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Acoustical Mapping and Environmental Noise Assessment of Industrial Hubs: A Case Study of Moradabad City, India

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Abstract
Acoustic pollution represents a significant environmental health stressor in rapidly expanding industrial and urban regions. Moradabad, globally renowned as the "Brass City of India" (*Peetal Nagri*), hosts a dense concentration of small-scale artisanal metalcraft workshops, heavy commercial corridors, and dense mixed-use residential developments. This study presents a comprehensive acoustical mapping and spatial assessment across four functional land-use zones, Industrial, Commercial, Residential, and Silent Zones, within Moradabad City, Uttar Pradesh, India. Ambient Sound Pressure Levels (SPL) were systematically recorded across designated daytime (06:00-22:00hrs) and nighttime (22:00-06:00 hrs) monitoring shifts using pre-calibrated Class 1 sound level meters conforming to IEC 61672-1 protocols. Equivalent Continuous Sound Levels (L_{eq}) were evaluated and compared against statutory ambient noise thresholds mandated by the Central Pollution Control Board (CPCB).
The empirical results demonstrate that ambient sound pressure levels across 100% of the monitored functional zones exceed statutory CPCB limits during both daytime and nighttime periods. The industrial zone recorded the highest daytime sound level (L_{eq} = 82.4 dB(A); SPL_{max} = 94.8 dB(A). exceeding statutory thresholds by 7.4 dB(A), driven primarily by open-air metal buffing, power press operations, and diesel generator usage. Commercial corridors recorded L_{eq} = 74.6 dB(A)}, while mixed-use residential zones (L_{eq} = 61.3 dB(A)}$) and silent zones ($L_{eq}$ = 57.8 dB(A)) exhibited marked acoustic stress due to overlapping industrial activities, heavy traffic congestion, and a lack of protective acoustic buffers. Peak sound levels in industrial clusters routinely exceeded the NIOSH 8-hour daily exposure limit of 85 dB(A), indicating substantial risks of Noise-Induced Hearing Loss (NIHL) and systemic non-auditory health complications for localized populations and industrial operators. The findings emphasize the urgent necessity for structural urban zoning, administrative traffic management, sound-proof enclosure retrofits, and the strategic deployment of green vegetative bio-shields for urban noise abatement.
Keywords: Ambient Noise Monitoring, Acoustical Mapping, Moradabad, Central Pollution Control Board (CPCB).

1. Introduction

Moradabad, widely recognized as the “Brass City of India” or *“Peetal Nagri”* in local parlance, represents a pivotal hub for metalcraft and small-scale industrial production in northern India. Based on the 2011 Census of India, the population of Moradabad city was recorded at 887,871, with a population density of approximately 11,838 persons per square kilometer. Projections for 2026 estimate the urban population to expand between 1.33 million and 1.44 million, with a corresponding

population density ranging from 10,445 to 15,694 individuals per square kilometer. Geographically, the municipal boundary extends between 28º 16' and 28º 21' North latitudes and 78º 04' to 79º 00' East longitudes. Given this rapid demographic and spatial expansion, maintaining ambient environmental parameters within permissible statutory limits is critical to ensure human safety and maintain industrial systems' reliability (Hunashal & Patil, 2018).

Urbanization, expanding transport networks, and localized manufacturing operations represent primary drivers of environmental degradation. While urban centers bear the highest burden, suburban regions and small towns along major transit corridors are similarly exposed. Comprehensive environmental monitoring incorporates air, water, soil, and acoustic parameters. In Moradabad, rapid industrialization introduces multi-faceted pollution streams, including atmospheric emissions from combustion, industrial chemical effluents, soil pollution from metal scrap accumulation, and pervasive acoustic pollution from high-density vehicular movement, sound systems, and artisanal metal-working units. Rapid industrial growth paired with informal urban expansion progressively worsens local acoustic degradation, creating continuous sound stress in mixed-use residential areas (Garg et al., 2020).

Etymologically derived from the Latin *nausea* (denoting unwanted or disturbing sound), noise pollution poses severe systemic risks to human health. Nobel laureate Robert Koch famously foretold that a day would come when humanity must combat noise as relentlessly as disease pathogens. In industrial environments, prolonged exposure to high sound pressure levels increases the risk of Noise-Induced Hearing Loss (NIHL) and systemic non-auditory complications. According to guidelines set by the National Institute for Occupational Safety and Health (NIOSH), daily occupational noise exposure should not exceed an 8-hour time-weighted average (TWA) of 85 dBA to prevent permanent hearing damage.

2. Literature Review

The systematic evaluation of acoustic environments and occupational noise exposure has been widely documented across diverse industrial and urban contexts.

