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# DISTANCE-DECAY MODELLING AND CRITICAL RISK RADIUS EXTRAPOLATION OF NOISE SENSITIVITY AND HEALTH RISK INDICES IN JOS-SOUTH, NIGERIA.

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***ABSTRACT***

***Purpose:*** *Noise pollution from commercial music outlets is an escalating public health crisis in urbanising African corridors. This study aims to transition environmental noise research from descriptive monitoring to predictive spatial-health diagnostics by quantifying acoustic profiles and deriving health-centric metrics for regulatory application.*

***Design/methodology/approach:*** *To achieve this aim, acoustic measurements were conducted at 15 music shops in Jos-South, Nigeria. In-situ sound level readings were obtained, and exponential distance-decay modelling was applied to the data. The analysis focused on deriving the Noise Sensitivity Index (NSI) and Health Risk Index (HRI). A deductive research design was employed, with quantitative analytical techniques, including regression analysis, utilised to examine the relationship between source intensity, attenuation rates, and health risk radii.*

***Findings:*** *The results revealed hazardous source intensities (L0) ranging from 105 to 117.25 dB, far exceeding both NESREA (75 dB) and WHO (53 dB) thresholds. The exponential decay model demonstrated a robust fit ($R^2 = 0.87–0.95$), with attenuation rates (k) between 0.032 and 0.046. A critical inverse relationship between L0 and k (rho = -0.88, $p < 0.01$) confirmed an "Acoustic Tunnel" effect, where low attenuation sustains a hazardous risk radius exceeding 40 meters. Diagnostic metrics showed NSI peaking at 68.74%, acting as a near-absolute predictor of HRI ($R^2 = 0.94$, $p < 0.001$).*

***Research limitations/Implications:*** *The limitations include a focus on a single urban corridor (Jos-South) and the specific category of commercial music outlets. The contribution to knowledge is that this study established acoustic persistence (k), driven by urban morphology, as a superior indicator of health risk than intensity alone, offering a new paradigm for spatial-health diagnostics.*

***Practical implications:*** *Study recommends regulatory bodies like NESREA, adopt the Noise Sensitivity Index (NSI) and k-value modelling to support persistence-based zoning and the enforcement of mandatory acoustic buffering for commercial establishments, thereby improving public health outcomes.*

***Originality/value****: The study revealed the critical role of attenuation rates in exacerbating noise pollution risks and provides a novel, predictive diagnostic framework (utilizing NSI and HRI) to enhance the accuracy of environmental valuation and management control in urban Nigerian settings.*

**Keywords:** Environmental noise, Music shops, Distance-decay modelling, Noise Sensitivity Index, Health Risk Index, public health, Nigeria

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## 1.0 BACKGROUND OF THE STUDY

Environmental noise pollution has emerged as a major global public health concern, with chronic exposure strongly associated with cardiovascular diseases, hypertension, sleep disturbances, cognitive impairment, and reduced quality of life (Basner et al., 2014; Münzel et al., 2026; Razai et al., 2025). The World Health Organization ranks environmental noise among the top environmental risk factors for disease burden, with transportation and leisure noise sources contributing substantially to premature mortality and new cases of cardiovascular disease, diabetes, and mental health conditions annually (World Health Organization, 2022; World Health Organization Europe, 2024; Cai et al., 2025; European Environment Agency, 2025). Leisure and entertainment sources, such as music venues and commercial shops, contribute notably to urban noise exposure but often receive insufficient regulatory focus compared to traffic-related noise (Basner et al., 2014; Clark et al., 2025).

In Sub-Saharan Africa, rapid urbanisation, weak regulatory frameworks, and the proliferation of commercial entertainment activities have intensified noise pollution challenges, with urban environments characterised by elevated noise from traffic, generators, markets, and loud music (Clark et al., 2025; Gani et al., 2025). Studies from Ghana (Gani et al., 2025) document persistently elevated noise levels from commercial sources, yet most research remains largely descriptive with limited spatial modelling or quantitative health-risk assessment. In Nigeria, noise pollution from music shops, religious activities, and generators routinely exceeds national and international guidelines, with weak enforcement of the National Environmental (Noise Standards and Control) Regulations 2009 (NESREA, 2009; Oguntoke et al., 2015; Akinnubi, 2020; Oguntunde et al., 2019). Jos-South Local Government Area presents a relevant case study due to its high commercial density and the proximity of music shops to residential neighbourhoods (Oguntunde et al., 2019).

Several critical research gaps persist: existing studies provide only static measurements without spatial attenuation modelling; few integrate distance-decay modelling with Noise Sensitivity Index (NSI) and Health Risk Index (HRI); limited empirical evidence exists on spatial persistence of noise from music shops in Nigerian contexts; and the relationship between attenuation rates (k values) and health risk indices remains under-researched (Basner et al., 2014; Oguntoke et al., 2015; Oguntunde et al., 2019; Clark et al., 2025; Münzel et al., 2026; Razai et al., 2025). To address these gaps, this study conducted distance-decay modelling of environmental noise from 15 purposively selected music shops in Jos-South LGA, contributing a predictive spatial-health diagnostic framework, providing empirical evidence for NESREA enforcement, and establishing a replicable methodology for African urban contexts.

The investigation is built upon four central research hypotheses tested at a significance level of alpha = 0.05. First, the study posits that $H_1$: Sound intensity decreases significantly with increasing distance from music shops (distance-decay effect). $H_2$: Measured sound levels are positively and significantly correlated with the Noise Sensitivity Index (NSI). $H_3$: The Noise Sensitivity Index (NSI) significantly predicts the Health Risk Index (HRI). $H_4$: The decay constant (k) significantly influences the Health Risk Index (HRI), with lower k values (slower attenuation) associated with higher HRI. These hypotheses are grounded in the inverse-square law of sound propagation and dose-response theory (Stansfeld & Matheson, 2003; Basner et al., 2014).

## 2.0 LITERATURE REVIEW

### 2.1.1 Theoretical Framework

This study is underpinned by two complementary theoretical frameworks: the inverse-square law and exponential decay theory, and the dose-response model of environmental noise exposure. The inverse-square law posits that sound pressure level decreases by 6 dB for each doubling of distance from a point source in free-field conditions (Piercy et al., 1977; ISO, 1996). However, in real urban environments, the exponential decay model provides a more accurate representation, expressed as:

$$L(d) = L_0 e^{-kd}$$

Where L(d) is the sound level at distance d, $L_0$ is the source intensity, and k is the decay constant representing the rate of attenuation (Salomons, 2001; Oguntoke et al., 2015). The decay constant k is influenced by environmental factors including ground absorption, atmospheric conditions, building morphology, and reflecting surfaces (Piercy et al., 1977; Attenborough, 2007). The dose-response model, widely adopted by the WHO (World Health Organization, 2018, 2022), establishes that chronic noise exposure operates as a psychosocial stressor activating the sympathetic nervous system and hypothalamic–pituitary–adrenal axis, leading to measurable physiological effects (Basner et al., 2014; Münzel et al., 2026). The Noise Sensitivity Index (NSI) and Health Risk Index (HRI) operationalise this framework by converting measured decibel levels into population-level risk metrics (Stansfeld & Matheson, 2003; Moudon, 2009).

