Participatory Noise Mapping using GIS in Community Barrio Obrero Oeste, Caño Martín Peña Special Planning District

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Abstract — *This study investigates the pervasive issue of noise pollution in urban environments, focusing on Barrio Obrero Oeste in San Juan, Puerto Rico. By integrating Geographic Information Systems (GIS) and participatory noise mapping, the research identifies critical noise hotspots and evaluates the relationship between noise levels and land-use zoning. Utilizing the NIOSH Sound Level Meter App, 81 noise samples were collected to measure equivalent continuous sound levels (LAeq) and maximum sound levels (Lmax). Key findings reveal significant noise contributions from transportation corridors, air traffic, and mixed-use zones, with residential areas exhibiting the highest sensitivity. Kernel density analysis highlights clusters of noise pollution exceeding regulatory thresholds established by Puerto Rico's Environmental Quality Board, emphasizing the role of zoning and infrastructure in shaping noise dynamics. The study underscores the feasibility of smartphone-based participatory noise mapping as a cost-effective approach to environmental monitoring.*

Keywords — *Crowdsource Mapping, GIS, Noise Mapping, Noise Pollution Assessment.*

INTRODUCTION

The geographic boundaries of Barrio Obrero Oeste are distinctly illustrated within the Caño Martín Peña Special Planning District, as depicted in the district map. This map (**Figure 1**) highlights the community's unique spatial characteristics, including its dense urban layout, proximity to major thoroughfares, and adjacency to other neighborhoods within San Juan. These features amplify the community's susceptibility to noise pollution, given its location near high-traffic avenues and transportation infrastructure, including an international airport and train station. This spatial context underscores the importance of this study's focus on urban noise dynamics in Barrio Obrero Oeste.

Noise pollution is a pervasive environmental and public health issue, profoundly affecting worldwide urban populations. This investigation contributes to the United Nations Sustainable Development Goals (SDGs), specifically Goal 11: Sustainable Cities and Communities, by addressing the multifaceted challenges of urban noise pollution and its socio-environmental repercussions. Effective noise management also aligns with Goal 3, promoting health and well-being while fostering inclusive, resilient, and sustainable urban environments [1] [2] [3].

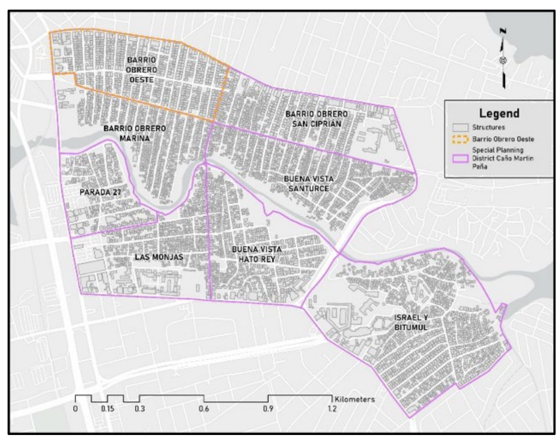

Figure 1
Special Planning District Caño Martin Peña & Community of Barrio Obrero Oeste

The focal area of this study is the Special Planning District of Caño Martín Peña, a historically significant region in San Juan, Puerto Rico. Renowned for its dense population and intricate urban fabric, this district includes Barrio Obrero Oeste—a unique community with distinctive demographic and spatial dynamics. According to the U.S. Census, the district accommodates 10,977 residents, with an extraordinary population density of 15,984 inhabitants per square mile. These figures contrast Puerto Rico's average density of 960 inhabitants per square mile and San Juan's municipal density of 7,147 inhabitants per square mile. The study area encompasses approximately 700 structures, providing a representative microcosm of urban noise challenges.

Figure 2
Photos of Military C-17 (Top Side) & Commercial Boeing 747 (Button side) Aircrafts Spot on Site

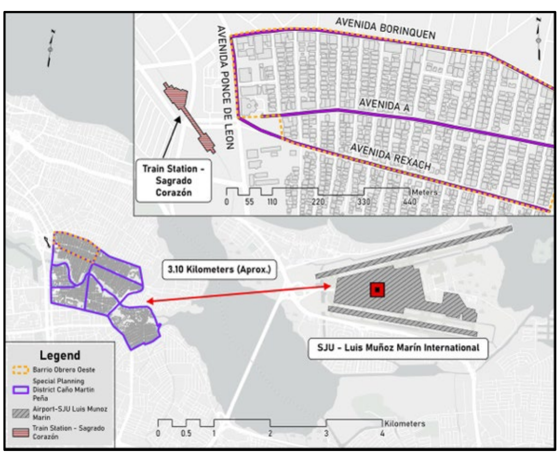

Figure 3
Map of Noise Pollution Sources such as Main Avenues & Transportation Infrastructure

