

Hospital Noise Pollution in a Tertiary Hill-State Hospital: A Spatio-Temporal Assessment

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ABSTRACT

Background: Hospitals are sensitive acoustic environments where excessive noise can adversely affect patient recovery and staff performance. Despite global recommendations to maintain hospital noise levels within 30–45 dB(A), evidence suggests that actual sound levels often exceed these limits, particularly in developing and geographically constrained regions such as Uttarakhand. **Aim & Objectives:** To measure and analyse noise levels across key functional zones of a tertiary care teaching hospital in Uttarakhand and evaluate temporal variation over a two-week period in order to inform evidence-based policy and hospital-level noise mitigation strategies. **Methodology:** A cross-sectional observational study was conducted using a calibrated digital sound level meter to measure LAeq values across five hospital zones (ICU, OPD, General Ward, Administrative Office, and Utility Area) during both day and night shifts over two consecutive weeks. Statistical analyses were performed to assess spatial and temporal differences in noise exposure. **Results:** All measured zones exceeded recommended international noise limits. The OPD recorded the highest LAeq values (≥ 74 dB), followed by the General Ward and Utility Area. Administrative zones also breached the 45 dB threshold. Night-time levels were marginally lower but consistently above permissible standards. Major noise sources included human activity, medical equipment, and external traffic. **Conclusion:** The findings confirm widespread acoustic non-compliance across both clinical and non-clinical zones within a tertiary hill-state hospital. This spatio-temporal assessment provides context-specific evidence to inform environmental noise management, structured noise audits, and integration of acoustic standards into hospital accreditation and infrastructure planning frameworks.

KEYWORDS

Noise, Hospitals, Intensive Care Units, Outpatients, Noise measurement

INTRODUCTION

Hospitals are sensitive environments where patient recovery, safety, and clinical efficiency depend on a calm, controlled environment, including acoustics. Among environmental stressors, noise pollution remains an under-addressed yet critical factor that impacts both patient outcomes and healthcare staff performance.

Noise levels are typically measured using LAeq, or the *equivalent continuous sound level* that represents the average sound pressure level over a specified period, reflecting both intensity and duration of noise exposure.

The World Health Organization (WHO) recommends that indoor noise levels in hospital wards should not exceed 30 dB(A), and in treatment

areas, should stay below 35-45 dB(A)(1). The United States Environmental Protection Agency (USEPA) sets the general upper limits of 45 dB(A) indoors and 55 dB(A) in areas surrounding hospitals to help safeguard public health and the well-being of nearby communities(2). However, studies across both developed and low- and middle-income countries consistently report hospital noise levels exceeding these thresholds.(3-12,17-20,23-29)

Noise can have both auditory effects like hearing loss and non-auditory effects like annoyance, disturbed sleep, higher stress levels and distraction in staff and affects patient sleep and recovery, communication between patient and staff and staff productivity.(13-17)

Noise sources in hospitals are both external - such as traffic, ambulance sirens, and HVAC systems- and internal, including alarms, staff communication, equipment, patient movement, treatment procedures, and mobile phones.(17-20,8)

While the clinical zones are widely studied, non-clinical and administrative spaces remain under-researched despite their proximity to care areas and indirect impact on patient experience. In the Indian public healthcare context, challenges such as overcrowding, high patient-to-bed ratios, and limited zoning amplify acoustic burden.(21-23,8) These issues are compounded in hill states like Uttarakhand, where echo-prone topography, constrained horizontal space, and compact legacy buildings contribute to unique acoustic dynamics. Empirical field studies suggest that terrain-amplified noise reflections and poor acoustic zoning exacerbate environmental stress in such facilities.(9) The present study aims to address this gap.

Aims and Objectives:

1. To measure and analyse noise levels across key functional zones of a tertiary care hospital.
2. To evaluate spatio temporal variations in noise levels.
3. To inform recommend noise mitigation strategies.

