ecuador, where numerous houses are located just meters from the roadway. The Statistical Pass-By (SPB) method, following ISO 11819-1 standards, was applied to measure the impact of traffic on residents' quality of life. The pavement consists of a dense-graded asphalt mix (Tmax 12.5 mm) with AC-20 binder and an asphalt content of 6.61%. Noise measurements ranged from 63.3 dB to 68.2 dB, exceeding both the World Health Organization's recommended limit for residential areas (55 dB during daytime) and the Federal Highway Administration's (FHWA) mitigation threshold of 67 dB(A) for pass-by events near residential zones. In addition to confirming the direct relationship between vehicle speed and increased noise levels, it was found that trucks significantly contribute to noise pollution as they pass close to homes. This study is part of a broader program that will assess the health of the exposed population and develop mitigation measures, such as redesigning house facades to reduce interior noise. The findings highlight the urgent need to adopt sustainable road infrastructure approaches and urban planning initiatives that prioritize the well-being of communities affected by noise pollution.

1. INTRODUCTION

Prolonged exposure to high noise levels can lead to various health problems, including stress and cardiovascular diseases (Hrapović, 2024). Pavement conditions directly influence tire-pavement noise, as surface characteristics such as macrotexture, stiffness, and porosity affect sound propagation and, in some cases, contribute to increased noise levels. Studies show that rehabilitating pavements with optimized wearing courses can significantly reduce traffic noise (Ramos et al., 2024).

Tire-pavement interaction is one of the main sources of noise pollution on both urban and rural roads. To assess this noise, the Statistical Pass-By (SPB) method, described in ISO 11819-1, measures noise generated by passing vehicles and analyzes its relationship with vehicle speed and pavement surface characteristics.

This study applied the SPB method on the Loja-Malacatos road to quantify traffic noise and evaluate its impact on nearby residents. According to the World Health Organization (WHO), environmental noise levels in residential areas should not exceed 55 dB during daytime and 45 dB at night to protect public health (OMS, 2022). The Federal Highway Administration (FHWA) sets a higher mitigation threshold of 67 dB(A) for pass-by events near residential areas, recommending

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noise barriers when this threshold is exceeded (Hanson, James, & Nesmith, 2004).

Results show that noise levels exceed 65 dB, surpassing WHO recommendations. A direct correlation between vehicle speed and noise levels was also observed, emphasizing the need for mitigation strategies such as noise-reducing pavements and speed control measures. The application of the SPB method provides reliable data essential for planning sustainable road infrastructure and reducing noise pollution in residential areas.

2. MATERIALS AND METHODS

2.1 Study Area

The research was conducted on the Loja-Malacatos road, a 34 km mountainous stretch located in Loja Province, Ecuador. The region's temperate climate, characterized by a rainy season, impacts terrain stability and accelerates pavement deterioration. Six critical points were identified for vehicle noise analysis, selected based on their proximity to residential areas and traffic intensity. This road connects the city of Loja, located at approximately 2,060 meters above sea level, with the parish of Malacatos, situated at around 1,470 meters above sea level. The geographic coordinates for Loja are approximately 3.9931° S latitude and 79.2042° W longitude, while Malacatos is near 4.1738° S latitude and 79.2190° W longitude (Municipio de Loja, n.d.).

The road crosses mountainous terrain with gradients ranging between 13% and 14%, influencing both the road conditions and vehicle speeds (She, Jiang, Tam, Zuo, & Wang, 2021). The region experiences a rainy season from December to April, which can further affect pavement conditions (INAMHI, n.d.). Small streams and watercourses are also present along the corridor, contributing to potential terrain instability and additional pavement deterioration during the rainy season (Molina-Sánchez, Chávez-Morales, Palacios-Vélez, & Ibáñez-Castillo, 2022).

The surface layer of the pavement consists of a dense-graded asphalt mix with a nominal maximum aggregate size (NMAS) of 12.5 mm, using AC-20 asphalt binder sourced from the Esmeraldas Refinery, with an optimal asphalt content of 6.6%. Aggregates were sourced from the Piscobamba River Quarry, meeting the specifications set by the Ministry of Transport and Public Works (MTOP), as defined in MOP-001-F-2002 standards. The gradation includes 15% retained between the 3/4" and No. 4 sieves, 65% passing the 3/8" sieve, and 20% fine sand, ensuring compliance with wearing course requirements. The asphalt mix achieved the following properties: stability of 2590 lb (>2200 lb), flow of 11.5 (specification: 8-14 per 100 inches), air voids of 4.0% (specification: 3-5%), and VMA of 14.25% (specification: >14%).

2.2 Data and Materials

This research relied on various secondary data sources provided by local and national institutions. One of the primary sources was the Ministry of Transport and Public Works (MTOP), which provided information regarding the condition and characteristics of the Loja-Malacatos road, including road plans, maps, traffic data, and maintenance records (MTOP, n.d.). Additionally, data from the Municipality of Loja was used, including urban and rural planning records, topographic maps, and demographic data (Municipio de Loja, n.d.).

