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Assessment and Mapping of Environmental Noise Levels in Chandigarh City: A Case Study

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Rapid urbanization and population growth in Chandigarh, India, have resulted in increased noise pollution levels, affecting the quality of life for its residents. This research paper aims to conduct a comprehensive analysis and noise mapping of Chandigarh City. In this study 25 monitoring sites throughout Chandigarh township were utilised to analyse traffic noise using noise descriptors (L10, L50, L90, NC, TNI and NPL). The hourly equivalent noise levels of 25 sites were monitored at peak morning hours (9AM-11AM) and peak evening hours (5PM-7PM) to analyse the environmental noise pollution scenario in the city. The study utilizes geographic information systems (GIS) to create a detailed noise map, identifying critical noise sources and providing insights for effective noise control strategies. A socio-acoustic survey conducted to analyse the public perception towards noise pollution and associated health hazards. The findings of this research can assist policymakers, urban planners, and environmentalists in developing sustainable urban development plans and mitigating the adverse effects of noise pollution.

Keywords: Noise pollution levels; Traffic noise descriptors; ArcGIS; Noise maps

1 Introduction

After air, water, and soil, noise is ranked as the most significant environmental pollutant. One of the biggest environmental problems on the planet today is noise pollution, which has grown as a result of technological growth[1]. Due to India's massive automotive boom and quick infrastructure upgrades, the urban population is experiencing higher noise levels[2]. Noise can have a variety of negative health effects, including physiological illnesses, disruption of routine activities and performances, heart diseases and hypertension[3-4]. It can also cause discomfort, insomnia, and harm to auditory processes. Permanent ear damage from noise exposure can result in deafness[5]. Currently, one of the primary challenges in urban areas is noise pollution[6], where the main contributor to noise pollution in cities is traffic[7].

In developing nations like India, where there are many automobiles with poor road conditions traffic noise is given more attention. Numerous factors, including various traffic parameters (such as traffic vehicular count and traffic speed), qualities of the road (like the surface roughness, grade and width), and others, have an impact on traffic noise[8-9]. Several studies have been done in the past to assess the exposure to the noise's consequences on human health[10–13]. According to a recent research by the World Health Organisation (WHO), 466 million people worldwide now have debilitating hearing loss, and by the year 2050, one in ten people, or 900 million people, are anticipated to have hearing loss[14]. According to projections, ambient noise will cause 1.6 million years' worth of disability-adjusted living years over all of Europe[15]. The European Environment Agency predicted that noise will cause 10,000 premature mortality each year[16]. A 1 dB(A) reduction in noise level, according to a recent research that took place in Madrid, Spain, could have avoided 284 early cardiovascular deaths and 184 early respiratory fatalities in the population[17].

The noise pollution (regulation and control) rules were released by India's Ministry of Environment, Forests, and Climate Change in 2000. The state must divide the land into quiet, residential, business, and industrial zones, according to the code. India's noise laws are found to be tougher in all zones when compared to WHO noise limits[18-19]. Long-term noise measurements are expensive and time-consuming to do. However, a number of well-known towns, notably Lille in France[20], Gdansk in Poland[21], and Dublin in Ireland[22], have constructed significant Noise

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Monitoring Stations. Infrastructure and financial constraints result from the high cost of developing and maintaining a permanent Noise Monitoring network in various urban zones. Noise maps are routinely produced using information from measurements taken at various sites. A technique for visualising the predicted noise levels throughout a certain geographic region is called noise mapping[23]. The creation of noise maps of various areas has been the subject of several publications in Europe and worldwide[24–27].

Understanding the degree of noise pollution and its possible impacts on human health depends on the assessment and mapping of environmental noise levels in Chandigarh City. The results of this study will offer important new information about Chandigarh City's present level of environmental noise pollution. They will serve as a basis for making decisions based on solid observed, enabling decision-makers to execute focused actions to lessen noise pollution and raise the standard of living for locals. Policymakers and urban planners can identify the areas most impacted by noise pollution and create efficient noise control and mitigation plans by analysing and visualising the noise data[28]. The results of the research can also be used to guide urban planning efforts, including the creation of noise buffer zones and the incorporation of noise reduction techniques into upcoming infrastructure projects.

2 Objective of Study

The present study is focused on the assessment and mapping of the hourly equivalent sound pressure levels at 25 locations in Chandigarh City. The following are the objectives of the paper:

- **Assessing Noise Exposure**: To evaluate and quantify the levels of noise exposure in Chandigarh city. This involves measuring noise levels at 25 various locations across the city and to understand the overall noise pollution scenario.
- **Temporal Analysis**: Assessment of noise descriptors such as L10, L50, L90, NC (Noise Criterion), NPL (Noise Pollution Level) and TNI (Traffic Noise Index)to describe the temporal characteristics of the noise.
- **Mapping Noise Levels**: The primary objective of this research papers is to create noise maps that visually represent the distribution of noise levels across the Chandigarh city. These maps can be helpful to identify hotspots of high noise exposure and provide a spatial representation of noise pollution patterns.
- **Frequency Analysis**: Frequency-based descriptors, such as octave band analysis, provide information about the distribution of noise energy across different frequency bands. This helps in identifying specific frequency components or tonal characteristics of the noise.
- **Socio-Acoustic survey**: To assess the impact of noise pollution on the residents of Chandigarh city by conducting a socio-acoustic survey, including gathering information on individuals perceptions, attitudes, and experiences related to noise.

