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High-Resolution Spatial-Temporal Mapping of Urban Noise Pollution in Chennai Using Mobile Sensing and GIS: A Ward-Level Public Health Assessment

(Occupational Noise and Mental Health)

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KEYWORDS

Decibels, Environmental Noise Pollution, NIOSH, Spatial, Temporal variation

ABSTRACT:

Background:

Noise pollution is a growing public health issue in urban India, contributing to cardiovascular diseases, cognitive decline, and psychological stress. Despite its serious health implications, environmental noise remains poorly monitored in Indian cities. This study focuses on mapping ambient noise exposure at the ward level in Chennai, Tamil Nadu, to identify hotspots and aid in urban noise management.

Methods:

A cross-sectional study was conducted across all 200 wards of Chennai. Ambient noise levels were measured using the NIOSH Sound Level Meter mobile app at three time intervals—morning, noon, and evening. For each ward, three readings per time slot were averaged. Spatial analysis and mapping were performed using QGIS, with spatial autocorrelation assessed via GeoDa.

Results:

Noise levels varied by time and location, with higher exposure observed in mornings and mid-days in dense residential and commercial zones. Evenings showed persistently high noise levels citywide. Wards such as Manali, Tondiarpet, and Sholinganallur consistently exceeded 85 dB, while peripheral wards remained relatively quiet. Spatial clustering revealed noise hotspots in northern and central Chennai.

Conclusion:

Ward-level noise mapping provides actionable data for targeted interventions. Combining mobile-based monitoring with spatial tools offers a scalable, cost-effective model for environmental noise assessment across Indian cities.

INTRODUCTION

Noise pollution is now widely perceived to be a major environmental and public health concern in urban settings worldwide. In India, where urbanization and motorization are sweeping across cities at a fast pace, noise has become a widespread and ill-controlled pollutant. Chennai, the state capital of Tamil Nadu, is one of the loudest cities in India, with average ambient noise levels often well above the permissible standards laid down by the Central Pollution Control Board (CPCB) [1]. Significant contributors are heavy traffic density, industrial areas, building activity, and uncontrolled commercial areas. Long-term exposure to high levels of noise is associated with a broad range of negative health consequences. These range from hearing loss, cardiovascular strain, sleep disruption, cognitive impairment in children, and psychological strain [2,3]. The World Health Organization (WHO) ranks environmental noise as one of the most important environmental threats to physical and mental health in city dwellers [4]. Chennai is governed into 15 zones and 200 wards that each comprise a heterogeneous mix of residential, commercial, industrial, and institutional land uses. This diversity leads to significant spatial heterogeneity in exposure to environmental noise. It is important to identify and comprehend this heterogeneity in order to be able to control noise pollution. Spatial analytical techniques like Geographic Information System (GIS)-based mapping and Local Indicators of Spatial Association (LISA) allow researchers to identify spatial clusters or "hotspots" and "cold spots" of noise pollution within urban geographies [5]. Also, temporal change in noise levels usually between different times of the day (morning, noon, and evening) offers additional insight into human activity patterns' influence. In Chennai, existing studies have reported highest levels of noise at rush hours and near arterial roads, markets, and construction sites [6]. The NIOSH Sound Level Meter (SLM) application, created by the National Institute for Occupational Safety and Health (NIOSH), offers a solid, smartphone solution for gathering sound information. The app is ANSI/ASA S1.4-2014/Part 1 Class 2 compliant and has shown accuracy within ±2 dBA across several validation studies [7]. Its portability and accuracy make it a perfect candidate for large-scale, real-time environmental noise surveys, particularly in resource-poor settings [8]. This research seeks to incorporate ward-level noise measurements obtained using the NIOSH SLM app with spatial analysis methods to map out high- and low-noise areas in Chennai. By collecting data at three different time periods—morning (8:00–11:00AM), noon (12:00–2:00PM), and night (6:00–9:00PM) this study not just emphasizes spatial distribution but also diurnal fluctuation of noise pollution in various zones and wards. The main objective of the study is to identify the Spatial temporal variation of noise pollution among the 200 wards in Chennai metropolitan city. The results will help in providing support for data-based policies in terms of sustainable urban noise mitigation and protection against public health in Chennai.

