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Geospatial Mapping of Construction Noise in High-Density Residential Areas

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***Abstract*—**Redevelopment in a high-density urban area can contribute to increased noise which might disrupt residents' health and wellbeing, but there is limited spatially-resolved assessment of construction noise. This study uses geospatial mapping methods and systematic field measurements to assess the auditory impact of ongoing redevelopment in a densely populated neighborhood in Mumbai, India. Based on satellite imagery, we selected sixteen measurement points surrounding major redeveloping neighborhood buildings and plotted their precise longitude – latitude coordinates. Ambient A-weighted sound levels were recorded at each location multiple times within multiple distances (≤ 100 m, 100–200 m, 200–300 m, > 300 m), and at different orientations (morning, afternoon, evening) to index the time and directional paths of concrete noise. We used geographic information system (GIS) methods to interpolate results and create high-resolution maps of sound impact zones (low ≤ 75 dB, moderate 76–85 dB, high 86–90 dB, and critical > 90 dB sound impact). Collectively, noise maps from this study show that audible disturbances can extend up to 350 m downwind of redevelopment activity, and peak levels travel along narrow street corridors and between clusters of high-rise buildings. Density of buildings and orientation of streets were considered key modulating factors of noise diffusion. Based on the findings and recommendations, this study recommends the temporary or permanent placement of acoustic barriers to further mitigate noise, work schedules be adjusted to avoid peak times, and urban redevelopers to incorporate a buffer zone for noise which are evidence-based approaches to reduce residential disturbance and encourage sustainability in urban design.

***Keywords*—** *Geospatial mapping, construction noise, high-density residential, Mumbai, noise propagation, GIS, field measurements, spatial noise map, noise mitigation, urban planning.*

I INTRODUCTION

Urban redevelopment in high density residential areas can bring many benefits associated with modern infrastructure; however, it can also contribute to transient neighborhood noise, congestion, and disruptive noise resulting from construction. For example, while atmospheric pollutants always present in urban environments provide background noise, construction noise fluctuations are highly variable nowhere is that variability illustrated more abundantly than in construction activities such as pile driving, jack hammering, and sawing, with characteristics that can be discontinuous, impulsive, and explosive. Construction noise is more than an annoyance the physiological responses to construction noise can trigger stress. Experimental studies reporting construction noise and human responses have shown significant and pronounced changes in cardiovascular and respiratory function such as respiration rate, heart rate, and heart rate variability from construction noise, where jack hammer or saw noise will create more substantial responses than bulldozer construction noise described. Prolonged exposure to construction noise or higher levels of construction sound intensity will also elicit an increase in physiological responses to construction noise where studies shown greater physiological responses can be detected from construction noise within the first minute or when heightened serious distractions and delayed responses are subjectively alarming, within 30 seconds was common in studies [1]. While large-scale surveys typically report population exposure to traffic and industrial noise, construction noise remains underreported in official statistics, despite experimental evidence confirming its adverse health effects. Hence construction noise is more than a transient or impeding nuisance; it is a public health issue. When added to the background noise common in urban living with construction in close proximity, known health effects from urban dwellings obviously have heightened impacts, forfeiting quality of life and community health[1].

Conventional approaches to noise auditing do not adequately reflect the spatial complexity of urban sound environments, hindering adequate strategies to mitigate the priority of noise. The research presents a new and integrated land use regression model that aligns GIS technology with systematic noise measurements so that spatial variability can be mapped across urban landscapes. Geospatial analysis employs satellite imagery, vehicular flow data, building morphology, and additional data to produce highly accurate models of noise levels, even at locations that were not measured. The study concludes that operational geospatial noise mapping provides practitioners a key tool to identify noise vulnerable areas and enhance development patterns for reduced acoustic impact.[2].

Urban neighborhoods endure high levels of noise pollution while there are generally limited and unsustainable approaches available for noise mitigation that coordinate with existing urban fabric. This research examines the potential of different types of green spaces to mitigate sound through systematic spatial analysis of the separation and sound absorbing properties of vegetation. Using field work and modeling, they estimate the sound attenuation potential of various existing green space types, from linear parks to randomly distributed trees. Results show, under different models of noise propagation, that shifting sound paths of travelers with planned vegetation could reduce sound levels 4-8 dB in urban settings, providing urban planning professionals who may not have thought of vegetated buffering as feasible an alternative if not cheaper option to traditional sound barriers than offer beneficial environmental side effects along with noise reduction[3].

African cities that are growing rapidly are now facing a level of unprecedented noise pollution that is disassociated with any robust monitoring mechanism or evidence-based framework for managing the situation. This research develops geospatial models that are specifically tailored to the urbanization and socioeconomic contexts in African cities. This approach combines sound monitoring communities with a combination of satellite imagery to produce detailed noise maps that can represent traffic and informal sector sources. This study provides timely and relevant evidence to develop policy approaches that address noise-related exposure while being sensitive to specific urban dynamics and connected sociopolitical resource contexts as a strategy to enhance public well-being [4].