3 Methodology

3.1 Study Area

The study was conducted in Chandigarh (Fig. 1), Chandigarh is a city located in the northern part of India and serves as the capital of both the states of Punjab and Haryana. Geographically, it lies at the foothills of the Shivalik range, near the border of these two states. The city is situated approximately 250 kilometers north of New Delhi, the capital of India and covers an area of around 114 square kilometers. Chandigarh is strategically positioned and well-connected to major cities in the region. It is located close to the important cities of Mohali and Panchkula, forming a tri-city area

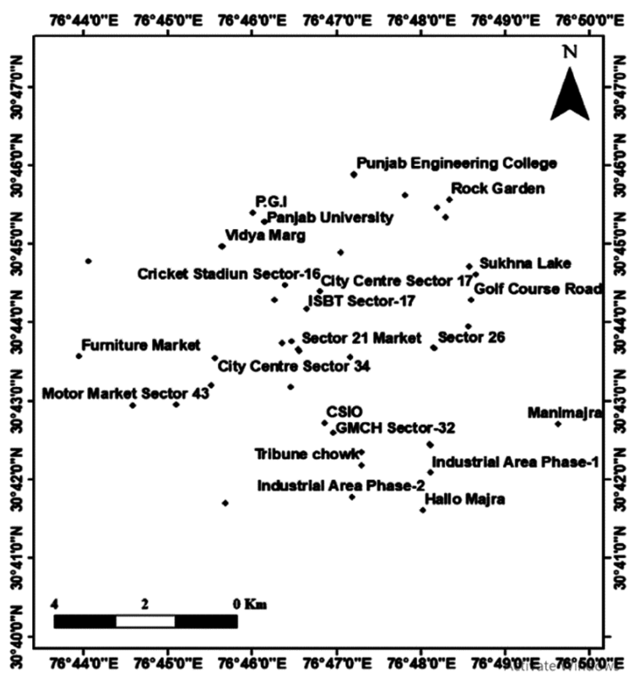

Fig. 1 — Location of the 25 monitoring sites.

known as the Chandigarh Tricity. The city enjoys favourable geographical proximity to various key urban centres and serves as an important transportation hub. Chandigarh witnesses a significant number of vehicles on its roads due to its urbanization, population growth and economic development. The city's well-planned road network including wide roads and well-maintained infrastructure accommodates the increasing vehicular traffic. As a result, Chandigarh has very high per capita car density in India.

3.1.1 Data Acquisition and Analysis

In the present study, primary Noise data of Chandigarh city was gathered at 25 various locations. A total of 50 noise data were collected for Peak Morning hours and Peak Evening Hours, based on these data noise maps were build. At each location, measurements were made for 30 minutes. ArcGis 10.8 was used for plotting noise contours with the help of IDW interpolation tool. The noise measurement presented in the noise maps is estimated to have a measurement uncertainty of ±1.5 dB (k = 2).

3.2 Ambient Noise Level Measurement

The instrument used for ambient Noise measurement is Optimus Green CK : 171C (conforming to IEC 61672-1:2002 class 1; IEC 60651:2001 type 1, a class 1 pre-polarized microphone, and a 1:3 Octave Band with measuring level and frequency ranges of 35–130 dB and 6.3 Hz–20 kHz respectively). Prior to taking measurements at each chosen site, the devices were calibrated using the class 1 acoustic calibrator. The device was held at a tripod 2 meter away from the source of noise and 1.5 meter above the ground. The microphone was directed at the alleged noise source, more than 3 m away from any potential reflective surfaces. Noise climate (NC), which is determined by subtracting L90 from L10, is helpful for assessing the variation of sound levels over a specific time period. On the basis of the background (L10) and peak (L90) levels observed, the traffic noise index (TNI) is calculated. The calculated TNI and noise dissatisfaction are significantly correlated. TNI[28] accounts for annoyances and discomforts such sleep disturbance. In this study, the level of noise pollution (Lnp) is also calculated. Equations 1 to 3[29-31] provide the formulas for determining NC, TNI and Lnp.

$$\mathrm{NC} = L_{10} - L_{90} \quad \text{... (1)}$$

$$\mathrm{TNI} = 4(\mathrm{NC}) + L_{90} - 30 \quad \text{... (2)}$$

$$\mathrm{NPL} = [\mathrm{NC}^2/60] + \mathrm{NC} + L_{50} \quad \text{... (3)}$$

3.3 Noise Mapping

Noise mapping of Chandigarh city involves the systematic assessment and analysis of noise levels across 25 key locations within the city. Noise maps of Chandigarh city for Peak Morning Hours and Peak Evening Hours were made using ArcGIS 10.8 software. By collecting data from multiple monitoring points, noise mapping provides a comprehensive understanding of the acoustic environment in Chandigarh[32]. The collected data is then analysed and represented through visual maps or diagrams, highlighting areas with high noise levels and identifying potential noise hotspots. Noise maps are generated using IDW (Inverse Distance Interpolation), with the help of weighted average of 25 noise monitoring points, the noise levels at unknown points values are computed. It may be noted that for fewer number of sites where interpolation was done by software, the interpolated values were compared with the measured values and were found to be within ±3dB(A).

4 Results and discussions

4.1 Noise Measurement

Table 1 & 2 displays the hourly equivalent noise levels L_{Aeq} at 25 noise-monitored locations comprising of 8 commercial, 4 industrial, 5 residential, and 8 silent zone locations. Measurements were taken during the time period of September 2022 to December 2022. Along with the L_{Aeq} Table 1 & 2 also includes the L10 (10-percentile surpassed sound levels), L90 (90-percentile exceeded sound levels), L50 (50-percentile exceeded sound levels), TNI (Traffic Noise Index), NC (Noise Climate), and NPL (Noise Pollution Level). Fig. 2 shows L_{Aeq} for Peak Morning and Evening hours.