METHODS AND MATERIALS

Study Design and Duration

This was a cross-sectional study that took place in the Chennai Metropolitan City, Tamil Nadu, India. The primary objective was to map and examine the spatial and temporal pattern of environmental noise pollution in the city using geospatial techniques.

Study Setting

Chennai is a large metro city of India located on the southeastern coast of the Bay of Bengal. It has a total area of approximately 426 square km and is the state capital of Tamil Nadu. It is geographically divided into 15 zones under 200 wards of the Greater Chennai Corporation. The region is characterized by high urban densities, mixed land use, large traffic corridors, and ongoing construction and metro rail project activity, all of which create varied. noise sources in space and time.

Noise Measurement Procedure

Environmental sound levels were recorded with the NIOSH Sound Level Meter (SLM) mobile app, created by the National Institute for Occupational Safety and Health. The app has been tested in peer reviewed research and offers reliable A-weighted equivalent continuous sound levels (Leq) in accordance with Type 2 sound level meters [8]. Each of the 200 wards was sampled at three time points to account for variability in ambient noise over time such as Morning between 8:00 AM to 11:00 AM, Noon between 12:00 PM to 2:00PM and Evening between 6:00PM to 9:00PM. Three independent measurements were taken at central and random public locations at each ward and time interval. The mean of the three measurements per session was used for analysis and a high-quality dataset of ward-level and time-specific noise levels in decibels (dB) was generated. Geo Processing and Data Analysis The collected noise data and geographical points were all imported into QGIS for spatial mapping. Point layers for noise readings were symbolized by decibel range in an attempt to represent gradients. Further spatial analysis

Journal of Chemical Health Risks
www.jchr.org
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was also carried out using GeoDa software to identify noise pollution hotspots and outliers. This GIS-spatial statistic integration enabled high-resolution visualization and mapping of noise-sensitive areas in Chennai to aid evidence-based policy planning and development.

Spatial Analysis

Investigated the spatial dependence and clustering characteristics of environmental noise across Chennai's 200 wards, a systematic spatial analysis was conducted using GeoDa software. This involved creating a spatial weights file, computing global spatial autocorrelation (Moran's I), and generating Local Indicators of Spatial Association (LISA) cluster maps for morning, midday, and evening periods.

A) Construction of Spatial Weights Matrix A contiguity-based spatial weights matrix of the queen type (1st order) was developed to represent the spatial connections among the 200 wards. This approach takes into account both edge and vertex contiguity, enabling the model to pinpoint neighbouring wards with shared edges or corners. Each ward was assigned a weight based on the number of adjacent wards it has, aiding in identifying spatial patterns in the noise data.

B) Spatial Autocorrelation (Moran's I) - Global Moran's I statistics were calculated for each of the time-period datasets (Morning Leq, Midday Leq, and Evening Leq). The Moran's I values ranged from 0.27 to 0.41, all significant at $p < 0.01$, indicating a moderate and positive spatial autocorrelation.

C) Local Indicators of Spatial Association (LISA) LISA cluster maps were generated to illustrate localized noise clustering patterns. Four spatial associations were identified: High-High (HH): Noisy wards adjacent to other noisy wards (noise hotspots). Low-Low (LL): Quiet wards adjacent to other quiet wards (quiet clusters). High-Low (HL): Noisier wards located next to quieter wards (potential noise outliers).

Temporal Variations

Analysed temporal variation of noise levels throughout the specified time frames (Morning: 8:00–11:00 AM, Midday: 12:00–2:00 PM, Evening: 6:00–9:00 PM), and the minimum, maximum, and average noise levels recorded across the 200 wards of Chennai during each session.