II LITERATURE REVIEW

Bhat et al. [5] illustrate a creative use of crowdsourced data and GIS technology to create dynamic urban noise maps that allow real-time acoustic condition monitoring. Through the integration of smartphone-based measurements with publicly available satellite imagery, this research indicates that cities can implement less expensive noise monitoring systems without a large infrastructure investment. The studies acknowledge that citizen science approaches can achieve a similar level of accuracy to professional monitoring equipment, but with a much larger extent of spatial and temporal coverage. While highlighting some useful approaches at a practical level for cities with few resources, the study also strengthens the case for democratizing environmental monitoring through technological innovation. While Bhat et al. study establishes the technical viability of smart noise mapping, their findings highlight some key limitations that impact the broader implementation and reliability of citizen science programs. They do not adequately address data quality control procedures or potential biases that may influence the accuracy and representativeness of noise maps from crowdsourced data. They also do not investigate privacy concerns, sustainability of community and participant engagement, or provide an examination of the implications of the digital divide on participation in citizen science programs. Bhat, et al. also acknowledge additional development should be applied in linking noise mapping data to the official regulatory framework and enforcement structure that means that implications of experiential knowledge and broader monitoring extends to noise management practices.

The study conducted by Ahuja et al.[6] provides thorough frameworks for incorporating noise into urban planning through multi-criteria appraisal and strategic zoning. They used case study research across various urban settings to show that incorporating noise consideration into planning can reduce post-construction costs for noise mitigation by 60% while also improving acoustical comfort for residents. The results offer evidence-based recommendations on noise-sensitive development control including buffer zones, land-use compatibility, and stages of construction timing. The research contributes to creating a policy basis for required noise impact assessments and provides rationale for more extensive noise management in urban planning contexts. Nonetheless, there are significant gaps in knowledge about both the challenges to implement this approach and its effectiveness in different urban governance contexts. The avowed study frameworks did not address requirements for institutional capacity, inter-agency coordination, or resource allocations to establish a full noise management and planning system. The study lacks consideration of stakeholder engagement strategies or mechanisms for conflict resolution when the noise planning relates to economic development. Longitudinal research that would provide insight on the sustainability of the strategic noise planning approach needs to be implemented to allow for modification and enhancement of urban development policy and norms.

The research conducted by Silva et al.[7] extensively examines traffic noise dispersion in urban corridors by utilizing updated two-dimensional mapping approaches, which elucidate the intricate and complex spatial relationships between roadway systems and acoustic consequences. With an extensive amount of field measurement and spatial interpolation modelling, the study illustrates how street designs, building arrangements, and traffic flows create noise exposure zones, which can change remarkably over short distances. Specifically, the research found that urban design changes decreased traffic noise exposure by 25-40 % with no major infrastructure investments. This study presents urban designers with measurable instruments to foster acoustically comfortable places and supports an evidence-based framework for noise-sensitive urban planning. While establishing defined relationships between urban forms and noise dispersion, several important areas still need further attention for nuanced noise management. The study does not investigate the contributions of different vehicle types, traffic management strategies, or emerging transport technology on noise patterns and impacts. The study also does not assess effects of seasonality, weather impacts, or other long-term changes in traffic patterns that affect exposure to noise over a time period. Finally, additional research is needed to examine traffic noise mapping with higher order urban environmental assessment methods or with multi-objective optimization to inform more holistic urban designs.

In Salame et al. The authors statistically assess the significant relationships among urban morphological characteristics and levels of traffic noise to provide the best building configurations and ability to provide some acoustic comfort. The authors show using specific urban measurements correlated with acoustic monitoring data, that height-to-width ratios of buildings have a significant impact on noise transference, and in some situations specific geometric relationships can produce reductions in noise of up to 12 dB. The results ultimately provide architects and urban planners with measurable guidelines to design a noise-sensitive, urban built fabric that considers acoustic comfort but also acknowledges the required urban density. Overall, the findings are the beginning of producing a scientific basis for design codes that are noise-sensitive to urban design and provide evidence that academic and evidence-based design considerations should be used to advocate for noise-sensitive conditions in building codes, zoning, and policies. Nevertheless, important limitations about generalizing the findings of these studies across multiple urban contexts and development conditions. In particular, the authors did not broadly discuss the ways varied architectural styles, materials, or facade typologies influenced the patterns of sound travelling through or reflecting from different urban contexts.

The author did not give any consideration of the economic feasibility and the costs associated with noise-optimized urban form, especially in a situation for retrofits or with limited resources. Conducting further research on combining noise with all urban design convergences of objectives such as energy efficiency, social interaction, and environmental sustainability will contribute to the generation of equally considered approaches to noise-sensitive, urban forms.