4.1.1. Peak Morning Hours (9AM-11AM)

It can be observed from Table 1 that L_{Aeq} varied in the range 67.4 to 77.8 dB(A). The minimum level of 67.4 dB(A) was observed at Rock Garden (S) and the maximum level of 77.8 dB(A) was observed at ISBT sector-17 (C). This can be explained by the fact that commercial sites are bustling hubs of economic activity, with numerous businesses, machinery, delivery trucks, construction work and daily commute vehicles. In contrast, silence zone sites are designated areas where noise levels are strictly regulated and minimized to ensure tranquillity such as libraries, parks, or residential neighbourhoods. Here, activities

Table 1 — Hourly equivalent noise levels for Peak Morning Hours at 25 sites in Chandigarh

S. No	Location	Zone	Leq	L10	L50	L90	NC	TNI	NPL
1	Aroma Chowk Towards sector-21 Residence	Residential	74.9	78.9	72.7	63.4	15.5	95.4	92.2
2	Chandigarh Club	Silence	69.5	73.2	65.6	65	8.2	67.8	74.9
3	City Centre Sector 17	Commercial	74	75.2	67.4	61.3	13.9	86.9	84.5
4	City Centre Sector 34	Commercial	76.4	79.4	73.9	62	17.4	101.6	96.3
5	Cricket Stadium sector-16	Commercial	72.7	76.4	68.9	61.5	14.9	91.1	87.5
6	CSIOmain gate	Silence	71.9	77.1	66.1	57	20.1	107.4	92.9
7	Furniture Market	Industrial	75.8	79.1	64.2	62	17.1	100.4	86.1
8	GMCH Sector-32	Silence	75.5	78.6	72	59.4	19.2	106.2	97.3
9	Golf Course Road	Residential	71.3	75.9	65.1	56.5	19.4	104.1	90.7
10	Hallo Majra	Residential	77.3	80.3	75	67.4	12.9	89	90.6
11	Industrial Area Phase-1	Industrial	76.6	78.7	72	60.1	18.6	104.5	96.3
12	Industrial Area Phase-2	Industrial	74.7	74.1	66.5	59.6	14.5	87.6	84.5
13	Industrial Area	Industrial	76.9	78.6	72	65.9	12.7	86.7	87.3
14	ISBT Sector-17	Commercial	77.8	80.4	74.7	67.4	13	89.4	90.5
15	PEC main gate	Silence	70.1	72.2	66.1	60.1	12.1	78.5	80.6
16	Manimajra	Residential	76.3	78.7	73.8	64.1	14.6	92.5	91.9
17	Motor Market Sector 43	Commercial	77.4	81.2	74.7	65.8	15.4	97.4	94.0
18	P.G.I main gate	Silence	75.4	77.4	72.3	67.6	9.8	76.8	83.7
19	PU Gate No.1	Silence	74.7	77.1	73.1	69.4	7.7	70.2	81.7
20	Rock Garden	Silence	67.4	69.1	61.5	56	13.1	78.4	77.4
21	Sector 21 Market	Commercial	71.5	74.9	68.9	61.9	13	83.9	84.7
22	Sector-26	Commercial	72.6	77.1	67.8	58.4	18.7	103.2	92.3
23	Sukhna lake	Silence	69.9	73.3	67.2	59.6	13.7	84.4	84.0
24	Tribune chowk	Commercial	76.2	78.8	73.7	66	12.8	87.2	89.2
25	Vidya Marg	Residential	71.3	75.9	65.1	56.5	19.4	104.1	90.7

that generate excessive noise are either prohibited or controlled to maintain a peaceful environment. Therefore, the inherently vibrant and dynamic nature of commercial sites contribute to a higher noise level compared to the intentionally quieter silence zone sites. Table 1 shows that the highest value for L_{10} was observed to be 81.2 dB(A) at Motor market sector-43 and minimum value was observed to be 69.1 dB(A) at Rock Garden (S). However, L_{90} is commonly used to measure the background noise levels and Table 1 shows that the minimum value of L_{90} was measured to be 56 dB(A) at Rock Garden (s) and maximum value of 69.4 dB(A) at Punjab University (S). This is because of the high background noise present near Punjab University due to honking and heavy traffic. The TNI (Traffic Noise Index) measures how much traffic flow varies and a value of TNI over 74 dB(A) is considered to be above the threshold[33]. TNI ranges from 67.8 dB(A) to 107.4 dB(A) and just 2 out of the 25 sites the Chandigarh Club and Punjab University, show TNI below the threshold limit of 74 dB(A). Additionally, NC (Noise Climate) refers to the range across which the sound levels vary over a given period of time. It is evident from Table 1 that the value of NC ranges between 7.7 dB(A) and 20.1 dB(A). In addition, Fig. 2 displays a frequency spectrum of L_{Aeq}at a few of the chosen sites for the peak morning hours. From Fig. 3, it can be seen that the peak occurs between 40 Hz to 80 Hz for lower frequencies and at 2.5 to 4 KHz for higher frequencies.

It can be observed from Table 2 that L_{Aeq} varied in the range 71.2 to 78.1 dB(A). The minimum level of 71.2 dB(A) was observed at Punjab Engineering College main gate (S) and the maximum level of 78.1 dB(A) was observed at industrial Area (I). This can be explained by the fact that industrial areas often involve the use of heavy machinery such as manufacturing equipment, generators, or construction tools. These machines generate significant noise as they operate, contributing to the overall noise level in the area. Additionally, industrial areas are characterized by constant activity, with multiple operations taking place simultaneously. This leads to a higher concentration of vehicles, trucks, and transportation activities, all of which generate noise through engine sounds, honking, and loading and unloading activities. Table 2 shows that the highest value for L_{10} was observed to be 80.4 dB(A) at City Centre Sector 17 and minimum value was observed to be 74.0 dB(A) at Rock Garden (S).

