



## Noise Mapping and Assessment of the Acoustic Environment in Coastal Puducherry, an Old French City: A Cross-Sectional Study

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### Abstract

**Introduction:** According to the Central Pollution Control Board (CPCB) National Ambient Noise Monitoring Network data (2019), about 90 % of monitoring stations in major Indian cities recorded noise levels above the accepted limits, both during day and night. Urban environments like Puducherry exhibit complex spatial and temporal variations in noise pollution due to diverse land use patterns, dense traffic networks, and mixed residential-commercial zones. **Aim:** This study aims to enhance ambient noise mapping across Puducherry's through the geospatial analysis techniques to identify the hot spots in Urban area of Puducherry. **Methods and Materials:** Cross-sectional research was undertaken in October 2023 in Puducherry's urban areas. The grid size was established by the physics rule, which stipulates that increased vehicle traffic causes higher levels of noise. Spatial analysis was conducted at preliminary 2-hour static monitoring at three suspected noise sources, Coefficient of variation  $CV < 0.5$ , successfully predicting high-variability in urban signals across 42 GPS points measuring 5-minute Leq. A systematic selection of 9 places was chosen by spatial analysis from 42 spots in Urban area. The sound level was measured with Larson Davis Sound Expert LxT meters and calibrated as pre-measurement according to CPCB/ISO 1996-2 guidelines. **Results:** Our results reported an increase in the Indhira Gandhi Square signal (Leq dB – 103.5), Maraimalai Adigal Salai near the bus stand to Nellitope (Leq dB(A) - 96.9), Vazhudavoor Road near Rajiv Gandhi Square (94.1), Saram signal, Kamaraj Salai, Lenin Street (93.1), and Anna Salai bus stand (90.8) of study sites from afternoon to evening measurements. Lmin and Lmax vary from 52 to 84 dB and 101 to 113 dB. **Conclusion:** The noise measurement given in this study reported that in urban Puducherry, vehicle traffic noise surpassed the CPCB's daytime ambient air quality standard in 90% of the studied areas.

**Keywords:** Noise pollution mapping, Geographic Information Systems, Geospatial, Spatial -temporal pattern, Puducherry

### Introduction

Noise exposure has been associated with an annual loss of 45,000 disability-adjusted life years (DALY) for children aged 7 to 19, as well as an increase in cardiovascular disease and mortality in high-income countries.<sup>1,2</sup> The term "noise pollution" describes undesired or damaging sounds in the environment that negatively impact ecosystem balance and human health by interfering with regular activities like sleep, communication, or concentration.<sup>3</sup> Ten percent of people on the planet are thought to be subjected to noise pollution, which can harm their hearing permanently.<sup>4</sup> According to estimates from the European Environment Agency (EEA, 2024), over 100 million individuals in Europe are exposed to dangerous road traffic noise, which results in roughly 12,000 premature deaths and 48,000 new cases of heart disease annually. Even when a person is not aware of it, noise causes the body's physiological stress reaction, making it an environmental stressor.<sup>5</sup> Environmental noise is associated with hearing loss, hypertension, arterial hypertension, ischemic heart disease, and stroke. A survey conducted in an Indian city found 52% reported irritation from noise, 46% reported hypertension symptoms, and 48.6% reported sleep disturbance.<sup>3,6</sup> Exposure to environmental noise above 85 dB

over a long period of time results in noise-induced hearing loss, tinnitus, sleep architecture, as well as cognitive functions including attention, memory, and learning in children.<sup>8,9</sup> Noise acts as an environmental stressor, causing annoyance, reduced well-being, elevated stress, and mental health burden (anxiety, depression), thereby lowering overall quality of life.<sup>4,10</sup>

In Puducherry, a 2024 study measured noise levels at traffic junctions and residential/commercial areas. Some locations exceed Indian regulatory standards (CPCB), but the study does not project to population-wide exposure.

<sup>11</sup> In Srinagar, a 2025 study measured road traffic noise spatially and temporally and examined health awareness.