Sampling and Mapping Framework

A detailed spatial mapping platform at the ward level was established using official administrative data sourced from the Government of Tamil Nadu's website. The study thoroughly analysed all 200 wards across the 15 municipal zones to ensure adequate spatial representation and coverage. Geospatial boundary and zoning shapefiles were obtained and processed using QGIS software (version 3.28), which enabled precise spatial visualization and analysis. A neighbourhood sampling approach was implemented to systematically include adjacent or neighbouring spatial units, enhancing the representativeness of local environmental and socio-demographic variations. This method allowed for greater resolution in spatial analysis and minimized sampling bias among adjacent wards.

RESULTS

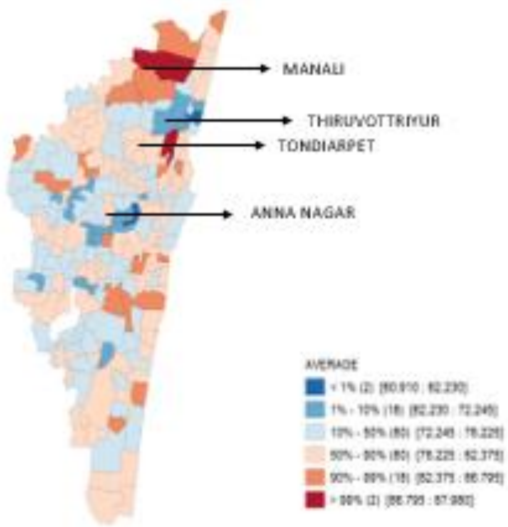

Figure 1: Spatial Distribution of Average Noise Levels Across 200 Wards in Chennai Categorized by Percentile Ranges

The spatial pattern of average noise levels over the 200 administrative wards of Chennai showed considerable heterogeneity. The wards have been classified into six percentile classes according to their average decibel (dB) values: <1% (60.910–62.230 dB), 1–10% (62.230–72.245 dB), 10–50% (72.245–78.225 dB), 50–90% (78.225–82.375 dB), 90–99% (82.375–86.795 dB), and >99% (86.795–87.980 dB). The least quiet wards had the lowest mean values of noise levels (<1%) in Ward No. 11 of Thiruvottriyur and Ward No. 104 of Anna Nagar, and

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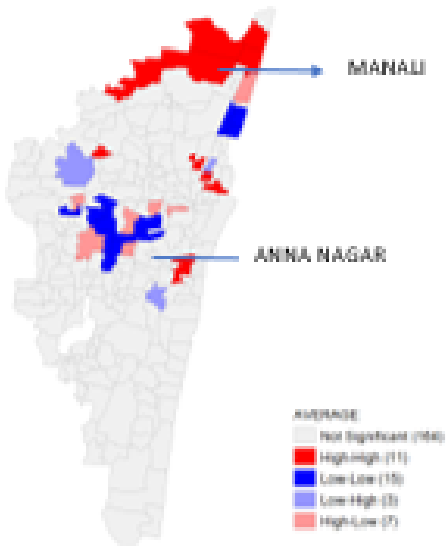
JCHR (2025) 15(4), 1143-1150 | ISSN:2251-6727

these both had relatively quieter places than others with mean values of less than 62.230 dB. Conversely, the highest average noise levels (>99 percentile) were found in Ward No. 16 in Manali and Ward No. 38 in Tondiarpet with noise levels above 86.795 dB, showing high noise pollution in these locations.

Nearly 18 wards had an average noise level in the range of 90–99th% with high average noise levels ranging between 82.375 and 86.795 dB. These were Ward No. 1 (Thiruvottriyur), Wards 15, 18, 19, and 20 (Manali), Ward 47 (Tondiarpet), Ward 49 (Royapuram), Wards 79 and 84 (Ambattur), Ward 65 (Thiru.Vi.Ka. Nagar), Wards 109, 118, and 120 (Teynampet), Wards 171, 172, and 173 (Adyar), and Wards 192 and 195 (Sholinganallur). These zones, predominantly found in the city's northern and central regions, are marked by lightly populated residential, commercial, or industrial areas with attendant high noise exposure. Most wards (160 out of 200) were allocated in the range between the 10th to the 90th percentile, and the mean noise levels varied from 72.245 to 82.375 dB, reflecting extensive prevalence of moderate to high ambient noises in Chennai. This trend reaffirms the immediate need for focused urban noise reduction measures in highly exposed as well as moderately affected areas.

