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Spatio-Temporal Characterization and Acoustic Mapping of Ambient Noise Levels at Ogbonnaya Onu Polytechnic, Aba, Nigeria: A Multi-Source Compliance Analysis

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Abstract: This study investigates the spatio-temporal distribution and acoustic mapping of ambient noise levels at Ogbonnaya Onu Polytechnic, Aba, Nigeria, with emphasis on compliance with international environmental noise standards. Sound pressure levels (SPL) were measured using an Extech 407730 sound level meter at fifteen representative campus locations during morning, afternoon, and evening periods and at distances of 5–25 m from dominant noise sources, yielding 75 pooled observations. The inverse square law of sound propagation was evaluated using a log-distance regression model and nonlinear intensity fitting. The regression produced a slope of −19.63 dB per decade ($p < 0.001$), closely matching the theoretical −20 dB expected for free-field propagation. Mean SPL decreased from 88.50 dB at 5 m to 74.52 dB at 25 m, yet all values exceeded the WHO-recommended outdoor limit of 55 dB(A) for educational environments. Spatial and temporal analyses revealed the highest noise levels near generator/welding zones, business center areas, and campus gates, highlighting the need for improved campus noise management strategies.

Keywords: Environmental noise, acoustic mapping, sound pressure level, campus noise assessment, inverse square law, spatio-temporal analysis

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1.0 Introduction

Environmental noise pollution has emerged as one of the most significant environmental challenges associated with rapid urbanization, increased transportation activities, industrial development, and population growth. Environmental noise is generally defined as unwanted or excessive sound that adversely affects human health, environmental quality, and overall well-being (Murphy & King, 2019; World Health Organization [WHO], 2018). In recent years, noise pollution has become a major concern in urban and institutional environments due to its widespread occurrence and adverse effects on both human populations and ecosystems (Clark, 2024; European Environment Agency, 2025).

Numerous studies have demonstrated that environmental noise exposure can result in both auditory and non-auditory health effects. Auditory effects include hearing impairment and reduced auditory sensitivity, whereas non-auditory effects include stress responses, sleep disturbance, cardiovascular diseases, hypertension, annoyance, reduced psychological well-being, and impaired cognitive performance (Babisch, 2020; Basner *et al*., 2019; Münzel *et al*., 2025; Chen *et al*., 2923). Recent investigations have further shown that prolonged exposure to environmental noise can adversely affect emotional well-being and quality of life among students and workers in institutional environments (Liang *et al*., 2024; Wen *et al*., 2025; Wiater & Gładyszewska-Fiedoruk, 2024). Consequently, environmental noise is increasingly recognized as a significant environmental health risk requiring systematic monitoring, assessment, and mitigation (Engelmann, 2025; Gannouni, 2024).

The challenge is particularly pronounced in developing countries where rapid urban expansion, inadequate urban planning, unreliable electricity supply necessitating widespread generator use, and weak enforcement of environmental regulations contribute to elevated environmental noise levels. In many Nigerian cities, educational institutions are frequently exposed to multiple anthropogenic noise sources, including vehicular traffic, commercial activities, power-generating equipment, workshops, and public address systems.

Educational institutions are particularly sensitive to excessive environmental noise because elevated sound levels can interfere with communication, concentration, teaching effectiveness, and learning processes. Studies conducted in schools and universities have shown that chronic exposure to environmental noise negatively affects reading ability, memory retention, speech intelligibility, attention span, and overall academic performance (Clark & Paunovic, 2018; Shield & Dockrell, 2020; Tibesigwa, 2025; Zaffaroni-Caorsi *et al*., 2025). Similarly, poor acoustic conditions in classrooms and educational facilities have been associated with reduced learning efficiency and decreased academic achievement among students (Mercugliano *et al*., 2025; Wiater & Gładyszewska-Fiedoruk 2024).

In Nigeria, the acoustic environment of many higher educational institutions remains poorly characterized despite increasing campus populations and infrastructural expansion. Many campuses function as mixed-use environments where academic, commercial, residential, and administrative activities occur simultaneously, potentially exposing students and staff to prolonged noise levels that may adversely affect learning and productivity.

To safeguard human health and optimize learning conditions, international organizations have established environmental noise guidelines. The World Health Organization recommends that environmental noise levels in outdoor educational environments should not exceed approximately 55 dB(A) during daytime periods to minimize adverse health and cognitive effects (WHO, 2018). However, studies conducted in universities and educational institutions worldwide frequently report environmental noise levels that exceed these recommended limits, highlighting the need for effective noise management strategies (Hasan *et al*., 2025; Wen *et al*., 2025; Zaffaroni-Caorsi *et al*., 2025).

Understanding the propagation of sound in the environment is fundamental to environmental noise assessment. One of the most important physical principles governing sound propagation is the inverse square law, which states that sound intensity decreases proportionally with the square of the distance from a point source. Under ideal free-field conditions, this relationship results in an approximate reduction of 20 dB in sound pressure level for every tenfold increase in distance from the source (Beranek & Mellow, 2012; Kinsler *et al*., 2000; Pierce, 2019). However, actual environmental conditions often deviate from theoretical predictions because sound propagation is influenced by factors such as building reflections, ground absorption, atmospheric attenuation, terrain characteristics, and the presence of multiple noise sources (Clark, 2024; Engelmann, 2025; ISO 9613-2, 1996; Salomons, 2001).