Cai et al. [9] presents evidence of significant progress in dynamic noise mapping with the integration of machine learning that provides the potential for real-time monitoring and active management of urban acoustic environments. The study shows how automated systems equipped with artificial developed intelligence algorithms and combined with acoustic propagation models will be used to continuously adapt noise maps with an acceptable degree of accuracy (90%), while providing cost savings of 70%. The implications of the study illustrate that AI-enhanced noise mapping provides city managers with fortuitous capabilities in responsive environmental management and real-time warning systems for noise pollution events. This study provides the technical basis for smart city noise management and advances the argument for investing in AI-centric environmental monitoring systems. While confirming the technical capabilities of machine learning approaches, there are some critical issues that will hinder immediate widespread use. The study inadequate and more detailed discussion on data security, privacy, and algorithmic transparency discuss public buy-in and regulatory acceptance of AI-based environmental monitoring systems were lacking. In addition to or complementary to these topics, there is room for comprehensive conversation into the types of training data, model generalizability, and maintenance requirements in applying these ML approaches to longer-term use. The inclusion of machine learning noise maps in existing urban management systems and decision-making processes would also require future consideration in the development cycle, to realize the full potential of enhancing urban acoustic environments.

The research conducted by Lan et al. [10] offers important insights on noise distribution patterns that are specific to the high-density urban setting that sometimes compromise conventional noise management techniques that are effective in quieter urban environments because of complex acoustic interactions. With extensive field measurements paired with spatial analysis that acknowledges urban-canyon effects and variations in the density of buildings, the investigation found evidence that, within the same city block, noise levels may differ more than 15 dB. This variance was due to geometric amplification effects. The research identifies key design factors that elevate noise issues in urban areas while providing data-driven recommendations that center on building orientation and traffic management. This research represents an initial step toward density-based, tailored noise management practices and informs the case for unique management regulations within high-density urban settings. However, challenges remain significantly under-explored, including a rich understanding of the various complexities at play within high-density noise environments and the need for different management strategies. This research does not fully address how differing types of high-density development patterns, through to high-rise areas used for residential purposes or mixed-use, commercial areas, create distinctive challenges related to noise and necessitate tailored solutions. Additionally, the research fails to offer detail on issues of social equity, in that, high density areas host vulnerable populations often with few, if any options to distance themselves from noise sources. Long-term study is necessary to assess the effectiveness of alternative noise mitigation measures tailored to high-density environments, extending knowledge regarding comprehensive urban planning measures.

Wu and Fang's (2015) study established evidencebased knowledge regarding noise reductions near major transportation infrastructure based on a comprehensive study of multiple intervention strategies such as barriers, vegetative buffers, and human modifications to building design. The researchers used field-testing and acoustic modeling in different environmental conditions to demonstrate combined mitigation strategies of barrier and vegetative buffer from 15 to 20 dB with additional environmental and aesthetic benefit. The researchers further mentioned cost-effectiveness in integrated mitigation strategies compared to single solutions, which appeared of particular benefit in urban contexts where space is limited for traditional solutions, such as barriers. This research contributes actionable knowledge for transportation planning and supports a case for mandatory noise mitigation in projects that require development of infrastructure. Although Wu and Fang are effective in demonstrating efficacy of multiple mitigation strategies, important knowledge gaps remain for learning potential for contextual considerations in noise control mitigation in multiple contexts. The study fails to sufficiently demonstrate that mitigation strategies for different transportation modes (e.g., highways, railways, and airports) can vary considerably based on the specialization in noise character and noise operations for mitigation strategies. Also, the research does not include a thorough analysis of the economic trade-offs between options for noise mitigation and construction costs, providing no practical value for project managers and developers. The effectiveness of long-term management options and the development of effective and practical management practices to parlay into and adapt to new technologies in construction requires a continual evaluation to remain relevant and effective.

The research conducted by Geng et al. [13] illustrates innovative computational approaches for assessing urban noise levels by connecting multiple data sources across different spatial scales (satellite imagery, socioeconomic proxies, and on-ground measurements) to predict noise across different urban contexts. Using machine learning techniques and remote sensing analysis, the study demonstrates that urban noise can be estimated in comprehensive ways using only a few data sources, even in contexts with limited noise data, with greater than 80% accurate predictions of noise levels in unmeasured urban locations. The study indicates that socioeconomic and urban morphology variables represented in satellite imagery provide accurate predictors of noise exposure patterns that enable mapping and visualizing noise in urban contexts. This work represents methodological advancements towards comprehensive urban environmental assessments, and robust arguments for including noise into urban monitoring and urban planning approaches. These findings demonstrate the technical feasibility of multi-scale urban noise estimation; however, there are important limitations around implementing across diverse urban areas, particularly in rapidly urbanizing contexts, or informal settlement contexts and how different urban development patterns (for example, in other geographic areas) impact the accuracy and transferability of the models used. Additionally, the study does not clearly demonstrate extensive validation across seasons, weather conditions, and measures of temporal patterning of urban noise that are important characteristics of urban noise making it even more representative of urban noise dynamics. The further development of multi-scale estimation approaches to integrate real-time monitoring systems and decision-support tools is necessary to convert knowledge-based research capabilities into operational urban management practice.