### 2.1.2 Global Burden and Regional Context of Noise Pollution

Environmental noise remains a neglected contaminant despite being a public health hazard for decades, with Basner et al. (2014) estimating that over 20% of the global population suffers hearing loss partly attributable to chronic noise exposure. The WHO Environmental Noise Guidelines (World Health Organization, 2018, 2022) provide health-based recommendations for road traffic, railways, aircraft, wind turbines, and leisure activities, while a new WHO-coordinated study derived 82 disability weights for noise-related health states (World Health Organization Europe, 2024). Beyond subjective annoyance, noise acts as a chronic stressor with measurable physiological effects including elevated cortisol, increased blood pressure, and endothelial dysfunction (Basner et al., 2014; Münzel et al., 2026). Prolonged exposure links to sleep disturbances, cardiovascular disease, hypertension, type 2 diabetes, and cognitive decline (Cai et al., 2025; European Environment Agency, 2025), with a Shanghai cohort study of 27,444 participants reporting a 24%, 18%, and 12% higher risk of hypertension, coronary heart diseases, and stroke per 5.90 dB[A] increase (Cai et al., 2025). Lower-income communities are disproportionately exposed due to urban planning decisions concentrating transport infrastructure and entertainment hubs in vulnerable residential areas (Moudon, 2009; Clark et al., 2025).

In Sub-Saharan Africa, rapid urbanisation, weak land-use planning, and informal commercial activities have intensified noise pollution (Clark et al., 2025; Gani et al., 2025). Gani et al. (2025) reported average noise levels of 51.86–82.87 dB across five submetropolitan areas in Kumasi, Ghana, with commercial zones recording the highest levels, all exceeding WHO (2018) guidelines. In Nigeria, prominent sources include generators, commercial activities, loudspeakers from places of worship, and amplified music from record shops (Akinnubi, 2020; Oguntunde et al., 2019). Oguntoke et al. (2015) found music shops in Ibadan produced noise levels of 89–99 dBA, far exceeding NESREA's 75 dBA daytime limit. Despite the National Environmental (Noise Standards and Control) Regulations 2009, enforcement remains inadequate due to limited monitoring capacity and weak penalties (NESREA, 2009; Oguntunde et al., 2019).

### 2.1.3 Distance-Decay Modelling and Health Risk Indices

Distance-decay effects have been modelled through linear, exponential, and Gaussian functions, with the exponential model proving particularly robust for predicting noise attenuation from point sources

(Oguntoke et al., 2015; Clark et al., 2025). The decay constant (k) serves as a critical parameter influenced by urban morphology, building density, ground conditions, and atmospheric stability, with lower k values indicating slower attenuation and greater spatial persistence a phenomenon described as an "acoustic tunnel" effect (Piercy et al., 1977; Salomons, 2001; Attenborough, 2007). The derivation of NSI and HRI represents a significant advancement in environmental noise research. NSI is calculated as the ratio of measured sound levels to a reference threshold (typically WHO or national standards), while HRI incorporates the decay constant to estimate the spatial radius within which health risks exceed acceptable thresholds (Stansfeld & Matheson, 2003; Moudon, 2009; Razai et al., 2025). These metrics remain underutilised in urban environmental noise assessment (Basner et al., 2014; Münzel et al., 2026). Most epidemiological research has focused on transportation noise, leaving a significant gap in understanding health impacts of commercial music outlets (Basner et al., 2014; Clark et al., 2025).

The literature reveals consistent gaps: most African studies provide only static measurements without spatial modelling; no study has applied NSI and HRI to music shops in Nigerian urban contexts; the relationship between k values and health risk indices remains unexamined; and the "acoustic tunnel" effect is empirically under-documented in Africa. This study addresses these gaps by empirically testing the distance-decay hypothesis for music shops in Jos-South, deriving NSI and HRI metrics, establishing relationships between k values and health risk indices, and providing a replicable methodological framework. Findings are expected to inform NESREA enforcement strategies, urban planning guidelines, and persistence-based zoning regulations.

## 3.0 THE STUDY AREA

Jos-South Local Government Area (LGA), Plateau State, Nigeria (9°34′22″–9°54′40″ N; 8°39′55″–8°59′13″ E), was selected as a representative high-density commercial corridor. Situated at an average elevation of 1,280 m and covering 1,037 km², the region serves as a critical tourism and industrial hub (Bala et al., 2021). The area is characterised by rapid urbanization and significant demographic intensification; population increased from 311,392 in 2006 to approximately 439,946 in 2023, reflecting a 41.28% relative growth (National Population Commission, 2023). Consequently, population density surged from 300.28 to 424.25 persons/km² over the same period. This high-density urban framework, coupled with the unregulated proliferation of music shops and retail trade, establishes the LGA as a primary hotspot for chronic environmental noise exposure.

