TEMPORAL STRUCTURE OF PERCENTILE SOUND LEVELS ACROSS URBAN ROAD TYPOLOGIES

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Abstract

Urban planning is a key tool for improving the quality of acoustic environments. The characteristics of urban roads, the elements they contain, and the services located along them directly influence their patterns of use and, consequently, the resulting noise levels. Most studies analyzing the relationship between urban variables and sound levels rely on energy-based average indicators, as these are the standard metrics used in noise mapping. However, recent research suggests that percentile sound levels may exhibit a stronger association with noise-related effects. In this context, percentile sound levels, by capturing temporal variability, may provide additional insight into the characterization of urban acoustic environments. Based on this hypothesis, temporal records collected in two Chilean cities were analyzed to assess the relationship between the temporal structure of percentile levels and the characteristics of the road typologies where monitoring stations were located. The results show that percentile sound levels are able to differentiate road functionality and provide improved insight into the temporal variability of urban noise. These findings suggest that percentile-based approaches may complement traditional energy-based indicators in urban noise assessment.

Keywords: *urban planning, percentile sound levels, urban road classification, temporal variability*

1. Introduction

Noise pollution remains one of the most pressing environmental challenges in urban areas, highlighting the need for more numerous and effective actions to improve the quality of the urban acoustic environment. Despite advances in noise calculation methods and the implementation of mitigation strategies, no substantial reduction in environmental noise levels is expected in European cities over the coming years [1]. Furthermore, although significant progress has been made in incorporating sound perception into regulatory frameworks [2,3], the generalization of current findings remains challenging because most studies have been conducted on relatively small and highly specific participant groups [4]. Consequently, quantifying the contribution of sound perception to quality of life and health outcomes at the population level is still a complex task.

As in other areas of acoustics, planning has the potential to become a powerful tool for achieving significant reductions in urban noise. However, likely due to the limited number of studies and the scarcity of dedicated funding, its potential benefits have not yet been comprehensively quantified [5].

The classification of urban roads, widely adopted in many cities as a traffic management strategy, has already demonstrated its value for urban noise analysis and prediction [6,7]. If stratifying urban roads according to their traffic characteristics enhances the effectiveness of noise mitigation measures, then stratifying urban environments based on residents' perception of their acoustic environment could similarly improve strategies aimed at enhancing urban sound quality. This hypothesis constitutes the starting point of the present preliminary study.

Recent research has shown that percentile sound levels are closely correlated with the effects of noise [8]. Beyond describing the overall sound energy to which people are exposed, these indicators also provide valuable information about the temporal variability of the acoustic environment and, indirectly, about the characteristics of the dominant sound sources. For this reason, percentile sound levels are increasingly recommended for soundscape studies [2]. For example,

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Can *et al.* [9] reported that the L_{50} (dB) can predict soundscape perception as effectively as loudness.
In view of the above, the aim of the present study was to analyze the distribution of percentile sound levels across different urban road categories in cities with varying population sizes.

2. Methodology

2.1 Study cities

The Chilean cities of Santiago and Talca were selected as the study areas for the present research (Fig. 1). Santiago, the capital of Chile, has a population of approximately 7 million inhabitants, whereas Talca is a medium-sized city with a population of around 200,000. These cities provide a marked contrast in terms of population size and urban morphology, particularly regarding the characteristics of their built environment. Despite these urban differences, they exhibit comparable spatial patterns and, as demonstrated in previous studies, models based on urban features are transferable across both cities [10].

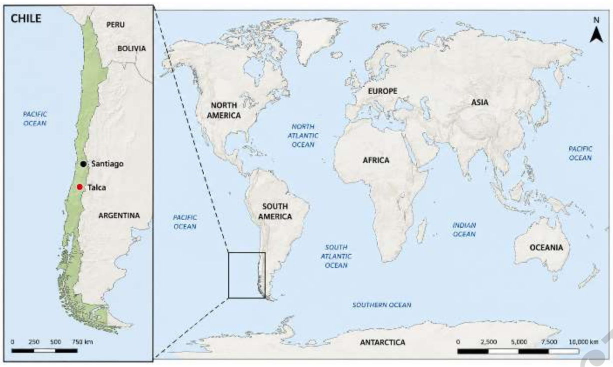

Figure 1. Location of the study cities (Santiago and Talca) in Chile

Approximately 150 sampling points were selected in each city and distributed proportionally according to the total length of each road category, while ensuring a minimum representative sample size for subsequent inferential statistical analyses. The spatial distribution of the sampling points is described in [10]. Urban roads were classified into five categories according to their functionality [6,7]:

- Category 1: Preferential streets for connection with other cities and interconnection of those preferential streets.
- Category 2: Streets that provide access to the primary distribution nodes of the city. It also includes roads used as alternatives to Category 1 streets in traffic congestion.
- Category 3: Streets that lead to regional roads, streets that provide access from Category 1 and Category 2 streets to centers of interest in a city, and streets that clearly allow communication between Category 1 and Category 2 streets.
- Category 4: Includes all other streets that allow communication between Category 1, Category 2, and Category 3 streets, as well as the main streets of principal neighborhoods that were not included previously.
- Category 5: Includes all the rest of the streets of the city except pedestrian-only streets.

Sounds measurements were conducted during different daytime periods on weekdays at each sampling point. A range of broadband and frequency-spectrum noise indicators were registered, together with information on the noise sources. For the purposes of the present study, particular attention was given to road traffic flow and traffic composition.

2.2 Statistical analysis

Descriptive and inferential statistical analyses were performed using the acoustic indicators measured within each road category. Descriptive analyses, based on violin plots, were used to characterize the distribution of the data across road categories and to identify potential overlaps in their central tendency. Correlation analyses were conducted to examine the relationship between total traffic flow and the measured sound levels. Finally, homogeneous group analyses were performed to compare the acoustic indicators among the different road categories.

3. Results and discussion

Road traffic was identified as the dominant source of urban noise, as evidenced by the results presented in Figs. 2 and 3. A simple linear correlation analysis between total traffic flow (without distinguishing between vehicle types) and the L_{Aeq} explained more than 90% of the observed variability. These findings highlight that any strategy aimed at improving the acoustic quality of urban environments should explicitly address road traffic, which remains the predominant noise source even in quiet areas [11,12].

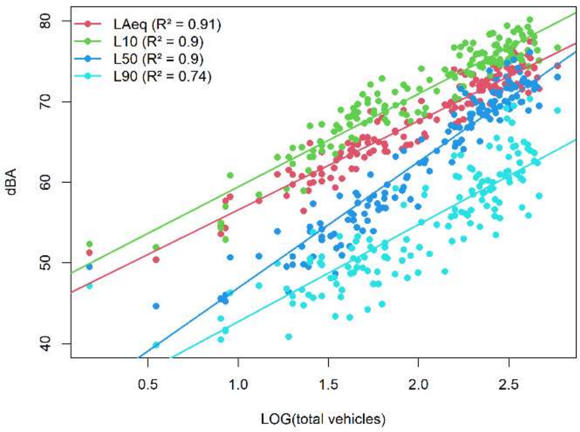

Figure 2. Linear relationship between the logarithm of total traffic flow and the sound levels measured using the different acoustic indicators in the city of Santiago.

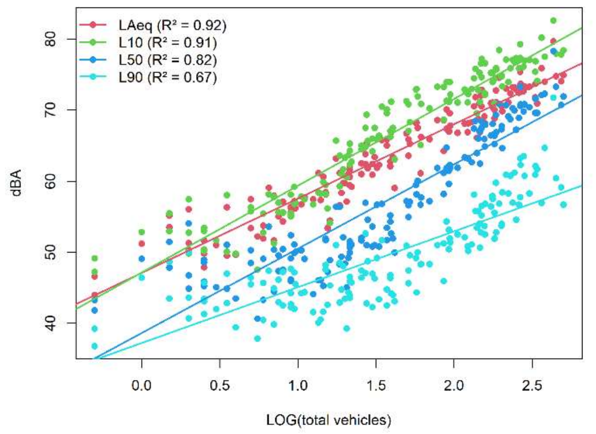

Figure 3. Linear relationship between the logarithm of total traffic flow and the sound levels measured using the different acoustic indicators in the city of Talca.

The distribution of the acoustic indicator values recorded across the different road categories in Santiago and Talca was subsequently examined (Figs 4 and 5). The results showed that, for some indicators, certain road categories did not follow a normal distribution, exhibiting skewness with tails toward higher values (e.g., Category 1) or toward lower values (e.g., Categories 4 and 5). As the assumption of normality required for the application of parametric tests was not satisfied, differences among road categories were assessed using non-parametric procedures. Specifically, pairwise comparisons were performed using the Wilcoxon rank-sum test with Holm correction to account for multiple comparisons.