Evidence by Zhang et al. [14] identifies critical relationships between urban development types and resident noise exposure and comprehensive development pattern analysis and acoustic monitoring demonstrates significant variations in noise effects of urban forms. Combining statistical analysis of urban morphology data with noise measurements provides comparisons of the average noise exposure for compact mixed-use development (n = 160) and sprawling residential development (n = 158) and demonstrates that the average noise exposure was reduced by 30% for mixed use development while still maintaining urban functionality. The data provides urban planners with quantitative evidence to inform a noise sensitive development strategy while accounting for noise comfort, density, and accessibility needs. The research is a foundation for evidence-based zoning policies and provide support for arguments to incorporate noise geography into environmental planning in urban spaces. Nonetheless, significant knowledge gaps remain for understanding how the development pattern effects on noise exposure interface with sustainability and livability objectives. The research does not consider how noise-sensitive developed patterns maximize or minimize other environmental conditions in urban settings, such as air quality, urban heat, and accessibility to transportation, that can collectively enhance or detract from the residential quality of life. Also, the research misses the specific cost and market feasibility analysis of various noise-sensitive development strategies, which does not provide practical guidance for developers and policymakers. Longitudinal assessment of the different development patterns' effectiveness in enhancing acoustic comfort as cities alter and grow over time, particularly to support adaptive planning strategies, is also needed.

Aletta et al.[15] provide an important basis of understanding of urban soundscape approaches that consider issues beyond conventional noise descriptors to recognize the subjective, qualitative dimensions of our acoustic environments and the factors that relate to human-perception that are directly linked to our wellbeing and satisfaction with the soundscape in urban settings. Their analysis, conducted using acoustic measurements and perceptual surveys, concludes that sound quality, context, and cultural framings rank equally alongside sound levels in terms of acoustic comfort and annoyance responses. In their findings, Aletta et al. noted that a soundscape dimension would result in residents having upwards to 40% more acoustic satisfaction than a noise-only approach, thus providing further justification for more rigorous, and nuanced approaches to the management of urban environments. This research lays the conceptual groundwork for a more holistic form of urban acoustic management, while also advocating for the delivery of soundscape principles into the policies and planning of urban noise. Despite providing essential theoretical bases for the soundscape approach in practice, the transition from a conceptual understanding to a tool for practical urban management of sound remains very challenging. The study did not address the practicalities of how practitioners implement soundscape principles, the level of consistency in measurements and standards, or the implications of the resources required across the existing planning and regulatory system to consider soundscape principles. Lastly, we found that there was a lack of full analysis regarding cultural difference in responses to urban soundscape as well as demographic and socio-economic differences that could further warrant tailored approaches to soundscapes for different urban populations. The creation of operational assessments, design guidance, and policy instruments based on soundscape principles requires substantial further research to fulfill the promise of acoustic management for human benefit.

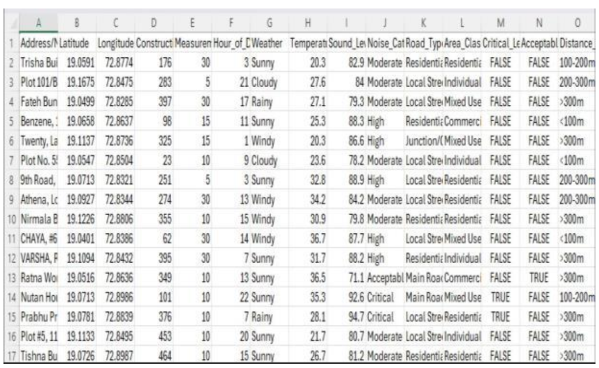
III METHODOLOGY

1. Data Collection

In order to assess the impact of construction noise on everyday life in the highly populated residential areas of Mumbai, a framework was developed for the systematic collection of field-based data.. The goal was to not only capture raw noise levels but to characterize how noise fluctuates with various places, times of day, and environmental conditions. In this way, the intention was to build a dataset that reflects the lived experience of communities existing side by side with construction activity. A group of diverse sites across the city was selected at the start of the study. Every site was identified by the actual address and GPS coordinates latitude and longitude so that the noise measurements could all be mapped and compared among neighborhoods later on. The locations were selected in a way that encompassed a variety of settings, including quiet residential streets, busy main roads, intersections with heavy traffic, and mixed residential commercial neighborhoods. The intention was to have a study that did not focus on only one type of neighborhood but rather to reflect the diversity of urban life in Mumbai. At three different times of day morning, afternoon, and evening, we also took measurements of noise to capture different time-of-day variations.