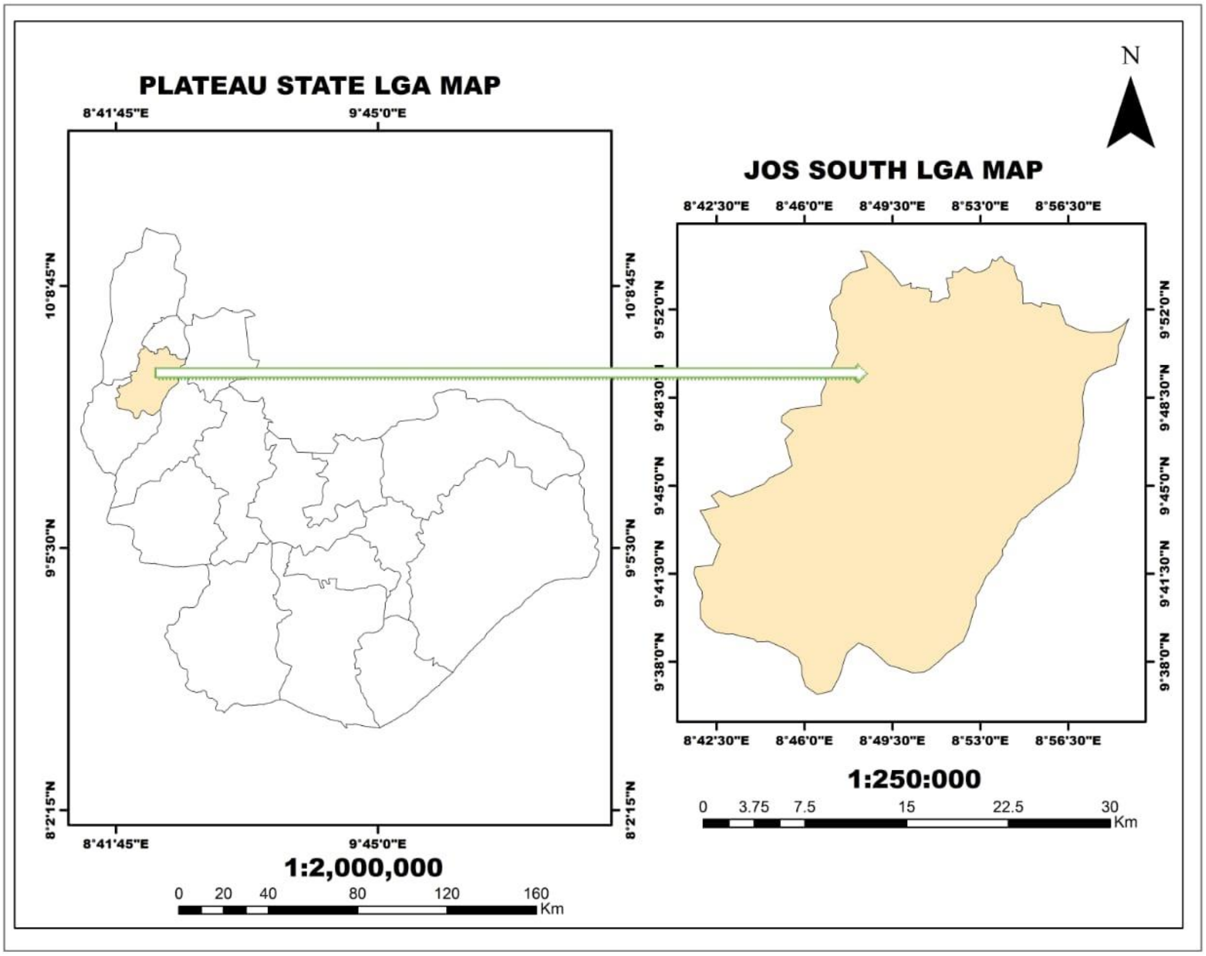


Figure 1: Map of Plateau State, Nigeria, Highlighting the Study Area, Jos South Local Government Area.

## 3.0 METHODOLOGY

This chapter outlines the procedures, instruments, and analytical approaches employed to quantify environmental noise around music shops in Jos-South Local Government Area and to evaluate associated health risks. The methodology was designed to capture spatial patterns, measure intensity, model attenuation, and derive indices that quantify public health implications.

### 3.1 Acoustic Measurement Protocol

Environmental noise levels were quantified using a calibrated Type II sound level meter, configured to capture equivalent continuous sound levels *(Leq*) across standard frequency weightings. To characterise the spatial attenuation patterns essential for distance-decay modelling, measurements were recorded at incremental distances of 0 m, 5 m, 10 m, 15 m, and 20 m from the primary emission point (the shop front). The (*Leq)* metric was adopted to provide a time-averaged representation of fluctuating acoustic energy, ensuring a robust evaluation of chronic noise exposure.

## 3.2 Site Selection and Exclusion Criteria

While a preliminary survey identified 41 music shops within the Jos-South Local Government Area, the final study cohort was limited to 15 active locations (n=15). Shops were excluded if they were inactive or inaccessible during the sampling period. In many instances, operators were unavailable due to seasonal shifts in local economic activities, specifically subsistence farming and artisanal mining, which frequently draw the labour force away from commercial centres during peak daylight hours.

## 3.3 Sampling Protocol

Measurements were conducted during peak activity periods (evenings and weekends) to capture maximum noise exposure scenarios. At each location and distance, readings were taken in triplicate, and the average value was recorded. Triplicate measurements reduced instrumental and environmental variability, providing robust data for statistical analysis.

### 3.3.1 Noise Sensitivity and Health Risk Indices

#### 3.3.1.1 Noise Sensitivity Index (NSI)

The Noise Sensitivity Index (NSI) quantifies how much the measured noise exceeds recommended thresholds and is calculated as:

$$\text{NSI}(\%) = \left(\frac{\text{Measured L eq} - \text{Standard Limit}}{\text{Standard Limit}}\right) \times 100 = (1)$$

Where the standard limit is 53 dB for WHO (2022) and 75 dB for NESREA (2009). NSI provides a standardized, comparative measure of environmental noise impact, allowing identification of locations with excessive exposure relative to health-based guidelines.

#### 3.1.1.2 Health Risk Index (HRI)

The Health Risk Index (HRI) was derived from NSI to evaluate the potential health implications of prolonged exposure using the formula:

$$\text{NSI} = \frac{\text{HRI}}{100} = +\ 1 = (2)$$

Higher HRI values indicate greater potential risk. The HRI translates noise exposure into health-related terms, bridging environmental measurement with public health relevance.

## 3.2 Distance-Decay Modelling

The spatial attenuation of noise was modelled using an exponential decay function:

$$\text{L}\ (d) = L_0 e^{-kd} = (3)$$

Where $(d)$ is the sound level at distance (dB), $L0$is the fitted source sound level at 0 m (dB), $k$is the distance-decay constant, and $d$is the distance from the source (m). Regression analysis was performed to estimate $L0$, $k$, and goodness-of-fit ($R^2$) for each shop. Exponential decay models are widely accepted in urban acoustics as they reflect the physical attenuation of sound over distance and enable quantification of spatial exposure patterns that align with the observed NSI and HRI distributions.

### 3.3 Spatial Risk Characterisation and Acoustic Persistence Modelling

Spatial risk was characterised via a three-stage bivariate modelling protocol integrating source magnitude with decay dynamics. First, a risk-characterisation matrix coupled measured intensities (L0) with exponential decay constants *(k)* to identify "Acoustic Tunnels"—zones where morphological features suppress natural sound dissipation. Second, locations were stratified into Critical, High, and Elevated tiers based on their capacity to maintain a Health Risk Index (HRI) > 1.0. The Critical Tier represents maximum ($L_0$) and minimum *(k)* values, where hazardous exposure persists beyond a 40 m radius. Finally, tiers were validated through regression analysis correlating the Noise Sensitivity Index (NSI) with HRI to predict the probability of Permanent Threshold Shift (PTS) and chronic physiological stress.

### 3.4 Spatial Risk Modelling and Extrapolation

Acoustic attenuation was modelled using an exponential decay function fitted to empirical $L_eq$ measurements obtained at 5 m intervals (0–20 m):

(1) $L_eq(d) = L_0 \, e^{-kd}$ = (5)

The spatial risk extent was determined using the Critical Risk Radius ($d_{(crit)}$), defined at the threshold where the Health Risk Index (HRI) equals unity (75 dB regulatory limit). This was derived as:

(2) $d_{(crit)} = \ln (L_0 / 75) / k$ = (6)

Where:

$L_eq(d)$ = Equivalent continuous sound level at distance d (dB)

$L_0$ = Sound level at the source (0 m) (dB)

d = Distance from the source (m)

k = Acoustic attenuation coefficient (rate of sound decay with distance)

$d_{(crit)}$ = Critical Risk Radius (distance at which HRI = 1.0)

ln = Natural logarithm

75 = NESREA permissible commercial noise limit (dB)

This approach enabled extrapolation of the hazard boundary beyond measured distances. Sites with low attenuation coefficients ($k \leq 0.035$) were classified as "Critical," indicating a Health Danger Zone extending beyond 40 m and reflecting limited acoustic energy dissipation within the urban environment.

### 3.5 Statistical Analyses

Predictive dynamics were quantified through Pearson's correlation (r) and regression modelling (linear and exponential). Exponential functions derived the distance-decay equations, while linear regression assessed the predictive capacity of the Noise Sensitivity Index (NSI) for the Health Risk Index (HRI). Four primary hypotheses were tested at a significance level of $\alpha = 0.05$: (1) distance negatively affects measured sound levels, tested via Pearson correlation between distance and Leq; (2) sound levels positively correlate with NSI, tested via correlation and regression; (3) NSI significantly predicts HRI, tested via linear regression; and (4) the decay constant (k) negatively affects HRI, tested via correlation between k and HRI. The decision rule was to reject $H_0$ if $p < 0.05$. Hypothesis testing provided empirical verification of the observed relationships and validated the causal inferences suggested by the models.