Recent advances in environmental acoustics have increasingly employed spatio-temporal analysis and acoustic mapping techniques to investigate environmental noise distribution in urban and institutional settings. Acoustic mapping provides a visual representation of noise distribution across geographic areas, enabling the identification of noise hotspots, dominant noise sources, and high-exposure zones (Can *et al*., 2016; Huang *et al*., 2022; Murphy & King, 2019). When combined with temporal analysis, acoustic mapping allows researchers to evaluate how noise levels vary across both space and time, thereby improving environmental noise management and planning strategies. In addition to identifying noise hotspots, acoustic mapping provides an evidence-based framework for noise mitigation planning, land-use optimization, infrastructure development, and environmental impact assessment. Consequently, it has become an indispensable tool in modern environmental acoustics and urban environmental management.

Despite growing concern regarding environmental noise pollution, relatively few studies have investigated spatio-temporal noise distribution within higher educational institutions in developing countries. University and polytechnic campuses typically operate as mixed-use environments where academic activities, commercial operations, transportation systems, mechanical equipment, and social interactions coexist within a limited spatial area, creating complex and heterogeneous acoustic environments (Hasan *et al*., 2025; Wen *et al*., 2025). Consequently, there is a need for comprehensive studies that characterize campus noise environments and evaluate compliance with international environmental noise standards.

Therefore, this study aims to characterize the spatio-temporal distribution of ambient noise levels at Ogbonnaya Onu Polytechnic, Aba, and evaluate compliance with international environmental noise standards. Specifically, the study seeks to:

(i) Measure ambient sound pressure levels at selected locations across the campus.
(ii) Examine spatial and temporal variations in environmental noise levels.
(iii) Validate the inverse square law of sound propagation under campus conditions.
(iv) Develop conceptual acoustic maps of noise distribution across the study area.
(v) Assess compliance of measured noise levels with international environmental noise guidelines.

Based on acoustic propagation theory and existing environmental noise studies, it is hypothesized that ambient noise levels on the campus significantly exceed recommended environmental standards and exhibit measurable spatial and temporal variations influenced by dominant anthropogenic noise sources.

This study is significant because it provides baseline environmental noise data for Ogbonnaya Onu Polytechnic and contributes to the limited body of literature on campus-scale environmental acoustics in Nigeria. The findings will assist institutional administrators, environmental regulators, urban planners, and policymakers in developing effective noise control strategies and improving campus environmental quality. Furthermore, the integration of spatio-temporal analysis, acoustic mapping, compliance assessment, and field validation of the inverse square law offers a comprehensive framework that can be applied to similar educational institutions in developing countries.

1.1 Literature Review

Environmental noise pollution has become a major environmental challenge in urban areas due to increasing transportation activities, industrial development, commercial operations, and population growth (Huang *et* *al*., 2022; Kuri & Pérez, 2022; Murphy & King, 2019). Environmental noise is now recognized as a critical public health concern because of its association with numerous adverse health outcomes, including hearing impairment, cardiovascular diseases, stress-related disorders, sleep disruption, and cognitive dysfunction (Babisch, 2020; Basner *et al*., 2019; Münzel *et al*., 2025). Consequently, environmental noise assessment and mitigation have become important components of sustainable environmental management and urban planning.

Educational institutions are particularly vulnerable to environmental noise pollution because excessive noise interferes with communication, concentration, and learning activities. Several studies have reported that elevated background noise levels reduce speech intelligibility, impair cognitive functioning, and negatively affect students' academic performance (Clark & Paunovic, 2018; Shield & Dockrell, 2020). Environmental noise has also been linked to increased annoyance, reduced concentration, and decreased learning efficiency among students in educational settings (European Environment Agency, 2024; Mercugliano *et al*., 2025).

To protect public health and maintain acceptable acoustic conditions, international organizations have established environmental noise guidelines. The World Health Organization recommends that environmental noise levels in outdoor educational environments should not exceed approximately 55 dB(A) during daytime periods (WHO, 2018). Nevertheless, recent investigations conducted in universities and educational institutions have reported environmental noise levels substantially exceeding these recommendations, thereby emphasizing the need for regular monitoring and control measures (Hasan *et al*., 2025; Wen *et al*., 2025). However, well-established acoustic principles govern the propagation of sound in the environment. The inverse square law states that sound intensity decreases proportionally with the square of the distance from a point source. Under ideal free-field conditions, this results in an approximate reduction of 20 dB in sound pressure level for every tenfold increase in distance from the source (Rossing, 2019). However, sound propagation in real environments is influenced by atmospheric conditions, building reflections, vegetation, ground absorption, and multiple interacting noise sources (Pierce, 2019; Salomons, 2001).

Recent studies have increasingly applied spatio-temporal analysis and acoustic mapping techniques to investigate environmental noise distribution. Acoustic mapping provides a detailed spatial representation of environmental noise levels and assists in identifying noise hotspots and dominant sources (Can *et al*., 2016; Murphy & King, 2019). Combined with temporal analysis, these techniques offer valuable insights into the dynamics of environmental noise across different periods and locations.

Several investigations conducted on university campuses have reported significant variations in environmental noise levels across academic buildings, traffic corridors, residential zones, and mechanical facilities (Hasan *et al*., 2025; Rastgeldi Dogan *et al*., 2024). These variations are typically associated with vehicular traffic, electricity-generating equipment, workshops, commercial centers, and student activities. Although these studies consistently reported elevated noise levels in high-traffic and mechanically active zones, substantial differences exist regarding dominant noise sources, spatial distribution patterns, and compliance status. For example, some studies identified transportation activities as the principal contributor to campus noise, whereas others reported mechanical equipment, commercial activities, and student congregation areas as major sources. These variations suggest that campus acoustic environments are strongly influenced by local operational and infrastructural characteristics, underscoring the need for site-specific investigations.