Literature Review

Hospital noise pollution has been extensively studied, particularly in high-acuity settings such as Intensive Care Units (ICUs) and Neonatal Intensive Care Units (NICUs). Studies across regions have consistently found that average ambient noise levels in these zones exceed the WHO's recommended limits of 30-45 dB(A).(19,24,25,28,29) Most of the ICU studies(19,24,25,28,29) revealed LAeq ranges from 52.85 dB(A) to 77.6 dB(A) with one study recording a Peak L_{Amax} of 98.3 dB(A).(28) Similarly, consistently higher noise levels in NICU

studies(23,26,27)ranging from 51.3 dB(A) to 82.32 dB(A) have drawn attention to the vulnerability of neonates to acoustic overstimulation.

Interventions such as staff education and physical redesign were shown to yield moderate improvements in the NICU in a longitudinal study by Nieto-Sanjuanero *et al.* (2015), although even post-intervention noise levels remained above recommended thresholds.(27)

A study in the adult critical care unit in Preston, Lancashire, UK showed that installing SoundEar monitors (noise monitoring and visual alert tools using color-coded displays to signal when sound levels exceed acceptable noise levels), near nurses' stations led to a reduction in median noise levels by 3.9 dB from a baseline of 57.4 dB and peak noise levels by 0.7 dB by improving staff awareness and encouraging behavioural changes regarding acoustic hygiene. This model exemplifies how real-time feedback can complement structural reforms-offering a practical pathway for similar adoption in Indian tertiary hospitals, especially in acoustically sensitive zones such as ICUs.(29)

Beyond critical care zones, Outpatient Departments (OPDs), Emergency units and wards have also been identified as significant contributors to hospital noise.(6,8,9,11,12,17) Filus *et al.* (2015) reported LAeq values ranging from 56.6 to 68.8 dB(A) in an Emergency trauma hospital in Brazil, particularly during peak periods.(18) In North India, Das and Kishore (2023) found that OPDs recorded day time LAeq levels above 73 dB(A) on most weekdays, similar to the average OPD noise levels in the study by Yarar *et al* in Istanbul.(8,10) Noise levels in wards varied in range from as low as 42 dB(A) to highs of 77.4 dB(A).(6,9,11,12,17,20)

Studies on non-clinical or administrative hospital areas are comparatively fewer but reveal similar trends in non-clinical areas as well underscoring the systemic nature of the problem.(6,8,9) Most existing literature, except the hill-state assessment by Laishram *et al.* (2023)(9) focuses primarily on urban or plain settings, with limited attention to geographically constrained hospital environments where terrain acoustics and legacy infrastructure may exacerbate noise propagation.

In sum, the literature confirms that noise pollution in hospitals is pervasive, with peak levels routinely exceeding global health standards across clinical and non-clinical zones. However, there are fewer studies considering:

- Acoustic conditions in hill-state hospitals, particularly in India (e.g., Uttarakhand).
- Spatio-temporal comparisons across diverse functional zones (clinical, nonclinical).
- Policy-oriented recommendations for future action.

This study addresses these gaps by offering a multi-zonal, time-variant noise audit in a tertiary care public hospital of Uttarakhand. It contributes new evidence for both local policy-making and broader understanding of hospital environmental factors.

Most literature(7-12,17-20,23-28) focuses on baseline noise assessment in clinical zones, primarily ICUs, Emergency, OTs, wards and OPDs, with limited evaluation of non-clinical areas. Only a few intervention-based studies demonstrate interventions to reduce noise.(27,29)

This underscores a persistent evidence gap not only in mitigation research but also in non-clinical zone inclusion.

Furthermore, while some research acknowledges elevated noise levels, few translate findings into concrete policy recommendations. By filling these gaps- non-clinical area noise mapping, regional acoustics, and policy-oriented framing- this study adds a novel and actionable layer to the field of hospital environmental health.