The time of day was recorded under Hour of Day. The dataset also included records of weather sunny, cloudy, rainy, or windy and the temperature at the time of measurement, which can have an effect on how sound travels and how people perceive it. At each location, calibrated sound level meters were used to document judging real sound levels in decibels (dB). To make the number easier to track for purposes of identifying exposure levels, we later categorized them as Acceptable, Moderate, High, and Critical with regard to crossing designated, official noise levels. The Dataset also registered if it was "acceptable" or "critical" as an easy true/false flag to track which sites were most affected. Recognizing that distance from the source of the noise contributes heavily to its loudness, The Dataset also records of the distance from the construction area to each measurement point by creating categories like, "within 100 meters," "100-200 meters," "200-300 meters," and "over 300 meters." Other useful contexts, like type of road e.g. residential lane, main road, junction, etc. and type of

area e.g individual housing, commercial, mixed-use, residential complex, etc. was also documented. All of this context served to provide a fuller picture of how loud the noise was but also where, when, and under what other conditions the noise was experienced. By undertaking consistent procedures at all areas e.g. calibrating equipment, obtaining measurements at the same time, same interval, and recording the same contextual details for measurements, This approach ensured that the data was consistent and comparable across areas. This approach allowed us to expand from basic readings of noise, and establish a dataset that captures the realities of complex urban environments. Crucially, the framework was developed to facilitate future replication in Mumbai for long-term tracking, or indeed in other cities facing similar challenges. This means the project will yield not just learnings from the present, but will also serve as a basis for further monitoring and enhanced planning around urban construction noise in the future. Shown in Fig.1.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Address/N	Latitude	Longitude	Construct	Measuren	Hour_of_D	Weather	Temperat	Sound_Le	Noise_Cat	Road_Typ	Area_Clas	Critical_Le	Acceptabl	Distance_
2	Trisha Bui	19.0591	72.8774	176	30	3	Sunny	20.3	82.9	Moderate	Residenti	Residenti	FALSE	FALSE	100-200m
3	Plot 101/B	19.1675	72.8475	283	5	21	Cloudy	27.6	84	Moderate	Local Stre	Individual	FALSE	FALSE	200-300m
4	Fateh Bun	19.0499	72.8285	397	30	17	Rainy	27.1	79.3	Moderate	Local Stre	Mixed Use	FALSE	FALSE	>300m
5	Benzene, :	19.0658	72.8637	98	15	11	Sunny	25.3	88.3	High	Residenti	Commerci	FALSE	FALSE	<100m
6	Twenty, La	19.1137	72.8736	325	15	1	Windy	20.3	86.6	High	Junction/(	Mixed Use	FALSE	FALSE	>300m
7	Plot No. 5!	19.0547	72.8504	23	10	9	Cloudy	23.6	78.2	Moderate	Local Stre	Individual	FALSE	FALSE	<100m
8	9th Road,	19.0713	72.8321	251	5	3	Sunny	32.8	88.9	High	Local Stre	Residenti	FALSE	FALSE	200-300m
9	Athena, Lc	19.0927	72.8344	274	30	13	Windy	34.2	84.2	Moderate	Local Stre	Residenti	FALSE	FALSE	200-300m
10	Nirmala B	19.1226	72.8806	355	10	15	Windy	30.9	79.8	Moderate	Residenti	Residenti	FALSE	FALSE	>300m
11	CHAYA, #6	19.0401	72.8386	62	30	14	Windy	36.7	87.7	High	Local Stre	Mixed Use	FALSE	FALSE	<100m
12	VARSHA, F	19.1094	72.8432	395	30	7	Sunny	31.7	88.2	High	Residenti	Individual	FALSE	FALSE	>300m
13	Ratna Wo	19.0516	72.8636	349	10	13	Sunny	36.5	71.1	Acceptabl	Main Roa	Commerci	FALSE	TRUE	>300m
14	Nutan Ho	19.0713	72.8986	101	10	22	Sunny	35.3	92.6	Critical	Main Roa	Mixed Use	TRUE	FALSE	100-200m
15	Prabhu Pr	19.0781	72.8839	376	10	7	Rainy	28.1	94.7	Critical	Local Stre	Residenti	TRUE	FALSE	>300m
16	Plot #5, 11	19.1133	72.8495	453	10	20	Sunny	21.7	80.7	Moderate	Local Stre	Individual	FALSE	FALSE	>300m
17	Tishna Bu	19.0726	72.8987	464	10	15	Sunny	26.7	81.2	Moderate	Residenti	Residenti	FALSE	FALSE	>300m

Fig. 1: Dataset Structure

2. Site selection and sampling design

To represent the varied soundscape of Mumbai, sixteen measurement sites across the city were selected. The selection process involved reviewing satellite imagery, municipal zoning plans and urban development maps to ensure the selected sites were representative of different land use types across the city.

The selected sites offered a variety of contexts, including:

- Residential complexes similar to typical housing clusters.
- Mixed-use neighborhoods in which residential, commercial and office properties cohabitate.
- Industrial plots adjacent to active construction corridors.
- Commercial districts with high levels of pedestrian activity and vehicular traffic.