2.1 Occupational Noise Exposure and Auditory Impact

The occupational risks associated with high noise exposure across heavy industries are well established. Wiley et al. (2015) conducted comprehensive workplace noise assessments in manufacturing environments, observing that ambient noise levels regularly exceeded safe occupational exposure limits. They highlighted the critical necessity of combining engineering controls with personal protective equipment (PPE) programs to mitigate hearing loss risk. Similarly, Sun and Azman (2018) analyzed Mine Safety and Health Administration (MSHA) safety records to assess the long-term effectiveness of hearing conservation programs, emphasizing that structural noise reduction measures are vastly superior to administrative controls alone.

In textile manufacturing, Roozbahani et al. (2009) evaluated acoustic exposure profiles among workers exposed to continuous machinery noise. Their risk analysis confirmed a direct correlation between duration of exposure, sound pressure level, and the incidence rate of occupational hearing impairment.

2.2 Non-Auditory and Physiological Consequences

Beyond auditory system degradation, acoustic stress triggers severe systemic non-auditory health complications. Ali (2011) evaluated noise-induced disturbance among 683 industrial personnel across 15 distinct manufacturing sites, documenting significant cognitive fatigue, psychological stress, and reduced operational efficiency. In a 3-year longitudinal study tracking 191 male industrial

operators across three manufacturing facilities, Nserat et al. (2017) demonstrated a statistically significant association between chronic exposure to elevated occupational noise and clinical hypertension (elevated blood pressure).

2.3 Identification of Research Gap

While extensive literature addresses noise pollution in heavy manufacturing sectors such as mining, textiles, and large-scale engineering plants, there is a notable scarcity of empirical acoustical mapping focusing on informal, highly dense, artisanal metalcraft clusters like those found in Moradabad. Most existing regional studies lack spatially mapped noise contours across mixed-use zones (where residential and small-scale brass workshops overlap). This research project addresses this critical gap by providing comprehensive spatial noise profiling across Residential, Commercial, Industrial, and Silent zones in Moradabad City.

3. Materials and Methods

3.1 Study Location and Zonal Categorization

The field monitoring program was established across four designated functional land-use zones—Residential, Commercial, Industrial, and Silent Zones—within Moradabad City. Monitoring locations were strategically selected to capture representative spatial sound profiles and account for variations in land-use activity, traffic movement, and localized industrial operations:

- Industrial Zone: Selected within high-density artisanal brass clusters (*Peetal Nagri*) and metal-working workshops characterized by continuous machinery operation, power press usage, and heavy vehicular loading.
- Commercial Zone: Stationed along major market corridors and transit hubs exhibiting high pedestrian density, active commercial trading, and frequent stop-and-go vehicular traffic.
- Residential Zone: Located within urban housing developments and residential neighborhoods to measure localized acoustic stress stemming from surrounding urban traffic and domestic activities.
- Silent Zone: Positioned in sensitive areas adjacent to major healthcare facilities and educational institutions to evaluate compliance with strict quiet-zone acoustic limits.

3.2 Acoustic Instrumentation and Calibration

Sound Pressure Level (SPL) measurements were recorded using a pre-calibrated digital Sound Level Meter (SLM Class/Type 1 conforming to IEC 61672-1 standards) set to the A-weighting frequency network (dB(A)) to emulate human ear response. Fast response time weighting (125 ms) was selected to capture rapid fluctuations in ambient noise. Field calibration was performed using a standard acoustic calibrator (94dB at 1kHz) before and after each sampling session to maintain instrumentation fidelity.

3.3 Data Acquisition Protocol and Sampling Schedule

Field measurements were carried out in May over predefined operational shifts covering daytime (6:00 to 22:00hrs) and nighttime (22:00 to 06:00 hrs) regimes.

- **Monitoring Frequency:** Acoustic data were sampled across seven distinct daily time slots (five daytime sessions and two nighttime sessions).
- **Sampling Interval:** At each selected location during a 10-minute sampling window, 20 instantaneous SPL readings were recorded at regular 30-second intervals.
- **Microphone Positioning:** In accordance with standard ambient monitoring guidelines, the sound level meter microphone was mounted on a tripod at a standard height of 1.5 m above ground level, maintained at a distance of at least 1.0 m away from the operator's body, and

positioned ≥ 3.5 m away from sound-reflecting vertical structures to minimize acoustic diffraction.

3.4 Computation of Acoustic Parameters

For each sampling site and time window, the minimum (SPL_{min}) and maximum (SPL_{max}) sound pressure levels were recorded. The Equivalent Continuous Sound Level (L_{eq}), which represents the energy-averaged A-weighted sound level over a specified time period, was computed using the following equation:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{N} \sum_{i=1}^{N} 10^{\frac{L_i}{10}} \right]$$

Where:

- N is the total number of sound level observations recorded (N = 20).
- L_i represents the individual A-weighted sound pressure level reading at the i-th sample interval.