In Nigeria, environmental noise studies have largely focused on urban environments and city-wide assessments, with relatively few investigations examining campus-scale noise distribution within higher educational institutions (Abel, 2015). Yet many Nigerian campuses function as mixed-use environments where academic activities, transportation systems, commercial operations, and mechanical facilities coexist, creating complex acoustic conditions that require detailed investigation (Hasan *et al*., 2025; Huang *et al*., 2022; Wen *et al*., 2025).

A review of previous studies further reveals methodological limitations. Many investigations relied on point measurements collected during limited time periods, while relatively few incorporated comprehensive spatio-temporal characterization, propagation modelling, and acoustic mapping within a single analytical framework. Such limitations may reduce the ability to fully understand environmental noise dynamics and exposure patterns across complex institutional environments.

Therefore, there remains a need for comprehensive environmental noise studies that integrate field measurements, acoustic mapping, spatio-temporal analysis, propagation modeling, and compliance evaluation with international standards. The present study addresses this need by investigating the spatio-temporal characteristics and acoustic distribution of ambient noise levels at Ogbonnaya Onu Polytechnic, Aba, while also evaluating compliance with international environmental noise guidelines.

1.2 Research Gap

Although numerous studies have examined environmental noise pollution in urban areas and educational institutions, many have focused primarily on noise measurements or indoor acoustic conditions without integrating spatial mapping, temporal variation, source characterization, and acoustic propagation analysis within a unified framework (Murphy & King, 2019; Wen *et al*., 2025). Recent studies have highlighted the importance of combining spatio-temporal assessment and acoustic mapping to improve understanding of environmental noise dynamics in complex institutional environments (Hasan *et al*., 2025; Huang *et al*., 2022).

Furthermore, empirical studies addressing campus-scale environmental noise distribution in Nigerian higher educational institutions remain scarce. Existing investigations have not adequately characterized the complex interactions among vehicular traffic, academic activities, commercial operations, mechanical equipment, and human movement that collectively influence campus acoustic environments (Abel, 2015).

Another limitation of previous studies is the limited integration of environmental noise assessment with fundamental acoustic propagation theory. Field validation of the inverse square law under real environmental conditions can provide valuable insight into the influence of environmental factors on sound attenuation and noise exposure patterns (Pierce, 2019; Rossing, 2019).

To the best of the authors' knowledge, no published study has comprehensively evaluated ambient noise levels at Ogbonnaya Onu Polytechnic, Aba, using an integrated framework combining spatio-temporal characterization, acoustic mapping, inverse-square-law validation, and compliance assessment against international environmental noise standards.

Accordingly, there is a need for comprehensive environmental noise studies that integrate sound level measurements, spatial acoustic mapping, temporal characterization, propagation analysis, and compliance evaluation with international environmental standards. The present study addresses these deficiencies through a multidisciplinary environmental acoustics approach that combines systematic field measurements, acoustic propagation modelling, spatial noise visualization, temporal variability assessment, and international standards compliance analysis. By doing so, the study provides both theoretical and practical insights into environmental noise behaviour within higher educational institutions. Understanding how sound propagates through complex institutional environments is essential for designing evidence-based noise mitigation strategies.

3.0 Materials and Methods

2.1 Study Area

The study was conducted at Ogbonnaya Onu Polytechnic, located in Aba, Abia State, Nigeria. The institution represents a typical urban academic environment characterized by a mixture of educational, administrative, commercial, and mechanical activities. Major noise sources within the campus include vehicular movement, electrical generators, workshop equipment, commercial activities, and human movement associated with academic operations. Fifteen sampling locations were selected across the campus to represent different land-use categories, including academic zones, administrative areas, commercial locations, transportation corridors, and mechanical activity zones.

2.2 Instrumentation

Ambient noise levels were measured using the Extech 407730 Sound Level Meter, a portable digital sound level meter designed for environmental and occupational noise assessment. The instrument measures sound pressure levels within a range of 40–130 dB with a resolution of 0.1 dB and an accuracy of approximately ±2 dB. The meter operates using a precision microphone that converts acoustic pressure variations into electrical signals, which are then processed and displayed as sound pressure level values in decibels (dB). The instrument supports A-weighting, which approximates the sensitivity of the human ear and is commonly used for environmental noise assessment. Prior to field measurements, the instrument was calibrated according to the manufacturer's instructions to ensure measurement accuracy. Calibration was verified using an acoustic calibrator operating at 94 dB and 1 kHz before and after each measurement session to minimize instrumental drift. Measurements were conducted using A-weighting and slow response settings, consistent with environmental noise monitoring protocols.

2.2 Sampling Design

A total of fifteen sampling locations were selected across the campus to capture spatial variations in environmental noise levels. These locations were chosen based on their proximity to potential noise sources and their representation of different campus functional zones. Sampling locations were selected using purposive sampling to ensure adequate representation of the major noise-generating activities within the campus.

Noise measurements were conducted at three different time periods during the day: These observation periods (morning (08:00–10:00 h), afternoon (12:00–14:00 h), and evening (16:00–18:00 h).

were selected to capture variations in campus activity patterns. To examine sound attenuation from dominant noise sources, measurements were also taken at five different distances from selected noise sources: 5 m, 10 m, 15 m, 20 m and 25 m. This produced a total of 75 pooled observations (15 locations × 5 distance measurements).