Dominant noise pollution sources within the study area include high-traffic thoroughfares such as Avenida Ponce de León, Avenida A, Avenida Rexach, and Avenida Borinquén. The district's proximity to a train station (**Figure 3**), primary state and local highways, and an international airport amplifies its noise exposure. Aircraft landing approaches (**Figure 2**), serving both military and commercial aviation, significantly impact the community. Furthermore, local zoning regulations and land-use patterns also critically influence the district’s acoustic environment.

This research employs Geographic Information Systems (GIS) to execute a comprehensive noise pollution assessment in Barrio Obrero Oeste. Utilizing participatory sensing methodologies, including crowdsourced data collection via the NIOSH Sound Level Meter App, this study explores affordable, community-driven approaches to environmental noise monitoring and mapping. This aligns with the open-science framework proposed by Picaut et al. [4], which underscores the value of community involvement in generating accurate and actionable noise maps. The study’s objectives include:

- Mapping community reports using GIS and analyzing the impact of prominent noise sources on urban landscapes.
- Assessing the accuracy and practicality of the NIOSH app for community-based noise assessments.
- Identifying correlations between noise pollution reports and land-use zoning to pinpoint critical hotspots.

By achieving these objectives, the research aims to deepen understanding of urban noise pollution dynamics and foster innovative, community-centered solutions for noise management in densely populated areas.

Methodology

This research integrates participatory sensing and geospatial analysis to evaluate environmental noise pollution within the Barrio Obrero Oeste community. The study's methodological framework encompasses the following components:

Noise Data Collection

The data collection process involved surveying the following key main roads:

- Ponce de León Avenue
- Avenida A. Avenue
- Rexach Avenue
- Borinquén Avenue

A total of 81 noise samples were recorded/collected, and the measurements captured included equivalent continuous sound levels (LAeq) and maximum sound levels (Lmax) over 5-minute intervals for a one-week diurnal between 11 am to 12 pm observation period. Volunteers prioritized areas with identified noise pollution sources, such as high-traffic intersections, industrial zones, and public transit hubs, while also conducting random sampling to ensure broad spatial representation.

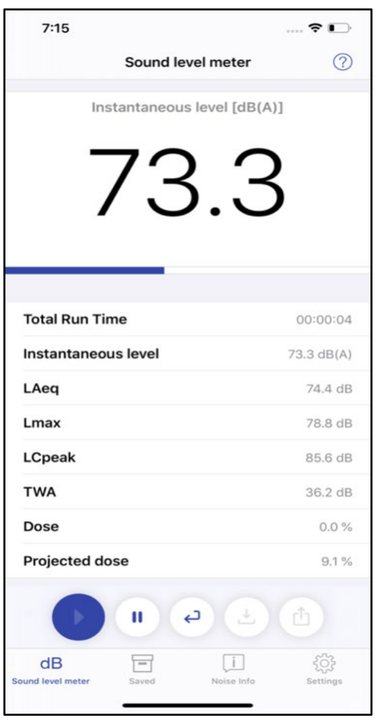

Figure 4
NIOSH Sound Level Meter App

The NIOSH Sound Level Meter App (**Figure 4**) was selected as the main software for sound or decibel meter using mobile phones. The app was developed by the National Institute for Occupational Safety and Health (NIOSH). It is designed to measure and analyze workplace noise exposure to help identify environments where sound levels might exceed safe limits, which can lead to hearing damage over time. Reports were collected using the iPhone (entirely) as the app could only be available on iOS due to Apple devices having consistent hardware and calibrated microphones, ensuring accurate noise measurements. Android devices vary in microphone quality and hardware, making it difficult to guarantee reliable results across all models.

Additionally, Field Maps were utilized to record the precise geographical locations (points) of the noise samples, ensuring spatial accuracy in the data collection process. This participatory data collection aligns with methodologies emphasizing community involvement, as demonstrated by Jacobs and Steenhaut [5]. Moreover, the utility of smartphone-based applications for environmental noise monitoring has been substantiated by Kardous and Shaw [6], validating their effectiveness in diverse contexts.

