Analysis and mapping of the indoor acoustic environment in university study spaces

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Abstract. The university setting significantly impacts the student's learning and academic achievement. A vital aspect shaping their productivity and well-being within this environment is the indoor soundscape. Different organizations, nationally and internationally, have emphasized the importance of addressing noise-related issues and have established guidelines. This study investigates how indoor soundscapes affect student learning and achievement in university classrooms. The present study analyses noise levels at nine locations during morning, afternoon, and evening study hours using a class 1 sound level meter. Results show noise levels ranging from 49.8 to 77.6 dBA, averaging 66.1 dBA. Over 96% exceeded the ANSI, CPCB noise limit of 50 dBA, with 62.96% surpassing WHO's 55 dBA standards. Seven of nine locations maintained acceptable noise levels 95% of the time, considering a ±10 dBA fluctuation allowed by CPCB. Libraries and computer labs generally had lower noise, while engineering labs had higher levels due to noisy equipment. This research holds significance for educational institutions, policymakers, and stakeholders in creating conducive learning environments. Understanding prevailing soundscapes informs the design and management of study areas, and helps optimize learning spaces for improved productivity.

Keywords. University Campus, Learning Environment, Soundscapes, Noise Pollution Level (NPL), Noise Mapping, GIS.

1 Introduction

Constantly, we are surrounded by sound, from the tranquil buzz of nature to the cacophony of city settings. While certain sounds are enjoyable and essential for communication, unwelcome or excessive noise can heavily affect our health, overall wellness, and cognitive abilities [1,2]. Excessive or disruptive undesired sounds in a specific location are categorized as noise. When such sounds persistently occur in the surrounding environment, it is termed noise pollution [3]. Noise pollution occurs when the sound volume exceeds permissible limits for a particular environment [4]. Elevated levels of noise often stem from diverse origins, broadly categorized as natural and manmade sources [5]. Natural noise consists of sounds produced by humans, insects, birds, barking dogs, thunderstorms, wind, etc. Conversely, man-made sources encompass traffic, industrial activity, construction work, loudspeakers during festivals, railways, and firecrackers

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[6], collectively contributing significantly to overall environmental noise pollution. Noise pollution has been increasingly impacting the worldwide populace, particularly in large urban areas [7]. Long-term exposure to loud noises can lead to both mental and physical health issues in individuals [8]. As per a recent study published by the World Health Organisation (WHO), approximately 100 million individuals in Europe are subjected to roadway noise, resulting in a yearly minimum loss of 1.6 million years of healthy life [9].

Noise in educational institutions such as schools and colleges is a major source of stress and irritability [10]. These institutions often experience high levels of external noise sources such as roadside traffic, construction activities, and other internal factors such as student conversations or sound-generating devices [11]. Factors such as teaching methodologies, student and educator behaviour, student demographics, and the nature of the learning activities can impact noise generation [12,13,14].

The operation of noisy equipment like laboratory machines, tools and audio-visual systems in a room can contribute to increased overall sound levels, leading to disturbances throughout the site space [15]. The specific type and intensity of the equipment, as well as its proximity to individuals, can impact the extent of noise disruption [16]. Old equipment that is malfunctioning or not maintained properly may produce disruptive sounds, which influences the acoustic environment [12]. Heating, ventilation, and air conditioning (HVAC) systems present in the space under study may also generate noise due to the operation of various components such as fans, compressors, air handlers, etc. Different types of HVAC systems produce different levels of noise [12,17].

Excessive external noise levels can increase indoor noise levels, making it challenging for occupants to concentrate and communicate effectively [18]. Studies have shown that on average, the noise level recorded in schools is around 57 dBA, with roadside traffic being the primary source of noise [19]. Noise from other sources like construction work or loud music can pass through windows, doors, or walls of a room[20]. The status of doors or windows in a room, whether they are open or closed, can have a substantial impact on noise levels. Closed ones provide a barrier that helps block the transmission of sound waves between rooms or from external sources, thereby reducing noise infiltration. On the other hand, open ones allow sound to travel more freely, leading to increased noise levels within the room [21,22]. Properly sealed pathways with soundproofing features can further enhance noise reduction capabilities [23]. Factors such as poor-quality acoustic, ceiling tiles, lack of acoustically treated furniture, lack of carpet, and single pane windows can enhance the background noise levels in classrooms, disrupt learning activities, and impact the performance of both students' and teachers' [24].

