

ACOUSTIC MAPPING AND NOISE LEVELS ON THE UNIVERSITY OF PANAMA CAMPUS DURING COVID-19 LOCKDOWN

Cartografía acústica y niveles de ruido en el campus de la Universidad de Panamá durante el confinamiento por COVID-19

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(Received: August 2025 ; accepted: November 2025)

Key words: Noise pollution, urban environment, sound measurements, vegetation acoustic barrier, environmental quality.

ABSTRACT

This study established an unprecedented acoustic baseline on the University of Panama campus during the COVID-19 lockdown to quantify the effects of morphological shielding and proposals for the reduction of anthropogenic noise. The continuous equivalent sound pressure level (L_{eq}) was measured at 14 strategic points. The results showed a clear variation in noise according to location, ranging from 50.2 dB(A) in the inner area to 71.0 dB(A) along the perimeter. Background noise (L_{90}) at the center reached 45 dB(A), remaining below the WHO guideline of 55 dB(A). The Anova analysis confirmed that location was the dominant factor, explaining 68.5% of the total noise variance ($\eta^2 = 0.685$). It is concluded that terrain morphology and vegetation have a significant effect on sound propagation, contributing to a quieter environment. This work provides an essential technical reference for the future management and revision of acoustic zoning regulations in educational environments.

Palabras clave: contaminación acústica, ambiente urbano, mediciones sonométricas, barrera acústica vegetal, calidad ambiental.

RESUMEN

Este estudio estableció una línea base acústica inédita en el campus de la Universidad de Panamá durante el confinamiento por COVID-19 para cuantificar el efecto de pantalla morfológico y evaluar propuestas para la reducción del ruido antrópico. Se midió el nivel equivalente continuo de presión sonora (L_{eq}) en 14 puntos estratégicos. Los resultados mostraron un claro cambio en el ruido según la ubicación: desde 50.2 dB(A) en la zona interna hasta 71.0 dB(A) en el perímetro. El ruido de fondo (L_{90}) en el centro fue de 45 dB(A), que está por debajo del límite de 55 dB(A) establecido por la OMS. El análisis Anova confirmó que el emplazamiento es el factor dominante, explicando el 68.5% de la varianza total del ruido ($\eta^2 = 0.685$). Se concluye que la forma del terreno

y la vegetación tienen un efecto importante en el sonido, ayudando a crear un ambiente más silencioso. Este trabajo es esencial para la gestión futura y la actualización de la normativa sobre zonificación acústica en centros educativos.

INTRODUCTION

Noise pollution is one of the main environmental issues in contemporary urban settings, closely linked to population density, vehicular traffic, and industrial or commercial activity (Ruíz et al. 2023, Solano et al. 2023). Since the Industrial Revolution, urban and technological expansion has intensified exposure to noise, directly affecting health and quality of life (Goines and Hagler 2007, Murgel 2007). Although sound and noise share the same physical nature (sound waves causing air pressure fluctuations), noise is subjectively defined as any unwanted or unpleasant sound for the listener (Wang et al. 2005).

For quantitative assessment, the World Health Organization (WHO) recommends the use of the A-weighted equivalent continuous sound pressure level ($L_{Aeq,T}$) as the primary descriptor of environmental noise. This quantity represents the energetic time average of the instantaneous A-weighted sound pressure level over a given time interval T (Bies et al. 2023) and is defined as:

$$L_{Aeq,T} = 10 \log_{10} \left(\frac{1}{T} \int_0^T 10^{\frac{L_A(t)}{10}} dt \right) \quad (1)$$

where $L_A(t)$ represents the instantaneous A-weighted sound pressure level in dB(A), and T denotes the total measurement time. When measurements are obtained at equal time intervals, a discrete approximation can be expressed as:

$$L_{Aeq,T} = 10 \log_{10} \left[\frac{1}{N} \sum_{i=1}^N 10^{\frac{L_{A_i}}{10}} \right] \quad (2)$$

where N is the total number of samples. The obtained $L_{Aeq,T}$ value allows the evaluation of environmental noise in situ during the measured interval, enabling the assessment of exposure to levels above 65 dB(A), which have been associated with adverse health effects (Zannin et al. 2013).