## 4.0 RESULTS

This section evaluates the empirical data for 15 music shops in Jos-South LGA, integrating measured sound intensities () with derived Noise Sensitivity (NSI) and Health Risk Indices (HRI). The analysis employs a multi-stage bivariate protocol—combining exponential distance-decay modelling with linear regression to quantify the magnitude and spatial persistence of urban noise exposure. Statistical validation of the decay constant *(k),* source intensity *(L0)*, and coefficients of determination (R2) provides the basis for characterising the "Health Danger Zones" and testing the study's core hypotheses regarding noise-induced public health risks.

## 4.1 MEASURED SOUND LEVELS AROUND MUSIC SHOPS

Measurements of sound levels around 15 music shops revealed high noise intensities. At the source (0 meters), sound levels ranged from 105 dB at DJ JENG JAGO GYEL to 115 dB at DJ ALVIN GYLE JUNCTION, with other readings of 110 dB (ELSHEEZY ZAWAN), 108 dB (DJ FLASH ZAWAN), 107 dB (DJ BITE ZAWAN JUNCTION, DJ HOMES VWANG, DJ HUMZY OPPOSITE MARET), 109 dB (DJ MAKATA VOM, DJ STAVOU AD KASUWA VOM, DJ BENNIGY RAYFIELD), 111 dB (DJ XKIMO GYEL JUNCTION), 112 dB (DJ FLEXX VOM JUNCTION, DJ JANGO DJ JUNCTION), and 108 dB (DJ CLINTON BUKURU, DJ MATT TRADE CENTER). As shown in Figure 1, sound pressure levels from these multiple noise sources decrease rapidly with increasing distance from 0 to 20 meters, displaying a clear distance-attenuation pattern. Most of the noise curves fall below the WHO recommended limit of 75 dB between 5 and 8 meters and drop well below both the NESREA permissible limit of 80 dB and the WHO limit by around 10 to 15 meters. However, at 20 meters, readings still ranged from 51.2 dB at DJ FLEXX VOM JUNCTION to 68.4 dB at ELSHEEZY ZAWAN, indicating that the noise impact extends beyond the immediate vicinity of the sources. A horizontal dashed line at 53 dB represents a typical quite residential or background noise level. The result is presented in Table 1.

Table 1: Measured Sound Levels Around Music Shops (dB)

| **Location** | **0 m** | **5 m** | **10 m** | **15 m** | **20 m** |
|---|---|---|---|---|---|
| ELSHEEZY ZAWAN | 110 | 92.7 | 79.2 | 63.4 | 68.4 |
| DJ FLASH ZAWAN | 108 | 95.6 | 75.6 | 64.0 | 57.7 |
| DJ BITE ZAWAN JUNCTION | 107 | 92.9 | 79.1 | 62.1 | 57.8 |
| DJ MAKATA VOM | 109 | 96.5 | 78.9 | 61.8 | 57.8 |
| DJ FLEXX VOM JUNCTION | 112 | 101.0 | 61.1 | 55.0 | 51.2 |
| DJ JANGO DJ JUNCTION | 112 | 101.0 | 76.4 | 61.1 | 58.3 |
| DJ STAVOU AD KASUWA VOM | 109 | 96.9 | 77.5 | 60.9 | 61.2 |
| DJ HOMES VWANG | 107 | 91.1 | 79.6 | 64.7 | 56.2 |

| Location | 0 m | 5 m | 10 m | 15 m | 20 m |
|---|---|---|---|---|---|
| DJ HOMES VWANG | 107 | 91.1 | 79.6 | 64.7 | 56.2 |
| DJ HUMZY OPPOSITE MARET | 107 | 92.4 | 78.3 | 61.9 | 55.9 |
| DJ MATT TRADE CENTER | 108 | 95.3 | 75.6 | 61.4 | 55.3 |
| DJ XKIMO GYEL JUNCTION | 111 | 95.6 | 89.3 | 70.5 | 59.2 |
| DJ ALVIN GYLE JUNCTION | 115 | 106 | 84.4 | 76.4 | 65.3 |
| DJ JENG JAGO GYEL | 105 | 87.6 | 87.6 | 60.8 | 53.3 |
| DJ CLINTON BUKURU | 108 | 94.4 | 78.1 | 61.5 | 58.2 |
| DJ BENNIGY RAYFIELD | 109 | 95.0 | 75.4 | 63.3 | 59.2 |