Table 2 — Hourly equivalent noise levels for Peak Evening Hours at 25 sites in Chandigarh

S. No	Location	Zone	Leq	L10	L50	L90	NC	TNI	NPL
1	Aroma Chowk Towards sector-21 Residence	Residential	75.1	77.8	73.7	67.9	9.9	77.5	85.2
2	Chandigarh Club	Silence	73.5	75	69.2	63.7	11.3	78.9	82.6
3	City Centre Sector 17	Commercial	75.9	80.4	72.4	65.2	13.9	90.8	89.5
4	City Centre Sector 34	Commercial	76.3	79.4	73.5	68.3	11.1	82.7	86.7
5	Cricket Stadium sector-16	Commercial	73.5	76.9	70.9	66.1	10.8	79.3	83.6
6	CSIOmain gate	Silence	73.1	75	69.2	63.7	11.3	78.9	82.6
7	Furniture Market	Industrial	77.6	79.1	74.7	67.4	13	89.4	90.5
8	GMCH Sector-32	Silence	76.2	78.8	73.7	66	12.8	87.2	89.2
9	Golf Course Road	Residential	73.4	76	70.3	59.7	16.3	94.9	91.0
10	Hallo Majra	Residential	76.8	79.5	71.7	63.5	16	97.5	92.0
11	Industrial Area Phase-1	Industrial	77.1	78	73.7	70.4	7.6	70.8	82.3
12	Industrial Area Phase-2	Industrial	74.5	77.6	72.6	65.9	11.7	82.7	86.6
13	Industrial Area	Industrial	78.1	75.2	68.8	61.5	13.7	86.3	85.6
14	ISBT Sector-17	Commercial	76.6	78.7	72	60.1	18.6	104.5	96.4
15	PEC main gate	Silence	71.2	74.7	66.4	59.3	15.4	90.9	85.8
16	Manimajra	Residential	77.6	79.8	77.2	75	4.8	64.2	82.4
17	Motor Market Sector 43	Commercial	75.7	78.5	73	62.2	16.3	97.4	93.7
18	P.G.I main gate	Silence	76.4	78.8	74.6	68	10.8	81.2	87.3
19	PU Gate No. 1	Silence	74.1	78.1	69.6	63.3	14.8	92.5	88.1
20	Rock Garden	Silence	71.3	74	65.1	59.6	14.4	87.2	83.0
21	Sector 21 Market	Commercial	74.8	77.3	74.3	69.8	7.5	69.8	82.7
22	Sector-26	Commercial	74.7	74.1	66.5	59.6	14.5	87.6	84.5
23	Sukhna lake	Silence	72.8	75.8	66.6	57.3	18.5	101.3	90.8
24	Tribune chowk	Commercial	74.1	77.7	71.9	62.6	15.1	93	90.8
25	Vidya Marg	Residential	74.3	74.5	70.1	66.6	7.9	68.2	79.0

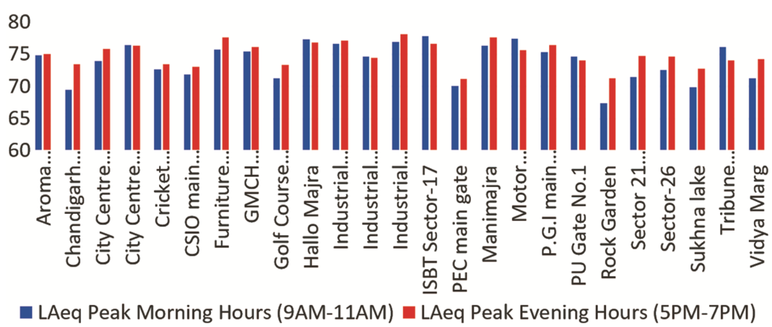

Fig 2 — A-weighted hourly sound levels (L_{Aeq}) for Peak Morning Hours and Peak Evening Hours.

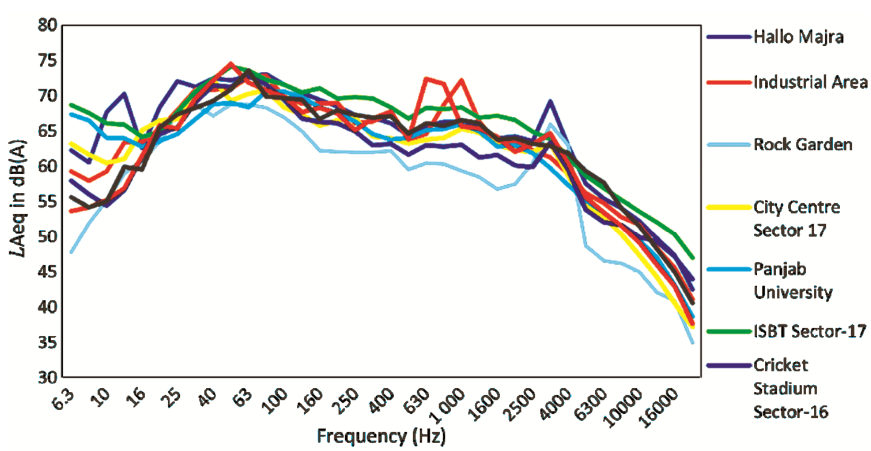

Fig. 3 — Frequency spectrum of Peak Morning Hours noise levels at some of the selected sites 4.1.2. Peak Evening Hours (5PM-7PM).

However, L_{90} is commonly used to measure the background noise levels and Table 1 shows that the minimum value of L_{90} was measured to be 57.3 dB(A) at Sukhna Lake (s) and maximum value of 70.4 db(A) at Industrial Area Phase-1 (I). This is because of the high background noise present at Industrial Area Phase-1 due to the operation of large equipment such as generators, compressors, and machinery, produces continuous noise emissions at high volumes. Additionally, transportation vehicles, including trucks and forklifts, contribute to the noise pollution through engine noise, tire squeals, and exhaust sounds. The TNI (Traffic Noise Index) measures how much traffic flow varies, and a value of TNI over 74 dB(A) is considered to be above the threshold[33]. TNI ranges from 64.2 dB(A) to 104.5 dB(A), and just 4 out of the 25 sites, the Industrial Area Phase-1, Manimajra, Sector 21 market and Vidya Marg show TNI below the threshold limit of 74 dB(A). Additionally, NC (Noise Climate) refers to the range across which the sound levels vary over a given period of time. It is evident from Table 2 that the value of NC ranges between 4.8 dB(A) and 18.6 dB(A).In addition, Fig. 3 displays a frequency spectrum of L_{Aeq}at a few of the chosen sites for the peak evening hours. From Fig. 4, it can be seen that the peak occurs between 60 Hz to 100 Hz for lower frequencies, and at 2.5 to 5 KHz for higher frequencies.