<sup>12</sup> GIS technology has been used to present and analyse the magnitude of problems in Karachi, Pakistan, Seoul, Republic of Korea, and the city of El-Mina in North Lebanon.<sup>13, 14</sup> Urban Puducherry (11°55'N, 79°50'E; pop. 244,377; 20 km<sup>2</sup>) is 170 km away from Chennai with 69.16% of the population living in the urban area and 3,232 people/km<sup>2</sup>, with good roads.<sup>15</sup> Puducherry is a fascinating coastal place to visit as it is a French settlement with French colonial culture reflected through the Yellow Houses of White Town and the cobblestone roads.<sup>16</sup>

Detailed cross-sectional study in urban Puducherry provided fragmentary, outdated, short-term data, underscoring the need for spatially resolved noise mapping to assess current pollution levels, as many areas already exceed prescribed limits. Traditional point measurements are insufficient to capture Puducherry's varied landscape, from noisy town cores to quieter coastal and green zones. In light of the limited and outdated data on noise pollution in Puducherry, this study aims to assess noise levels across different zones in Puducherry and prepare noise maps showing spatial variation and comparison with CPCB standards to identify areas requiring intervention or monitoring.

## Material And Methods

### Study Design and Duration

A cross-sectional study on noise mapping was conducted in the urban areas of Puducherry in October 2023.

### Study Setting

Puducherry is a Union Territory located on the southeast coast of India, where modernization meets colonial heritage. The administration of the Union territory of Puducherry is done by the following five municipalities and ten Commune Panchayats in and around Puducherry.

### Spatial Analysis

#### Spatial Screening Protocol

The detailed spatial analysis by 2-hour static verification ( $CV < 0.5$ ) the 5min roving measurement for temporal consistency at three noise junctions of Puducherry. According to ISO 1996-2/CPCB guidelines our study follows A-weighted Leq replicates per spot, at 50 GPS-defined spots with dense coverage in high-traffic wards and sparse coverage in residential wards over two days. These study shows the measures at the noise sources such as 1.Vazhudavoor Road near Rajiv Gandhi Square (Kadhirkamam Ward 9, Oulgaret Municipality; 2.Indira Gandhi Square signal (V.O.C Nagar Ward 6, Pondicherry Municipality) and 3.Maraimalai Adigal Salai from New Bus Stand to Nellithope Signal (Govindapet Ward 9, Pondicherry Municipality bus-stand side; Nellithope Ward, Nellithope Commune Panchayat) signal side followed by that 3-operator roving surveys across 50 GPS points (Figure 1: dense near roads/promenade wards 1,2,5,17,23; sparse residential wards 28-42), measuring 5-minute Leq continuously per spot across 3 replicate passes over 2 days (total 12 hours field time), averaging replicates to minimize temporal variability bias while maintaining optimal 500m site spacing and 73% coverage of the ward area to reduce the effect of bias, followed by IDW interpolation of the 9 locations + 41 GPS data to stratify the high-risk wards (5, 6, 9) at the municipal scale.<sup>17</sup>

In our study specifically monitoring location in Puducherry by using four criteria identified in nine main noise monitoring area such as

1. Highest volume of traffic: Annual Average Daily Traffic (AADT) > 20,000 vehicles per PWD records on the routes of NH45A, Beach Road, and RC-3
2. High-risk administrative wards: Ward 9, including Oulgaret Municipality and Pondicherry Municipality, and Ward 6, including Pondicherry Municipality, based on the findings from the initial CV screening with Leq values ranging from 94 dB to 104 dB and CV 13-29%.
3. Most complex signalized intersections:  $\geq 4$  road arms to ensure maximum noise generation from the crossing traffic streams.
4. Previous noise hotspots: Sites identified in previous Puducherry noise studies.<sup>11, 15</sup>