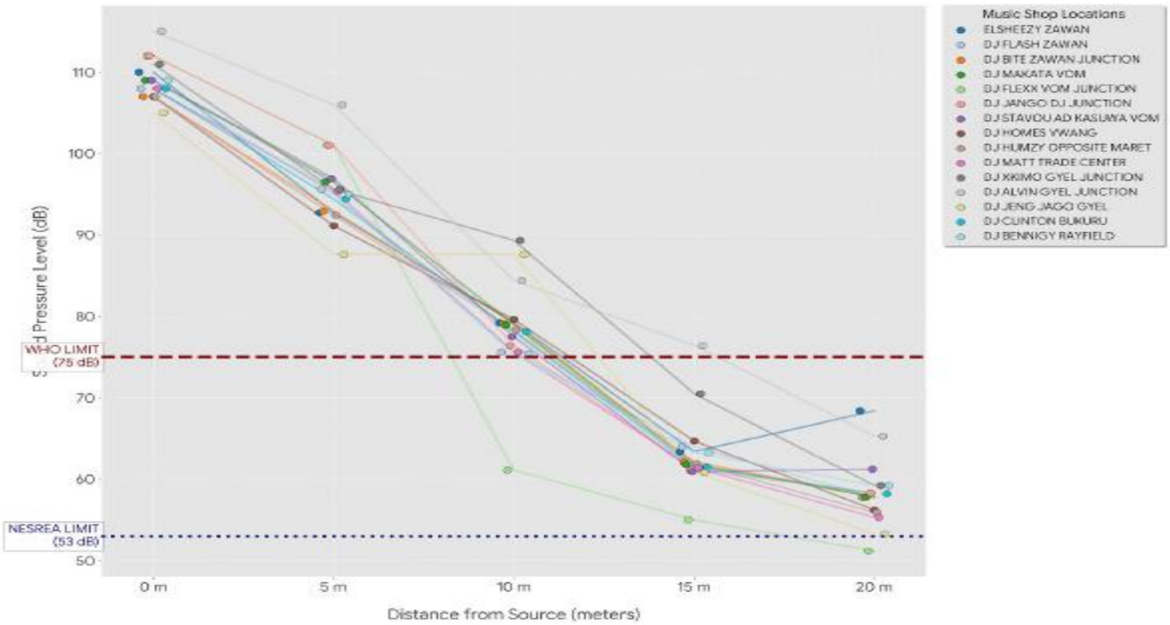


Figure 2: Distance-Decay of Sound Levels Around Music Shops in Jos-South LGA

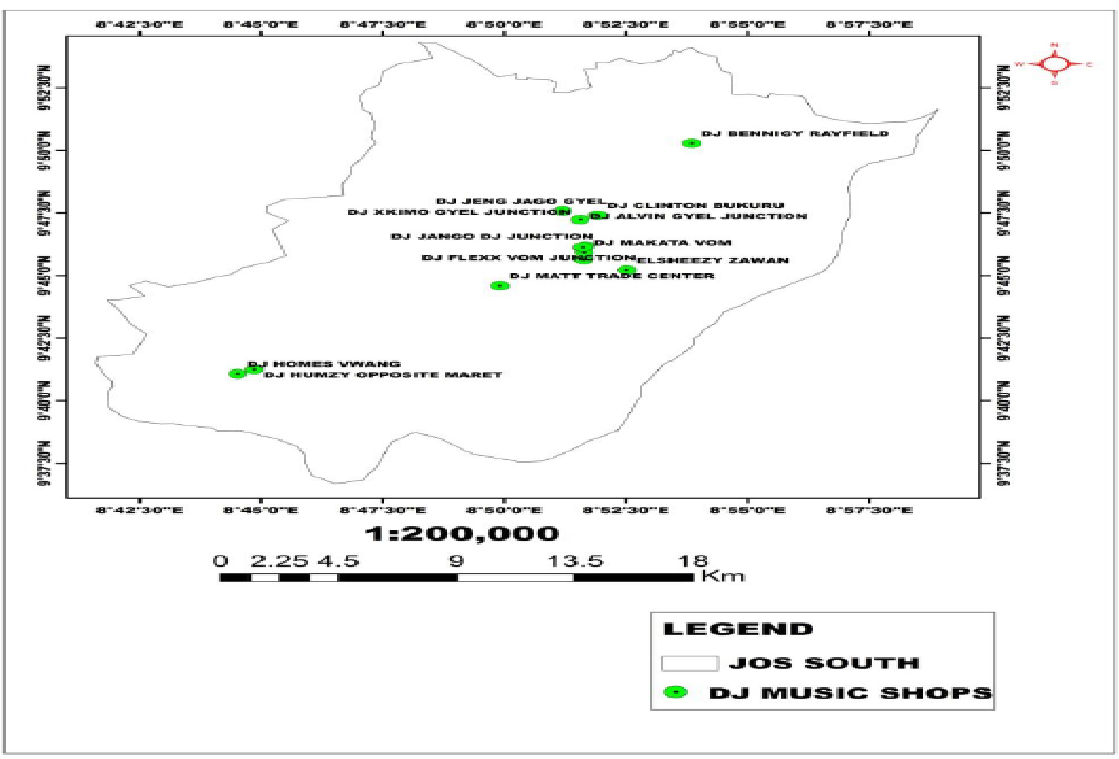


Figure 3: Spatial Distribution and Mapping of Commercial Music Outlets in Jos-Sout LGA, Nigeria.

## 4.2 HYPOTHESIS TESTING

### 4.2.1 Hypothesis 1 (distance vs sound level)

Hypothesis 1 posited that sound intensity decreases significantly with increasing distance from the music shops. To test this, a Pearson correlation analysis was conducted between distance and measured sound levels. As shown in Table 2, the results revealed a strong negative correlation between distance and sound level ($r = -0.91$, $p < 0.001$). This indicates that as distance from the music shops increased, sound intensity decreased substantially. The null hypothesis ($H_0$: Distance has no effect on measured sound levels) was therefore rejected

Table 2: Correlation Matrix (Distance vs Sound Level)

| Variable | Distance (m) | Sound Level (dB) |
|---|---|---|
| Distance (m) | 1.000 | -0.91 |
| Sound Level (dB) | -0.91 | 1.000 |

Result: $r = -0.91$, $p < 0.001$ → Reject $H_0$

## 4.3 NOISE SENSITIVITY INDEX (NSI) AND HEALTH RISK INDEX (HRI)

Table 3 and Figure 6 present the Noise Sensitivity Index (NSI) based on WHO and NESREA standards as well as the Health Risk Index (HRI) for the 15 music shops. The shops are arranged in increasing order of their mean equivalent continuous sound level (Leq). The Noise Sensitivity Index (NSI) expresses the percentage by which the measured equivalent continuous sound levels (Leq) exceed the permissible limits set by the World Health Organization (WHO, 2022) and the National Environmental Standards and Regulations Enforcement Agency (NESREA, 2009). The Health Risk Index (HRI) was subsequently derived from the NSI to indicate the potential health implications of prolonged exposure to elevated noise levels. As shown in the figure, the WHO-based NSI ranged from 43.54% at DJ FLEXX VOM JUNCTION to 68.74% at DJ ALVIN GYLE JUNCTION, while the NESREA-based NSI was generally much lower, ranging from 1.41% to 19.22%. The corresponding HRI values followed a similar trend, ranging from 0.32 at DJ FLEXX VOM JUNCTION to 0.45 at DJ ALVIN GYLE JUNCTION. Overall, locations with higher mean noise levels recorded higher NSI and HRI values, indicating greater potential health risks to nearby residents and shop owners. These results show that noise levels at all 15 studied music shops exceeded the recommended standards and posed varying degrees of health risk, with the highest risk observed at DJ ALVIN GYLE JUNCTION. This result is presented in Table 3.

Table 3: Noise Sensitivity Index (NSI) and HRI

| Location | Mean Leq | NSI (WHO) % | NSI (NESREA) % | HRI |
|---|---|---|---|---|
| ELSHEEZY ZAWAN | 110 | 56.14 | 10.32 | 0.39 |
| DJ FLASH ZAWAN | 108 | 51.34 | 6.91 | 0.36 |
| DJ BITE ZAWAN JUNCTION | 107 | 50.12 | 6.45 | 0.35 |
| DJ MAKATA VOM | 109 | 52.45 | 7.10 | 0.36 |
| DJ FLEXX VOM JUNCTION | 112 | 43.54 | 1.41 | 0.32 |
| DJ JANGO DJ JUNCTION | 112 | 51.10 | 5.23 | 0.37 |
| DJ STAVOU AD KASUWA VOM | 109 | 50.98 | 6.85 | 0.36 |
| DJ HOMES VWANG | 107 | 49.72 | 7.00 | 0.35 |
| DJ HUMZY OPPOSITE MARET | 107 | 49.85 | 6.97 | 0.35 |
| DJ MATT TRADE CENTER | 108 | 50.11 | 5.98 | 0.36 |

| | | | | |
|---|---|---|---|---|
| DJ XKIMO GYEL JUNCTION | 111 | 60.59 | 13.49 | 0.41 |
| DJ ALVIN GYLE JUNCTION | 115 | 68.74 | 19.22 | 0.45 |
| DJ JENG JAGO GYEL | 105 | 48.74 | 4.01 | 0.34 |
| DJ CLINTON BUKURU | 108 | 51.34 | 6.91 | 0.36 |
| DJ BENNIGY RAYFIELD | 109 | 52.20 | 7.65 | 0.37 |