4.2 Zone-Wise Analysis

A zone-by-zone analysis was also carried out to evaluate the ambient noise scenario of all Chandigarh City zones. Tables 3 & 4 display the frequency distribution of hourly equivalent noise levels in various Chandigarh City zones.

4.2.1 Silence Zone

There are a total of 8 silence zone sites out of the 25 locations where noise monitoring has been carried out. It can be observed from the Table 3 that for the peak morning hours out of 8 sites, 3 sites exhibits L_{Aeq} in the range 65 – 70 dB(A), 3 sites exhibits L_{Aeq} in the range 70 – 75 dB(A), while only 2 sites exhibits L_{Aeq} in the range 75 – 80 dB(A). It can be seen from the Table 4 that for peak evening hours out of 8 sites, 5 sites exhibits L_{Aeq} in the range 70 – 75 dB(A), while only 3 sites exhibits L_{Aeq} in the range 75 – 80 dB(A).

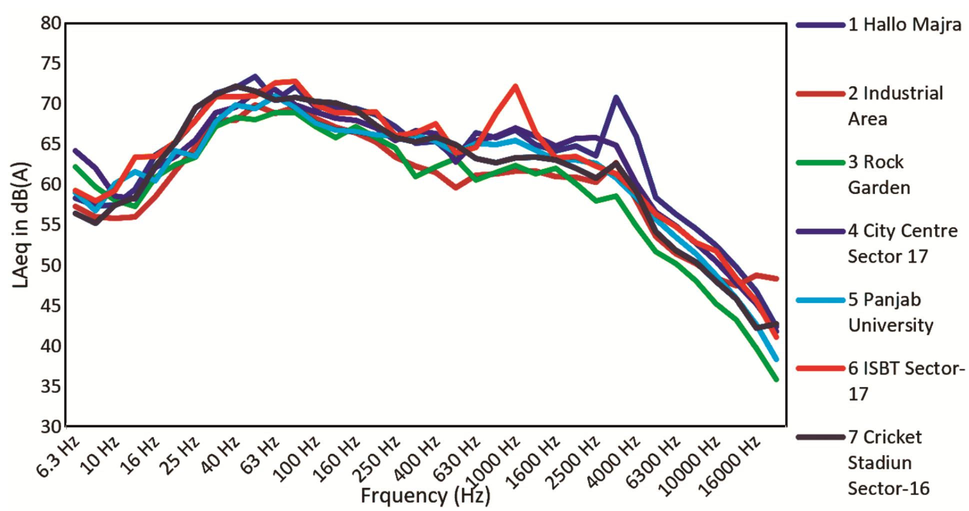

Fig. 4 — Frequency spectrum of Peak Evening Hours noise levels at some of the selected sites.

Table 3 — Frequency (in percentage) of Peak Morning hours equivalent noise levels in distinct zones for 25 sites in Chandigarh

Level range dB(A)	Silence (*N* = *8*)		Residential (*N* = *5*)		Commercial (*N* = *8*)		Industrial (*N* = *4*)	
	No of sites	Frequency percentage (%)	No of sites	Frequency percentage (%)	No of sites	Frequency percentage (%)	No of sites	Frequency percentage (%)
55-60	0	0	0	0	0	0	0	0
60-65	0	0	0	0	0	0	0	0
65-70	3	37.5	0	0	0	0	0	0
70-75	3	37.5	3	60	4	50	1	24
75-80	2	25	2	40	4	50	3	75
80-85	0	0	0	0	0	0	0	0

Table 4 — Frequency (in percentage) of Peak Evening hours equivalent noise levels in distinct zones for 25 sites in Chandigarh

Level range dB(A)	Silence (*N* = *8*)		Residential (*N* = *5*)		Commercial (*N* = *8*)		Industrial (*N* = *4*)	
	No of sites	Frequency percentage (%)	No of sites	Frequency percentage (%)	No of sites	Frequency percentage (%)	No of sites	Frequency percentage (%)
55-60	0	0	0	0	0	0	0	0
60-65	0	0	0	0	0	0	0	0
65-70	0	0	0	0	0	0	0	0
70-75	5	62.5	2	40	4	50	2	50
75-80	3	37.5	3	60	4	50	2	50
80-85	0	0	0	0	0	0	0	0

4.2.2 Residential Zone

There are a total of 5 residential zone sites out of the 25 locations where noise monitoring has been carried out. It can be observed from the Table 3 that for the peak morning hours out of 5 sites, 3 sites exhibits L_{Aeq} in the range 70 – 75 dB(A), while only 2 sites exhibits L_{Aeq} in the range 75 – 80 dB(A). It can be seen from the Table 4 that for peak evening hours out of 5 sites, 2 sites exhibits L_{Aeq} in the range 70 – 75 dB(A), while only 3 sites exhibits L_{Aeq} in the range 75 – 80 dB(A).

4.2.3 Commercial Zone

There are a total of 8 commercial zone sites out of the 25 locations where noise monitoring has been carried out. It can be observed from the Table 3 that for the peak morning hours out of 8 sites, 4 sites exhibitsL_{Aeq} in the range 70 – 75 dB(A), while 4 sites exhibits L_{Aeq} in the range 75 – 80 dB(A). It can be seen from the Table 4 that for peak evening hours out of 8 sites, 4 sites exhibits L_{Aeq} in the range 70 – 75 dB(A), while 4 sites exhibits L_{Aeq} in the range 75 – 80 dB(A).

4.2.4 Industrial Zone

There are a total of 4 industrial zone sites out of the 25 locations where noise monitoring has been carried out. It can be observed from the Table 3 that for the peak morning hours out of 4 sites, 1sites exhibits L_{Aeq} in the range 70 – 75 dB(A), while 3 sites exhibits L_{Aeq} in the range 75 – 80 dB(A). It can be seen from the Table 4 that for peak evening hours out of 4 sites, 2 sites exhibits L_{Aeq} in the range 70 – 75 dB(A), while 2 sites exhibits L_{Aeq} in the range 75 – 80 dB(A).