In Panama, noise regulations display institutional inconsistencies. Municipal Decree No. 56 of 1933 (Panamá 1933) defines high-sensitivity acoustic zones (hospitals, health centers, nursing homes), whereas the Ministry of Health establishes limits of 60 dB(A) during daytime (6:00 a.m.-9:59 p.m.) and

55 dB(A) at night (10:00 p.m.-5:59 a.m.), without a precise classification for educational areas.

Prolonged exposure to environmental noise has been associated with behavioral changes, cognitive difficulties, and physiological stress (Basner et al. 2014, Dzhambov et al. 2021). These effects are particularly critical in educational environments, where they negatively impact concentration and academic performance (Sánchez et al. 2020, Duque et al. 2023, Jha et al. 2024, Al-Asmar 2025). Indeed, the WHO considers noise the second most harmful environmental risk factor to human health (Costa Lima 2020).

For this reason, numerous studies have characterized the acoustic conditions of educational institutions in different geographical contexts, often reporting sound levels exceeding recommended limits (Ozer et al. 2014, Barboza de Souza et al. 2020, Doutres et al. 2023, Arbaoui et al. 2024, Sagel 2025). During the COVID-19 lockdown, several works observed unprecedented reductions in urban noise due to decreased vehicular traffic (Mitchell et al. 2021, Kumar et al. 2022, Meneses 2023, Puyana et al. 2023).

Nationally, previous studies documented elevated noise levels in areas adjacent to the University of Panama campus (Villarreal et al. 2003, Henríquez et al. 2007, Henríquez et al. 2018, Nicholson et al. 2022). However, these works did not result in public policies or acoustic planning strategies, highlighting the absence of a sound baseline and updated legislation for educational areas. This gap limits the ability to assess noise impacts and design effective mitigation strategies.

In this context, the present study evaluates sound pressure levels on the main campus of the University of Panama during the COVID-19 lockdown, an exceptional period characterized by minimal anthropogenic activity. The hypothesis proposes that the reduction in vehicular traffic and the presence of perimeter vegetation generate measurable acoustic attenuation toward the interior of the campus. To test this hypothesis, key acoustic metrics were analyzed through inferential statistical methods, and the results were integrated into a high-resolution acoustic map, establishing the campus sound baseline as a technical reference for future environmental planning and noise-control policies.

MATERIALS AND METHODS

The Octavio Méndez Pereira Campus of the University of Panama (**Fig. 1**) covers an approximate area of 204 828.14 m², comprising 13 faculties, more than 10 research institutes, and the Central Library. It is in the El Cangrejo sector of the Bella Vista district in Panama City. The urban morphology of this area is characterized by mixed land use and high building density. Being surrounded by major arterial roads, the site experiences intense vehicular flow (González et al. 2021).

The campus is bounded by Simón Bolívar Avenue (Transistmica Road), one of the busiest routes in the capital, classified as an acoustically critical area, where previous studies (Villarreal et al. 2003, Henríquez et al. 2007) reported levels close to 80 dB(A). Despite its proximity to residential, hospital, and educational zones, this avenue is designated by Municipal Decree No. 56 of 1933 (Panamá 1933) as a high-sensitivity acoustic area.

Fourteen measurement points were distributed across internal and perimeter zones of the campus, representing access routes, pedestrian corridors, green areas, and common spaces. This configuration was designed to capture the acoustic gradient from the perimeter exposure dominated by traffic noise toward the attenuated conditions expected inside the campus.

Sound-pressure measurements were performed using a PCE-322A integrating sound level meter (SLM), Class 2, compliant with IEC (2013), featuring a factory calibration certificate and accuracy of ± 1.4

dB ($k = 2$). The microphone was positioned 1.5 m above ground level, tilted 30° to 45° toward the dominant sound source, in open areas without reflective surfaces within a 2 m radius, and equipped with the original windscreen to minimize aerodynamic noise interference (Brüel and Kjær 2000).