Each site was assigned specific GPS coordinates latitude and longitude for accurate spatial mapping of noise patterns. To strengthen the representativeness of the sampling, sites were also selected in relation to different road types i.e. residential lanes, local streets, busy junctions, chowks and major arterial routes and urban area types.

3. Noise Measurement Protocol

Noise monitoring was conducted using digital sound level meters that were portable, properly calibrated, and appropriate to international standards (IEC 61672-1) to capture identical data with measurable accuracy reproducibility across each data record. At every sampled site, observation was performed, related to time three times per day morning, afternoons, and nights so as to account for natural variation in construction worker activity and the correlative noise generated by these activities. The protocol allows monitored environmental noise intently, as it was supposed to address multiple characteristics of exposure to noise. A-weighted sound pressure levels (dB (A)) were the preferred metric as they closely resemble human perception of noise. In order to examine the reduction in noise to increasing distance from the construction noise source, noise readings were documented within four categories of distance limits ranging from 100 meters, 100-200 meters, 200-300 miles, etc. Noise is often additionally transduced non-uniformly or exhibits directional trajectories in travel based on barriers, openings, or surfaces that sound. The team accounted for distance and transudative non-uniformity by offering multiple directional observations related to building approaches surrounding the site. The protocol further expanded beyond just noise reading documentation, to intricacies of the environment, to aid in estimating noise propagation in its entirety. Environmental context included documentation of the weather at the times the actual sound readings were made sunny, cloudy, rainy, or windy, it documented an ambient temperature too. Lastly, the protocol accounted for what the neighboring land-uses were high-rise buildings, fields, or mixed-uses for instance. These contextual factors also helped strengthen a clearer understanding of differences in recorded outcomes. For reliability with respect to quality control assurance, all field sessions were conducted after verifying all meters were calibrated. Then, the meters were then routinely measured at the same predetermined intervals at each of the sites to reduce bias and increase comparability. Collectively, these procedures ensured the measurements outcomes were both rigorous, and representative of the contingencies and complexities of a construction site in an active urban setting.

4. Data Processing and Structuring

Raw sound level data from each location were aggregated into a defined dataset. Multiple readings per site were averaged to lessen temporal and situational variability, which produced average sound readings for each site. The dataset contains these variables:

- **Centralized Data Aggregation:** All raw sound level data were assimilated from each monitoring site into a centralized dataset.
- **Noise Level Mitigation:** Averaged multiple samples per site to minimize short-term variability.
- **Record Maximum Decibel Levels:** Recorded maximum sound levels so that maximum noise exposures could be established at the sites.
- **Spatial Specificity:** Logged GPS coordinates (latitude and longitude) for each site for mapping and geospatial research.
- **Acoustic Metrics:** Average and maximum sound levels (dB(A)) were obtained as the primary metrics of construction noise.
- **Distance-Based Categorization:** Noise levels classified by distance from construction site (≤ 100 m, 100–200 m, 200–300 m, > 300 m) to investigate attenuation.
- **Transportation and Land-Use Context:** Roadway type identified (i.e., arterial, collector or local) and area designation (i.e., residential, mixed-use, industrial, commercial) to examine urban variability.
- **Environmental Context:** Weather attributes were recorded (sunny, cloudy, rainy, windy), along with contextual area descriptors, to examine external influences on noise propagation.
- **Time:** Each measurement was given a period indication for each morning, afternoon, and evening to normalize differences in construction activity for each day.
- **Analytical Structure:** The final dataset was used for both descriptive analysis (patterns, hotspots, comparisons) and more advanced statistical modeling.

5. Analytical Dashboard Development

To convert raw noise data into actionable knowledge, and embody analysis in an accessible way, we built an interactive analytical dashboard using Python and the Streamlit framework. The dashboard was intended as a research tool and as a policysupport method to visualize construction noise for spatial, temporal, and context-based exploration. The dashboard had two major components:

- **Interactive Spatial Mapping Module:** A geospatial interface where each monitoring station was plotted based on the GPS coordinates. Noise levels were represented using color-coded markers to allow for immediate recognition of the level of exposure.
- Four exposure categories were devised to assist with interpreting noise levels, as follows:

– Acceptable (≤ 75 dB) meeting environmental standards.

– Moderate (76–85 dB) which can be annoying, but acceptable.

– High (86–90 dB) associated with health risks regarding exposure time.

– Critical (>90 dB) where mitigation action is urgent.

Users in this module could zoom into any area of interest locally or visualize construction noise levels across the whole city.

- **Distance Analysis Module:** Provided scatter plots and associated trend lines to provide an indication of the association between distance and amplitude level. An interactive feature in this module allowed users to filter distance bands (≤ 100 m, 100–200 m, 200–300 m, > 300 m). Summarized statistical data also indicated the degree of attenuation at different distances which could be used for practical purposes in determining proposed buffer zones. This module counted which land-use districts carried the most noise burden, which will help inform mitigation efforts.