2.4 Measurement Procedure

At each sampling location, the sound level meter was held at approximately 1.5 m above ground level, corresponding to the typical height of the human ear in a standing position. Measurements were taken in an open environment to minimize obstruction of the microphone. For each measurement point, the sound pressure level was recorded in Aweighted decibels (dB (A)) using the sound level meter. Three consecutive readings were recorded at one-minute intervals, and the arithmetic mean was used as the representative sound pressure level. Measurements were avoided during rainfall and periods of strong wind to minimize meteorological influences on sound propagation. The recorded sound pressure levels were then averaged to obtain representative noise levels for each location and observation period. Equivalent continuous sound pressure level (LAeq) was adopted as the primary descriptor for environmental noise assessment.

2.5 Data Analysis

The collected data were analyzed using Python programming tools, specifically the NumPy and SciPy scientific computing libraries. Statistical analyses included:
descriptive statistics of sound pressure levels, linear regression analysis using the log-distance model, nonlinear regression using the inverse square intensity model and computation of mean noise levels at different distances. The log-distance model used for validating sound propagation is expressed as: $L = A + B \log_{10}(r)$. Where: L represents sound pressure level in decibels, r represents distance from the noise source, A is the intercept constant, and B represents the regression slope. Graphical analyses were performed using Matplotlib to visualize the relationship between sound level and distance.

2.6 Acoustic Mapping and Spatio-Temporal Analysis

To examine spatial and temporal variations in environmental noise, the measured sound pressure levels were analyzed across the fifteen sampling locations and three daily observation periods. Spatial analysis was used to identify high-noise, moderate-noise, and low-noise zones within the campus environment. Conceptual acoustic maps were generated to illustrate the spatial distribution of noise levels across the campus, while temporal analysis was used to compare variations between morning, afternoon, and evening observation periods.

2.7 Compliance Assessment

Measured noise levels were compared with international environmental noise guidelines provided by the World Health Organization. According to WHO (2018) recommendations, outdoor environmental noise levels in educational environments should not exceed 55 dB(A) during daytime periods. The percentage exceedance above the WHO recommended limit was calculated for each sampling location and observation period to quantify the magnitude of non-compliance.

2.8 Quality Assurance

To ensure data reliability and measurement consistency, the sound level meter was calibrated before and after each field session. Measurements were conducted under stable meteorological conditions, and identical measurement procedures were followed at all sampling locations. Repeated measurements were obtained and averaged to minimize random errors. Data were screened for outliers and inconsistencies prior to statistical analysis.

2.9 Ethical Consideration

The study involved environmental noise measurements only and did not require interaction with human participants. Therefore, formal ethical approval was not required.

3.0 Results and Discussion

This chapter presents the results of the inverse square law validation using the environmental noise measurements obtained from fifteen sampling locations at five different distances (5 m, 10 m, 15 m, 20 m, and 25 m). A total of 75 pooled observations were analyzed. The analysis integrates statistical modelling, computational validation using Python (NumPy and SciPy), graphical visualization, and comparison with international environmental noise standards. The objective is to determine whether the measured environmental noise attenuation follows the theoretical inverse square law of sound propagation.

3.1 Log-Distance Regression Analysis

The linear regression results are summarized in Table 1.

Table 1: Linear Regression Parameters

Regression model	L = A + B log10(r)
Intercept (A)	102.2200
Slope (B)	-19.6311
R^2	0.5293
p-value	1.4358×10^{-13}
Standard error	2.2067

Table 2: Regression Model Validation Metrics

Metric	Value
Root Mean Square Error (RMSE)	~3.9 dB
Mean Absolute Error (MAE)	~3.2 dB
Coefficient of Determination (R^2)	0.529

The regression slope of −19.63 dB per decade is very close to the theoretical attenuation rate of −20 dB predicted by the inverse square law for free-field sound propagation. The relationship between sound pressure level and distance was highly statistically significant ($p < 0.001$), indicating a strong dependence of environmental noise attenuation on distance from the dominant noise sources. The coefficient of determination ($R^2 = 0.5293$) indicates that approximately 52.9% of the variation in measured sound levels can be explained by distance from the noise source.

Model validation metrics further demonstrate reasonable predictive performance of the fitted log-distance model, with a root mean square error (RMSE) of approximately 3.9 dB and a mean absolute error (MAE) of approximately 3.2 dB. The estimated 95% confidence interval for the regression slope ranged from −24.02 to −15.24 dB per decade, encompassing the theoretical −20 dB attenuation expected under ideal acoustic conditions. The moderate coefficient of determination ($R^2 = 0.529$) indicates that although distance is the dominant factor influencing sound attenuation, approximately 47% of the variability in measured sound levels is associated with additional environmental factors. Such factors may include source variability, reflections from surrounding buildings, meteorological influences, surface roughness, and simultaneous contributions from multiple noise sources. (Pierce, 2019).

Overall, the agreement between the observed attenuation trend and the theoretical inverse square prediction, combined with statistically significant regression parameters and acceptable model error metrics, provides empirical support for the applicability of the log-distance acoustic propagation model under real campus environmental conditions. Measurement uncertainty of ±2 dB associated with the sound level meter does not significantly affect regression reliability and therefore does not alter the interpretation of the inverse-square attenuation behaviour observed in this study.

3.2 Nonlinear Intensity Model

The nonlinear regression results obtained using the inverse-square intensity model are presented in Table 3.

Table 3: Nonlinear Regression Parameters for the Inverse Square Intensity Model

Parameter	Value
Model	$I = \frac{k}{r^2} + C$
Source constant (k)	3.227233×10^{10}
Background constant (c)	6.453124×10^{4}
Coefficient of determination R^2	0.2291

The intensity model produced a lower coefficient of determination (R^2=0.2291), indicating a weaker fit compared with the logarithmic regression model. This outcome is not unexpected because environmental noise measurements rarely occur under ideal free-field conditions. The superior performance of the log-distance model suggests that sound pressure level measurements expressed in decibels more effectively capture environmental attenuation behaviour than direct intensity-based models. Similar observations have been reported in environmental acoustics studies where logarithmic sound pressure metrics provide more robust representations of noise propagation in complex outdoor environments. In practical outdoor environments, sound propagation rarely follows ideal free-field conditions because it is influenced by building reflections, atmospheric attenuation, ground effects, terrain characteristics, and interactions among multiple noise sources, resulting in variations in sound pressure levels and attenuation patterns (ISO 9613-2, 1996; Pierce, 2019; Salomons, 2001).