Due to restricted mobility and limited access to technical services during the COVID-19 health emergency, it was not possible to perform on-site calibrations with a traceable acoustic reference. Nevertheless, all observations were conducted under stable and favorable meteorological conditions, with internal consistency checks performed before and after each session. These procedures ensured data reliability and continuity even in the absence of field calibration.

The temporal protocol consisted of three-minute recordings per measurement point. This sampling duration is considered statistically adequate to characterize sound pressure levels in university noise-mapping studies (Zannin et al. 2013). Data were acquired at a fixed sampling rate to ensure reproducibility and representativeness of results (10 Hz). Measurements were carried out in three representative periods, morning (6:00-8:00 a.m.), midday (11:00 a.m.-1:00 p.m.), and evening (5:00-7:00 p.m.), on non-consecutive working days, if weather conditions allowed (avoiding temperature and humidity gradients and wind speeds exceeding 5 m/s), each point produced 32 400 individual sound-pressure samples ($n = 32\ 400$), which were used for all subsequent statistical and spatial analyses, including the calculations presented in the tables and contour maps.

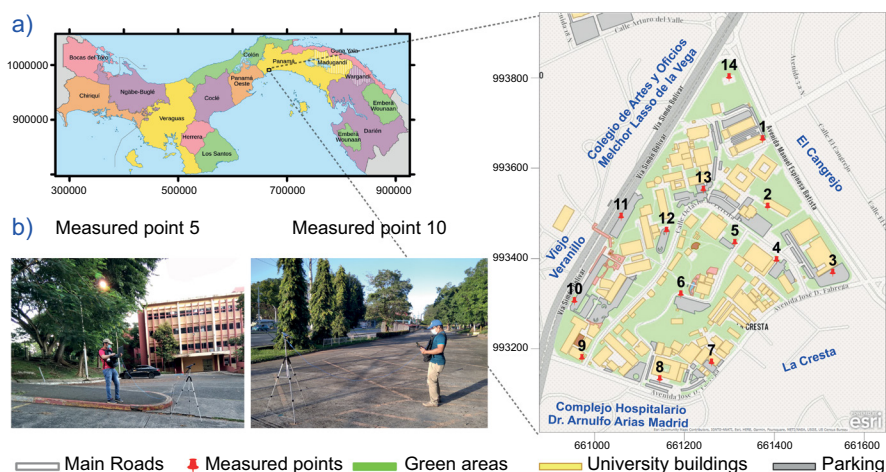


Fig. 1. Location of the Octavio Méndez Pereira Campus and spatial distribution of the 14 measurement points. a) National location. b) Campus detail showing green areas, buildings, and sampling sites.

These condensed samples were treated as representative of the extended time periods L_{day} , L_{evening} , and L_{night} , in accordance with WHO (2016) and ISO 1996 (2017) guidelines. The following acoustic descriptors were calculated: L_{eq} , L_{10} , L_{50} , L_{90} , and L_{den} , with L_{90} being particularly relevant as it defines background noise and establishes the baseline sound level of the campus, free from transient influences.

For statistical analysis, the mean, standard deviation (reflecting variability of noise levels), and 95% confidence intervals (95% CI) were computed. The Kolmogorov-Smirnov test was used to assess the normality of data distribution, and differences in average L_{eq} between internal and peripheral zones were evaluated using one-way analysis of variance (Anova). The magnitude of the effect was quantified with η^2 (eta squared) to assess the practical impact of location on sound levels.

Finally, the acoustic maps were generated using kriging interpolation in version Surfer[®] (Golden software), with isophonic contours every 5 dB(A). The L_{den} parameter was presented only in tabular form due to its European-standard formulation to preserve the cartographic rigor of L_{eq} and avoid overestimating the precision of the map.

RESULTS

The acoustic monitoring results obtained on the central campus during the lockdown period are presented through descriptive and inferential statistical

analyses of acoustic metrics, spatial variance assessment, and geospatial representation of sound-pressure levels.

The average equivalent continuous sound-pressure level (L_{eq}), together with the percentile metrics (L_{10} , L_{50} , L_{90}) and the day-evening-night level (L_{den}) for the 14 measurement points, are summarized in **table I**.