Figure 2: Identification of Noise Pollution Hotspots and Cold spots in Chennai (Ward-Level Spatial Analysis)



The figure 2 illustrates areas in Chennai experiencing high and low levels of noise pollution across 200 wards through spatial analysis. Five classifications are utilized to categorize the wards according to Local Indicators of Spatial Association (LISA): High-High, Low-Low, Low-High, High-Low, and Not Significant. A total of 11 wards have been identified as High-High clusters, indicating noise pollution hotspots where both the ward and adjacent wards experience elevated noise levels. These include the Thiruvottriyur zone (wards 2 and 3), Manali (wards 15, 16, and 17), Madhavaram (ward 32), Tondiarpet (wards 40 and 48), Royapuram (ward 52), and Teynampet (wards 115 and 119). These locations raise considerable concerns due to frequent exposure to high noise levels, likely linked to industrial activities, dense traffic, and commercial zones. Conversely, Low-Low clusters, or cold spots, can be found in 15 wards where both the ward and the surrounding area have lower noise levels. These wards consist of Thiruvottriyur (wards 9–14), Anna Nagar (wards 99, 100, 103, 105, 106, 107, and 108), Kodambakkam (ward 130), and Ambattur (ward 89). These regions are relatively peaceful and could benefit from measures like residential zoning, increased green spaces, or reduced traffic volumes. Low-High outliers, characterized by low-noise wards bordered by high-noise areas, include Ambattur (ward 83), Tondiarpet (ward 42), and Teynampet (ward 122). These wards may represent buffer or transitional zones between noisy and quieter areas, suggesting a potential need for interventions to prevent the encroachment of noise. In contrast, the High-Low outliers, such as Teynampet (ward 109), Kodambakkam (ward 127), Anna Nagar (ward 102), Ambattur (ward 88), Thiruvika Nagar (wards 74 and 78), and Thiruvottriyur (ward 5), are those with elevated noise levels surrounded by quieter localities. These specific areas demand attention as their higher noise levels could adversely affect neighboring low-noise regions. Overall, this spatial analysis aids in identifying key areas for intervention, highlighting hotspots that require immediate noise control measures while recognizing cold spots that exemplify effective noise management practices suitable for replication in other areas.

Journal of Chemical Health Risks
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Figure 3: Spatial Autocorrelation Analysis of Noise Pollution in Chennai Using Moran's I Index

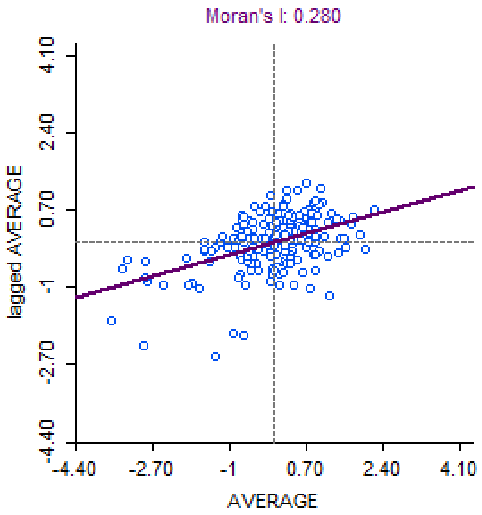
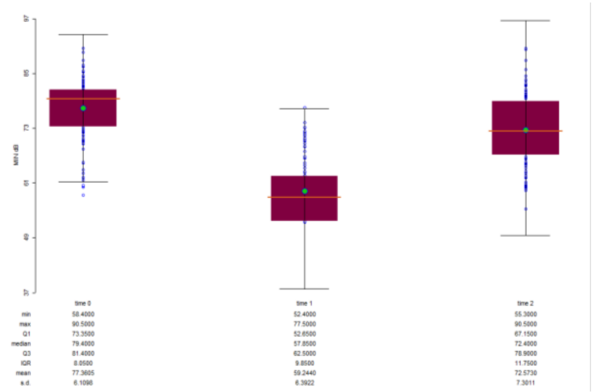