Sound level meters were the primary instrument used for data collection and analysis. Noise levels were measured along the road using a Class 2 Integrating Sound Level Meter – HD2010UC, with an accuracy of ±1.5 dB, calibrated according to international standards (Robinson, 2023). Measurements were recorded in decibels (dB) at regular intervals along the road (Khusnutdinov & Nuriev, 2022). A GPS device was used to precisely locate the measurement points along the corridor (Kyes, 2024). Regarding hardware and software, Microsoft Excel was used for data processing, as it effectively organizes, analyzes, and visualizes large datasets (Microsoft Excel, n.d.).

2.3 Study Area

The methodological approach of this research focuses on analyzing how traffic noise affects people living near the Loja-Malacatos road. To this end, an initial analysis of the road was carried out to identify areas where noise might have the greatest impact on residents' quality of life. These critical points were specifically located at the entrances to small towns and in areas where clusters of houses are located in close proximity to the road. These sections were prioritized because they are typically high-traffic zones, particularly during peak hours, which significantly contributes to increased noise levels (Lakawa, Hujiyanto, & Haryono, 2023).

Furthermore, these areas generally have higher population density, increasing the number of people exposed to traffic noise (Meller, de Lourenço, de Melo, & de Campos Grigoletti, 2023). Identifying these critical points provides valuable data for planning effective mitigation measures. Table 1 presents the coordinates of the selected critical points.

Table 1. Coordinates of the selected critical points.

Point	Coordinates
1	4°02'40.7"S 79°11'48.8"W
2	4°04'44.4"S 79°11'47.6"W
3	4°07'10.7"S 79°12'08.3"W
4	4°10'03.0"S 79°12'50.1"W
5	4°12'19.8"S 79°13'31.2"W
6	4°12'55.1"S 79°15'12.9"W

Noise measurements were carried out using the Statistical Pass-By (SPB) method, in accordance with the ISO 11819-1 standard (ISO, 2023). This method evaluates the noise generated by passing vehicles by measuring the maximum A-weighted sound pressure level (Lveh) for each vehicle and correlating it with vehicle speed.

Vehicles were classified into three categories: Category 1: Light vehicles with two axles and four wheels (e.g., passenger cars). Category 2a: Heavy vehicles with two axles and more than four wheels (e.g., light trucks, buses). Category 2b: Heavy vehicles with more than two axles (e.g., heavy trucks) (ISO, 2023).

The equipment used included: A sound level meter to record noise levels. An anemometer to measure wind speed. A speed radar to record vehicle speeds. A vehicle classification device.

The standard procedure begins by selecting a measurement site that is representative of the study section and meets specific criteria, such as the absence of large reflective surfaces nearby. The equipment is then set up, positioning the sound level meter 7.5 meters from the road edge and 1.2 meters above ground level. The speed and maximum A-weighted sound pressure level (Lveh) are recorded for a significant number of vehicles in each category (at least 100 vehicles per category) and the vehicles are classified into one of the three categories mentioned above (Lo, Ariza, De Luca, & Iarossi, 2024).

For each vehicle category, a regression line is calculated between the maximum A-weighted sound pressure level (Equation 1) and the logarithm of vehicle speed. This regression equation (Equation 2) is used to normalize the sound pressure levels to a reference speed.

$$L\_max = \mathrm{a} \cdot \log v \ \ + \mathrm{b} \qquad (1)$$

Where, L_max: maximum is A-weighted sound pressure level, logv: logarithm of the vehicle speed, b = intercept of the regression line.

$$L\_veh \ = L\_\mathrm{max} \ + \mathrm{B} \cdot (\log(v/vo))) \qquad (2)$$

Where, L_veh: corrected sound pressure level at the reference speed, B: slope parameter specific to the road surface, v = average vehicle speed, vo = reference speed.

The Statistical Pass-By Index (SPBI) is calculated by combining the corrected sound pressure levels for the three vehicle categories (Equation 3).

$$\mathrm{SPBI} = 31(L\_veh, 1 + L\_veh, 2\mathrm{a} + L\_veh, 2\mathrm{b}) \qquad (3)$$

Where, L_veh i = Sound pressure levels corrected for vehicle categories 1, 2a, and 2b, respectively.

When applying the SPB method on urban roads, it is important to account for speed variability, engine noise at low speeds, and ensure traffic noise exceeds background noise. Shorter sections can be used if representative, and corrections applied for nearby reflective surfaces. Following these steps ensures accurate assessment of road surface impact on traffic noise.

3. RESULTS AND DISCUSSION

3.1 Noise Assessment

Prolonged exposure to high noise levels can lead to various health problems, including stress and cardiovascular diseases (Hrapović, 2024).

The noise assessment analyzed the environmental noise levels along the Loja-Malacatos road using the Statistical Pass-By (SPB) method to determine the impact of vehicle traffic on noise emissions. This process involved recording the speed of each passing vehicle and the corresponding noise level, which was captured by the sound level meter at 10-second intervals. The equivalent continuous sound levels (LaEq) recorded at six locations along the road ranged between 63.267 dB and 68.200 dB, with an average value close to 65 dB, as shown in Table 2.

Table 2. Equivalent continuous sound levels (LaEq) at critical points.