Theoretical Framework

This study draws on two complementary theoretical perspectives- Environmental Stress Theory and Salutogenic Theory- to conceptualize how hospital noise functions as an environmental health stressor. Environmental Stress Theory, articulated by Evans and Cohen (1987), emphasizes the cumulative physiological and psychological effects of environmental stimuli such as noise, crowding, and pollution.(30) In hospital contexts, these stressors can disrupt patient recovery, increase fatigue and error rates. This theory informed the selection of high-exposure zones (e.g., ICU, OPD, General ward), where individuals are particularly vulnerable to repeated acoustic disturbances under high-stakes conditions. Salutogenic Theory, proposed by Antonovsky (1979), focuses on factors that support human health and resilience rather than merely those that cause illness.(31) It emphasizes the creation of structured, predictable, and supportive environments as a buffer against stress. This theory is relevant not only for clinical spaces but also for non-clinical zones- such as administrative offices and utility areas- where staff concentration, decision-making, and coordination activities take place. Reducing acoustic disturbances in these zones contributes to an overall healing atmosphere and supports systemic well-being.

Together, these theories guided the design of the study as follows:

Zone Selection: Environmental Stress Theory justified focusing on clinical zones; Salutogenic

Theory supported inclusion of administrative and utility areas.

Temporal Focus: Both frameworks support capturing variations across day-night and weekday-weekend periods to examine rhythms of environmental stress and recovery.

Analytical Priorities: The use of both average (LAeq) and peak (LAm_{ax}) noise levels was designed to capture both chronic and acute stressor exposures.

This theoretical framework informed the study's hypothesis that noise exposure would vary significantly across hospital zones and time shifts, and that higher levels would correlate with zones experiencing higher patient throughput or limited zoning controls.

MATERIAL & METHODS

Study Type and Study Design: This was a cross-sectional observational study to assess noise levels across various functional zones of a hospital.

Study Setting: The study was conducted at a tertiary care teaching hospital located in Uttarakhand, a northern hill state in India. To control for seasonal variability in ambient noise-particularly that caused by monsoonal rainfall and associated infrastructural dampening or intensification of sound- data collection was purposefully scheduled during a dry-weather window in the pre-monsoon season in India (April-May).

Study population

Environmental noise measurements recorded across the selected functional zones.

Study Duration

Noise measurements were taken over a two week period.

Sample size

Five functional zones were selected for this study: Intensive Care Unit (ICU), Outpatient Department (OPD), General Ward, Administrative Office, and Utility Area. This selection was made based on the following rationale:

Functional diversity: These zones represent a spectrum of hospital operations, including clinical areas (ICU, OPD, General Ward), and non-clinical support zones (Administrative, Utility).

Proximity to noise-sensitive spaces: Administrative and utility areas are often physically adjacent to clinical care areas, potentially influencing the overall acoustic environment.

Operational feasibility and access permissions: While operation theatres are important noise-sensitive areas, they were excluded due to limited accessibility during the observation period and the need to avoid disruptions to sterile environments or ongoing medical procedures.

Temporal Coverage Justification

Data were collected across **two consecutive weeks** to account for potential fluctuations in hospital activity patterns. This duration was chosen based on:

Feasibility considerations: Continuous long-term monitoring in a live hospital setting is logistically challenging and resource intensive.

Pre-study pilot observations: which indicated that patient throughput and noise levels tended to stabilize over weekly cycles, with predictable variations between weekdays and weekends.

Temporal representativeness: The two-week period included both weekday and weekend cycles, as well as day and night shifts, allowing for a reasonable estimation of typical spatio-temporal variation in noise exposure.

Inclusion Criteria

Routine functional zones, areas where monitoring was possible without interfering with patient care or procedures.

Exclusion Criteria

Operation theatres and areas where monitoring could interfere with sterile conditions or procedures, areas where access permission was not available.