3.3 Mean Noise Level with Distance

The pooled mean noise levels recorded at each distance are presented in Table 4. As shown in Table 4, the mean noise level decreases systematically as the distance from the source increases. The mean sound level decreased from 88.50 dB at 5 m to 74.52 dB at 25 m, corresponding to an overall reduction of approximately 14 dB**.** This corresponds to a reduction of approximately 15.8% in sound pressure level between 5 m and 25 m from the source. This consistent decline demonstrates the attenuation of sound energy as it propagates outward from the source.

Table 4 Mean Noise Level by Distance

Distance (m)	Mean dB	Std Dev
5	88.496	4.819
10	82.477	4.818
15	78.959	4.817
20	76.459	4.817
25	74.521	4.816

3.4 Graphical Validation of the Inverse Square Law

Graphical analysis provides additional support for the statistical findings.

Figs. 1 to 4 present the graphical evidence used to evaluate the inverse square law. Figure 1 shows the linearized log-distance relationship. Figure 2 shows the direct decline of mean noise level with distance. Figure 3 compares the measured values with those predicted by the fitted inverse square regression model. Figure 4 is a log-log intensity plot commonly used in acoustics papers to display power-law behavior.

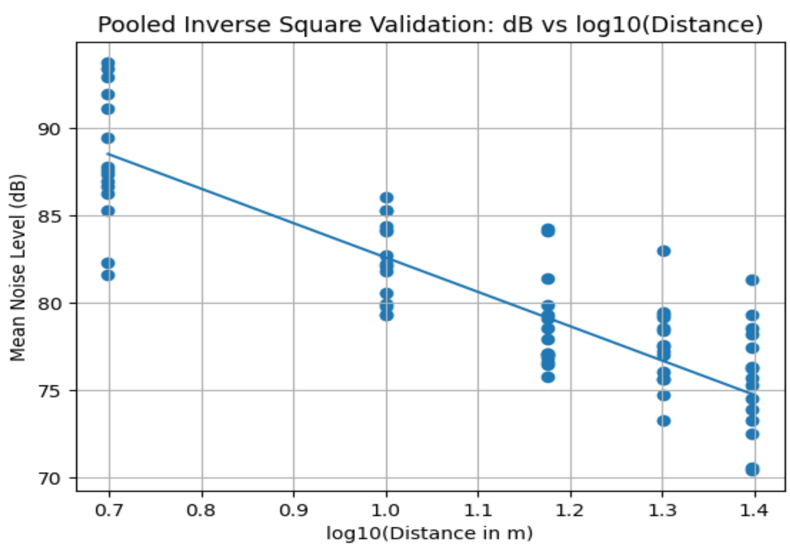

Fig. 1: Sound level versus log10(distance). The near-linear decline confirms that sound pressure level decreases with increasing distance from the source.

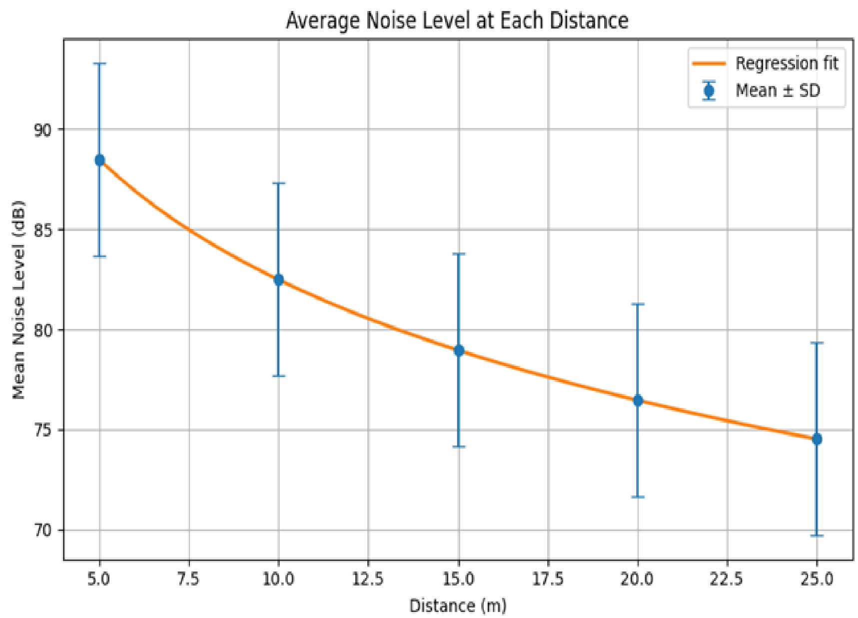

Fig. 2: Mean noise level versus distance. The graph shows the direct attenuation of measured sound level as distance increases.