4.3 Noise Mapping and Hotspot Identification

4.3.1 Noise Map of Peak Morning Hours (9AM-11AM)

The maximum noise level recorded at ISBT Sector-17 (C) during the Peak Morning Hours (9AM-11AM) was 77.8 dB(A), as shown in Fig. 5. Additionally, Rock Garden (S) recorded a minimum noise level of 67.4 dB(A). All of the sites had noise measurements above 67 dB(A).

4.3.2 Noise Map of Peak Evening Hours (5PM-7PM)

The maximum noise level recorded at Industrial Area (I) during the Peak Evening Hours (5PM-7PM) was 77.8 dB(A), as shown in Fig. 6. Additionally, Punjab Engineering College (S) recorded a minimum noise level of 71.2 dB(A). All of the sites had noise measurements above 71 dB(A).

5 Environmental Noise Perception Survey

A survey was conducted among 500 individuals in which a questionnaire of six questions. Different age groups in the community were given this questionnaire through physically and online mode (Gmail, Whats App *etc*.). The purpose of the survey was to understand the community perception towards the annoyance to environmental noise pollution.The participants included 24.2% females and 75.8% males (Table 5). In the socio-acoustic survey, 40% of participants were in the age group 18-25 years, 35% of individuals were in the age group of 25-40 years and only 25% of the individuals were in the age group of 40-60 years. Fig. 7 pictorially represents the outcome of the survey. It can be observed that 67% of the individuals were aware about the noise pollution. It has been noted that 17.27% individuals were extremely annoyed, and 24.3% individuals were moderately annoyed by the noise pollution. 24% of the individuals were extremely annoyed by the traffic noise, while 48% individuals felt moderately annoyed by the traffic noise. 40% of the individuals which participated in the survey feels extremely annoyed by the honking noise, while 37% individuals felt moderately annoyed to the honking noise. Additionally, it is highlighted that 43% individuals felt extremely annoyed by the construction noise whereas 34% individuals felt moderately annoyed by the construction noise.

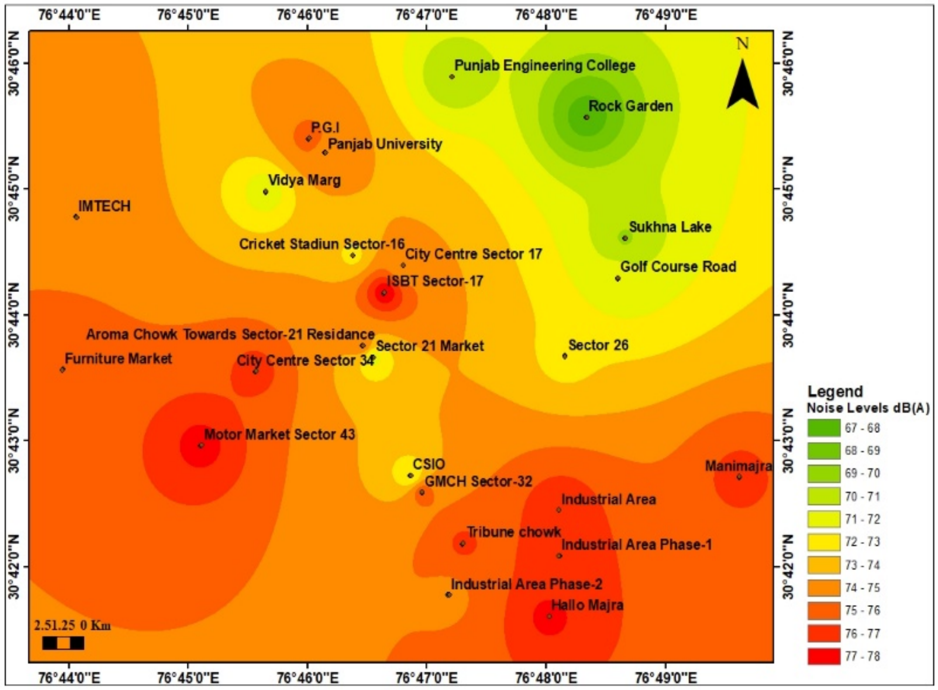

Fig. 5 — Noise Map of 25 noise monitoring sites in Chandigarh during Morning peak hours (9AM-11AM).

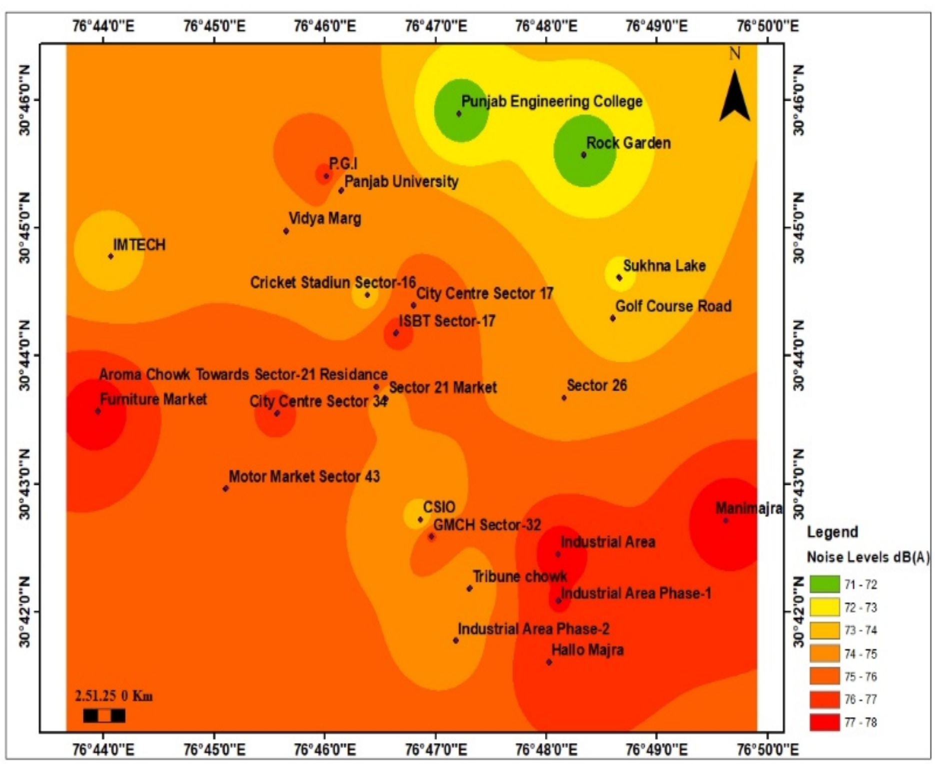

Fig. 6 — Noise Map of 25 noise monitoring sites in Chandigarh during Peak Evening Hours (5PM-7PM).