3.5 Comparative Analysis Against Statutory Standards

The evaluated equivalent noise levels (L_{eq}) across the four functional zones were compared against the permissible ambient noise thresholds prescribed under Schedule III of the Environment (Protection) Rules, 1986 and CPCB Ambient Noise Standards:

Zone Category	Daytime Limit (06:00–22:00 hrs)	Nighttime Limit (22:00–06:00 hrs)
Industrial Zone	75 dB(A)	70 dB(A)
Commercial Zone	65 dB(A)	55 dB(A)
Residential Zone	55 dB(A)	45 dB(A)
Silent Zone	50 dB(A)	40 dB(A)

(Note: Data collected were compiled into baseline noise tables [Tables 2 and 3] to evaluate spatial variations, peak exposure levels, and statutory compliance ratios across Moradabad).

4. Results and Discussion

4.1 Assessment of Ambient Sound Levels Across Zonal Categories

The acoustic monitoring executed across four designated land-use zones in Moradabad City revealed significant spatial and temporal variations in Equivalent Continuous Sound Levels (Leq). The empirical findings, including minimum (SPLmin), maximum (SPLmax), and calculated daytime and nighttime Leq values, are summarized alongside Central Pollution Control Board (CPCB) statutory limits in **Table 1**.

Table 1: Ambient Noise Levels Across Functional Zones in Moradabad City

Monitoring Zone Category	Representative Sampling Locations	Recorded SPLmin dB(A)	Recorded SPLmax dB(A)	Daytime Leq dB(A)	CPCB Daytime Limit dB(A)	Nighttime Leq dB(A)	CPCB Nighttime Limit dB(A)
Industrial Zone	Peetal Nagri Industrial Area / Metal Workshops	64.2	94.8	**82.4**	75.0	**73.1**	70.0
Commercial Zone	Brass Market / Bus Stand Corridor	58.5	88.2	**74.6**	65.0	**62.8**	55.0

Residential Zone	Civil Lines / Urban Housing Clusters	46.1	72.4	**61.3**	55.0	**51.2**	45.0
Silent Zone	District Hospital / School Precincts	42.0	68.5	**57.8**	50.0	**46.5**	40.0

4.2 Spatial and Sectoral Evaluation

4.2.1 Industrial Zone (Peetal Nagri Industrial Pocket)

In the industrial sector, daytime Leq reached 82.4 dB(A), exceeding the CPCB statutory limit of 75 dB(A) by 7.4 dB(A). Peak sound levels reached SPLmax=94.8 dB(A). The elevated noise regime is primarily driven by small-scale artisanal brass manufacturing, heavy-duty metal casting, mechanical buffing, power presses, and diesel generators. Because many small workshops operate within open-front or poorly insulated structures, acoustic energy spills directly into adjacent thoroughfares.

4.2.2 Commercial Zone (Market and Transit Hubs)

Commercial zones recorded a daytime Leq of 74.6 dB(A), exceeding the CPCB threshold (65 dB(A)) by 9.6 dB(A). The dominant noise vectors in these sectors include concentrated vehicular traffic, frequent horn honking, open-air public address systems, and loading/unloading activities associated with the export of brass products.

4.2.3 Residential and Silent Zones

- **Residential Zones:** Recorded a daytime Leq of 61.3 dB(A) and a nighttime Leq of 51.2 dB(A), exceeding permissible limits by 6.3 dB(A) and 6.2 dB(A) respectively. This pattern reflects mixed-use urban development, where small home-based brass workshops operate inside residential neighborhoods.
- **Silent Zones:** Areas near educational institutes and hospitals recorded a daytime Leq of 57.8 dB(A) against the strict 50 dB(A) limit. Ambient noise in these zones stems from vehicular transit on adjoining arterial roads and a lack of vegetative acoustic buffers.

4.3 Evaluation of Compliance and Statutory Deviations

To quantify the extent of noise pollution across Moradabad City, the statutory compliance ratio and percentage exceedance over CPCB guidelines were calculated as shown in Table 2.

Table 2: Exceedance Analysis Against CPCB Ambient Noise Standards

Zone Category	Daytime Deviation (dB(A))	Daytime Exceedance (%)	Nighttime Deviation (dB(A))	Nighttime Exceedance (%)	Statutory Status
Industrial	+7.4	+9.87%	+3.1	+4.43%	Non-Compliant
Commercial	+9.6	+14.77%	+7.8	+14.18%	Non-Compliant
Residential	+6.3	+11.45%	+6.2	+13.78%	Non-Compliant
Silent	+7.8	+15.60%	+6.5	+16.25%	Non-Compliant

The data demonstrate that 100% of the monitored functional zones in Moradabad exceed statutory acoustic limits during both daytime and nighttime periods.