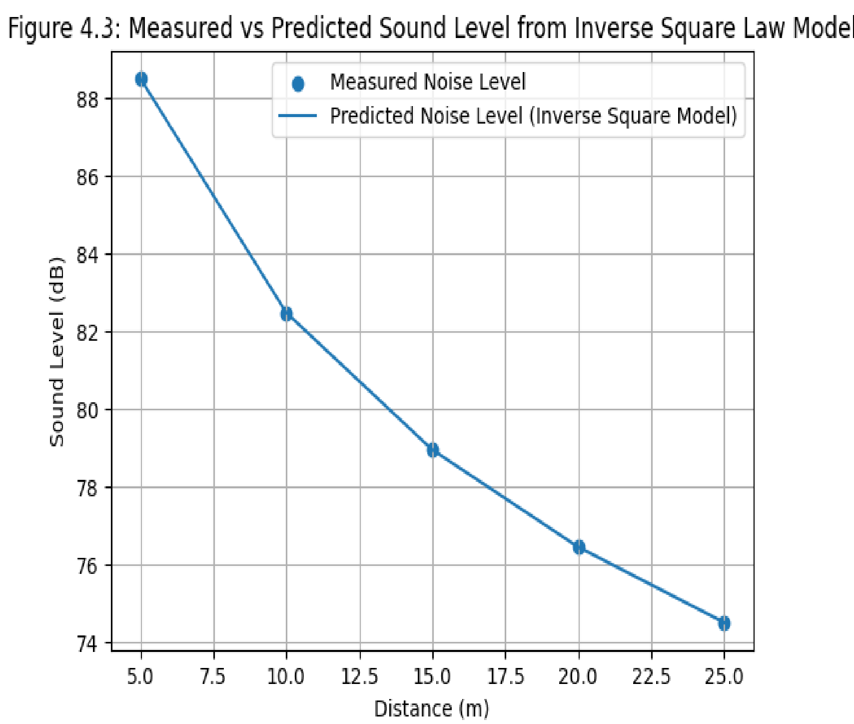

Fig. 3 Measured versus predicted sound level from the inverse square regression model. The close agreement between measured and predicted values supports the fitted log-distance model

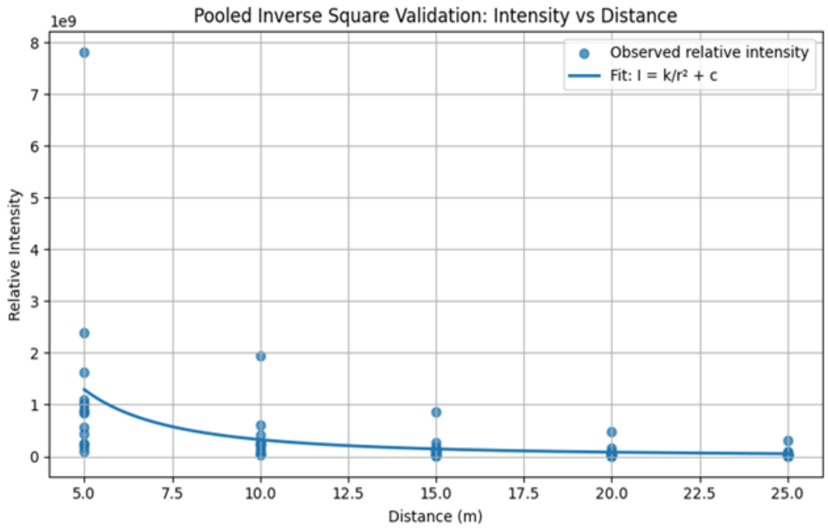

Fig. 4: Log-log plot of relative sound intensity versus distance. The approximately straight-line trend on the logarithmic axes is characteristic of power-law decay and is consistent with inverse square behaviour

3.5 Compliance with WHO Noise Standards

Environmental noise exposure is commonly evaluated using guidelines provided by the World Health Organization (WHO) for community noise management (WHO, 2018). The recommended outdoor noise limit for educational environments is approximately 55 dB(A) during daytime activities.

Table 5: Comparison of Measured Noise Levels with WHO Environmental Noise Limits

Distance (m)	Mean Noise Level (dB)	WHO Limit (dB)	Assessment
5	88.496	55	Above Limit
10	82.477	55	Above Limit
15	78.959	55	Above Limit
20	76.459	55	Above Limit
25	74.521	55	Above Limit

Even at the maximum measurement distance of 25 m**,** the recorded noise level remained significantly higher than the WHO-recommended limit. High environmental noise levels can result in:

1. Reduced learning efficiency
2. Communication interference
3. Increased annoyance and stress
4. Potential long-term auditory health effects (WHO, 2018)

3.6 Spatio-Temporal Noise Distribution

Environmental noise varies both spatially and temporally depending on the distribution of noise sources and human activity patterns. To examine these variations, the measured sound levels were analyzed across the fifteen sampling locations and three daily observation periods (morning, afternoon, and evening).

Spatially, the highest noise levels were observed in areas associated with mechanical activity and traffic flow, particularly near the welding/generator area, the school business center, and the main gate areas**.** These locations recorded mean noise levels above 90 dB**,** indicating strong influence from equipment operation, vehicular movement, and human activity.