Overall, the survey results indicate a significant level of awareness about noise pollution and its effects among the respondents. Noise annoyance was commonly reported, with a substantial portion of individuals expressing various levels of annoyance.

Table 5 — Basic socio-demographic features of survey participants (N = 500)

Parameter		Frequency (%)
Gender	Male	75.8
	Female	24.3
Age (years)	< 15	7.0
	15-25	30
	26-40	40
	41-60	18
	>60	5.0
Educational qualification	High School	10.0
	Graduate	45.0
	Post-Graduate	30.0
	Doctorate	15.0
Residential Area	Sector 21	35.2
	Sector 34	25.0
	Sector 8	18.8
	Manimajra	21.0
Noise annoyance	Highly sensitive	43.0
	Medium sensitive	34.0
	Low sensitive	21.0
	Not sensitive at all	2.0
Health effects due to noise	Stressed	16.0
	Sleeping disorder	18.0
	Hypertension	10.0
	Hearing impairment	8.0
	Mentally tired and headache	37.0
	Other health effects	5.0

Traffic noise and vehicular horns were identified as significant sources of annoyance and stress while traveling. Construction noise was found to be highly disruptive for a considerable portion of the respondents. In terms of health impacts, increased Headache and mentally tired were the most frequently reported consequence of noise pollution, followed by Hypertension, sleep disturbances and hearing problems. Reduced concentration and productivity were also recognized as health impacts, albeit to a lesser extent. These findings emphasize the need for effective measures to mitigate noise pollution and raise awareness about its adverse effects on individuals well-being. Strategies such as improved urban planning, noise barriers, and public education campaigns can contribute to reducing noise pollution and its negative impacts on the population.

6 Environmental Noise Control of Chandigarh City

During the noise monitoring at 25 various locations across Chandigarh's for Peak Morning and Peak Evening Hours, the following primary sources of noise pollution were discovered:

- **Traffic Noise**: The heavy vehicular traffic on roads, especially during peak hours, contributes significantly to noise pollution. It includes the noise generated by cars, buses, motorcycles, and trucks.
- **Construction and Industrial Activities**: Construction sites and industrial areas produce considerable noise due to machinery, equipment, and construction activities. These activities can lead to prolonged exposure to loud noise levels.

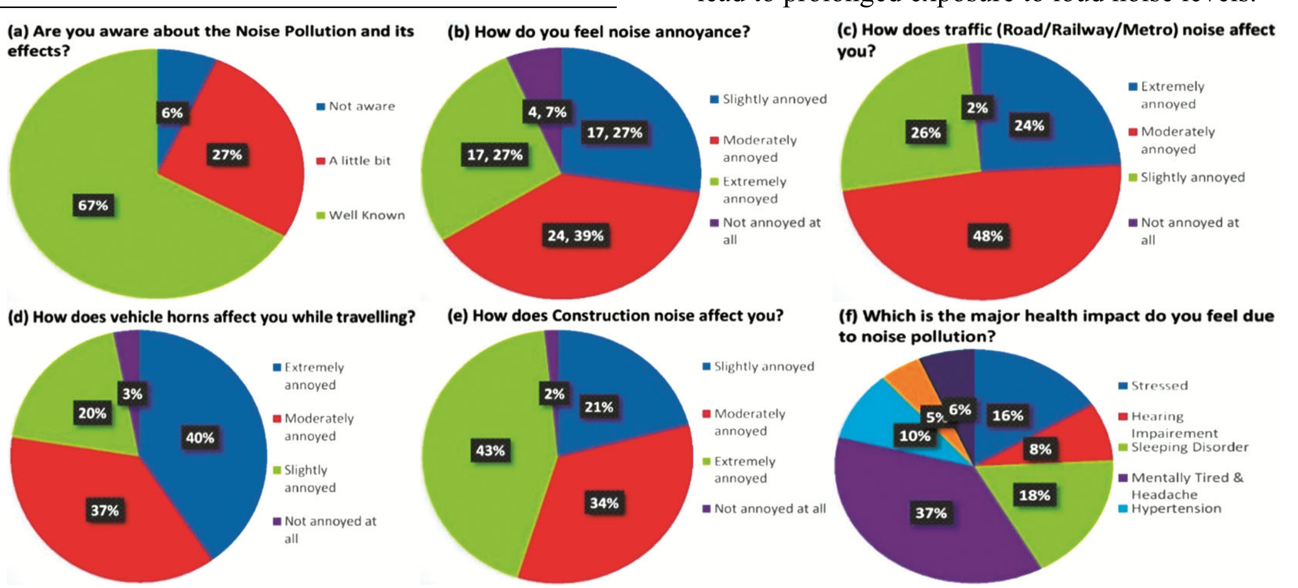

Fig. 7 — Results of Socio-Acoustic Survey conducted among various individuals sites in Chandigarh.