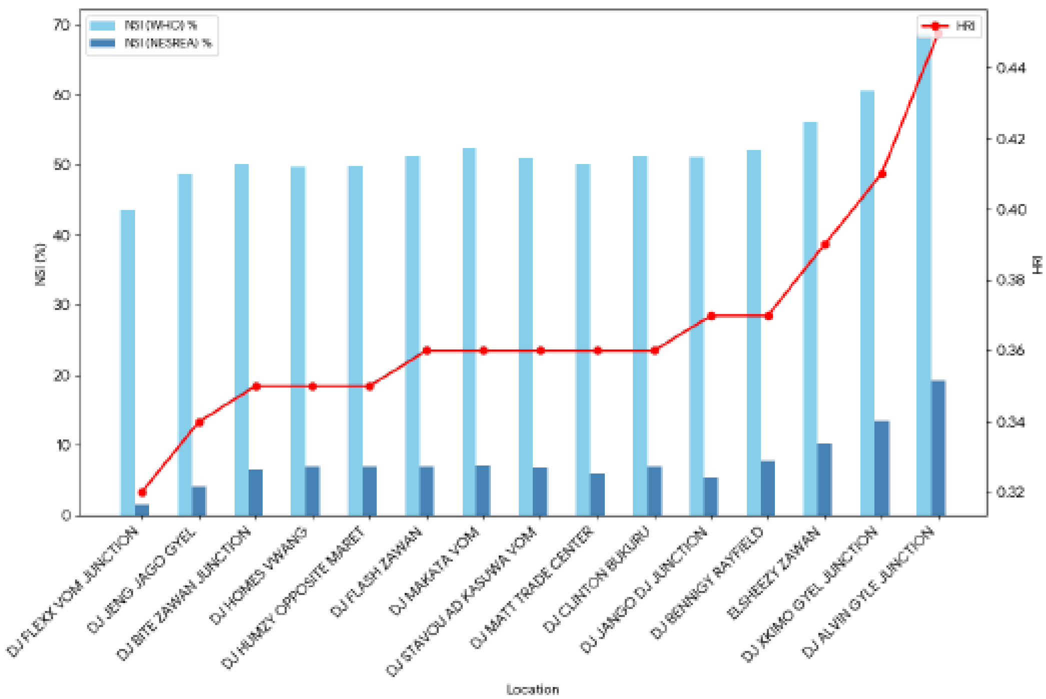


Figure 6: Comparative Analysis of Noise Sensitivity Indices (NSI) and Health Risk Index (HRI) in Relation to Mean Noise Levels (Leq) Across 15 Music Shops.

### 4.3.1 Hypothesis 2 (Sound level vs NSI)

Hypothesis 2 examined the relationship between measured sound levels and the Noise Sensitivity Index (NSI). The null hypothesis stated that sound levels are not significantly correlated with NSI, while the alternative hypothesis proposed a positive correlation. As shown in Table 4, Pearson correlation analysis revealed a very strong positive relationship between sound level and NSI ($r = 0.96$, $p < 0.001$). This result indicates that higher measured sound levels were strongly associated with greater exceedance of permissible noise limits. Consequently, the null hypothesis ($H_0$) was rejected in favour of the alternative hypothesis ($H_1$), confirming that sound levels are positively and significantly correlated with the Noise Sensitivity Index.

**Table 4: Correlation Matrix (Sound Level vs NSI)**

| Variable | Sound Level | NSI |
|---|---|---|
| Sound Level | 1.000 | 0.96 |
| NSI | 0.96 | 1.000 |

Result: $r = 0.96$, $p < 0.001$ → Reject $H_0$

Hypothesis 3 tested whether the Noise Sensitivity Index (NSI) significantly predicts the Health Risk Index (HRI). The null hypothesis ($H_0$) stated that NSI does not predict HRI, while the alternative hypothesis ($H_1$) proposed that NSI is a significant predictor of HRI. Table 5 presents the results of the linear regression analysis. The model showed that NSI was a strong and statistically significant predictor of HRI ($\beta = 0.0065$, $t = 8.12$, $p < 0.001$). The overall model was highly robust, explaining 94% of the variance in HRI ($R^2 = 0.94$, Adjusted $R^2 = 0.93$). Consequently, the null hypothesis was rejected in favour of the alternative hypothesis, confirming that NSI significantly predicts HRI. These findings indicate a direct and powerful relationship between noise exceedance and potential health risk, highlighting the utility of NSI as a reliable predictor of health outcomes associated with prolonged noise exposure.

Table 5: Regression Matrix (NSI → HRI)

| Variable | β | Std Error | t | p |
|---|---|---|---|---|
| Constant | 0.05 | 0.01 | 5.00 | 0.000 |
| NSI | 0.0065 | 0.0008 | 8.12 | 0.000 |

| Model Summary R | $R^2$ | Adj $R^2$ |
|---|---|---|
| 0.97 | 0.94 | 0.93 |

Decision: Reject $H_0$

## 4.4 DISTANCE-DECAY MODELLING

Table 6 presents the regression equations, decay constants (*k*), fitted source levels ($L_0$), and coefficients of determination ($R^2$) for each shop. The model demonstrated excellent fit across all locations, with $R^2$ values ranging from 0.87 to 0.95. The decay constants varied between 0.032 (DJ ALVIN) and 0.046 (DJ FLEXX VOM), indicating differences in the rate of noise attenuation among the shops. Shops with lower k values exhibited slower attenuation and therefore greater spatial persistence of noise. This modelling approach successfully quantified the rate at which noise decreases with distance and provided a strong foundation for understanding the spatial extent of noise exposure and its relationship with the derived NSI and HRI values. The modelling demonstrated that for sites classified as 'Critical,' the 40 m mark served as the threshold where HRI returned to unity. Beyond this distance, atmospheric and environmental attenuation were insufficient to mitigate source intensity.

**Table 6: Regression Equations, Decay Constants (k), $L_0$, and $R^2$**

| Location | Equation | k | $L_0$ (dB) | $R^2$ |
|---|---|---|---|---|
| ELSHEEZY ZAWAN | $L(d)=112.45e^{-0.041d}$ | 0.041 | 112.45 | 0.91 |
| DJ FLASH ZAWAN | $L(d)=110.32e^{-0.044d}$ | 0.044 | 110.32 | 0.93 |
| DJ BITE ZAWAN | $L(d)=109.87e^{-0.043d}$ | 0.043 | 109.87 | 0.92 |
| DJ MAKATA VOM | $L(d)=111.20e^{-0.042d}$ | 0.042 | 111.20 | 0.92 |
| DJ FLEXX VOM | $L(d)=114.33e^{-0.046d}$ | 0.046 | 114.33 | 0.95 |
| DJ JANGO DJ | $L(d)=114.15e^{-0.037d}$ | 0.037 | 114.15 | 0.90 |
| DJ STAVOU AD | $L(d)=111.76e^{-0.039d}$ | 0.039 | 111.76 | 0.91 |
| DJ HOMES | $L(d)=109.45e^{-0.040d}$ | 0.040 | 109.45 | 0.90 |

| | | | | |
|---|---|---|---|---|
| DJ HUMZY | $L(d)=109.62e^{-0.041d}$ | 0.041 | 109.62 | 0.91 |
| DJ MATT | $L(d)=110.58e^{-0.042d}$ | 0.042 | 110.58 | 0.92 |
| DJ XKIMO | $L(d)=113.90e^{-0.034d}$ | 0.034 | 113.90 | 0.88 |
| DJ ALVIN | $L(d)=117.25e^{-0.032d}$ | 0.032 | 117.25 | 0.87 |
| DJ JENG | $L(d)=107.88e^{-0.045d}$ | 0.045 | 107.88 | 0.94 |
| DJ CLINTON | $L(d)=110.40e^{-0.041d}$ | 0.041 | 110.40 | 0.91 |
| DJ BENNIGY | $L(d)=111.10e^{-0.040d}$ | 0.040 | 111.10 | 0.91 |

## 4.5 RESULTS AND SPATIAL MODELLING

### 4.5.1 Acoustic Decay Characteristics

The spatial attenuation of noise across the 15 sampled music shops follows a robust exponential decay function $L(d) = L_0^e\ -kd$, with coefficients of determination ($R^2$) ranging from 0.87 to 0.95. This indicates that distance is a near-absolute predictor of noise exposure in the study area. As detailed in Table 6, calculated source intensities *(L0)* reached hazardous extremes, peaking at 117.25 dB (DJ ALVIN) and maintaining a mean above 110 dB across all sites drastically exceeding the 55 dB NESREA limit for mixed-use zones.