The combination of these noises can create disturbances in the classroom environment, thereby creating an unhealthy environment for students and teachers [11]. Various researchers have investigated the impact of various meteorological variables such as temperature, relative humidity, and wind speed on exacerbating or mitigating urban noise pollution [25]. Regression analysis revealed that wind speed plays a positive role in reducing noise levels, while temperature tends to increase ambient noise levels. Additionally, lower relative humidity was found to significantly decrease noise levels [26,27].

According to studies by the WHO, exposure to noise levels above 53 dBA can lead to increased blood pressure, heart rate, and muscle weakness [2]. While students may become accustomed to these noise levels over time because this is what they hear daily, the potential dangers associated with it should not be overlooked [1]. Studies by leading scientists suggest that intermittent exposure to 100 dBA may have little effect on human health, but continuous

exposure throughout the day can lead to psychological ailments like anxiety, depression, stress, and fatigue [9]. It may also cause cardiac, auditory, or cognitive problems in individuals of all ages from foetuses to the elderly [10,28]. It is therefore crucial for individuals to be conscious of their daily exposure to elevated levels of noise to protect their overall health. Generally, verbal communication, teaching, learning, mental tasks, and sleep are typically the most impacted [29]. Exposure to disturbing noises can lead to a delay of up to one month in the reading and comprehension abilities of young individuals. Many people may not fully comprehend the negative effects that noise can have, particularly those who are consistently exposed to lower levels of noise over extended periods [9].

Researchers and the public, are increasingly raising their concerns about this issue and there has been a surge in the development of laws and policies to reduce and mitigate the impact of these unacceptable noises on the social environment [30]. International standards for classroom listening environments have been laid down by the World Health Organization (WHO) [9], American National Standard Association (ANSI) [31], American Speech Language Hearing Association (ASHA) [32], and Indian national standards by the Central Pollution Control Board (CPCB), India [33]. Various organizations have also established standards for building design and acceptable acoustic levels to manage background noise and reverberation in classrooms.

Larger classrooms have longer reverberation times, leading to increased background noise levels. The research found that increasing classroom size is co-related with worse speech intelligibility [34]. Additionally, larger spaces may require louder speaking volumes from teachers or students to be heard, contributing to overall noise levels [12,35,36,37]. Researchers have also discovered that classrooms with tall ceilings reduced noise levels and facilitated higher comprehensibility of speech than classrooms with small height ceilings [38,39]. Ceiling shape can also affect noise levels in a variety of ways. Flat ceilings can contribute to sound reflection and reverberation, thereby increasing noise levels. In some cases, a slatted, vaulted, or pitched roof can reduce the acoustic energy input compared to a flat roof, thus reducing the overall noise level [40].

Material of construction of interior and exterior walls, ceilings, and floors can significantly affect reflection and noise excitation. Thick walls, partitions, and hard finishes provide excellent acoustic insulation, thus reducing noise transmission and reducing indoor noise levels [36,41]. Buildings made of hard materials such as brick, concrete, and stone provide better sound insulation compared to lighter materials such as wood or vinyl siding [36]. However, wear and tear of buildings over time leads to gaps, cracks, or structural weaknesses in the building envelope, allowing more external noise to infiltrate the walls of the room. Acoustic ceiling tiles or panels with sound-absorbing nature help reduce noise levels by absorbing excess sound energy. Conversely, hard roof materials such as concrete or metal can reflect sound, resulting in increased noise levels and poor sound quality [42]. The composition of furniture affects noise levels through its acoustic properties. Soft, upholstered surfaces absorb sound waves, helping to muffle noise and reduce reverberation. In contrast, dense furniture reflects sound and can contribute to increased noise levels [36,43]. Similarly, soft flooring materials such as carpets or mats absorb sound waves and reduce noise whereas, solid materials such as tile or hardwood floors reflect sound, which amplifies the noise [36]. Factors such as substandard acoustic ceiling tiles, absence of acoustically treated furniture, lack of carpeting, and single-pane windows can amplify background noise levels in classrooms. This can disrupt learning activities and impact the performance of both students and teachers [24].