#### Specific locations monitored (October 2023): [Figure 1]

1. Vazhudavoor Road near Rajiv Gandhi Square (S1, Ward 9, Oulgaret Municipality)
2. Kamarajar Salai, Lenin Street junction (S2, Ward 11, Oulgaret Municipality)
3. Anna Salai near Raja Theatre signal (S3, Ward 6, Pondicherry Municipality)
4. Indira Gandhi Square Signal (S4, Ward 6, Pondicherry Municipality)
5. Maraimalai Adigal Salai, New Bus Stand to Nellithope Signal (S5, Ward 9 Govindapet/Nellithope Ward)
6. Anna Salai Old Bus Stand signal (S6, Ward 3, Pondicherry Municipality)
7. Mahatma Gandhi Road near Chinnamanikudu (S7, Ward 9, Oulgaret Municipality)
8. Puducherry-Cuddalore Bypass, Ariyakuppam signal junction (S8, Ariyakuppam Commune)
9. Puducherry-Cuddalore Bypass, Thavalakuppam signal junction (S9, Thavalakuppam area)

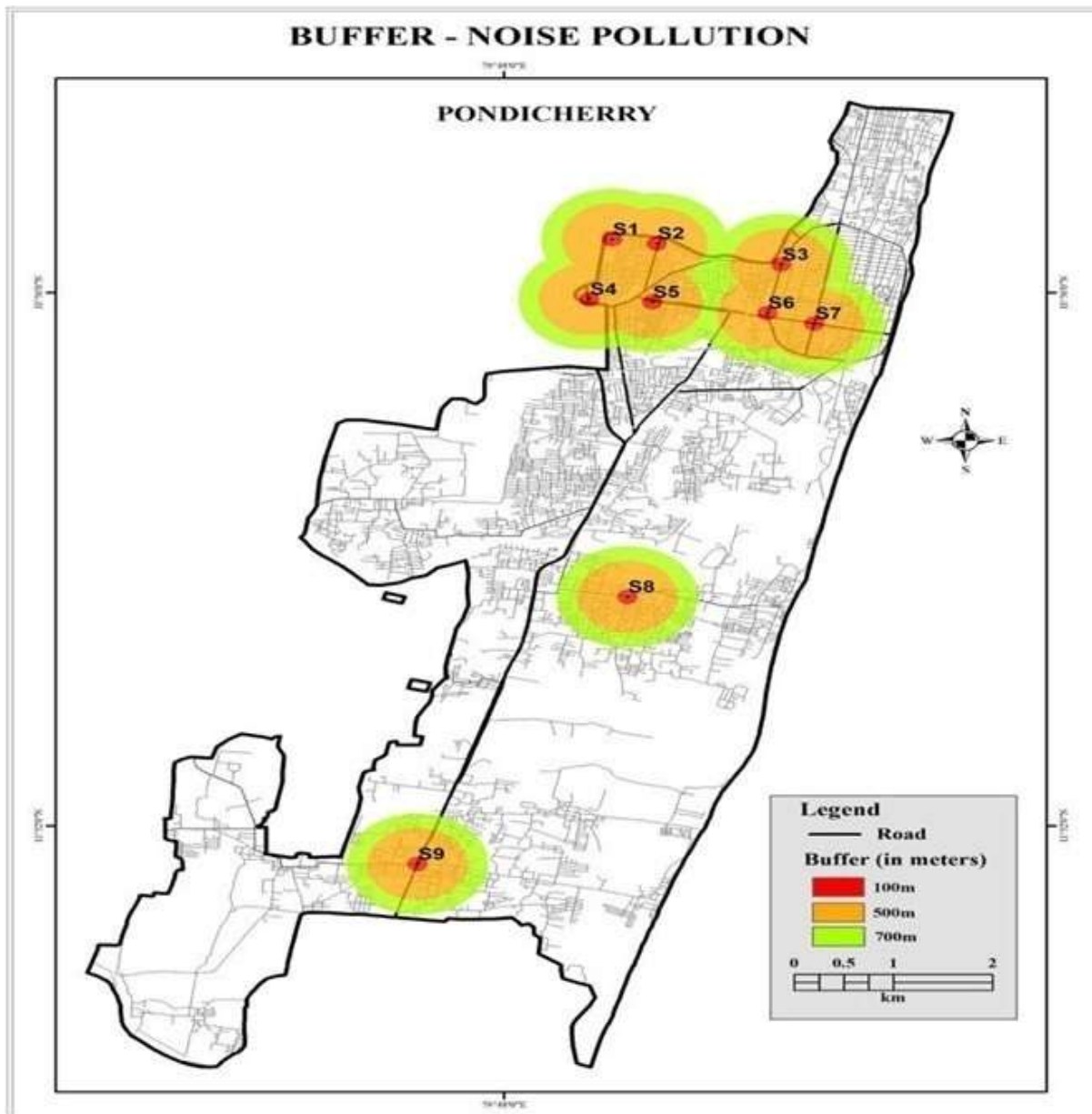


Figure 1: Map of India and location of Puducherry. The location of study sites in Puducherry is shown in the inset. All maps were generated by the authors using ArcGIS Desktop v10.3 software.

#### Study procedure and tools:

To measure the sound level, a Larson Davis Sound Expert LxT (LXT1-SE-FF/RI) device, a portable battery-operated sound level meter, was used. The device has a frequency range of 8 Hz to 16 kHz and a sound level range of 0 to 120 dB. The device was placed on a tripod stand 1 m away from the observer and 1.5 m above the ground, without any obstructions. The device was calibrated prior to each use, and the  $Leq(A)$ ,  $L_{max}$ , and  $L_{min}$  values were recorded for 8 hours. The GPS coordinates for the nine locations were recorded by a Garmin GPS device, having 95% accuracy within 3 to 5 m, and the same data was used for the subsequent time slots. The noise mapping was done by the inverse distance-weighted interpolation method by the ArcGIS Desktop v10.3.00 software. The data was collected via USB for the Larson Davis device and the GPS coordinates via the DNR Garmin device, and the data recording was done on Fridays between 1:00 pm and 9:00 pm.

Euclidean Buffer Analysis. 500 m (red/orange) and 1000 m (yellow) Euclidean distance buffers were generated around nine primary noise monitoring sites (S1-S9) in ArcGIS 10.8 software using the Buffer tool (Analysis Tools to Proximity) with the planar method. These buffers achieved 14.3 km<sup>2</sup> coverage (73% of Puducherry municipality; 19.6 km<sup>2</sup> total area) with minimal overlap (<20%), confirming optimal 500 m site spacing as shown in Figure 2.

