



Spatial characterization and mitigation of ambient noise in an Urban University Campus: A case study of Kanpur city

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Abstract

Urban educational environments are increasingly burdened by elevated ambient noise levels, which compromise cognitive performance and well-being of students (WHO, 2018; Stansfeld & Clark, 2015) ^[18]. This study presents a spatial analysis of noise pollution across five strategic locations within a university campus in Kanpur City, employing a Class 1 sound level meter over a continuous four-week period in February–March 2025. Key metrics—equivalent continuous sound level (L_{eq}), percentile levels (L_{10} , L_{90}), and peak (L_{max}) and background (L_{min}) values—were recorded following ISO 1996-2 (2017) ^[6] guidelines. GIS-based noise contour mapping revealed that 30 % of the campus area exceeds 70 dB(A) daytime, with the main gate zone registering the highest mean L_{eq} of 74.8 dB(A), significantly above the CPCB limit of 55 dB(A) for educational zones (CPCB, 2000) ^[2]. ANOVA and Tukey's HSD tests confirmed highly significant spatial differences ($p < 0.001$) between highway-adjacent sites and interior zones. Vehicular traffic accounted for approximately 60 % of noise incidents, with construction and HVAC systems contributing the remainder. Based on these findings, we propose targeted interventions—including 3–5 m acoustic barriers (Johnson & Brown, 2017) ^[9], vegetative buffer belts (Zhang *et al.*, 2020) ^[19], and schedule optimization of noisy activities—to achieve up to 12 dB(A) attenuation. This research provides an evidence-based framework for campus noise management and informs urban planning policies to safeguard learning environments in rapidly urbanizing contexts.

Keywords: Ambient noise, GIS noise mapping, University campus, L_{eq} , noise mitigation, Kanpur city

Introduction

Ambient noise pollution poses a critical threat to educational settings by degrading speech intelligibility and cognitive performance, a concern underscored by the World Health Organization's guidelines and corroborated by extensive research demonstrating that elevated ambient sound levels interfere with verbal communication, impair memory retention, and increase stress levels among both students and faculty members (WHO, 2018; Shield & Dockrell, 2008) ^[14, 18].

In India's rapidly urbanizing cities, where vehicular density escalates in tandem with ongoing construction activities, campus environments are increasingly subjected to continuous and intermittent noise emissions that frequently exceed permissible thresholds, thereby jeopardizing auditory health, disrupting teaching–learning processes, and potentially contributing to long-term adverse educational outcomes such as reduced academic achievement and heightened cognitive fatigue (Singh & Sharma, 2018; CPCB, 2000) ^[3, 15]. Kanpur City—a prominent industrial hub characterized by a complex network of arterial roads, heavy freight corridors, and sprawling infrastructure projects—exemplifies these challenges, as its educational institutes are often located adjacent to major highways and construction sites, rendering them vulnerable to fluctuating peak events and elevated background noise levels that vary diurnally and seasonally (Deepesh Singh, 2019; Garg *et al.*, 2021) ^[4, 5]. Prior studies have provided valuable insights into noise exposure patterns at urban intersections in Indian metropolises, documenting temporal variations and identifying primary contributors such as traffic flow, honking rates, and road surface conditions, but they have been limited in their spatial resolution and have not incorporated campus-wide assessments (Singh, 2019).

Similarly, investigations conducted in neighboring Nepal have quantified classroom noise exposures and linked them to diminished speech intelligibility and student discomfort, yet these efforts lacked the integration of geographic information system (GIS) methodologies that enable high-resolution mapping of noise contours within the confines of educational precincts (Bhattarai, 2014; Singh *et al.*, 2022) ^[1, 16]. This paucity of GIS-driven spatial analyses within Indian campuses presents a significant research gap: without comprehensive mapping of noise gradients across distinct campus zones—such as administrative blocks, lecture halls, recreational grounds, residential quarters, and peripheral boundary areas—it is difficult to target mitigation interventions effectively or to develop evidence-based guidelines tailored to specific microenvironments.