Strategy for Data Collection

Noise levels were measured using a calibrated integrating sound level meter (Lutron SL-4035SD), which satisfactorily fulfilled the IEC 61672 sound level metering standards. Calibrated instruments: Instrument was calibrated before data collection for accuracy and reliability of measurements.

Five different zones of the hospital were selected for measurements - Intensive Care Unit (ICU), Outpatient Department (OPD), General Ward, Administrative Office & Utility Area.

Data were collected on consecutive days, over a two-week period, to ensure temporal stability and representativeness. Measurements were collected across both day (08:00–20:00) and night (20:00–08:00) shifts to accommodate diurnal variation in hospital activity levels. All monitoring cycles incorporated weekday and weekend observations to reflect potential changes in patient volume, staffing trends, and operational atmosphere.

The sound level meter was placed at a standard height of approximately 1.2–1.5 meters above ground to mimic the average ear height of an adult sitting(9). The device was positioned at least 1–3 meters from any reflective surfaces (walls, large equipment, etc.) to reduce sound reflection and sound measurement interference. Recording sessions had also been meticulous in creating a space that mitigated interference or obstruction from natural phenomena (ie: direct physical constraint or limitation).

Working definitions

The device recorded key acoustic metrics:

1. **LAeq (Equivalent Continuous Sound Level)**- obtained by averaging 5-minute readings over an hour
2. **LAmx (Maximum Sound Level)**- maximum of the 5-minute readings during the hour
3. **Lmin (Minimum Sound Level)**- minimum of the 5-minute readings during the hour

All readings were A-weighted (dBA), logged at 5-minute intervals. Hourly average for LAeq were calculated for each zone. LAmx and Lmin were the highest and lowest 5-minute readings, within each hour (from the 12 data points per hour). These hourly values were then used for spatio-temporal comparisons between zones and day/night. Pre-survey calibration was performed using a reference pistonphone to ensure measurement accuracy and periodic calibration checks were conducted every 24 hours.

Ethical Issues

Institutional clearance was obtained prior to data collection. No patient identifiers or personal data were recorded, and measurements were confined to ambient sound only, ensuring ethical compliance. Ethical approval was obtained for publication of the work from the Institutional Research Committee (Ref. no. SRHU/HIMS/RC/2025/169).

Data Analysis

Descriptive statistical analysis was used to summarize the distribution of noise levels by the different hospital zones and time periods. Mean equivalent continuous sound levels (LAeq), measured maximum (Lmax) and minimum (Lmin) were calculated to describe acoustic exposure in each functional area. These more description-based indicators also allowed comparisons across monitoring locations and shifts both in space and time.

Paired sample t-tests were done to determine statistically significant differences between day (8:00 AM–8:00 PM) and night (8:00 PM–8:00 AM) measurements to investigate temporal differences in noise levels. Paired comparisons were also carried out between Week 1 and Week 2 recordings to assess consistency, and whether there was evidence of short-term variability of acoustics.

To evaluate differences in noise exposure among hospital regions (ICU, OPD, General Ward, Administrative Office, and Utility Area), ANOVA was conducted using LAeq as the outcome variable. In the case of significant differences, post hoc comparisons (Tukey's HSD etc.) were performed to determine the zone-wise differences.

IBM SPSS Statistics version 26 was used to conduct all statistical analyses. A $p < 0.05$ type threshold was used to determine statistical significance. Assumptions of normality (Shapiro–Wilk test, Q–Q plots) were determined before inferential testing. Taking into account that the data showed an approximately normal distribution and the robustness of parametric tests to modest violations of normality, paired sample t-tests and ANOVA were considered suitable for the analyses.

RESULTS

Overview of Noise Levels across Hospital Zones:

Table 1 presents the mean LAeq (equivalent continuous noise level) values recorded in five selected hospital zones during two consecutive weekly cycles, across both day and night shifts.