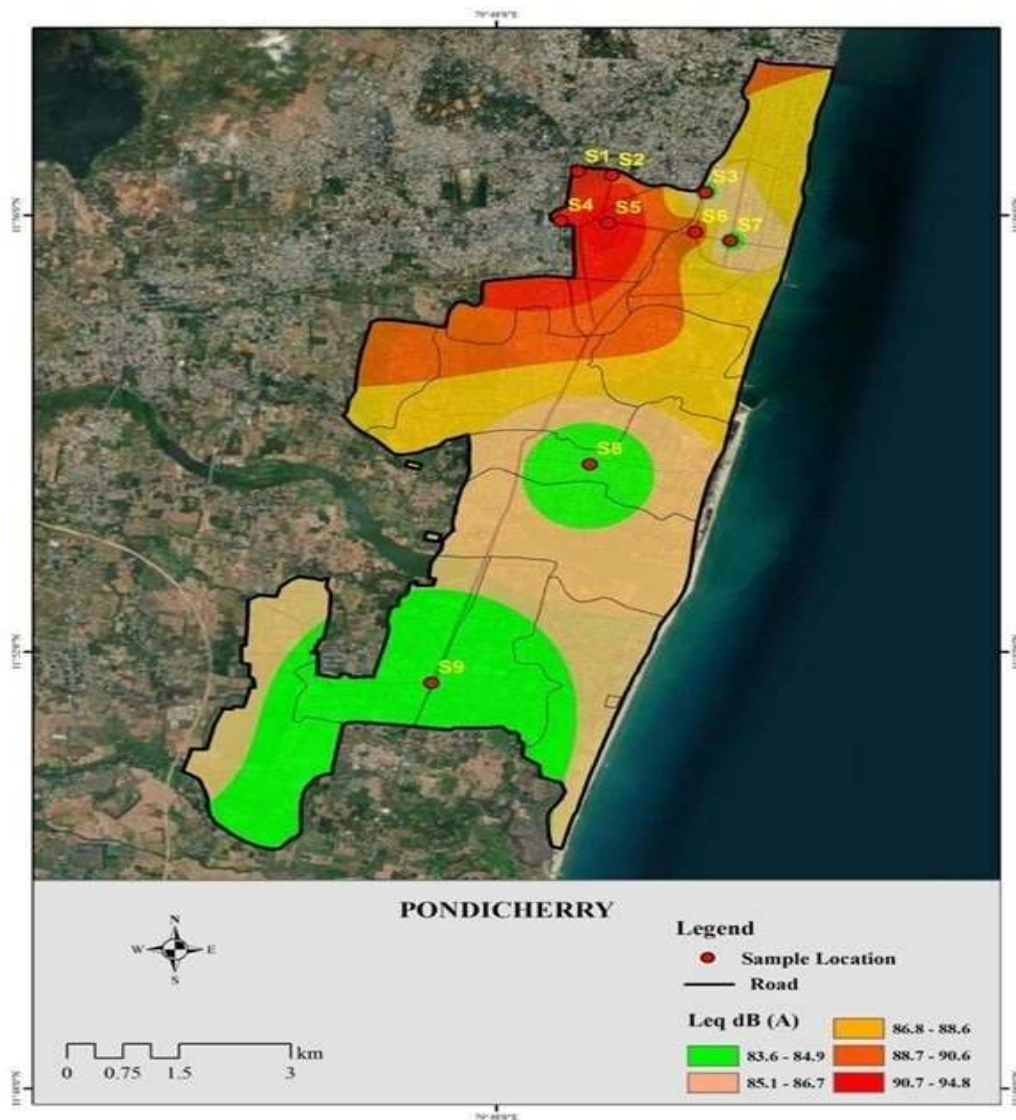


Figure 2: Inverse distance Weighted interpolation of noise level during 1:00 pm – 9:00 pm. Average noise level (Leq) map. All maps were generated by the authors using ArcGIS Desktop V 10.3 software.

**Ethical Approval:** Ethical approval for this study was obtained from the Scientific Advisory Committee and Institute Ethics Committee of Indira Gandhi Government General Hospital and Postgraduate Institute, Puducherry, India. (Approval No. GHSAC/2020).

## Results

The impact of acoustic environment on French colonial street of coastal Puducherry, the French colonial town with its leafy boulevards and wrought iron balconies, the soundscape of the urban environment could not be more different. The stability of noise levels was confirmed by 2-hour static noise measurements at three locations as shown in table 1, where the coefficients of variation (CVs) of 3.6-3.9% were well within the 4%.

**Table 1.** Preliminary Static Noise Monitoring Results at Three Suspected Hotspots

Site	Mean (dB(A))	Leq (dB(A))	SD (dB(A))	CV (%)
Vazhudavoor Road near Rajiv Gandhi Square (Kadhirkamam Ward 9, Oulgaret)	78.4		2.8	3.6
Indira Gandhi Square signal (V.O.C Nagar Ward 6, Pondicherry Municipality)	82.1		3.2	3.9
Maraimalai Adigal Salai (Govindapet Ward 9 bus-stand side; Nellithope Ward signal side)	79.6		2.9	3.6