Figure 3 presents the scatter plot for Moran's I visually depicts the spatial autocorrelation of average noise pollution levels across the 200 wards of Chennai. The x-axis represents the standardized average noise levels for each ward, while the y-axis shows the spatial lag, indicating the average noise levels of neighbouring wards. The plot demonstrates a positive trend, as indicated by the upward slope of the regression line, with a calculated Moran's I of 0.280. This suggests a moderate yet statistically significant degree of spatial autocorrelation of noise levels throughout the city. In essence, wards with elevated noise levels tend to be adjacent to other high-noise wards, while quieter wards are generally located near other low-noise wards. The spatial distribution represented across the quadrants further clarifies this trend. The top-right quadrant reflects "High-High" clusters, which imply that wards with high noise levels are located near other wards with similar noise profiles, indicating areas of intense noise pollution. Conversely, the bottom-left quadrant illustrates "Low-Low" clusters, highlighting regions where low-noise environments prevail. The top-left and bottom-right quadrants reveal spatial outliers' wards that exhibit significant deviations in noise levels compared to their neighbouring areas. This spatial correlation indicates that the distribution of noise pollution in Chennai is not random but influenced by geographical and structural factors like traffic patterns, industrial zones, commercial enterprises, and population density. The moderate spatial autocorrelation indicated by Moran's I emphasizes the importance of implementing geographically tailored noise reduction strategies, especially in identified hotspots such as Thiruvottiyur, Manali, Madhavaram, Tondiarpet, and Royapuram.

Figure 4: Minimum Noise Levels in 200 Wards of Chennai at Different Times in a single day



The Figure 4 displays the lowest noise levels (in decibels) recorded across 200 wards in Chennai at three different times of day: morning (8:00–11:00 AM), afternoon (12:00–2:00 PM), and evening (6:00–9:00 PM). The results show that noise levels peak in the morning, with an average of 77.36 dB and a median of 79.4 dB. This indicates that most areas within the city experience very high noise exposure during morning hours, significantly exceeding the acceptable limit of 55 dB for residential zones. In contrast, the afternoon sees a notable decrease in noise levels, with a mean of 59.24 dB and a median of 57.85 dB, suggesting a relatively peaceful environment likely due to diminished traffic and human activity. However, even during this quieter period, many wards still surpass the safety noise threshold. In the evening, noise levels rise again, with an average of 72.57 dB and a median of 72.4 dB, approaching the morning levels. The variability of evening noise is also greater, indicating that while some areas are quite noisy, others are experiencing significant noise pollution. Overall, the data indicates a concerning trend of consistently elevated noise levels in Chennai throughout the day, especially notable during morning and evening hours.

Journal of Chemical Health Risks
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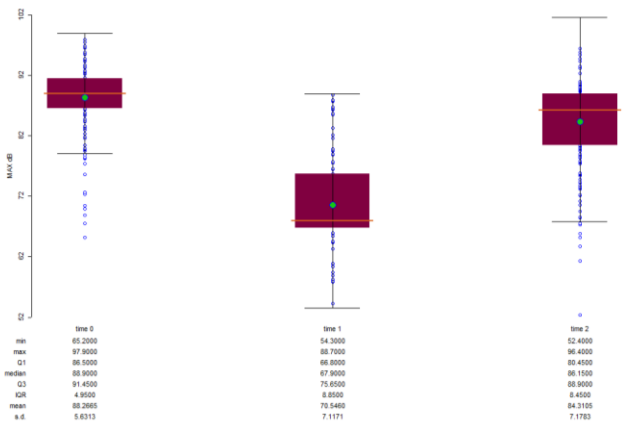
JCHR (2025) 15(4), 1143-1150 | ISSN:2251-6727