Average L_{eq} values ranged from 50.2 dB(A) (Point 2, internal zone) to 71.0 dB(A) (Point 11, perimeter zone), establishing a clear acoustic gradient across the campus. The perimeter points (1, 5, 8, 9, 10, 11, and 14) exhibited levels exceeding the national daytime limit of 60 dB(A), while the interior points showed a progressive attenuation of noise as the distance from main roads increased.

Table I and **figure 2** display the hourly distribution of sound-pressure levels, showing that daytime levels (L_{day}) were consistently higher than nighttime levels (L_{night}), confirming vehicular traffic as the main noise source. Measurement points adjacent to Simón Bolívar Avenue (Points 9, 10, and 11) recorded L_{eq} values above 70 dB(A) and a maximum L_{den} of 79.5 dB(A) (Point 11). In contrast, interior points showed minimum L_{90} values around 45 dB(A), representing the stable background noise during lockdown conditions.

The dispersion analysis (**Fig. 3**) revealed greater variance and higher central values at the perimeter points. The Kolmogorov-Smirnov test indicated a non-normal distribution ($p < 0.001$); however, the normality coverage (1.96σ) above 92% justified the use of parametric methods.

TABLE I. ACOUSTIC INDICATORS PER MEASUREMENT POINT AT THE OCTAVIO MÉNDEZ PEREIRA CAMPUS DURING THE COVID-19 LOCKDOWN (VALUES EXPRESSED IN dB(A)).

Point	L_{eq}	L_{10}	L_{50}	L_{90}	L_{day}	L_{evening}	L_{night}	L_{den}
1	60.8	63.6	58.7	52.6	57.8	62.2	61.2	67.5
2	54.1	55.4	49.6	45.5	54.2	54.3	53.7	60.2
3	61.2	63.0	59.0	54.7	59.8	63.6	58.9	66.3
4	55.6	56.8	52.6	49.1	55.1	55.9	55.7	62.0
5	60.3	63.1	52.9	47.9	61.5	61.4	56.4	64.6
6	56.0	57.5	53.6	50.3	54.2	58.1	54.4	61.4
7	60.7	63.1	57.5	53.1	59.1	60.3	62.1	68.1
8	60.2	62.7	58.0	52.6	61.8	58.6	59.4	66.1
9	65.0	68.1	62.7	56.6	65.0	64.3	65.6	71.8
10	70.8	73.1	69.9	66.2	71.1	70.4	70.8	77.2
11	72.7	74.9	71.6	66.2	72.6	71.8	73.4	79.5
12	55.3	55.7	51.5	47.3	55.6	55.2	55.1	61.5
13	55.5	56.7	51.4	46.8	56.2	56.2	53.5	60.7
14	62.2	64.4	61.3	56.7	62.7	62.0	62.0	68.4