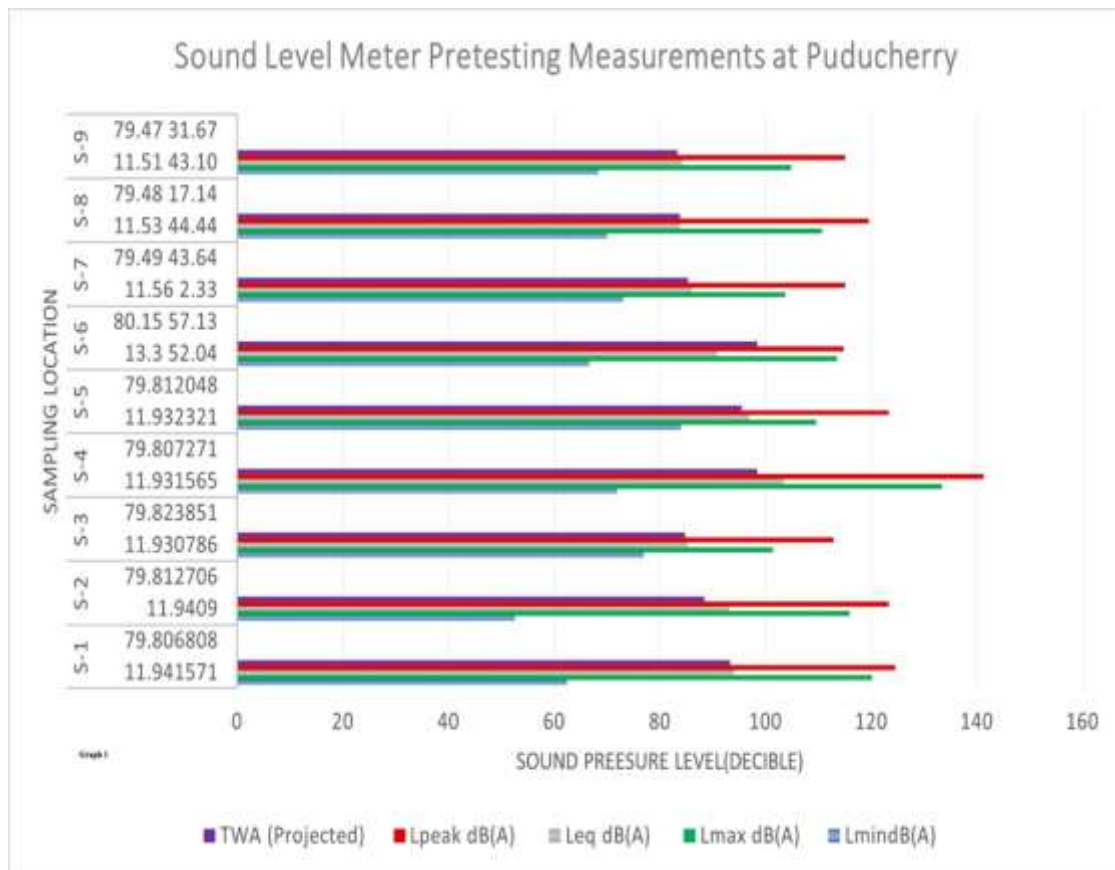
The results findings reveal that west and south of White Town (Quartier Blanc), entry points and by passes exhibit sharper increases from the mixed heavy traffic, contrasting the moderated increases in White Town due to buffers such as the Indira Gandhi Square signal (Leq dB – 103.5), Maraimalai Adigal Salai near the bus stand to Nellithope

(Leq dB(A) - 96.9), Vazhudavoor Road near Rajiv Gandhi Square (94.1), Saram signal, Kamaraj Salai, Lenin Street (93.1), and Anna Salai bus stand (90.8) study sites from afternoon to evening. The Lmin and Lmax vary from 52 to 84 dB and 101 to 113 dB. The Leq dB(A) moderate-risk zone mean (85.53) is approximately 1.76% higher than the lower-risk zone ( $\leq 85$  dB), and the high-risk zone mean (95.68) is approximately 13.84% higher than the lower-risk zone, S-4 achieved the highest maximum level of 133.4 dB(A) and greatest peak level of 141.3 dB(A), as shown in Graph 1.

#### Analysis of Noise Levels Leq (A):

A. Highest Noise Locations (Hotspots): Major traffic crossings produce the loudest noise levels: S-4: 103.5 decibels (A). This is the highest recorded Leq (A), indicating that it is a severe noise hotspot. S1, S2, S5, and S6 with 94.1, 93.1, 96.9, and 90.8 decibels, respectively.