Figure 5: Maximum Noise Levels in 200 Wards of Chennai at Different Times in a single day



The Figure 5 presents the maximum noise level measurements (in decibels) taken across 200 wards in Chennai at three different times of the day: morning (8:00–11:00 AM), afternoon (12:00–2:00 PM), and evening (6:00–9:00 PM). The findings reveal that the highest levels occur in the morning, with an average of 86.26 dB and a median of 86.5 dB. This suggests that most areas in Chennai experience significant noise pollution during the morning hours, likely due to heavy traffic and the start of business activities. In the afternoon, noise levels drop slightly, with a mean of 78.56 dB and a median of 78.5 dB. Although this period is relatively quieter, the noise remains significantly above the acceptable limit of 55 dB in residential zones, indicating ongoing exposure to harmful sound levels. Again, in the evening, noise levels rise, with a mean of 84.3 dB and a median of 84.15 dB, indicating another peak likely caused by evening traffic and public engagements. The data for all time intervals shows that most wards in Chennai regularly exceed recommended noise thresholds. This persistent high exposure to noise underscores the urgent need for effective noise control strategies, thoughtful urban planning, and public awareness initiatives to reduce environmental noise pollution and protect community health.

DISCUSSION

This study provides a detailed spatial assessment of environmental noise pollution across 200 wards in Chennai, employing established methodologies and geospatial technologies. By utilizing the NIOSH Sound Level Meter (SLM) app from the U.S. National Institute for Occupational Safety and Health, achieved accurate, user-friendly, and uniform measurements of A-weighted equivalent continuous sound levels (Leq). The research has demonstrated the app's reliability and alignment with Type 2 sound level meters, positioning it as a robust instrument for urban environmental assessments [9]. Moreover, the app's application in diverse urban settings is validated through its use in global public health noise studies. One of the significant outcomes of the study is the notable variation in noise levels throughout the day, with peak exposure generally observed during midday and evening hours. This trend reflects the correlation between population density in urban areas and land use patterns. Areas with high density, such as Tondiarpet, Royapuram, and Sholinganallur, consistently registered elevated average decibel levels, consistent with previous studies linking high-density environments to heightened noise levels due to increased human activities [10]. These activities include commercial dealings, school functions, market activities, and heavy traffic.

The diversity of land use proved to be a strong predictor of noise exposure. Areas with mixed land use, where residential spaces coexist with markets, workshops, and roadways, registered higher ambient noise levels across all time periods. Previous studies in both Indian and global urban contexts have highlighted this intersection between zoning and noise exposure [11,12]. Additionally, ongoing construction work, metro rail expansion, and road maintenance in Chennai's central and northern regions further intensified cumulative noise exposure, contributing intermittent, high-decibel bursts to the overall sound environment. Transportation infrastructure and the volume of mobility significantly influenced elevated dB levels. Wards located near major roads, bus terminals, and railway tracks, such as Manali and Adyar, exhibited noticeably high noise levels during midday and evening hours. Urban noise research in Mumbai and Delhi similarly documents the dominant role of vehicular traffic in daily noise patterns [13,14]. In Chennai, unregulated honking, narrow streets, and a lack of noise barriers further amplify these effects, resulting in chronic exposure for the urban poor.

The economic status and social infrastructure are also key factors. Low-income neighbourhoods are often situated closer to industrial hubs or extensive road networks and tend to experience a disproportionate share of higher environmental stressors like noise [15].