- **Public Events and Celebrations**: Festivals, cultural events, and public gatherings often involve loud music, sound systems, and fireworks, which contribute to noise pollution. The volume of speakers and amplifiers used in such events can be excessively high and disturbing.
- **Commercial Establishments:** Markets, shopping centers, restaurants, and entertainment venues in Chandigarh can be sources of noise pollution. Activities such as loud music, crowd noise, and equipment noise from commercial establishments can add to the overall noise levels.
- **Public Transport:** Public transport systems, including buses and trains, can generate noise pollution due to the movement of vehicles and the noise produced by engines and brakes.
- **Horn Honking:** Excessive and unnecessary honking by motorists is a prevalent source of noise pollution in Chandigarh. Honking contributes to noise levels on roads and can be a significant cause of annoyance and discomfort.
- **Construction of Infrastructure Projects:** Ongoing construction of infrastructure projects like roads, flyovers, and bridges can generate high levels of noise due to heavy machinery, drilling, and excavation activities.
- **Generator Sets and Air Conditioners:** The use of generator sets and air conditioners, especially in residential areas, can contribute to noise pollution. Improper maintenance and older equipment can further amplify the noise levels.

To mitigate noise pollution in Chandigarh city, several measures can be implemented. Here are some potential mitigation measures:

- **Implement and Enforce Noise Regulations:** Establish comprehensive noise regulations and standards that specify permissible noise levels for different areas and times of the day. Strict enforcement of these regulations will help in curbing excessive noise sources.
- **Public Awareness and Education:** Launch public awareness campaigns to educate residents about the harmful effects of noise pollution and promote responsible behavior. Encourage individuals to avoid unnecessary honking, use quieter modes of transportation, and be mindful of noise levels in public spaces.
- **Traffic Management:** Improve traffic management strategies to reduce congestion, such as implementing efficient traffic flow patterns, optimizing signal timings, and promoting public transportation. Smooth traffic flow can help minimize the noise generated by vehicles.
- **Acoustic Planning and Design:** Incorporate noise control measures in urban planning and design processes. This includes strategic placement of residential areas away from major noise sources, implementing noise barriers along highways and busy roads, and incorporating noise-absorbing materials in buildings and infrastructure.
- **Green Spaces and Urban Landscaping:** Increase the number of green spaces and parks in the city. Vegetation helps absorb sound waves, acting as a natural noise barrier and reducing noise pollution. Urban landscaping should also include the use of noise-absorbing plants and trees.
- **Soundproofing and Insulation:** Encourage the use of soundproofing techniques and materials in buildings, especially in areas close to noisy sources like roads or industrial zones. Insulating windows, walls, and roofs can significantly reduce indoor noise levels.
- **Strict Regulation of Construction Activities:** Enforce regulations on construction activities to limit noise generated by machinery, equipment, and construction work. Implement time restrictions on construction activities in residential areas and require contractors to use noise-reducing equipment whenever possible.
- **Noise-Reducing Infrastructure:** Install noise barriers along major roads, highways, and railway tracks to minimize the impact of traffic and train noise on nearby residential areas. This can include physical barriers, sound-absorbing surfaces, and vegetation.
- **Community Engagement:** Encourage community involvement in noise pollution reduction efforts. Establish local committees or groups to monitor and report noise pollution incidents, collaborate with authorities, and suggest further mitigation measures.
- **Research and Development:** Promote research and development of new technologies and innovations to reduce noise pollution. This can include the development of quieter vehicle engines, noise-reducing construction materials, and innovative urban design solutions.

7 Conclusions

The present study conducts assessment of noise levels at 25 different locations including 8 commercial, 4 industrial, 5 residential, and 8 silence sites in Chandigarh city by analysing noise descriptors such as L10, L90, NC, NPL, TNI and hourly equivalent noise levels. In addition to noise assessment, noise maps were developed for peak morning hours (9AM-11AM) and peak evening hours (5PM-7PM) for these sites using ArcGIS v 10.8 software. The following conclusions are depicted from the study:

- The 25 monitored sites equivalent noise levels were found to vary between 67.4 and 77.8 dB(A). Most sites display equivalent noise levels between 67 dB(A) and 79 dB(A).
- The investigation revealed that, for the Peak Morning Hours (9AM-11AM) the smallest hourly equivalent level was reported at the Rock Garden, a site in a silent zone, the maximum hourly equivalent noise level was reported at ISBT sector-17, a location in a commercial zone.
- Also, for Peak Evening Hours (5PM-7PM) the smallest hourly equivalent noise level was reported at the Punjab Engineering College, a site in a silent zone, the maximum hourly equivalent level was reported at Industrial Area, a location in a Industrial zone.
- It was observed that for Peak Morning Hours TNI varied between 67.8 dB(A) and 107.4 dB(A), and only 2 of the 25 sites displayed TNI below the 74 dB(A) threshold. And for Peak Evening Hours TNI ranges from 64.2 dB(A) to 104.5 dB(A), and just 4 out of the 25 sites, the Industrial Area Phase-1, Manimajra, Sector 21 market and Vidya Marg, show TNI below the threshold limit of 74 dB(A).
- The frequency spectrum analysis of the ambient noise levels for the Peak Morning Hours revealed that for the lower frequency the peak was observed at 40 Hz to 80 Hz whereas peak for the higher frequency was observed at 2.5 to 4kHz. For Peak Evening Hours the peak was observed at 60 Hz to 100 Hz in lower frequencies, while for the higher frequencies, the peak is observed at 2.5 to 5 kHz.

The socio-acoustic survey indicates a significant level of awareness about noise pollution and its effects among the respondents. Traffic noise and vehicular horns were identified as significant sources of annoyance and stress while traveling 40 % of individuals were highly annoyed due to the honking noise, while 37 % of individuals were slightly annoyed due to honking. In terms of health impacts 18 % of individuals were exposed to sleeping disorder, 37 % of individuals felt mentally tired and headache, and 10 % of subjects were exposed to hypertension due to road traffic noise.

The study assessed and mapped the distribution of noise levels across various sites in Chandigarh city. This comprehensive understanding is crucial for urban planners, policymakers, and city authorities to develop targeted strategies and implement effective measures to mitigate noise pollution. The research has highlighted specific noise hotspots and identified areas that require immediate attention and intervention. By utilizing the findings, policymakers can make informed decisions regarding land use planning, infrastructure development, and urban design to create healthier and more sustainable living environments. Future work shall focus on developing new approaches to forecast Noise levels from time series data.

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