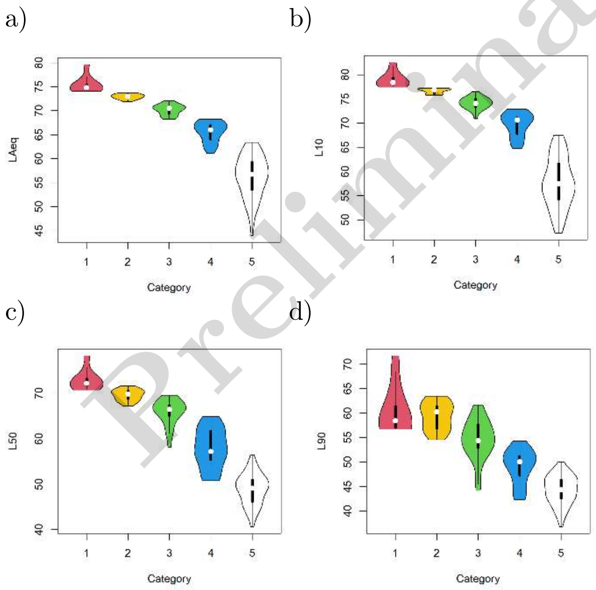

Figure 4. Violin plots of the acoustic indicators L_{Aeq}, L_{10}, L_{50}, and L_{90} measured across the road categories in the city of Talca.

Another noteworthy aspect of Figs. 4 and 5 is the difference in the central tendency of the acoustic indicators across road categories. As shown by this descriptive analysis, most acoustic indicators exhibit a clear stratification among the different road categories, with statistically distinct levels that reflect the hierarchical classification of the road category.

The patterns suggested by Figs. 4 and 5 were formally tested through a homogeneous group analysis based on pairwise Wilcoxon rank-sum tests with Holm correction. The resulting homogeneous groups are presented in Table 1.

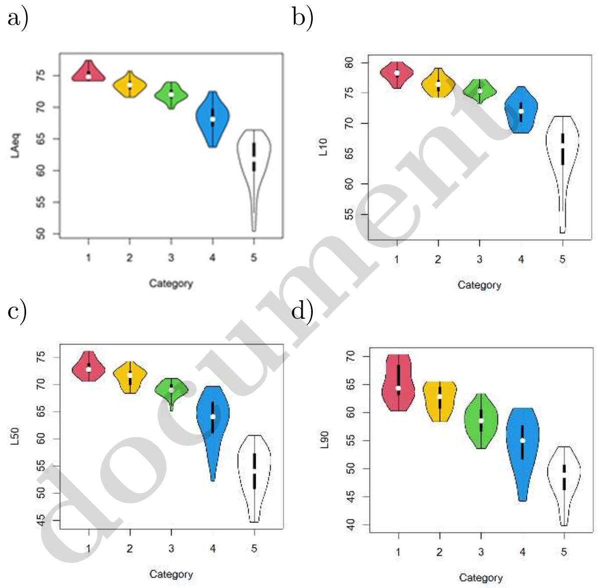

Figure 5. Violin plots of the acoustic indicators L_{Aeq}, L_{10}, L_{50}, and L_{90} measured across the road categories in Santiago.

The results presented in Table 1 are of considerable interest.

Table 1. Homogeneous groups of road categories for the acoustic indicators in Talca and Santiago, based on pairwise Wilcoxon rank-sum tests with Holm correction for multiple comparisons. *Note:* Road categories sharing the same letter are not significantly different (Holm-adjusted $p > 0.05$).

City	Category	L_{Aeq}	L_{10}	L_{50}	L_{90}
Talca	1	a	a	a	a
	2	b	b	b	a
	3	c	c	c	b
	4	d	d	d	c
	5	e	e	e	d
Santiago	1	a	a	a	a
	2	b	b	b	b
	3	c	c	c	c
	4	d	d	d	d
	5	e	e	e	e

As expected, L_{Aeq} (dB) showed significant differences among road categories, consistent with previous studies [7,13]. However, significant differences were also observed for the percentile noise levels, including

L_{90} (dB), despite this indicator being more strongly influenced by background and non-traffic sound sources. The only overlap was found in Talca for L_{90} (dB) between Categories 1 and 2, a pattern that has also been reported in previous studies conducted in some small-sized cities [13].
These findings are particularly relevant because percentile noise levels have been associated with a range of noise-related effects and provide complementary information to L_{Aeq} (dB) [8]. The observed stratification across road categories supports the implementation of city-wide noise management strategies, rather than interventions focused exclusively on specific locations or isolated hotspots.