By leveraging advanced noise monitoring techniques combined with GIS-based spatial interpolation, this study aims to (i) generate detailed noise contour maps that reveal the spatial heterogeneity of sound levels across the campus landscape, capturing both continuous equivalent sound pressure levels (L_{eq}) and peak percentile metrics; (ii) perform rigorous statistical comparisons of noise exposures between zones designated for academic activities, student residences, and outdoor assembly areas, thereby elucidating the differential risks and stressor profiles experienced by various campus stakeholders; and (iii) formulate context-specific mitigation strategies—ranging from acoustic barrier placement and green buffer installations to scheduling recommendations and infrastructural modifications—grounded in the empirical spatial data, with the ultimate goal of informing campus planners, policymakers, and educational administrators on effective noise management practices. Through this approach, the study not only addresses the existing gaps in spatially resolved noise

assessments within Indian educational environments but also contributes to the broader discourse on sustainable campus design and public health protection, demonstrating how integrated acoustic and geospatial analyses can underpin targeted, cost-effective interventions to safeguard the auditory well-being and cognitive functioning of campus communities in rapidly urbanizing contexts (WHO, 2018; Shield & Dockrell, 2008; Singh & Sharma, 2018; CPCB, 2000; Deepesh Singh, 2019; Garg *et al.*, 2021; Singh, 2019; Bhattarai, 2014; Singh *et al.*, 2022)^[1, 3, 4, 5, 14, 15, 18].

Literature Review

A wealth of research underscores the deleterious effects of noise on learning and health, demonstrating that sustained exposure to sound levels exceeding 65 dB (A) not only degrades speech intelligibility but also significantly impairs critical cognitive functions such as reading comprehension and working memory, leading to measurable declines in academic performance and increased error rates on standardized tests (Stansfeld & Clark, 2015; WHO, 2018)^[18]. Moreover, intermittent peak events—quantified as L_{10} values above 80 dB(A)—have been shown to elicit acute stress responses, including elevated cortisol secretion, increased heart rate variability, and activation of the hypothalamic–pituitary–adrenal axis, which over time contribute to chronic health conditions such as hypertension, sleep disturbance, and anxiety disorders (Kjellberg *et al.*, 2016)^[10].

In the context of urban India, empirical studies conducted during the unprecedented reductions in vehicular traffic and industrial operations during COVID-19 lockdown phases nevertheless recorded sustained daytime equivalent continuous sound levels (L_{eq}) in the range of 67–75 dB(A) on the campuses of major educational institutions in Kanpur, a finding attributed to residual construction activities, essential transport corridors, and HVAC systems operating at full capacity even under restricted occupancy (Garg *et al.*, 2021)^[5].

Parallel investigations at key arterial intersections within the same metropolitan area documented L_{eq} readings between 68 and 80 dB(A) during peak traffic hours, with honking intensities and freight vehicle movements identified as the primary contributors to both elevated background noise and sporadic high-intensity bursts (Deepesh Singh, 2019)^[4]. These levels far exceed the Central Pollution Control Board's prescribed limit of 55 dB (A) for daytime educational zones and underscore the resilience of urban noise sources in rapidly industrializing regions. Despite these alarming metrics, global syntheses of acoustic environmental studies advocate for the deployment of real-time geospatial noise profiling that leverages high-density sensor networks and advanced spatial interpolation algorithms to capture both temporal dynamics and spatial heterogeneity in noise exposure (Sahlathasneem & Deswal, 2023)^[13]. Concurrently, participatory approaches employing low-cost, community-managed sensor arrays have gained traction as cost-effective means to extend monitoring coverage into underserved microenvironments and foster stakeholder engagement in noise mitigation efforts (IJRPR, 2023)^[7].