Journal of Chemical Health Risks
www.jchr.org
JCHR (2025) 15(4), 1143-1150 | ISSN:2251-6727

Conversely, some wealthier residential areas with greenbelt buffers and controlled traffic flow (for instance, parts of Anna Nagar) recorded lower average noise levels, reinforcing the link between social privilege and reduced environmental burdens. This aligns with broader environmental justice discussions that suggest noise pollution disproportionately affects marginalized populations [16,17]. Utilizing spatial autocorrelation techniques such as Moran's I and LISA provided valuable insights into spatial patterns and noise dispersion among adjacent wards. A notably strong positive spatial autocorrelation confirmed that wards with high noise levels are geographically clustered, a finding that mirrors similar urban studies in Seoul and Barcelona [18]. The presence of spatial continuity indicates that strategies to mitigate urban noise need to be formulated at the cluster or zonal level rather than targeting isolated hotspots.

This research demonstrates that Chennai experiences considerable and uneven levels of environmental noise, influenced by various factors such as land use patterns, transportation density, socio-economic inequalities, and unchecked urban expansion. By combining precise mobile measurement techniques with GIS technology, this study adds essential evidence to aid in governing and planning for noise pollution in Chennai. Additionally, further integration of this data with health outcome information could enhance the public health approach and help achieve sustainable urban development goals.

CONCLUSION

This study presents a comprehensive spatial analysis of ambient noise exposure at the ward level across Chennai, aligning with the smart city goals of environmental monitoring and sustainable urban management. Utilizing sound level measurements through a mobile app and integrating GIS-based spatial analysis, this research proposes an innovative and scalable method for urban noise mapping that is both economical and applicable to other metropolitan areas. The findings indicate that a considerable number of Chennai's 200 wards face ambient noise levels surpassing the acceptable limits set by the Central Pollution Control Board (CPCB), particularly during peak traffic periods. Wards such as Manali, Tondiarpet, and Sholinganallur frequently showed average decibel levels within the high exposure range, between 75 dB and 85 dB. These figures exceed the acceptable thresholds for residential and commercial zones, emphasizing the urgency for urban noise management strategies. The patterns of noise distribution demonstrate a strong association with land utilization, population density, traffic volume, and industrial activity. Suburban districts and newly developed urban corridors, once believed to be quieter, now exhibit elevated noise levels, indicating the impact of urban expansion and transportation demands. In contrast, only a small number of wards (like Alandur and parts of Velachery) are classified as having low exposure, showcasing the disparity in the acoustic environment quality throughout the city. Importantly, this research pioneers noise monitoring on a localized, ward-level scale, which is particularly beneficial for crafting targeted policies. Standard city-wide approaches often mask the variations in noise exposure within urban areas, whereas ward-specific data enables precise interventions and supports health planning at the community level. Additionally, this spatially detailed data can guide planners in identifying priority regions for noise-reducing measures such as green buffers, acoustic zoning, and traffic management.

The findings further underline the health implications of environmental noise as an emerging public health issue in urban areas. Continuous exposure to elevated noise levels is associated with adverse effects, including sleep disturbances, cardiovascular issues, cognitive decline, and increased annoyance—factors that are often overlooked in the planning processes of Indian cities. Moreover, the study advocates for incorporating noise pollution into the broader smart city framework. Environmental noise assessment should be regarded as a crucial component of urban sustainability, comparable to monitoring air and water quality. Implementing real-time noise tracking through IoT sensors, integrating findings with municipal GIS platforms, and fostering community engagement in noise mapping through citizen science initiatives can dramatically transform how cities like Chennai manage their acoustic environments. While this research is limited by its time frame and does not directly assess health outcomes, it paves the way for forthcoming interdisciplinary investigations that connect environmental exposure data to health indicators. Furthermore, it illustrates the potential for utilizing affordable mobile technologies for environmental monitoring in areas with constrained resources. Lastly, addressing environmental noise pollution is not solely an environmental or infrastructural issue; it significantly

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JCHR (2025) 15(4), 1143-1150 | ISSN:2251-6727

influences urban liveability, public health, and social equity. Policymakers, urban planners, and public health officials must collaborate based on this research's findings to develop a comprehensive city-wide action plan on noise, integrate noise reduction strategies into development plans, and engage the public in efforts to transform Chennai into a quieter, healthier city by 2047.

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