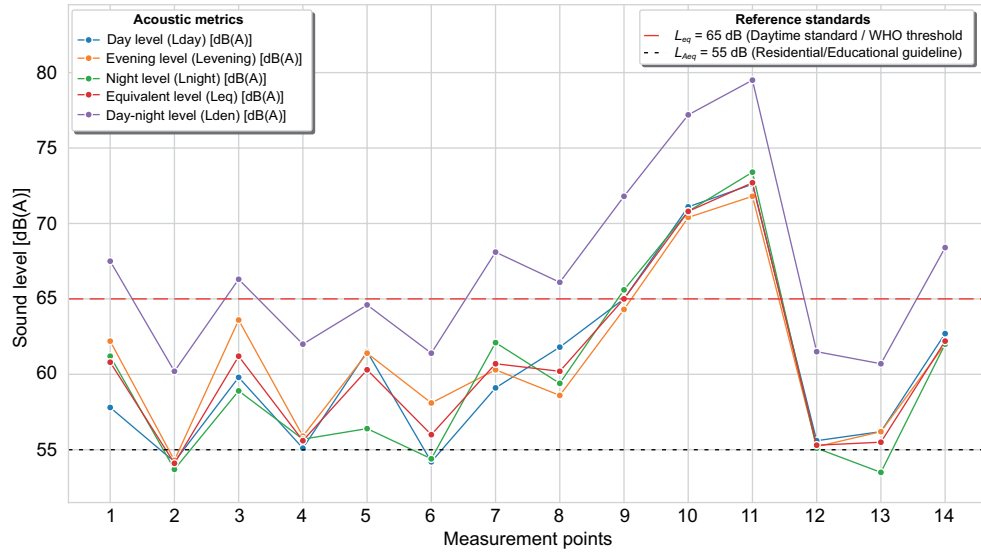


Fig. 2. Comparison of equivalent sound-pressure levels (L_{eq}) and their indicators per measurement point and time, contrasted with WHO reference thresholds for educational environments and daytime standards.

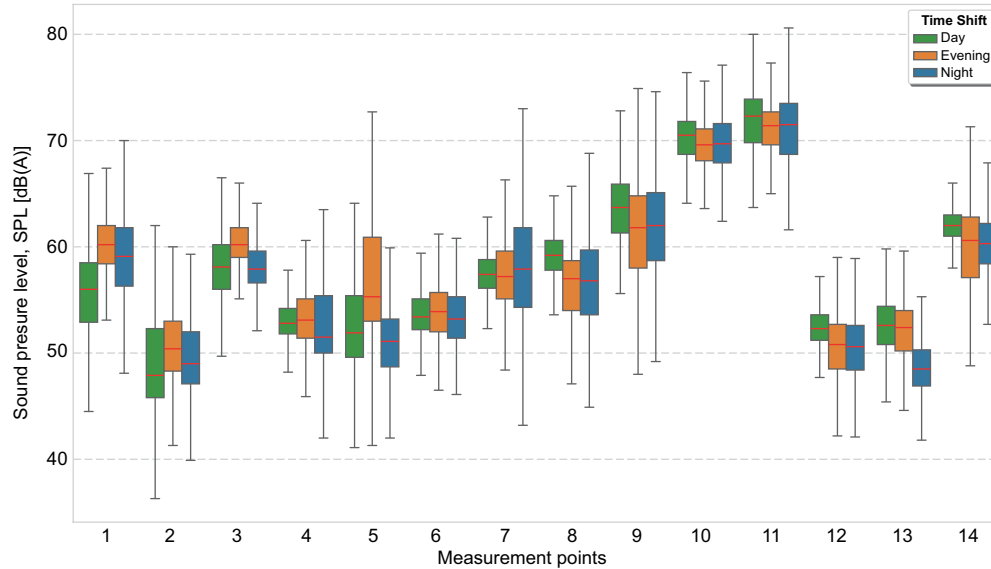


Fig. 3. Comparison of sound-pressure levels (dB(A)) across different time periods (day, evening and night).

Table II summarizes the main descriptive statistics, showing acceptable consistency in the measurements, with standard deviations below 6 dB(A) and normality coverage above 92%. The Anova analysis revealed statistically significant differences ($p < 0.001$) between internal and peripheral zones. The effect size ($\eta^2 = 0.685$) indicated that location explains 68.5% of the total noise variance, confirming the high practical relevance of spatial factors on sound levels.

This pattern confirms the acoustic shielding effect produced by vegetation and the campus structures, as well as the persistent influence of perimeter traffic. Moreover, comparison across the three time periods showed no significant temporal variations ($p > 0.05$) except in the central area, suggesting temporal stability of the sound environment during lockdown. This validates the obtained model as representative of the period of minimal anthropogenic activity. **Figure 4** shows a comparative analysis

TABLE II. DESCRIPTIVE STATISTICS OF ACOUSTIC MEASUREMENTS PER POINT: MEAN, STANDARD DEVIATION, 95% CONFIDENCE INTERVAL (CI) AND KOLMOGOROV-SMIRNOV (KS) STATISTICS.