4. Conclusions

The results show that the categorization of urban roads provides a robust framework for characterizing the urban acoustic environment in both Santiago and Talca. Significant differences were identified not only for L_{Aeq}, but also for the percentile noise indicators (L_{10}, L_{50}, and L_{90}) across most road categories. These findings indicate that the influence of an urban road's function extends beyond equivalent sound levels and is consistently reflected in different indicators of the urban sound environment.
The descriptive and inferential analyses showed that most acoustic indicators exhibited a clear stratification among road categories. The homogeneous group analysis confirmed that the majority of categories were statistically distinguishable, with the only notable overlap occurring for L_{90} between Categories 1 and 2 in Talca. This result is consistent with previous observations in small-sized cities and suggests that background noise conditions may become more homogeneous in certain urban contexts.
Overall, these findings support the use of road category as a reliable predictor of urban noise conditions and demonstrate that percentile noise indicators can effectively discriminate between road classes, complementing the information provided by L_{Aeq}. From a practical perspective, the observed acoustic stratification reinforces the need to implement city-wide noise management strategies rather than focusing exclusively on isolated hotspots, thereby supporting more comprehensive urban planning and environmental noise mitigation policies.

5. Acknowledgments

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References

[1] European Environment Agency, "Zero pollution monitoring assessment," report no. 03, 2022.

[2] ISO/TS 12913-3, "Acoustics – Soundscape – Part 3: Data analysis", 2025.

[3] ISO/TS 16755 – 1, "Acoustics — Non-acoustic factors influencing the perception, interpretation and response to environmental sounds — Part 1: Definition and conceptual framework", 2025.

[4] F. Aletta, A. Mitchell, T. Oberman, J. Kang, S. Khelil, … and T.L. Nguyen, "Soundscape descriptors in eighteen languages: Translation and validation through listening experiments," *Applied Acoustics*, vol. 224, 110109, 2024.

[5] G. Rey-Gozalo, J.M. Barrigón Morillas, and D. Montes-González, "Analysis and Management of Current Road Traffic Noise," *Current Pollution Report*, vol. 8, pp. 315–327, 2022.

[6] J.M. Barrigón Morillas, G. Rey Gozalo, D. Montes-González, R. Vílchez-Gómez, and V. Gómez Escobar, "Variability of traffic noise pollution levels as a function of city size variables," *Environmental Research*, 199, 111303, 2021.

[7] A.L. Montenegro, G. Rey Gozalo, J.P. Arenas, and E. Suárez, "Streets classification models by urban features for road traffic noise estimation," *Science of the Total Environment*, vol. 932, 173005, 2024.

[8] J.M. Barrigón Morillas, D. Montes González, R. Vílchez-Gómez, G. Rey-Gozalo, "Percentile-level examination of ten acoustic indicators pinpoints urban noise factors affecting noise effects on pedestrians," *Building and Environment*, 285, 113572, 2025.

[9] A. Can, P. Aumond, S. Michel, B. De Coensel, C. Ribeiro, D. Botteldooren, and C. Lavandier, "Comparison of noise indicators in an urban context," in: *Proc. of the INTER-NOISE 2016 - 45th International Congress and Exposition on Noise Control Engineering: Towards a Quieter Future*, (Hamburg, Germany), pp. 5678–5686, 2016.

[10] V. Poblete, G. Rey-Gozalo, E. Suárez, J.P. Arenas, L. Veas-Castillo, J.P. Salazar, R. Hayde, L. Llanca, and D. Vergara, "Interpretable machine learning of urban noise levels from street-scale morphology and functionality," *Sustainable Cities and Society*, vol. 143, 107356, 2026.

[11] G. Rey Gozalo, and J.M. Barrigón Morillas, "Perceptions and effects of the acoustic environment in quiet residential areas," *Journal of the Acoustical Society of America*, vol. 141, pp. 2418–2429, 2017.

[12] G. Rey-Gozalo: *Urban green spaces: A key urban infrastructure for air and acoustic quality,*

Advances in Chemical Pollution, Environmental Management and Protection, Elsevier, vol. 14, pp. 61–94, 2026.

[13] G. Rey Gozalo, J.M. Barrigón Morillas, and V. Gómez Escobar, "Urban streets functionality as a tool for urban pollution management," *Science of the Total Environment*, vol. 461–462, pp. 453–461, 2013.