Spatial Framework and Grid Indexing

The study area was divided into 80 m x 80 m grids to facilitate precise spatial analysis, corresponding to 1 inch by 1 inch on a US survey map. Each grid cell served as a sampling unit for aggregating noise measurements and mapping spatial patterns. This grid-based approach has proven effective in prior participatory noise mapping studies, such as those conducted by Guillaume et al. [1], Aletta and Kang [3], and Stevens and D'Hondt [7], which underscore its utility for identifying noise pollution hotspots in urban environments.

Analytical Approach

The recorded noise data underwent rigorous analysis to discern patterns and correlations, focusing on:

- Identifying noise hotspots where levels exceeded regulatory thresholds, as detailed by Rana et al. [8].

- Correlating noise levels with land-use zones to uncover spatial relationships between urban planning and environmental noise.
- Evaluating the feasibility of crowdsourced data as a cost-effective alternative for large-scale community noise assessments, informed by frameworks proposed by Silva et al. [2].

Participatory and Context-Aware Methods

The participatory component engaged community members in the noise data collection process, leveraging local knowledge to enhance data granularity. Volunteers underwent brief training sessions focused on the proper use of the NIOSH Sound Level Meter App (**Figure 4**), ensuring consistency in data collection procedures. The training emphasized:

1. **Device Setup:** Ensuring proper smartphone calibration and optimal microphone placement to avoid interference.
2. **Sampling Protocols:** Identifying key noise sources, such as high-traffic intersections and public transport hubs, while maintaining random sampling for broader representation.
3. **Data Logging:** Recording timestamps, locations, and contextual observations, such as weather conditions or atypical events affecting noise levels.

This approach aligns with recommendations by Aletta and Kang [3], who emphasize participatory approaches for sustainable soundscape management. Furthermore, context-aware methods, as proposed by Rana et al. [8], ensured temporal and spatial accuracy in noise monitoring. Studies such as Misra et al. [9] and Murphy and King [10] have corroborated the efficacy of participatory noise mapping, demonstrating the complementarity of community-driven efforts with traditional assessments.

Device Calibration and Validation

Device calibration is a critical component of ensuring the reliability of noise measurement data collected via the NIOSH Sound Level Meter App. Calibration was performed by comparing the app's outputs with those from professional-grade sound level meters under controlled conditions. Specifically, the process involved:

1. **Baseline Calibration**: Initial comparison with a Class 1 sound level meter to establish reference values across a range of frequencies and sound pressure levels.
2. **Field Calibration**: Routine checks are conducted using a portable calibrator to account for environmental variables, such as temperature and humidity, that might affect device accuracy.
3. **Microphone Sensitivity Adjustments**: Addressing known discrepancies in smartphone microphone sensitivity, as documented by Kardous and Shaw [6] [11], to minimize over- or underestimations of decibel levels.

Figure 5
TOPTES Decibel Level Meter Uses a Precise Condenser Microphone to Capture Sound
It is equipped with A-weighting and C-weighting facilities that measure noise levels from 30 to 130 dB with an accuracy of 1.5 dB, frequency from 30 to 8000Hz.

Additionally, a comparative analysis was conducted between the NIOSH Sound Level Meter App on iPhone and the TOPTES Sound Meter (**Figure 5**) to assess measurement accuracy. The comparative analysis between the NIOSH Sound Level Meter App on iPhone and the TOPTES Sound Meter revealed varying degrees of accuracy. While many readings displayed a close alignment, deviations ranged from ±0 to ±2.7 dB(A), depending on the recorded noise levels. Table 1 highlights these differences, emphasizing the importance of device calibration for ensuring reliability in environmental noise monitoring.

Table 1
iPhone Pro Max NIOSH App vs TOPTES Decibel Level Meter

iPhone 12 Pro Max (NIOSH App)	TOPTES Sound Meter	Difference (± dB)
70.1	70.1	±0
68.9	70.3	±1.4
66.9	67.6	±0.7
79.8	77.1	±2.7
80.5	83.1	±2.6
83.4	83.4	±0
79.9	80.1	±0.2
82.7	80.1	±2.6
88.7	91.0	±2.3
93.1	93.1	±0
80.0	80.89	±0.89

These calibration methods and comparative analyses confirm that the iPhone's NIOSH app can provide reliable measurements for participatory noise mapping. However, calibration remains essential to ensure the accuracy and consistency of data collected in diverse environments.