Point	Mean (μ) [dB(A)]	Standard deviation (σ) [dB(A)]	95% CI Lower [dB(A)]	95% CI Upper [dB(A)]	Normality ± 1.96 σ [%]	KS statistics
1	58.5	4.4	58.4	58.5	95.1	0.037
2	50.2	4.5	50.1	50.2	95.6	0.070
3	58.8	4.0	58.7	58.8	93.5	0.076
4	53.0	3.8	52.9	53.0	94.8	0.082
5	54.1	6.0	54.1	54.2	94.0	0.112
6	53.7	3.6	53.7	53.7	92.8	0.082
7	57.7	4.4	57.7	57.8	93.2	0.064
8	57.7	4.2	57.7	57.8	93.7	0.055
9	62.5	4.5	62.4	62.5	94.8	0.019
10	69.8	3.0	69.7	69.8	94.6	0.046
11	71.0	3.8	70.9	71.0	95.0	0.088
12	51.6	4.1	51.6	51.7	95.2	0.095
13	51.7	4.5	51.7	51.8	94.8	0.080
14	60.9	3.3	60.9	61.0	94.4	0.077

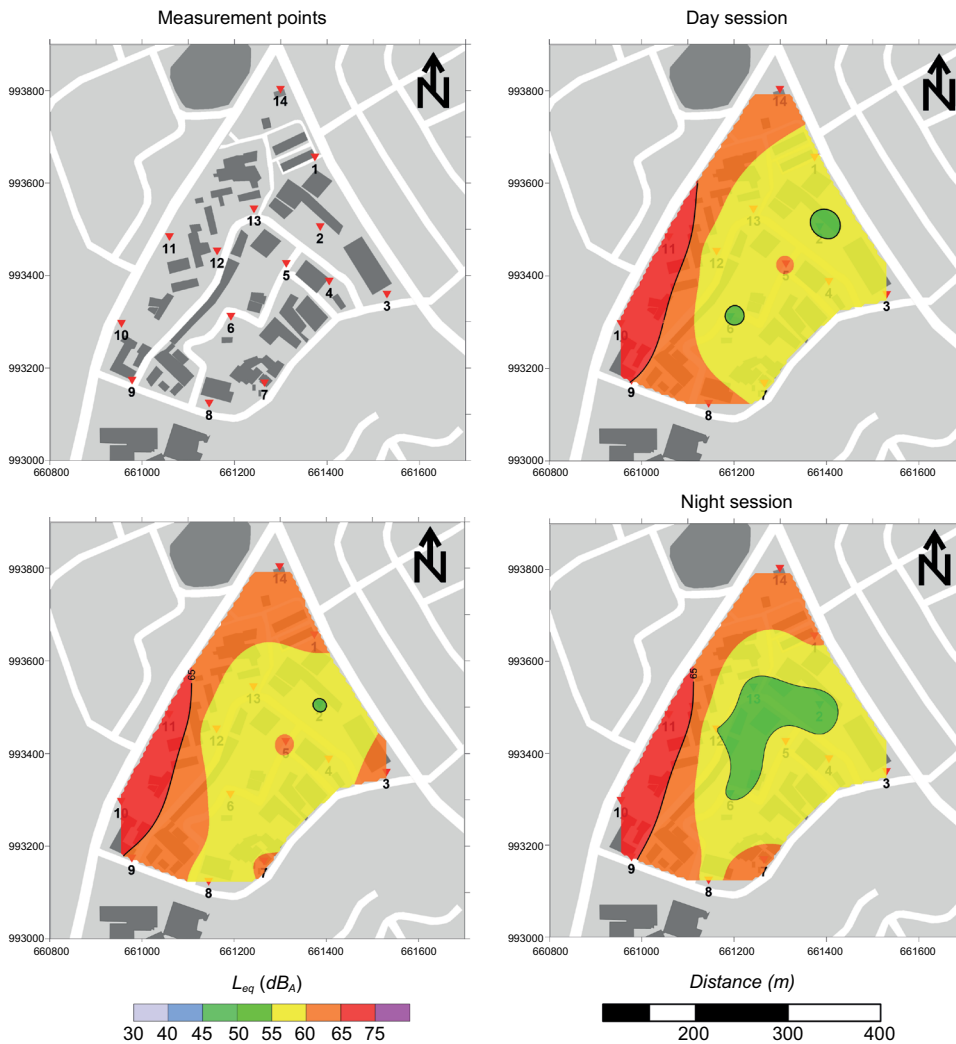


Fig. 4. Acoustic mapping of the central campus. Isophonic contour maps generated by ordinary kriging interpolation for morning, midday, and evening sessions. Experimental variograms fitted to spherical models (range = 45-70 m; RMSE < 3.5 dB(A); MAPE < 6%) confirmed the spatial dependence and predictive accuracy of the interpolation. The maps highlight the spatial acoustic gradient and the shielding effect of vegetation and buildings.

between the measured equivalent continuous sound pressure levels (L_{Aeq}) and the regulatory limits established for high acoustic sensitivity zones, allowing an assessment of compliance and potential risk areas.

DISCUSSION

The results obtained show that the campus morphology and the presence of vegetation play a decisive role in acoustic attenuation, generating a marked sound gradient between the perimeter areas and the inner zones. This behavior confirms the shielding effect associated with both buildings and vegetative barriers, consistent with the findings reported by Robles et al. (2019) regarding the role of green spaces as noise-mitigation elements, and with the studies of Barboza de Souza et al. (2020), Doutres et al. (2023), and Arbaoui et al. (2024) conducted in university environments internationally.

The average reduction of 6 to 9 dB(A) observed during the lockdown, compared with previous measurements in the same area (Villarreal et al. 2003; Henríquez et al. 2007), highlights the strong dependence of the sound environment on vehicular mobility, a phenomenon also documented globally during the pandemic (Mitchell et al. 2021, Kumar et al. 2022, Puyana et al. 2023).

Furthermore, the minimum background noise value recorded ($L_{90} \approx 45$ dB(A)) represents a novel acoustic baseline for the campus, falling below the threshold recommended by the WHO for educational environments (Berglund et al. 1999, Basner and McGuire 2018). This finding aligns with the observations of Costa Lima (2020), who indicate that low L_{90} values favor more pleasant soundscapes.