Table 1. Mean LAeq Values with Standard Deviations by Hospital Zone and Time Period (in dB)

Zone	Day-Week 1	SD	Night- Week 1	SD	Day-Week 2	SD	Night- Week 2	SD
ICU	63.2	2.05	61.5	2.15	64.1	2.29	60.9	1.59
OPD	72.8	2.22	67.2	1.94	74.4	2.03	69.1	1.52
General Ward	66.5	2.10	62.8	2.39	68.0	2.07	63.9	2.33
Administrative	60.1	2.04	58.7	2.46	61.4	2.43	59.3	2.28
Utility Area	65.8	1.92	62.3	1.88	67.2	1.57	63.6	2.37

Note: All zones exceeded WHO and USEPA thresholds consistently across time periods. Standard deviations reflect observed variability within each measurement window.

Temporal Trends in Noise Levels: Across all zones, daytime LAeq levels were consistently higher than night-time values. The Outpatient Department (OPD) registered the highest mean noise level in both weeks. Week 2 values were slightly elevated in most zones, suggesting cumulative or persistent environmental noise factors.

Lmax and Lmin Ranges: The highest Lmax observed was in the OPD (88.5 dB), while the lowest Lmin was recorded in the Administrative Zone (49.2 dB). These extremes reflect the acute spikes in patient-facing areas during peak hours, and relative calm in administrative functions.

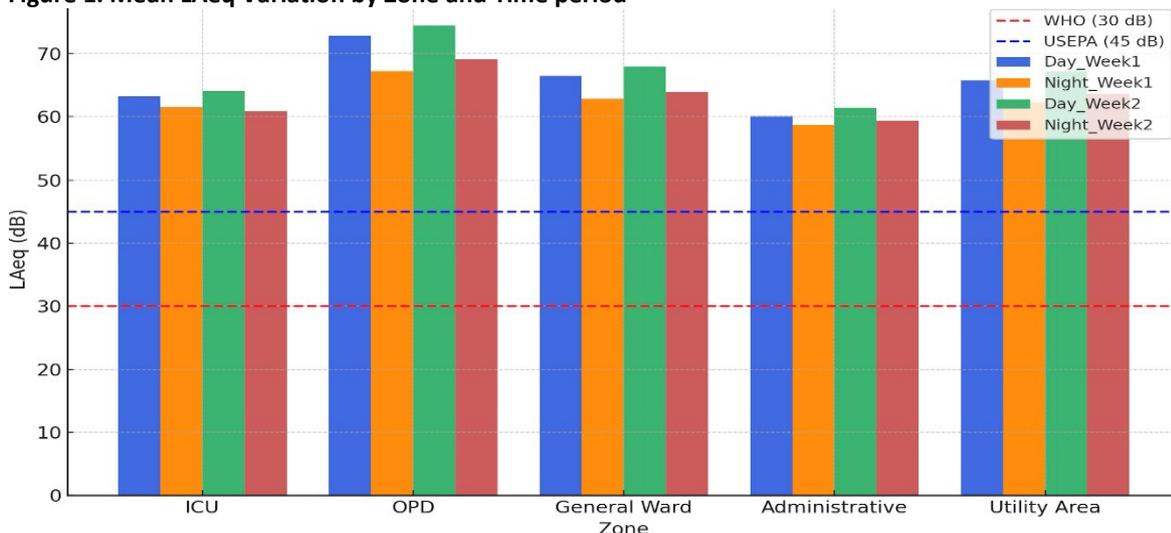
Figure 1 illustrates average LAeq levels for each zone across four measured time windows

(Day/Night over two consecutive weeks), while Figure 2 depicts trends across those time periods.