- **Weather and Time of Day Analysis:** Integrated meteorological data to investigate how sun, rain, wind, or cloud cover modified noise dispersion. Timestamped data morning, afternoon, evening allowed users to capture daily peaks and off-peak trends, representing actual construction timetables and exposure risks to humans.
- **Raw Data Access and Export:** Delivered an open-data option for users to download the designed dataset csv, excel. This promotes transparency in the tool and allows policymakers, researchers, and urban planners the ability to do their own statistical modeling or simulations in addition to the dashboard. Shown in Fig.4.

6. Statistical and Geospatial Analysis Framework

The research used a description and inference statistical framework to systematically evaluate patterns of exposure to construction noise. Average sound levels were computed to provide representative indicators for each site. Peak sound levels were also measured to illustrate moments of maximum exposure. These measures were then evaluated against national noise standards such as the Central Pollution Control Board (CPCB) guidelines and international noise benchmarks such as recommendations from the World Health Organization (WHO) to assess compliance and identify exceedances. Risk categorization was then performed by classifying readings into categories based on thresholds acceptable, moderate, high, and critical. This approach also provided a means to translate numerical findings into valuable indicators of community impact.

To extend the analysis beyond isolated measures, geospatial interpolation methods were employed, specifically inverse distance weighting (IDW) to create continuous noise surface maps to allow for visualizing intensity gradients within the boundaries of our study. This technique assessed community risk at both the localized hot spots of excess noise, as well as cumulative exposure throughout the geographic area. Applying spatial analysis provided a broader context of how noise due to construction is manifesting both through different urban morphologies and how it matters to the neighborhood and then the impact in the larger city.

The methodology described in this research was created with scalability as principal objectives. By melding standardized field measurement methods with statistical testing, geospatial modeling, and visualization methods, the framework provides a formal, systematic, transparent process for assessing urban noise. As a systematic process, it can be replicated in other high-density urban centers as a mechanism for long-term monitoring, cross-city comparisons, and policy-related applications. For urban planners and policymakers, the framework provides an evidence-based decision support tool for evaluating the impacts of construction noise, developing regulations around it, and prioritizing mitigation solutions. For researchers, it offers a methodological template that encompasses rigor but is flexible enough to be used in varying urban contexts. In addition to providing a characterization of the current state of construction noise in Mumbai, the framework creates mechanisms for scalable

strategies for long-term monitoring, informed planning, and advancing healthier and more sustainable urban contexts.

IV RESULTS

The study of construction noise at the sixteen selected sites in Mumbai indicated clear spatial and temporal trends. The average noise levels ranged from a low of 71 dB in residential clusters to a high of 93 dB in industrial areas next to busy construction corridors. The peak levels were consistently during the afternoon (12:00–16:00), which aligned with periods of increased construction activity. Shown in Below Fig.2.

The geospatial mapping of maximum noise levels through inverse distance weighting (IDW) identified significant levels of noise around industrial plots and major traffic junctions. Measurements obtained at 100 meters past the construction activity clearly identified levels above the national noise standard of 75 dB, and sites located 200–300 meters past the construction activity indicated a moderate level of noise.

Fig. 2: Map Legend

Recording sites beyond 300 meters indicated sound levels that remained mostly within a range of acceptable levels. Shown in Below Fig.3.

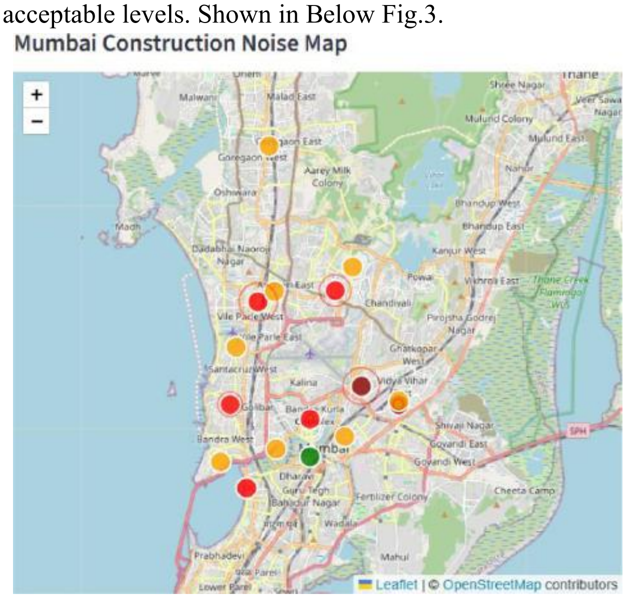


Fig. 3: Dashboard for Mumbai Construction Sites

When the area types were reviewed and assessed, mixed-use zones experienced changing noise levels due to both commercial and construction activity while noise levels in pure residential areas were lower and showed less variation. When a road type analysis was conducted, it demonstrated that noise levels were highest near main roads and junctions and comparatively lower in residential and local lane settings. Shown in Below Fig.4, 5.