4.4 Comparative Discussion with Past Scientific Literature

The empirical results obtained in this study align closely with previous findings regarding urban-industrial acoustic environments:

1. **Comparison with Occupational Health Baselines:** The peak noise levels observed in Moradabad's brass clusters (SPLmax=94.8 dB(A)) consistently exceed the NIOSH 8-hour time-weighted threshold of 85 dB(A). This elevated exposure pattern mirrors the observations of Wiley et al. (2015) and Roozbahani et al. (2009), who noted that unregulated mechanical operations without protective gear significantly heighten the incidence rate of Noise-Induced Hearing Loss (NIHL).
2. **Systemic Health Consequences:** Long-term exposure to Leq>70 dB(A) in industrial corridors poses systemic non-auditory risks. Longitudinal studies by Nserat et al. (2017) and cross-sectional evaluations by Ali (2011) confirm that chronic exposure to noise regimes in this range correlates with elevated blood pressure, psychological fatigue, and cardiovascular stress.
3. **The Mixed-Use Planning Deficit:** Unlike structured industrial parks in larger metropolitan cities, Moradabad presents an overlapping mixed-use urban architecture. The integration of artisanal brass workshops within residential zones explains the high noise levels in residential areas (61.3 dB(A) daytime), highlighting the need for localized spatial mapping and biological vegetative barriers (Aylor, 1972; Van Renterghem et al., 2012).

5. Conclusion and Recommendations

5.1 Conclusion

This empirical case study evaluated the spatial distribution and severity of noise pollution across the distinct functional zones of Moradabad City. The synthesis of field-monitored acoustic metrics leads to the following key conclusions:

1. **Systemic Exceedance of Statutory Limits:** Ambient Equivalent Continuous Sound Levels (Leq) across all four designated functional zones (Industrial, Commercial, Residential, and Silent) systematically exceeded the statutory limits prescribed under Schedule III of the Environment (Protection) Rules, 1986 and CPCB guidelines.
2. **Industrial and Commercial Vulnerability:** Industrial sectors (notably the Peetal Nagri artisanal clusters) and commercial transit corridors bear the most acute acoustic burden. Continuous exposure to Leq>80 dB(A) and peak sound pressure levels reaching up to 94.8 dB(A) presents severe occupational health hazards to informal brass craft workers.
3. **Impact of Unplanned Mixed-Use Zoning:** Residential and silent zones recorded significant noise exceedance (+11.45% and +15.60% above daytime CPCB norms, respectively). This is largely attributable to Moradabad's historical urban layout, where home-based brass handicraft workshops directly interface with residential neighborhoods without buffer zones.
4. **Public Health Implications:** The observed sound pressure levels exceed international safety baselines established by NIOSH and WHO, placing industrial operators and residents at heightened risk for both auditory degradation (e.g., Noise-Induced Hearing Loss) and non-auditory physiological ailments such as hypertension, sleep disturbance, and cognitive fatigue.

5.2 Recommendations for Noise Mitigation

To address the elevated acoustic stress in Moradabad, a multi-tiered noise abatement framework combining engineering controls, urban planning, and biological buffers is recommended:

- **Zoning and Structural Relocation:** Phased relocation or structural isolation of high-noise brass workshops (e.g., heavy power presses and mechanical buffing units) from dense mixed-use residential areas into dedicated, acoustically insulated industrial estates.
- **Engineering and Acoustic Retrofitting:** Implementation of low-cost acoustic enclosures, vibration-damping mounts, and sound-absorbing baffles around noisy machinery within

small-scale workshops, accompanied by mandatory distribution and enforcement of Personal Protective Equipment (PPE) such as earplugs and earmuffs.

- **Vegetative Bio-Shields:** Strategic planting of multi-canopy green belts using high acoustic absorption tree and hedge species (*e.g., Photinia × fraseri, Nerium oleander, Viburnum odoratissimum, Cedrus deodara*) along major arterial roadways, market borders, and around silent zones (hospitals and educational institutions).
- **Traffic and Administrative Management:** Designation of strict "No-Honking Zones" near sensitive receivers (hospitals, schools) and traffic rerouting during peak hours to reduce transit-generated noise spikes.
- **Continuous Monitoring and Public Awareness:** Establishing real-time digital noise monitoring displays across key public intersections in Moradabad to raise civic awareness and ensure statutory compliance by localized industrial operators.

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