B. Lowest Noise Locations (Relative): The lowest recorded Leq (A) values remain very high in absolute terms but are significantly lower within the dataset: S-8: 83.8 decibels (A). S-9: 84.3 decibels (A). S3 and S-7: 85.3, 85.3, and 86.1 decibels, respectively, shown in Graph 1.



**Information Type:** The legend indicates that a commonly used scale for noise levels in an environment, namely Leq dB(A), was used. For S1 to S9, maps were produced showing Leq, Lmax, and Lmin levels with increasing levels from north to south, as can be seen in the interpolated surface for Lmin and Lmax as shown in Figure 1.

**Sample Locations (S1-S9):** The red dots labelled S1 through S9 indicate the locations where noise measurements were taken. Locations S1, S2, S3, S4, S5, S6, and S7 are inside high-risk zones (red & orange colour). Low Noise Concentration: Locations S8 and S9 fall under the lowest noise contours low-risk zone (green), as shown in Figure 2.

The northern urban core has the maximum noise levels, and extreme hotspots of noise pollution, i.e., the areas coloured red corresponding to the range 90.7–94.8 dB(A), have been identified at S1, S2, S4, S5, and S6. This implies the presence of main traffic corridors. Areas coloured darker orange corresponding to the range 88.7–90.6 dB(A) and lighter orange corresponding to the range 86.8–88.6 dB(A) has been identified in the surroundings. Lower moderate and lowest zones corresponding to the ranges 85.1–86.7 as shown in Figure 2.

#### Geographic and Source Analysis:

In Puducherry, vehicles are predominant, as indicated by the presence of red/orange zones along the northern routes. Severe hotspots are recorded at S1 (94.1 dB), caused by commercial-industrial activities, and at S4 (103.5 dB), caused by commercial-industrial activities and intersections. S5 (96.9 dB) and also by a bus stand, while S2 (93.1 dB) and S6 (90.8 dB) are caused by high-traffic intersections. The greener zones are recorded at S8 and S9, as shown in Graph 1.

**Table 2:** Comparison to CPCB Standards Limit Ambient air quality standards in Respect of Noise, the Noise Pollution (Regulation and Control Rules, 2000).<sup>18</sup>

Zone Category	CPCB Daytime Standard Leq (A)	Highest Mapped Level Leq (A)	Status
Residential Area	55 dB(A)	Up to 94.8 dB (A)	Massive Exceedance
Commercial Area	65 dB(A)	Up to 94.8 dB (A)	Massive Exceedance
Industrial Area	75 dB(A)	Up to 94.8 dB (A)	Major Exceedance

Even the lowest contour, i.e., 83.6–84.9 dB(A), exceeds the daytime limits for all zones, i.e., industrial and residential, as presented in Table 2. The noise level in the red zones is 94.8 dB(A), and this poses environmental and health risks to the public. It has been proven that exposure to noise above 75 dB(A) for long periods not only affects hearing but also cardiovascular health. The noise level map indicates that there is a severe noise crisis in the urban area of Puducherry, where the whole area has exceeded the legal limits, and the northern core has emerged as the major hotspot for noise, especially during heavy traffic.

## Discussion

The present findings confirm that traffic is the predominant source of environmental noise in the north-western urban part of the city of Puducherry due to the increased vehicle entry of tourists on weekends from afternoon. Similar studies conducted in Indian cities like Asansol, Agartala, Kolhapur, and Delhi have reported traffic congestion, speed, and land use as major contributors to high Leq (A) and frequent exceedances of the CPCB threshold near major roads and bus stations.<sup>21-23</sup> The recorded Leq (A) values in this study [up to 103.5 dB(A)] indicate a marked increase compared to earlier Puducherry studies (70–80 dB(A)), suggesting a significant rise in vehicular density and urban expansion over the past two decades. The research conducted in Kolhapur found that industrial zones and industrial-cum-residential zones were slightly below the CPCB's daytime ambient noise threshold. The maximum recorded noise level during the day was 72.25 decibels (A).<sup>24</sup> Similar findings were observed from Asansol, West Bengal. Daytime noise levels range from 59 dB(A) to 89 dB(A), with traffic congestion, vehicle speed, and vehicle type being noted as the primary causes of excessive noise levels in traffic junctions.<sup>21</sup>