Key insights include:

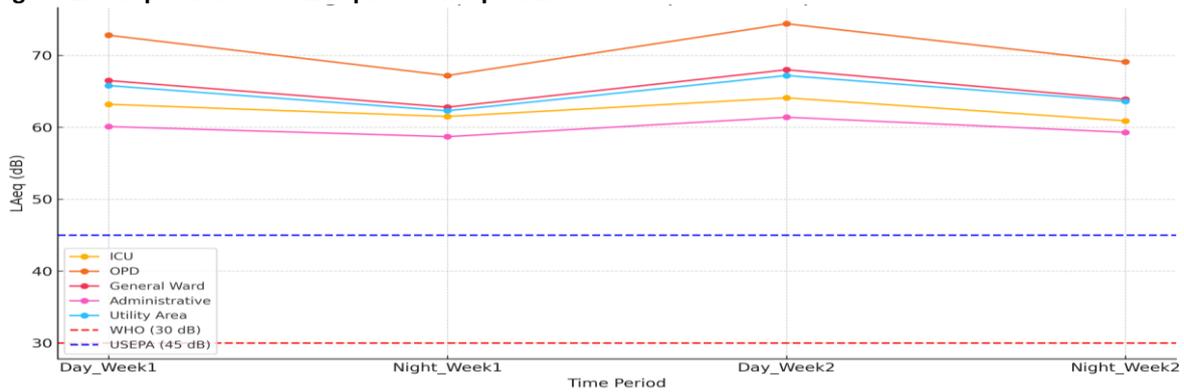
- The OPD consistently recorded the highest LAeq values, with peaks exceeding 74 dB—far above WHO’s 30 dB and USEPA’s 45 dB recommendations.
- All zones, including administrative and utility areas, regularly breached the 45 dB threshold, indicating that noise is pervasive and not confined to patient-care zones.
- Night-time noise levels, while marginally lower, remained above permissible limits, particularly in zones with shared service corridors.

Figure 1. Mean LAeq Variation by Zone and Time period



Source: Primary data, Lutron SL-4035SD, April-May 2024. Dashed lines represent WHO (30 dB) and USEPA (45 dB) thresholds.

Figure 2. Temporal trend of LAeq across hospital zones



Source: Primary data, Lutron SL-4035SD, April-May 2024. Dashed lines represent WHO (30 dB) and USEPA (45 dB) thresholds.

Statistical Test Results and Interpretation: This section interprets the outcomes of statistical tests applied to assess the significance of observed differences in LAeq levels across hospital zones and time periods. (Table 2)

A One-way ANOVA showed that there is a statistically significant difference in LAeq levels across hospital zones. The OPD exhibited the highest mean LAeq, significantly different from administrative zones.

Paired sample t tests demonstrate that LAeq levels vary significantly between day and night shifts. Across all zones, day-time noise levels were

significantly higher than night-time levels. The disparity was particularly prominent in the OPD and utility areas.

However, Independent samples t-test show that there is no significant difference in noise levels between Week 1 and Week 2, suggesting consistent noise patterns over time.

The statistical analysis confirms that zone type and time of day are critical determinants of noise exposure, while weekly variation is less influential. These results validate the need for zone-specific and temporal noise mitigation strategies.

Table 2. Statistical Test Results Summary

Hypothesis	Test Applied	Test Statistic	p-value
H1: Difference in LAeq across zones	One-way ANOVA	F (4, 15) = 6.82	< 0.01
H2: Difference between day and night	Paired t-test	t (4) = 3.47	< 0.05
H3: Difference between Week 1 and Week 2	Independent t-test	t (38) = 1.14	> 0.05

DISCUSSION

The findings of this study are consistent with a growing body of evidence indicating that hospital environments routinely exceed recommended acoustic thresholds. Notably, the OPD and ICU zones in the present study recorded average LAeq values well above WHO’s recommended 30 dB(A) limit, aligning with results from studies by Das & Kishore (2023)(8), Laishram (2023)(9) and Yasar (2018)(10), where OPDs were identified as critical noise hotspots. Similarly, consistent high noise levels were reported in wards ranging from 62.8 to 68 dB across day and night shifts; several other studies reported similar or even higher levels.(8,9,11,20)