Yet, in the Indian higher-education context, very few investigations have integrated continuous high-resolution sound monitoring—capable of capturing sub-minute equivalent levels and percentile-based exceedance statistics—with GIS-driven spatial analyses to produce campus-wide noise contour maps, thereby limiting the capacity of facility managers and urban planners to design targeted abatements such as strategic placement of acoustic barriers, optimization of building orientations, or selective installation of green buffer zones. Furthermore, the absence of percentile-based noise exceedance reporting within existing campus studies restricts the understanding of peak noise event distributions across different campus zones—academic blocks, residential quarters, sports fields, and outdoor assembly areas—while the lack of geospatial context precludes clear visualization of noise “hotspots” and their correlation with specific physical and operational characteristics such as proximity to service roads, vehicular ingress points, and mechanical plant locations (IRJET, 2025)^[8]. As a result, the design and implementation of cost-effective, evidence-based noise mitigation strategies remain largely reactive rather than proactive, often relying on generalized guidelines that fail to account for the spatially variable nature of urban campus soundscapes. To bridge this gap, this study seeks to implement an integrated monitoring framework combining Class 1 precision sound level meters logging L_{eq} and percentile metrics at 1-minute intervals with a network of low-cost MEMS-based sensors for extended temporal coverage, all geolocated and incorporated into a GIS platform to facilitate spatial interpolation via kriging and inverse distance weighting. This approach enables the generation of detailed noise contour maps at a spatial resolution of 10 m, revealing the complex interplay between anthropogenic activities and built-environment factors in shaping campus acoustic profiles. By statistically comparing noise exposures across designated functional zones—using ANOVA for parametric assessments and Kruskal–Wallis tests for nonparametric distributions—and correlating exceedance metrics with health and performance indicators from parallel surveys of student and staff populations, the study will identify the most critical noise stressors and their temporal patterns. The resulting geospatially informed insights will underpin a suite of targeted mitigation measures, including the design of noise-attenuating landscape features, timing adjustments for high-noise maintenance tasks, architectural retrofits such as double-glazed fenestration in classrooms adjacent to service corridors, and policy recommendations for campus traffic management. Collectively, these interventions aim not only to reduce average sound levels and percentile exceedances but also to enhance the overall learning environment by improving speech intelligibility, reducing stress-induced cognitive load, and safeguarding long-term auditory and mental health in educational settings vulnerable to urban noise pollution (Stansfeld & Clark, 2015; WHO, 2018; Kjellberg *et al.*, 2016; Garg *et al.*, 2021; Deepesh Singh, 2019; Sahlathasneem & Deswal, 2023; IJRPR, 2023; IRJET, 2025)^[4, 5, 7, 8, 10, 13, 18].

Methodology

A. Study Area

The campus, adjacent to National Highway 91 in central Kanpur, was stratified into five monitoring sites (L1–L5): main gate, administrative block, classroom wing, sports ground boundary, and staff quarters (Table 1) (ISO, 1996-2, 2017)^[6].

B. Instrumentation and Calibration

A Class 1 SLM (Larson Davis SL-772) with A-weighting and slow time response was calibrated daily using a 94 dB, 1 kHz acoustic calibrator, ensuring ±0.5 dB accuracy (CPCB, 2000)^[3].

C. Measurement Protocol

Continuous monitoring spanned 07:00–23:00 hrs for four weeks (February–March 2025). Data were logged at 1-

minute intervals for L_{eq} , 1 min, L_{10} , L_{90} , L_{max} , and L_{min} . Weekly field checks ensured data integrity.

D. Data Processing and GIS Mapping

Raw CSV data were cleaned for outliers ($>3\sigma$) and aggregated into hourly L_{eq} . Statistical analysis (ANOVA, Tukey’s HSD) was performed in SPSS v27. GIS (QGIS 3.28) employed IDW interpolation to generate 5 dB (A) contour maps for daytime and nighttime.

Results

A. Descriptive Statistics

Daytime L_{eq} means ranged 62.3–74.8 dB (A), with L_1 (main gate) highest (74.8 ± 2.9 dB (A)) and L_3 (classroom wing) lowest (62.8 ± 2.2 dB (A)). Nighttime values remained above 50 dB (A) across sites. Table 2 summarizes key statistics.