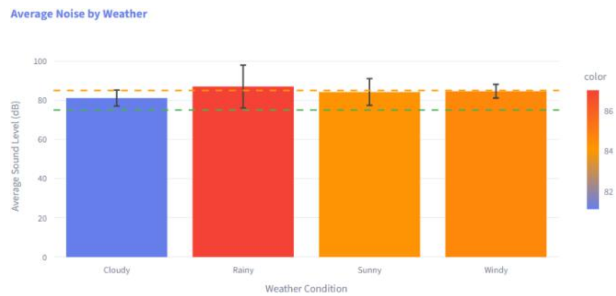


Fig. 4: Analysis of Noise Level in Mumbai Based on Road Type

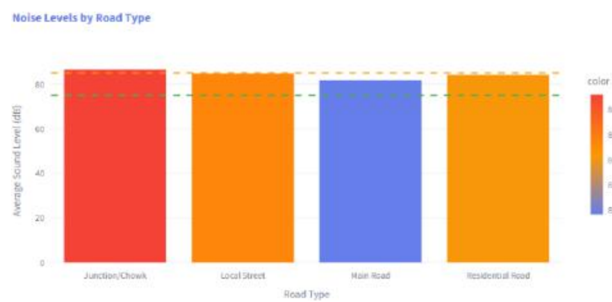


Fig. 5: Analysis of Noise Level in Mumbai Based on Area Type

When a weather and time analysis was done, the weather factors, such as wind and rain, indicated an observable, yet limited effect on the noise levels redirecting or absorbing the sound through time, with the conditions of being sunny and calm slightly increasing the decibel level. When measured using multiple directions, observations confirmed that at times noise would disperse anisotropically, where higher readings were along open corridors and lower readings were in areas shielded by buildings. Shown in Below Fig.6, 7.

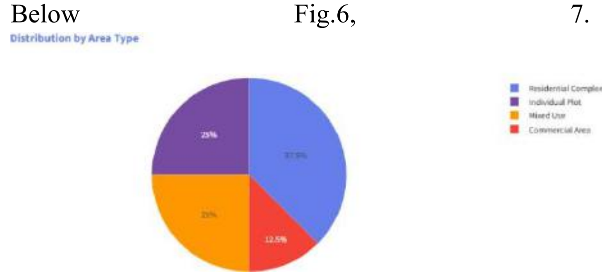


Fig. 6: Analysis of Noise Level in Mumbai Based on Weather

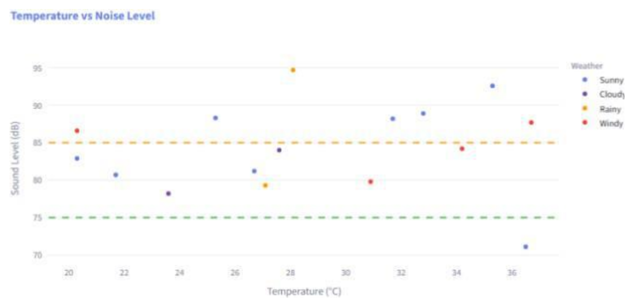


Fig. 7: Analysis of Noise Level in Mumbai Based on Temperature vs Noise Level

V CONCLUSION

An analysis of construction noise across sixteen sites in Mumbai indicates a relationship between urban typology, construction activity proximity, and noise exposure. Overall average and peak sound measurements suggest that neighborhoods experience moderate noise, and mixed-use and industrial zones in proximity to construction corridors experience high to critical noise levels. Geospatial analysis using IDW models identifies noise hot spots near industrial and major traffic junctions and shows the influence of urban typology and road hierarchy on noise propagation. Hourly averages show that noise levels peak in the afternoon during construction activities, and weather-related variables have limited effects on noise propagation. Multi-directional measurements show that structural shielding effects, along with open corridors impact noise dispersion. The research offers a characterization of urban construction noise to support mitigation management and urban planning.

Future Scopes

- **Expanded Monitoring:** Site selection in more areas of Mumbai and additional noise measurements would allow for more robust spatial coverage and communication of noise models throughout the City.
- **Longitudinal Monitoring:** Continuous, persistent monitoring will enable the identification of seasonal trends and construction phase trends and could lead to appropriate predictive modeling of those trends.
- **Mitigation Strategy Evaluation:** When assessing noise reduction strategies (for example, acoustic barrier, scheduling of construction projects, and management of traffic) an evaluation would assist planning the mitigation strategy.
- **Health Assessment:** Noise exposure data could be connected with health indicators that quantify the impact construction noise has on health, sleep, productivity, etc., for residents of affected regions.
- **Collaboration with Smart City Initiatives:** The suggested project of a real-time dashboard for noise, and integrated with the urban planning platform, would help to manage noise in a more responsive and proactive method and provide the basis for better policies.
- **Machine Learning Uses:** AI and ML can be used to predict noise propagation depending upon the urban fabric (morphology), types of construction, features of traffic, etc. and to also inform future planning and mitigation.

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