In our study conducted in Puducherry, the noise level at the traffic junctions was between 70 and 80 dB(A), and the Indira Gandhi Square noise level was 103.5 dB(A), showing a sharp increase over the 20-year period. The traffic police at these locations are especially at risk for exposure to high noise levels.<sup>15,25</sup> White Town, despite the high volume of traffic, has less noise because of the strict enforcement of the silence zone and the large green belts, like the ones seen at Gandhi Square and Aurobindo Ashram Junction. The large number of expatriates and the French legacy contribute to the compliance of the regulation, resulting in a peaceful and quiet environment with little fluctuation in noise level.<sup>15</sup>

Noise levels observed in sensitive zones such as hospitals [76–82 dB (A)] and educational institutions [69–79 dB(A)] are considerably above the prescribed standards for quiet zones.<sup>[26]</sup> Long-term exposure to such elevated noise levels has been associated with adverse health outcomes. The WHO identifies environmental noise as the second largest environmental health risk in Europe after air pollution, linking chronic exposure to sleep disturbance, annoyance, cardiovascular diseases, cognitive impairment in children, and increased risk of ischemic heart disease.<sup>27</sup>

In comparison to the Yoga Moorthi research, Leq at various hospital regions ranges from 76 dB (A) to 82 dB (B), representing a 20 dB (A) increase from 1996 to 2015, four times the noise level. Similarly, in educational institutions, Leq varies from 69 to 79 dB(A), representing a 10 dB(A) rise over 20 years. According to the report, long-term noise exposure can cause annoyance, sleep disturbance, cognitive impairment in children, and negative effects on the cardiovascular and metabolic systems, resulting in ischaemic heart disease and premature death.<sup>28,29</sup>

In our study, we reported that Saram Signal, Kamarajar Salai, and Lenin Street range from Lmin dB (A) 52.6 to Lmax 116; Vazhdavoor Road near Rajiv Gandhi Square ranges from Lmin dB (A) 62.4 to Lmax(A) – 120; and Maraimalai Adigal Salai, near the bus stand, to Nellitope Signal ranges from Lmin dB(A) 84 to Lmax (A) – 110. In fact, GIS mapping shows the presence of clusters of high noise zones in the built-up, commercialized northern part of Puducherry, as indicated by urban core studies of high noise levels resulting from surfaces, road width, and traffic density. GIS helps in better visualization of hotspots of noise pollution by integrating it into urban planning.<sup>30</sup>

The map displays the spatial distribution of noise pollution in Pondicherry, emphasizing a considerable concentration of high noise levels [90.7–94.8 dB (A)] in the northern, presumably urban core, and noticeably quieter zones in the central and southern regions of the studied territory. To offer a more comprehensive analysis, the search results, which provide critical context for noise levels, support and greatly improve the map's first interpretation.

Future studies should include the assessment of noise and health impacts on by standers and drivers in the future, moving beyond the limited time windows and the absence of seasonal, 24-hour, and meteorological data. Long-term, seasonal, and epidemiological studies, along with the expansion of surveillance to peri-urban and rural areas,

could help characterize regional noise, and noise-compliant vehicles, quiet zones, barriers, and awareness could be used to mitigate noise.

## Conclusion

Nowadays acoustic noise in the urban Puducherry increases daytime ambient air quality standard in 90% of the studied areas. In this study replicate the major sources of noise emission are public, private, and commercial automobiles; motor vehicles; population expansion; and urbanization, all of which contribute to a significant increase in noise levels. In the future perspective, we need to include the non-auditory health impacts on human beings and changes in the aquatic ecosystems of Puducherry due to rising noise pollution in daily life.

### Data availability statement:

The data that support the findings of this study are available on request from the corresponding author. It is available from the corresponding author for academic and non-commercial use upon request.

### Acknowledgements

The authors would like to express their thanks to the participants who volunteered for this study

### Conflict of interest

The authors declare that there are no conflicts of interest.

**Funding Statement:** This research did not receive fund from any specific grant or any funding agency

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