Regulatory Noise Thresholds

The permissible noise level thresholds based on the percentage of time a noise level is exceeded (L10) during diurnal (D) were as follows:

Table 2
Reglamento para el Control de la Contaminación por Ruidos [12]

LIMITE DE NIVELES DE SONIDO
dB(A)
Nivel de Sonido Excedido en 10 % del Periodo de Medición (L_{10})

FUENTE EMISORA	ZONAS RECEPTORAS							
	Zona I (Residencial)		Zona II (Comercial)		Zona III (Industrial)		Zona IV (Tranquilidad)	
	D	N	D	N	D	N	D	N
Zona I (Residencial)	60	50	65	55	70	60	55	50
Zona II (Comercial)	65	50	70	60	75	65	55	50
Zona III (Industrial)	65	50	70	65	75	75	55	50
Zona IV (Tranquilidad)	65	50	70	65	75	75	55	50

Nota: "**D**" implica el periodo diurno y "**N**" implica el periodo nocturno.

To contextualize the analysis, the study adhered to the regulatory noise thresholds established by Puerto Rico's Environmental Quality Board (Junta de Calidad Ambiental). Table 2 specifies noise level limits in decibels (dB[A]) for various source and receptor zones, categorized as Residential (Zone I), Commercial (Zone II), Industrial (Zone III), and Tranquility (Zone IV).

For example:

1. Residential zones have thresholds of 60 dB(A) during the day and 50 dB(A) at night.
2. Commercial zones allow higher levels, with thresholds of 65 dB(A) during the day and 55 dB(A) at night.

These values served as benchmarks for analyzing noise levels across different zoning areas. Compliance with these standards was evaluated by integrating the noise data into GIS and comparing it with the spatial distribution of zoning classifications. This approach allowed identifying zones where noise pollution exceeded acceptable limits and its correlation with land-use patterns.

RESULTS

Among the 81 reports (noise samples) collected, the noisiest were found to be distributed across three zoning areas: ZU-R2 (Residential) with 25 incidents, ZU-G1 (Light Commercial) with 20 incidents, and ZU-G2 (General Commercial) with 9 incidents. Residential areas exhibited the highest noise sensitivity, highlighting the disproportionate impact of noise pollution on residential zones.

Figure 6
Kernel Point Density Map Report of the 81 Noise Samples

Kernel Point Density Analysis (**Figure 6**) revealed pronounced clustering of noise incidents near major thoroughfares, such as Avenida Borinquén and Avenida Rexach. This finding corroborates prior studies by Picaut et al. [4], which demonstrated the utility of crowdsourced data in identifying urban noise hotspots. This approach aligns with methodologies highlighted by Guillaume et al. [1] and Silva et al. [2] which emphasize the utility of spatial clustering techniques in identifying noise hotspots and understanding their spatial dynamics. These hotspots were associated with mixed-use zoning, characterized by intensive commercial and residential activity. Additionally, air traffic patterns significantly influenced noise levels in the district. Studies on urban environments adjacent to major airports indicate that aircraft noise contributes substantially to elevated sound levels, particularly during takeoff and landing phases [2] [10]. The proximity to a major international airport resulted in frequent aircraft noise, particularly during military and commercial landing approaches. This overlay of maximum decibel levels (Lmax) corroborated these findings, emphasizing the intersection of noise intensity and frequency in heavily trafficked and air-traffic-impacted areas. These results underscore the critical interplay between zoning, infrastructure, air traffic, and urban noise dynamics.

The map (**Figure 7**) further corroborates the findings, showing that most noise samples were collected in ZU-R1 and ZU-R2 (residential areas). These zones experienced pronounced noise impacts due to their proximity to ZU-G1 (light commercial areas) and major traffic arteries. This spatial overlap highlights the critical need for tailored noise mitigation strategies in residential zones affected by adjacent commercial and transportation activities.