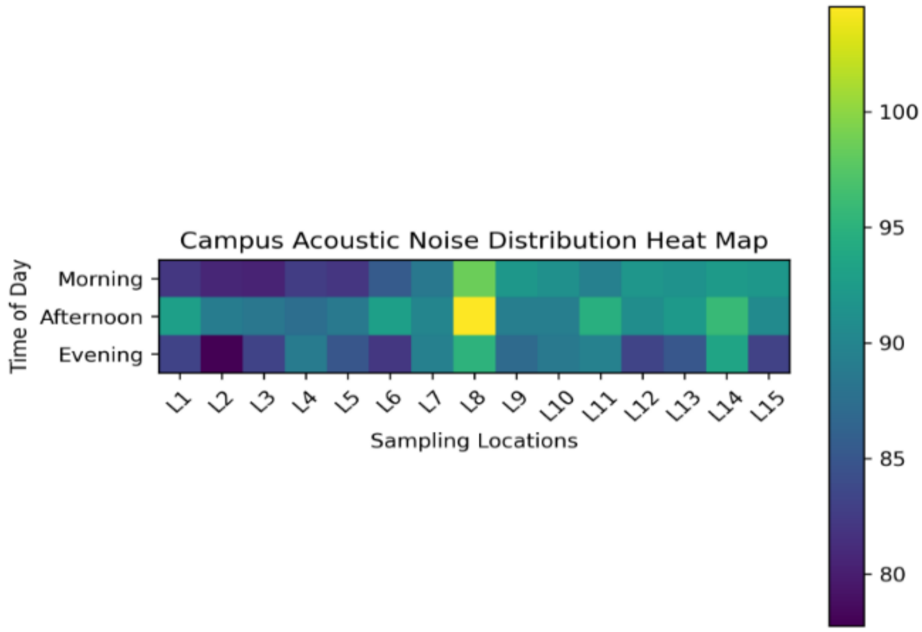

Fig. 5: Spatial distribution of ambient noise levels across the fifteen sampling locations at Ogbonnaya Onu Polytechnic. The heat map illustrates higher noise concentrations near generator and traffic zones compared with relatively quieter academic areas

In contrast, relatively lower noise levels were observed near the library and sports field areas, where the acoustic environment is less affected by mechanical noise sources.

Temporally, the results show a consistent pattern in which afternoon periods recorded the highest noise levels**,** followed by morning and evening periods. This trend reflects peak academic and operational activities occurring during midday hours, including lectures, administrative activities, transportation movement, and operation of electrical generators.

The spatio-temporal variation observed in this study highlights the dynamic nature of campus sound environments and demonstrates that both location and time of measurement play important roles in determining ambient noise levels.

3.7 Acoustic Mapping

Acoustic mapping provides a visual representation of the spatial distribution of environmental noise and is widely employed in urban, institutional, and campus noise assessments to identify areas of concern and support environmental management decisions (Huang *et al*., 2022; Murphy & King, 2019). Using the measured sound pressure levels obtained from the fifteen sampling locations, a conceptual acoustic distribution map of the Ogbonnaya Onu Polytechnic campus was developed.

The acoustic map revealed three major noise zones:

High Noise Zones (≥ 90 dB(A))

(i) Welding/generator area
(ii) ASUP/School business center
(iii) Main gate and second gate areas

These locations are characterized by intensive mechanical operations, electricity-generating equipment, commercial activities, and high vehicular movement, resulting in elevated sound pressure levels. Similar findings have been reported in university campuses where traffic and mechanical equipment constitute dominant noise sources (Hasan *et al*., 2025; Rastgeldi Dogan *et al*., 2024).

Moderate Noise Zones (80–90 dB(A))

Engineering block

Administrative block

ABC block
Pavilion area
Noise levels in these areas are primarily associated with student movement, classroom activities, pedestrian interactions, and nearby transportation routes. Comparable observations have been reported in educational institutions where academic activities contribute significantly to ambient noise generation (Wiater & Gładyszewska-Fiedoruk, 2024).
Low Noise Zones (< 80 dB(A))

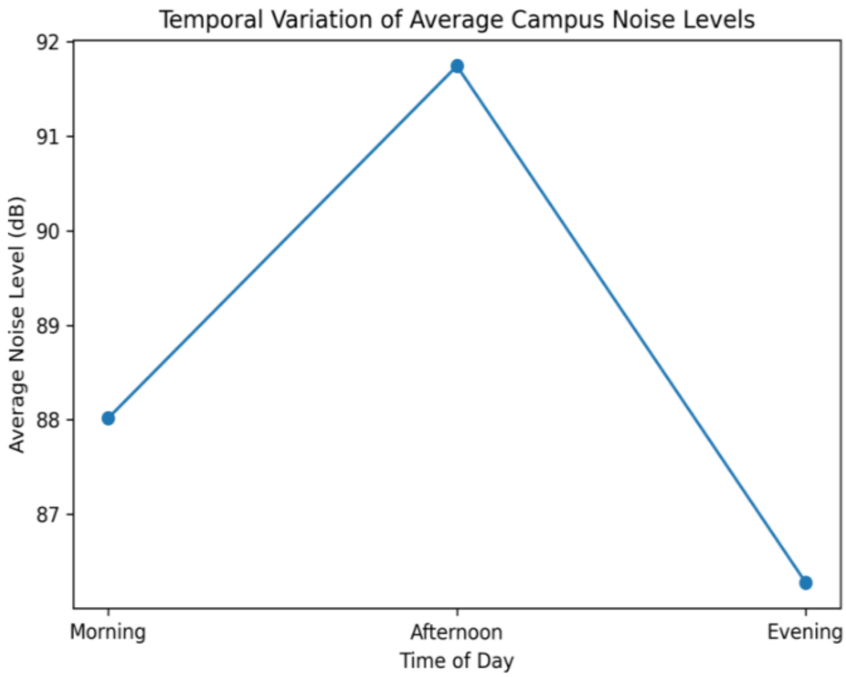

Fig. 6. Temporal variation of average ambient noise levels measured across the campus during morning, afternoon, and evening periods. Afternoon measurements show the highest noise levels due to peak academic and operational activities.