This study also corroborates findings from Filus et al. (2015)(18) and Yasar (2019)(10) who reported significantly higher noise levels during the daytime, often driven by patient load, staff movement, and mechanical equipment. Hu et al.(19) noted sound

levels ranging from 56.5 to 70.1 dB(A), with surgical ICUs showing especially high daytime values.(20) Delaney and colleagues reported average nighttime levels of 52.85 dB, with peaks reaching 98.3 dB, mostly attributed to staff conversations.(28)

In a Saudi CSICU(24), daytime noise levels were significantly higher, averaging up to 68.8 dB, with potential long-term hearing risks for nurses. A study from the Democratic Republic of Congo(25) revealed the widest range of readings, with peaks up to 94.6 dBA and sustained weekly averages well above acceptable limits. Taken together, while current study reflects mid-range values- 60.9 to 64.1 dB(A)- within this broader dataset, it reinforces a consistent and concerning pattern: ICU environments around the world routinely exceed safe noise thresholds, posing potential risks to both patients and healthcare professionals.

Unlike most prior studies, however, the current research extends beyond clinical areas to include

administrative and utility areas, revealing that these support zones also contribute substantially to the hospital's acoustic environment—an area often overlooked in traditional acoustic assessments.

An unexpected yet important observation was that administrative zones, typically assumed to be acoustically calmer, regularly breached the 45 dB threshold. This could be attributed to potential factors like shared corridors with clinical traffic, presence of office equipment like printers and copiers, staff communication in open-plan areas, and mechanical noise from centralized HVAC systems. These findings suggest that acoustic zoning must extend beyond patient-care areas to include all functional units of the hospital.

Finally, studying a hill-state tertiary care setting, this paper responds to the documented evidence gap regarding how terrain-induced acoustics, spatial zoning limitations, and legacy infrastructure influence hospital noise. The results underscore the necessity for regionalized acoustic policies.

CONCLUSION

The findings of this study demonstrate that noise levels in all zones exceeded recommended thresholds set by the WHO and the USEPA. The OPD emerged as the noisiest area, with significant daytime peaks, while administrative and utility zones—often overlooked—also registered sustained acoustic loads. Statistical analysis reinforced that zone and shift time significantly influence noise exposure, whereas week-to-week variation was minimal. These results not only affirm global concerns regarding hospital acoustics but also extend them by documenting challenges unique to hill-state public hospitals—terrain-driven acoustic amplification, spatial constraints, and infrastructural legacy.

Among the sources of noise identified in this study, the noise resulting from road traffic due to hospital users (staff/ patients/ visitors) and ambulance sirens was one of the external sources of noise that were identified. This hospital related traffic also greatly impacts the surrounding community and mitigation measures must be planned to reduce noise as far as feasible. Hospital traffic management, Noise audits and Acoustic zoning can be extended to the broader community settings especially in similar geographic contexts (hill state).

RECOMMENDATIONS

Based on the study's findings and international best practices, the following recommendations are proposed to mitigate hospital noise pollution in tertiary care public hospitals, particularly in hill-state settings:

1. **Implement Visual noise monitoring systems** such as SoundEar in high-noise areas like ICUs, and nursing stations (Plummer, 2018) for real-time visual feedback on noise thresholds, improving staff awareness and prompting quieter behaviours. Studies report up to 25% reductions in Laeq when such systems are used (Delaney, 2017). Estimated cost: ₹50,000-₹1,50,000 per unit; feasibility: mid-level (requires initial investment but minimal training).
2. **Enforce Zoning and Acoustic Buffering:** Redesigning internal layouts for better spatial segregation between clinical, administrative, and utility zones. Introducing acoustic barriers (e.g., curtains, screens, sound-absorbing wall panels) in high-traffic corridors and shared service areas—particularly critical in hill-state hospitals where terrain constrains horizontal zoning. Estimated cost: ₹1 lakh-₹10 lakhs, feasibility: capital intensive (best integrated with infrastructure upgrades).
3. **Introduce Time based Noise Controls:** Deploying shift-based acoustic control measures such as reduced monitor volumes at night, 'quiet hours' signage, and restricted use of public address systems during rest periods. Lowering alarm volumes and limiting staff access to certain zones can create a more acoustically supportive environment for patient care. (Lokwani, 2024). Estimated cost: ₹5000-10,000 (signage, protocols); feasibility: low cost (Immediate implementation possible).
4. **Establish Hospital-Wide Noise Protocols:** Develop SOPs for acceptable Laeq by zone, schedule periodic audits, and conduct staff sensitization. Estimated cost: ₹25,000-₹1 lakh (training + audit tools); feasibility: mid-level (needs leadership buy-in and monitoring).
5. **Integrate Acoustic Planning in Infrastructure Projects:** Estimated cost: additional 5-10% to project costs, feasibility: capital intensive (requires early stage design alignment).
6. **Launch Behavioural Change Campaigns:** posters, digital signages, to sensitize patients and staff. Include short modules on acoustic hygiene in induction programs. Estimated cost: ₹5,000-₹50,000, feasibility: low-cost high impact if done regularly.
7. **Encourage Region-Specific Research & Innovation:** Support future hill state hospitals studies (impact on stress levels, patient recovery, staff performance and impact on community). Encourage innovation in low-cost, indigenous acoustic solutions and Artificial Intelligence/Machine Learning tools. Estimated cost: ₹1 lakh-₹5 lakhs (pilot grants); feasibility:

mid-level (dependent on research capacity and institutional support).

These recommendations can be prioritized based on available budget, hospital size and noise hotspot zones identified in local audits. For resource-constrained public hospitals, a phased implementation strategy beginning with low-cost behavioural and monitoring interventions may provide a feasible pathway toward long-term acoustic infrastructure upgrades.

LIMITATIONS OF THE STUDY

Despite its comprehensive scope, this study is subject to limitations:

1. The data collection was conducted over a two-week period, which may not capture seasonal variations (e.g., holiday peaks, monsoon-related closures) in patient load and noise patterns.
2. As the assessment was limited to one tertiary care teaching hospital in Uttarakhand, the generalizability of the findings to other hill-state or national hospitals remains constrained.
3. Although day and night shifts were measured over multiple days, continuous 24-hour sound logging was not used, potentially missing acute peak events (e.g., emergencies, mass casualty events).
4. While the study measures acoustic exposure, it does not directly correlate these levels with patient recovery rates, staff stress, or clinical errors.
5. Sound level meters used were accurate and standardized but may have had limitations in differentiating between overlapping or impulse noise sources in real-time.

RELEVANCE OF THE STUDY

This study contributes a region-specific, evidence-backed foundation for policy recommendations aimed at improving patient and staff wellbeing through targeted acoustic interventions.

By integrating theoretical perspectives such as the Environmental Stress Model and Institutional Design Theory, it provides a scaffold for future studies exploring long-term mitigation and behavioural adaptation strategies.

To ensure lasting improvements, acoustic quality should be integrated into accreditation standards (like NABH) and other regulatory frameworks governing hospital infrastructure and patient safety in India.

Understanding the effects of noise in the hospital also reinforces the importance of noise control as a public health priority for the surrounding

community. The study highlights the need for zoning and spatial planning within hospital to segregate noisy areas and these concepts can be applied to urban planning as well that would greatly benefit the community.

AUTHORS CONTRIBUTION

Conception of study design- SS, SAJ, RSS, NS; Generation and interpretation of data- SS, SAJ, DCJ, KB, RSS; Manuscript drafting-SS, SAJ, DCJ, KB, NS; Critical Inputs-SS, SAJ, DCJ, RSS, NS

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CONFLICT OF INTEREST

There are no conflicts of interest.

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DECLARATION OF GENERATIVE AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of the manuscript, the authors used AI for language clarity and refinement.

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