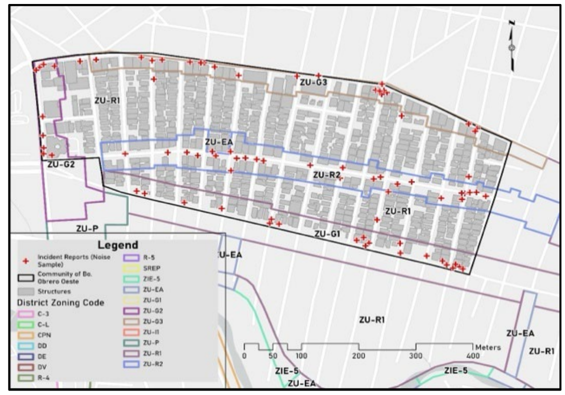

Figure 7
Zoning Districts in Bo. Obrero Oeste Map & the Spatial Distribution of the 81 Noise Samples

The spatial distribution of noise measurements, visualized in the LAeq (**Figure 8**) and Lmax (**Figure 9**) maps, provides further insights into the noise pollution dynamics in the study area. The LAeq map reveals that zones along Avenida Rexach and Avenida Borinquén exhibit the highest continuous sound levels, with values ranging from 80.1 to 90.3 dB(A). These areas correlate with mixed-use zones, characterized by dense urban activities and transportation corridors. Conversely, quieter zones, with LAeq levels between 64.3 and 67.3 dB(A), are primarily found in interior residential streets, farther from major traffic arteries.

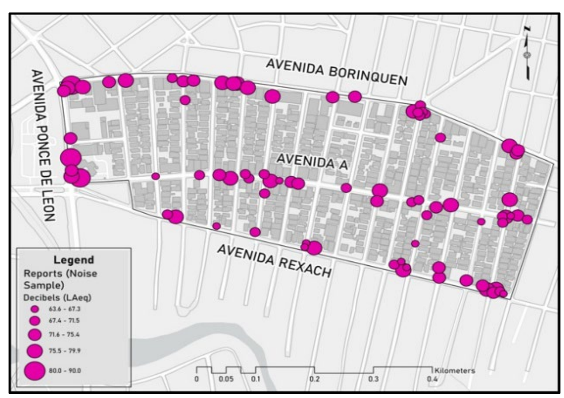

Figure 8
LAeq Exposure Analyzed from the 81 Reports

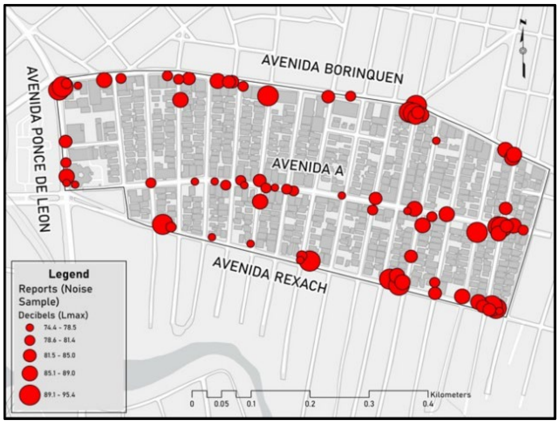

Figure 9
Lmax Exposure Analyzed from the 81 Reports

The Lmax events (**Figure 8**) highlights areas with peak noise events, with maximum levels exceeding 90 dB(A) near Avenida Borinquén and high-traffic intersections. These noise spikes are likely attributed to transient sources such as passing vehicles, buses, and air traffic. Residential zones near these intersections also show elevated peak noise levels, underscoring the disproportionate impact on these communities. Comparatively, areas with lower Lmax values, ranging from 76.4 to 78.5 dB(A), align with quieter residential zones away from traffic-intensive areas.

CONCLUSION

This study highlights the pervasive issue of noise pollution within densely populated urban areas, using Barrio Obrero Oeste as a case study. By integrating participatory sensing and GIS-based spatial analysis, the research demonstrates the potential of community-driven approaches for effective environmental noise management. The findings underscore the significant contributions of major transportation corridors and air traffic to urban noise dynamics, revealing critical hotspots where noise levels exceed acceptable thresholds.

The results validate the use of smartphone-based applications like the NIOSH Sound Level Meter App for noise monitoring while emphasizing the necessity of calibrating against professional-grade devices to ensure measurement accuracy. Additionally, the study identifies strong correlations between land-use zoning and noise pollution intensity, providing actionable insights for urban planners and policymakers.

However, several limitations were identified during the research process, including challenges in coordinating with volunteers, addressing knowledge gaps in technology usage, and ensuring security in specific areas, which required collaboration with local leadership. Furthermore, hardware constrains limited data collection to iPhones, potentially reducing the inclusivity of participatory efforts.

In conclusion, this research advances the understanding of noise pollution's spatial and social dimensions, offering a replicable framework for other urban contexts. Future work should focus on enhancing calibration techniques, integrating more sophisticated modeling tools, and exploring long-term community engagement strategies to sustain noise monitoring efforts and promote sustainable urban development.

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