The inferential analysis reinforces the importance of location as the main explanatory factor of noise, since it accounted for 68.5% of the variance ($\eta^2 = 0.685$), in agreement with results reported in Asian university campuses (Huang et al. 2022, Kallankandy and Deswal 2024).

Although the use of a Class 2 sound level meter and short sampling times constitutes a limitation, the internal verification procedures and statistical consistency support the reliability of the generated model.

Finally, the resulting acoustic map constitutes a relevant technical tool for environmental planning on campus and for supporting future passive noise-mitigation strategies, as recommended by Robles et al. (2019) and Al-Asmar (2025).

CONCLUSIONS

This study made it possible to establish, for the first time, an acoustic baseline for the University of Panama campus under conditions of minimal activity, which represents its most significant contribution. This characterization showed that background noise levels comply with the standards recommended for educational settings and confirmed that the spatial configuration of the campus favors more stable and less intrusive acoustic conditions in its inner areas. It also enabled a clearer understanding of the magnitude of the effect that reduced vehicular flow has on overall sound levels, providing technical input for institutional environmental management.

Based on these results, it is recommended to strengthen acoustic-planning strategies by expanding green areas and regulating vehicular flow near campus access points. Future research should compare this baseline with conditions of regular activity to assess the actual influence of daily campus use, as well as extend measurement durations and employ higher-precision instruments to improve the estimation of sensitive indicators such as L_{den} and L_{90} . These improvements would allow refining the acoustic model and contribute to updating the regulations applicable to educational spaces in the country.

ACKNOWLEDGMENTS

The authors express their gratitude to the authorities of the University of Panama for facilitating the research permits, and to Yadira Echeverría from the University of Panama's Instituto de Geociencias for her valuable support in the GIS processing.

ChatGPT (version 2025) was used exclusively as a support tool for instructional reviewing, as well as for spelling verification and the structuring of bibliographic references according to the journal's formatting guidelines. The conceptual development, data analysis, interpretation of results, and all scientific content of the manuscript were carried out entirely by the authors.

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