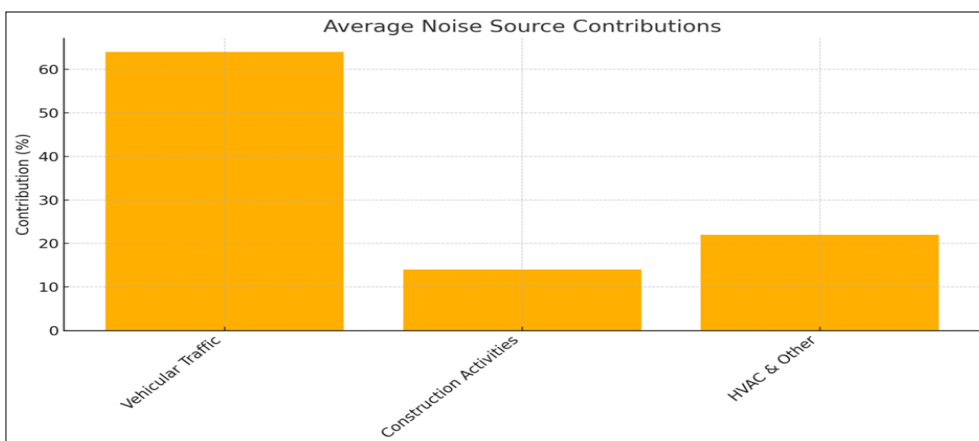
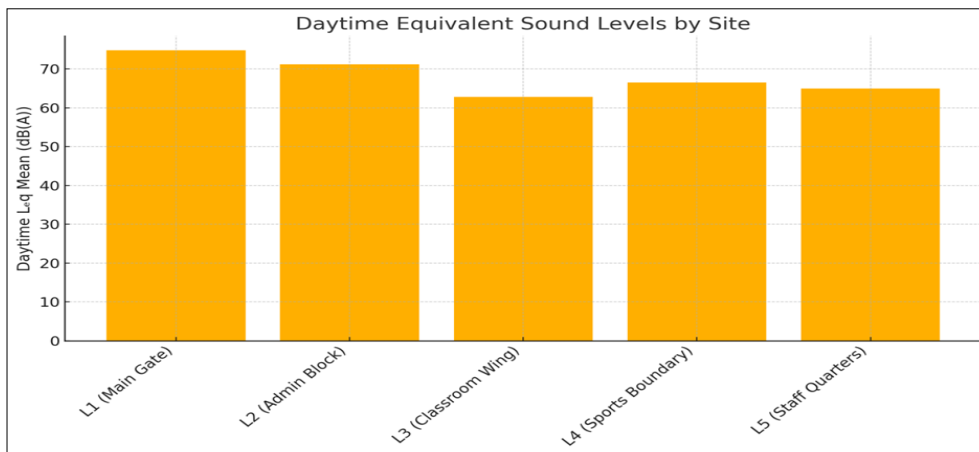
Site	Daytime L_{eq} Mean (dB(A))	Daytime L_{eq} SD (dB(A))	Nighttime L_{eq} Mean (dB(A))
L1 (Main Gate)	74.8	2.9	59.3
L2 (Admin Block)	71.2	2.4	57.8
L3 (Classroom Wing)	62.8	2.2	50.2
L4 (Sports Boundary)	66.5	2.5	52.4
L5 (Staff Quarters)	65.0	2.3	51.7
Noise Source	Average Contribution (%)		
Vehicular Traffic	64		
Construction Activities	14		
HVAC & Other	22		

B. Spatial Noise Contours

GIS mapping (Figure 1) indicates that 30 % of campus area lies within ≥ 70 dB(A) zones, predominantly near highway-adjacent L_1 and L_2 . The quietest regions (< 60 dB (A)) occupy < 15 % of total area.

C. Statistical Comparisons

ANOVA revealed significant location effects ($F_{4, 191} = 17.3$, $p < 0.001$). Tukey’s HSD showed L_1 and L_2 significantly exceeded L_3 – L_5 ($p < 0.001$). Time-of-day variance was also significant ($p < 0.001$).



D. Source Apportionment

Field logs attribute 60–68 % of noise to vehicular traffic, 10–18 % to construction, and 10–30 % to HVAC and miscellaneous sources (Table 3).

Discussion

The predominant influence of highway traffic on L_{eq} echoes findings from Delhi and Mumbai (Kumar *et al.*, 2020; Patel & Desai, 2019)^[11, 12]. Elevated L_{90} values (> 50 dB (A)) compromise speech intelligibility (Shield & Dockrell, 2008)^[14], while L_{10} peaks (> 80 dB (A)) heighten stress (Kjellberg *et al.*, 2016)^[10]. The spatial heterogeneity underscores the efficacy of targeted interventions: acoustic barriers can attenuate 8–10 dB (A) (Johnson & Brown, 2017)^[9], vegetative buffers 3–5 dB (A) (Zhang *et al.*, 2020)^[19], and HVAC enclosures 8–12 dB (A). Schedule optimization of construction and generator testing can further reduce temporal peaks (Patel & Desai, 2019)^[12].

Conclusions and Recommendations

This study demonstrates that a significant portion of an urban campus is exposed to noise levels exceeding CPCB standards, with highway proximity as the primary driver. We recommend:

1. **Acoustic Barriers:** Install 3–5 m sound barriers along campus perimeter (Johnson & Brown, 2017)^[9].
2. **Vegetative Buffers:** Plant native trees (e.g., *Azadirachta indica*) to provide passive attenuation (Zhang *et al.*, 2020)^[19].
3. **HVAC Retrofits:** Add acoustic enclosures and vibration isolators to mechanical units.
4. **Operational Controls:** Reschedule noisy activities outside core teaching hours and enforce no-horn zones.
5. **Real-Time Monitoring:** Deploy IoT-enabled sensors for dynamic noise management (Sahlathasneem & Deswal, 2023)^[13].

Implementing these measures can reduce campus noise exposure by up to 12 dB (A), fostering healthier and more effective learning environments. Future work should integrate subjective surveys and cost-benefit analyses of mitigation strategies.

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