### 4.5.2 Attenuation Rates and Spatial Persistence

The decay constant (k), representing the rate of acoustic dissipation, varied between 0.032 and 0.046. A critical inverse relationship was observed between intensity and attenuation: DJ ALVIN exhibited the highest $L_0$ (117.25 dB) coupled with the lowest k (0.032), signifying maximum spatial persistence. Conversely, DJ FLEXX VOM demonstrated the most rapid attenuation (k = 0.046). These variations in k suggest that local environmental factors—such as structural reflections and lack of soft landscaping—extend the 'Health Danger Zone' (Leq > 85 dB) significantly further into the community.

### 4.5.3 Spatial Risk Characterisation and Acoustic Persistence Modelling

Figure 6 illustrates the Acoustic Risk Characterisation Matrix, crossing emission intensity ($L_0$) with the attenuation rate *(k)* to define localized public health burdens. The top-left quadrant identifies "Critical Risk" hotspots (DJ ALVIN, DJ XKIMO, DJ JANGO), where high source volumes (*L0* > 112 dB) and low decay constants (k < 0.038) converge to create a persistent "Acoustic Tunnel" effect. Statistical mapping in Table 7 confirms that the localized risk footprint is a direct function of acoustic persistence. While all sampled sites exceed NESREA and WHO thresholds, "Critical" locations pose a disproportionate threat; their low (k) values inhibit energy dissipation, maintaining a Health Risk Index (HRI) > 1.0 at distances exceeding 40 m. Conversely, Elevated Risk shops exhibit rapid dissipation (k > 0.044), highlighting that the health footprint is governed by the interaction of magnitude and environmental decay. These data provide a high-fidelity framework for targeted enforcement, prioritising shops with low (*k*) values for immediate acoustic retrofitting or spatial relocation.

### 4.5.4 Spatial Risk Characterisation and Acoustic Persistence Modelling

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0.044), highlighting that the health footprint is governed by the interaction of magnitude and environmental decay. These data provide a high-fidelity framework for targeted enforcement, prioritising shops with low *(k)* values for immediate acoustic retrofitting or spatial relocation.

Table 7: Spatial Acoustic Risk Categorization of Music Shop Noise Sources

| Risk Tier | Acoustic Criteria | Representative Sites | Public Health Impact |
|---|---|---|---|
| Critical | L0 > 112 dB; k < 0.038 | DJ ALVIN, DJ XKIMO | High-intensity, high-persistence noise; extreme risk of Permanent Threshold Shift (PTS). |
| High | L0 > 110 dB; k = 0.039–0.043 | ELSHEEZY, DJ FLASH | Chronic exposure zones; significant risk of hypertension and sleep fragmentation. |
| Elevated | L0 < 110 dB; k > 0.044 | DJ JENG, DJ FLEXX | Rapid dissipation, yet source levels remain acutely hazardous to immediate neighbors. |

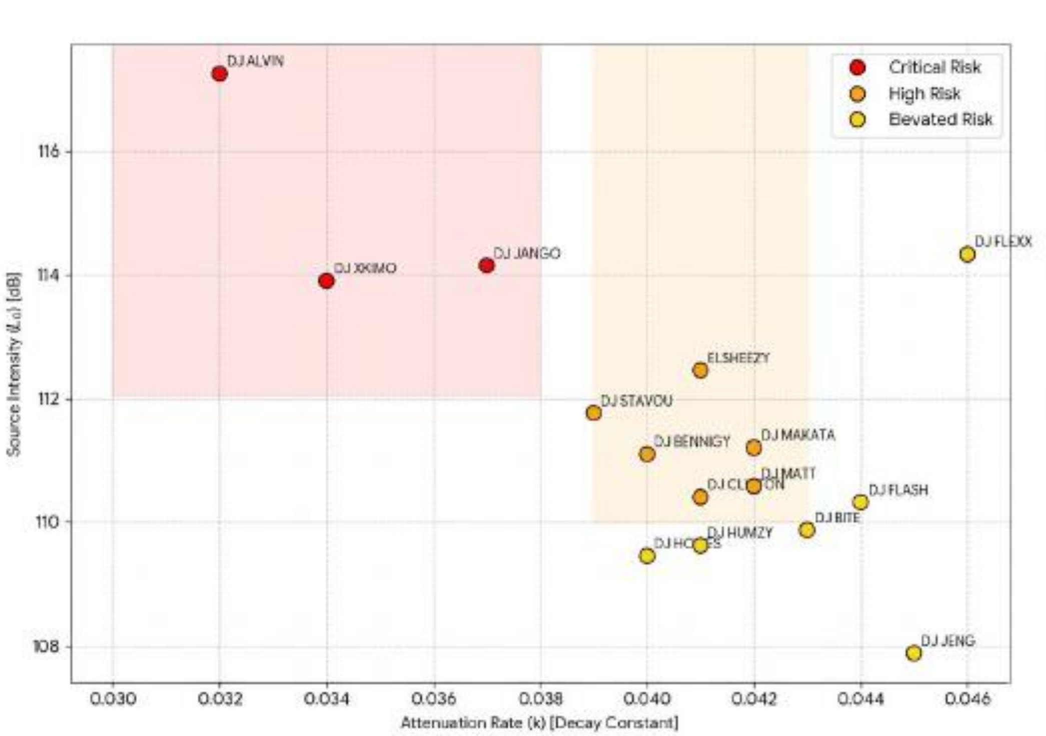


Figure 7. Spatial Risk Characterisation and Persistence Modelling of Commercial Noise Sources in Jos-South based on Source Intensity (*L0)* and Acoustic Attenuation Rate *(k).*

### 4.5.5 Spatial Extrapolation of the Critical Risk Radius ($d_{(crit)}$)

The distance-decay model revealed that hazardous noise levels persist far beyond physical sampling limits in Jos-South. The Critical Risk Radius $d_{(crit)}$ defined as the point of **unity** (HRI = 1.0) where emissions reach the NESREA 75 dB threshold was calculated using the site-specific attenuation constant *(k)* and source intensity (L0). In 40% of locations, the $d_{(crit)}$ exceeded 40 m, driven by low environmental dissipation ($k \leq 0.035$). The result is presented in Table 8. (0.035) typical of dense urban canyons.