Library area
School field near the sports complex
These locations are relatively quieter because of reduced mechanical activities and their greater distance from major noise-generating sources. Similar acoustic conditions have been observed in campus environments where green spaces and designated study areas are separated from traffic corridors (Liang *et al*., 2024; Tibesigwa, 2025).
Overall, the acoustic mapping analysis indicates that noise distribution across the campus is spatially heterogeneous, with localized high-intensity zones concentrated around mechanical equipment, commercial centers, and transportation routes. This observation agrees with previous studies demonstrating that campus noise environments are strongly influenced by land-use patterns and human activities (Can *et al*., 2016; Wen *et al*., 2025).
4.8 Multi-Standard Compliance Analysis
To evaluate the environmental implications of the measured noise levels, the results were compared with internationally recognized environmental noise standards and occupational exposure guidelines. These include the recommendations of the World Health Organization (WHO), the Federal Environmental Protection Agency (FEPA) of Nigeria, and the Occupational Safety and Health Administration (OSHA).
WHO Environmental Noise Guideline

The World Health Organization recommends that outdoor daytime noise levels in educational environments should not exceed 55 dB(A) to minimize adverse effects on learning, communication, and health (World Health Organization, 2018). The average noise levels recorded in this study ranged from 74.52 dB(A) to 88.50 dB(A), exceeding the WHO guideline at all monitoring locations. Prolonged exposure to such elevated noise levels may adversely affect cognitive performance, concentration, and overall well-being among students and staff (Basner *et al*., 2019; Clark & Paunovic, 2018).

FEPA Environmental Noise Standard (Nigeria)

The FEPA recommended daytime noise limit for educational and residential environments is approximately 60 dB(A). Similar to the WHO comparison, all measured locations exceeded this threshold, indicating that ambient noise levels within the campus environment are above acceptable limits for educational settings. Previous studies in Nigerian urban environments have similarly reported elevated environmental noise levels exceeding national recommendations (Abel, 2015).

OSHA Occupational Noise Exposure Limit

The OSHA permissible exposure limit for occupational environments is 90 dB(A) for an eight-hour exposure period. Although most locations recorded average noise levels below this threshold, some operational areas, particularly the welding and generator zones, approached or exceeded this limit. Continuous exposure in such locations may pose risks to hearing health and occupational safety if adequate protective measures are not implemented (Babisch, 2020; Münzel *et al*., 2025).

Overall, the compliance assessment indicates that:

The campus environment does not comply with WHO and FEPA environmental noise recommendations for educational settings.

Certain operational zones approach or exceed occupational noise exposure thresholds.

Prolonged exposure to existing noise levels may adversely affect learning efficiency, acoustic comfort, and human health.

These findings underscore the need for effective noise-control strategies, including generator enclosure systems, routine equipment maintenance, traffic management measures, vegetative noise barriers, and improved acoustic planning of campus infrastructure (Kuri & Pérez, 2022; Murphy & King, 2019).

4.0 Conclusion

This study investigated the spatio-temporal characteristics, acoustic distribution, and compliance status of ambient noise levels at Ogbonnaya Onu Polytechnic, Aba, Nigeria, through systematic field measurements conducted at fifteen representative campus locations and multiple distance intervals from dominant noise sources. The study successfully characterized spatial and temporal variations in environmental noise, validated sound attenuation behaviour using acoustic propagation models, developed acoustic distribution patterns, and evaluated compliance with international and national environmental noise standards.

The results revealed a consistent reduction in sound pressure levels with increasing distance from noise sources, with mean noise levels decreasing from 88.50 dB(A) at 5 m to 74.52 dB(A) at 25 m. Log-distance regression analysis produced a slope of −19.63 dB per decade, which closely approximates the theoretical −20 dB attenuation predicted by the inverse-square law of sound propagation. The statistically significant regression relationship ($p < 0.001$) and acceptable model performance metrics provide empirical evidence that the inverse-square law remains applicable under real campus environmental conditions despite the influence of reflections, multiple sound sources, and other environmental factors.

Spatial analysis identified the welding/generator area, business centre, and campus gate zones as the major noise hotspots, while comparatively lower noise levels were recorded around the library and sports complex areas. Temporal analysis showed that noise levels were highest during afternoon periods, reflecting increased academic, commercial, and transportation activities across the campus. The acoustic mapping results further demonstrated that environmental noise distribution within the institution is spatially heterogeneous and strongly influenced by land-use patterns, human activities, and the location of mechanical facilities.

Compliance assessment revealed that all measured noise levels exceeded the World Health Organization recommended daytime limit of 55 dB(A) for educational environments, while several operational areas approached or exceeded occupational exposure thresholds. These findings indicate that prolonged exposure to existing noise conditions may adversely affect communication, concentration, learning efficiency, acoustic comfort, and overall well-being of campus users.

Overall, the study demonstrates that environmental noise constitutes a significant environmental management challenge within the campus environment. The integration of spatio-temporal assessment, acoustic mapping, propagation modelling, and multi-standard compliance analysis provides a comprehensive framework for environmental noise evaluation in higher educational institutions. To improve acoustic quality and safeguard the health and productivity of students and staff, the implementation of generator enclosure systems, traffic management measures, routine equipment maintenance, vegetative noise barriers, strategic acoustic zoning, and periodic environmental noise monitoring is strongly recommended. The findings provide valuable baseline data for campus planning, environmental policy formulation, and sustainable noise management in Nigerian higher educational institutions.

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Author Contributions

lNdukwe Peter Uchechukwu conceptualized the study, designed the methodology, conducted field measurements, performed data analysis, and drafted the manuscript. Ejikeme Ezo Igbokwe contributed to study design, acoustic measurements, data interpretation, and critical revision of the manuscript. Dike Ijeoma Inyang contributed to data collection, acoustic mapping, literature review, interpretation of results, and critical editing of the manuscript. All authors approved the final manuscript.

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