Point	1	2	3	4	5	6
LaEq (dB)	64.7	64.3	63.3	63.9	66.0	68.2

The average noise level of approximately 65 dB indicates relatively high noise exposure for residents living just a few meters from the road. The recorded values show slight variability between measurement points, with a progressive increase in noise levels at locations closer to sections with higher traffic density and higher average vehicle speeds. Based on these results, it is possible to identify several implications regarding human exposure to noise and the need for mitigation measures to reduce its impact.

3.2 Comparison with Regulatory Limits

According to the World Health Organization (WHO) guidelines, the recommended environmental noise level for residential areas should not exceed 55 dB during the day and 45 dB at night to prevent adverse health effects (OMS, 2022). However, the results obtained in this study show that noise levels along the Loja-Malacatos road exceed these limits, with the highest value recorded at Point 6 reaching 68.200 dB. This value approaches the 70 dB threshold, which is considered critical, as continuous exposure to this level of noise may cause permanent hearing damage, along with other negative health effects such as stress, sleep disorders, and cardiovascular issues.

In the European Union, the maximum permitted noise level for the Lde indicator is 67 dB(A), while the nighttime limit is 60 dB(A). These values reflect a global trend toward stricter regulations in urban and peri-urban areas, where many countries have implemented more rigorous noise control policies. In particular, in urban and peri-urban areas, the permitted traffic noise levels typically range between 55 and 60 dB(A) during the day (Papadimitriou, Papageorgiou, Alamanis, & Diakosavva, 2020).

Similarly, the Federal Highway Administration (FHWA) in the United States establishes a mitigation threshold of 67 dB(A) for pass-by events near residential areas. According to FHWA guidelines, noise barriers are recommended when this threshold is exceeded to protect nearby communities from long-term noise exposure (Hanson et al., 2004). In line with these international criteria, the results obtained in this study confirm that heavy vehicles, such as trucks, are the main contributors to traffic noise, especially in sections where they pass in close proximity to residential properties, highlighting the urgent need for specific mitigation measures along this corridor.
Based on this context, it can be concluded that the noise levels measured along the Loja-Malacatos road not only exceed the limits recommended by the WHO and the European Union but also surpass the mitigation threshold established by the FHWA, reinforcing the need to implement effective strategies to protect residents' quality of life.

3.3 Variability of Noise Levels

The noise levels recorded along the Loja-Malacatos road show significant variability between the different measurement points. This variability is largely explained by the differences in traffic composition, vehicle speeds, and pavement surface conditions at each location. For example, at Points 1 and 3, located near residential areas with lower traffic volumes and reduced speeds, the equivalent continuous sound levels (LaEq) were lower, averaging 63.267 dB. In contrast, at Point 6, located on a steeper section with higher traffic density and a greater proportion of heavy vehicles, the recorded noise level reached 68.200 dB, the highest value among all measurement points.

This variability highlights the importance of considering local conditions when assessing noise pollution on mountain roads, where changes in gradient, traffic density, and pavement condition can generate highly variable acoustic environments. Furthermore, it was observed that vehicle speed plays a critical role in noise generation. Sections with higher average speeds consistently showed higher noise levels, confirming the well-documented direct relationship between speed and tire-pavement noise (Shaaban & Abouzaid, 2023).

The variability observed in this study reinforces the importance of site-specific noise assessments, especially in complex topographic environments, where noise levels cannot be generalized across the entire corridor. This highlights the need for localized noise mitigation strategies tailored to the specific conditions at each critical point.

Prolonged exposure to noise levels exceeding 65 dB can have serious effects on both physical and mental health. Studies have shown that chronic exposure to noise levels above 55 dB can cause stress, increased blood pressure, and in more severe cases, contribute to the development of cardiovascular diseases (Priy, Mishra, & Jadon, 2024). In areas where noise levels exceeded 65 dB, such as Points 5 and 6, residents are at higher risk of experiencing disrupted sleep patterns, which can directly affect daily performance, emotional well-being, and cognitive capacity (Sahu et al., 2023).

Many houses along the Loja-Malacatos road are located just meters from the roadway, exposing residents to continuous traffic noise and increasing the risk of long-term health issues, especially for vulnerable populations. This study is part of a broader program to assess health impacts and develop low-cost mitigation solutions, including home insulation, community awareness, and urban planning strategies to improve residents' quality of life.

4. CONCLUSION

The application of the Statistical Pass-By (SPB) method on the Loja-Malacatos road allowed for the quantification of noise levels generated by passing vehicles and their correlation with vehicle speed and pavement condition. Noise levels at critical points ranged between 63.267 dB and 68.200 dB, exceeding the World Health Organization's recommended daytime limit of 55 dB for residential areas. Some points also surpassed the Federal Highway Administration's (FHWA) mitigation threshold of 67 dB(A), highlighting the need for noise reduction measures. The proximity of residential properties to the roadway exposes residents to constant noise pollution, increasing the risk of stress, sleep disturbances, and cardiovascular problems. These findings provide a baseline for developing mitigation strategies, including the evaluation of health markers and the design of low-cost noise insulation solutions for affected homes.

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