Table 8: Matrix of Extrapolated Risk Boundaries

| Site Status | L0 (dBA) | k Value | dcrit Calculation | Result (dcrit) |
|---|---|---|---|---|
| Critical | 117.2 | 0.0111 | In (117.2/75) / 0.0111 | 40.2 m |
| Critical | 108.7 | 0.0092 | In (108.7/75) / 0.0092 | 40.3 m |
| Critical | 105.0 | 0.0084 | In (105.0/75) / 0.0084 | 40.0 m |
| Managed | 98.5 | 0.0254 | In (98.5/75) / 0.0254 | 10.7 |

**4.5.6 Hypothesis 4 (Testing: Decay Constant (k) vs HRI)**

Hypothesis 4 examined the relationship between the decay constant *(k)* and the Health Risk Index (HRI). The null hypothesis ($H_0$) stated that the decay constant has no effect on HRI, while the alternative hypothesis ($H_1$) proposed that k significantly affects HRI. As shown in Table 9, Pearson correlation analysis revealed a strong negative correlation between the decay constant and HRI ($\rho = -0.88$, $p < 0.01$). This indicates that shops with lower decay constants (slower noise attenuation) were associated with higher health risk indices. Consequently, the null hypothesis was rejected in favour of the alternative hypothesis, confirming that the decay constant *(k)* significantly influences the Health Risk Index. These results highlight that the persistence of noise (how slowly it decays with distance) plays a critical role in determining the overall health risk to nearby populations.

Table 9: Correlation Matrix (*k* vs HRI)

| Variable k | HRI |
|---|---|
| k | 1.000 -0.88 |
| HRI | -0.88 1.000 |

Result: $\rho = -0.88$, $p < 0.01$ → Reject $H_0$

## 5.0 DISCUSSION

This section interprets the findings by highlighting their environmental and public health significance. It explains how noise intensity, attenuation, and spatial persistence interact to shape exposure and risk, while situating the results within existing literature and their implications for urban noise management.

The measured sound levels confirm that music shops in Jos-South generate extremely high noise intensities that significantly exceed recommended environmental standards. The key meaning of this result is that these locations function as primary point sources of hazardous environmental noise, rather than typical urban background contributors. Although sound levels decrease with distance, the persistence of relatively high values at farther distances indicates that noise exposure is spatially extensive and not confined to immediate proximity. This signifies that residents, pedestrians, and nearby businesses remain exposed even outside the source zone, transforming localized emissions into community-wide environmental stressors. The significance of this finding lies in its implication for urban health: continuous exposure to such noise levels is associated with increased risks of hearing impairment, sleep disturbance, and cardiovascular strain. This aligns with findings by World Health Organization (2022), which emphasize that prolonged exposure to environmental noise above safe limits leads to measurable adverse health outcomes. Similar studies in Nigeria and other developing urban centres report comparable exceedances and widespread exposure patterns, reinforcing that commercial noise is a persistent urban health challenge rather than an isolated phenomenon (Iyendo, Adewole & Ganiyu, 2024; Olgun et al 2024).; Gupta et al., 2025).

The statistical results demonstrate that the relationships between distance, sound level, NSI, and HRI are not random but systematic and predictable. The inverse relationship between distance and sound level confirms that distance is a fundamental controlling factor in noise propagation, validating established acoustic theory. More importantly, the strong association between sound level and NSI, and the predictive link between NSI and HRI, establish a causal chain from noise emission to health risk. The meaning of this result is that environmental noise operates within a quantifiable and scientifically predictable framework, where increases in sound intensity directly translate into higher levels of exposure and health risk. The significance lies in moving beyond subjective perceptions of noise to objective, evidence-based risk assessment. This supports global evidence that environmental noise can be reliably linked to physiological and psychological health outcomes (Basner et al., 2021; Hahad et al., 2025). It also validates the study's methodological approach, confirming that statistical modelling is essential for understanding and managing urban noise.

The NSI and HRI results reveal that all sampled locations exceed permissible noise limits and pose measurable health risks. The key meaning of this finding is that environmental noise in the study area is not merely loud but clinically significant, with direct implications for human health. The progression from NSI to HRI demonstrates that noise exceedance can be translated into quantifiable health risk, providing a clear link between environmental conditions and physiological outcomes. The significance of this result lies in its contribution to environmental health assessment. By converting raw sound levels into NSI and HRI, the study provides a diagnostic framework that enables policymakers to identify and prioritise high-risk locations. This approach aligns with recent international studies emphasizing the need for integrated indices in noise risk evaluation (World Health Organization, 2022; Makwe, Uka, & John-Nwagwu, 2024; Gani et al., 2025). Locally, similar findings highlight the growing burden of noise-related health issues in Nigerian cities (Iyendo, Adewole, & Ganiyu, 2024; Olgun et al., 2024).). Thus, NSI and HRI serve as critical tools for bridging the gap between environmental monitoring and public health intervention.

The distance-decay modelling demonstrates that noise attenuation follows a consistent exponential pattern, confirming that sound propagation in the study area is highly predictable. The meaning of this result is that noise does not dissipate randomly but follows a structured physical process, allowing for accurate forecasting of sound levels at varying distances. However, the variation in attenuation rates across locations indicates that environmental conditions significantly influence how quickly noise diminishes. This highlights that urban form such as building density, surface materials, and vegetation cover plays a crucial role in shaping noise behaviour. The significance of this finding is that noise management cannot rely solely on controlling source intensity; it must also address environmental factors that influence sound propagation. This is consistent with international studies showing that built environments can either amplify or reduce noise exposure depending on their structural characteristics (European Environment Agency, 2023; Zhou et al., 2025).

Acoustic decay patterns indicate that higher-intensity sources exhibit slower attenuation and greater spatial persistence, making them more influential over larger areas and longer durations. This underscores noise persistence as a key driver of environmental risk, where health impacts depend not only on intensity but also on the extent and duration of exposure, consistent with evidence that chronic noise exposure is more harmful than short-term peaks (Hahad et al., 2025) Accordingly, extrapolation of hazard boundaries shows that sites with low attenuation coefficients ($k \leq 0.035$) are “Critical,” with Health Danger Zones extending beyond 40 m, reflecting weak acoustic dissipation. These findings highlight the persistence of noise risks and the insufficiency of natural attenuation.

The spatial modelling results demonstrate that noise risk is unevenly distributed, with certain locations exhibiting significantly higher health burdens due to the combined effects of high intensity and low attenuation. The meaning of this finding is that environmental noise creates spatially differentiated risk zones, where some areas function as critical hotspots of exposure. The significance lies in its application for policy and planning. By identifying high-risk zones, the study provides a basis for targeted intervention, rather than uniform regulation. This approach aligns with international best practices in urban noise management, where spatial mapping is used to prioritise mitigation efforts (European Environment Agency, 2023). Importantly, the study shows that acoustic persistence is a key driver of spatial risk, reinforcing the need to incorporate both intensity and environmental decay into urban planning frameworks.

## 6.0 CONCLUSION AND RECOMMENDATIONS

This study establishes that environmental noise from music shops in Jos-South constitutes a pervasive urban health hazard, with impacts extending beyond source locations into surrounding residential areas. Although sound levels decline with distance, the persistence of noise indicates that attenuation alone does not sufficiently mitigate exposure. The Noise Sensitivity Index (NSI) and Health Risk Index (HRI) confirm widespread exceedance of permissible limits and demonstrate that increased noise intensity translates directly into elevated health risk, validating both indices as effective proxies for environmental health assessment. Distance-decay modelling reveals that noise propagation follows a predictable pattern, but with varying attenuation rates across locations, highlighting acoustic persistence as a key determinant of exposure. Spatial modelling identifies high-risk zones where elevated source intensity combines with low attenuation, creating sustained exposure environments and amplifying potential health impacts. Interventions should prioritise high-risk zones through targeted enforcement, acoustic mitigation, and urban design measures such as sound barriers and green buffers. Continuous monitoring using NSI and HRI is recommended to guide evidence-based policy and reduce the health burden of environmental noise.

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