In 2001, R. Murray Schafer, a renowned Canadian musician, and composer, introduced a concept known as "soundscape," which refers to any specific auditory snapshot of the

surrounding sound environment that is recognized as a distinct field of study. Schafer's definition of "soundscape analysis" encompasses the comprehensive examination of all kinds of sounds present in a particular area or region [44]. A Sound level meter is a tool that empowers soundscape
design by enabling precise measurement of ambient noise levels [45] and identification of specific
noise sources. This data informs the creation of soundscapes that are both aesthetically pleasing and functionally suited to the environment. Noise mapping is a contemporary method that illustrates noise level metrics of various areas on a unified map [5], offering a visual representation of noise level within a specific region. This tool is valuable for acoustic urban planning as it aids in pinpointing noise pollution hotspots within an area [46].

The significance of a favourable listening environment is well acknowledged; however, there remains a noticeable dearth of data on sound environments within higher education institutions in India. This study delves into a previously uncharted territory: the acoustic ecology of study areas within university settings. While past research has outlined the sound environments of university campuses, this research goes further by concentrating on the distinctive sonic ambiance within specific indoor study spaces. The purpose of this research is to quantify the acoustic environment of various study spaces within Delhi Technological University (DTU). This involves measuring noise metrics like L_{eq}, L_{10}, $L_{50,}$ $L_{95,}$ and NLP using a sound level meter, mapping their distribution across these study areas on QGIS, and comparing them to the standards prescribed by regulatory bodies like CPCB [33], ANSI [31] and WHO [9]. The authors anticipate that this study will serve as an asset for educational authorities by proposing potential improvements to existing study areas and offering guidance for future university construction projects, thereby striving to create more optimal listening conditions.

2 Materials and Methods

2.1 Study Area

The research investigation was conducted at the primary campus of Delhi Technological University (DTU) situated in New Delhi, India. Spanning an expansive total area of 163.9 acres (equivalent to 66.3 hectares), DTU's campus comprises 10% dedicated to building structures, with the remaining portion allocated to open grounds, lush gardens, and interconnected pathways. Noteworthy is the campus's sizable population, accommodating a student body of 11,000 individuals enrolled in various undergraduate and postgraduate programs. For the research endeavour, a meticulous selection process identified a total of nine indoor classrooms and study areas (referenced in Table 1 and visually depicted in

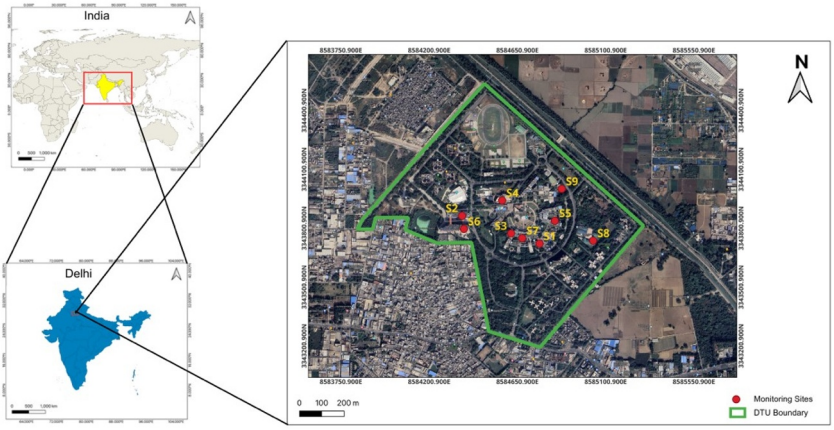

Fig**. 1**) dispersed strategically within the campus premises. The rationale behind choosing these specific locations was rooted in their distinct positional diversity, unique classroom attributes, and the widespread representation of students across the campus landscape. The objective was to capture an exemplary sample of the campus environment to analyse spatial and temporal variations in noise levels.

Table 1. List of selected sites on the campus along with their location codes, latitude, and longitude

Code	Site Name	Latitude (° N)	Longitude (° E)
S1	Water Engineering Laboratory	28.748876	77.118243
S2	Machine Learning Laboratory	28.749993	77.114696
S3	Power Electronics Laboratory	28.749286	77.116941
S4	Library Reading Classroom	28.750609	77.116529
S5	Mechanical Engineering Workshop	28.749793	77.118948
S6	Academic Block Classroom	28.749468	77.114776
S7	Old Department Classroom	28.749096	77.117449
S8	Pragya Bhawan Classroom	28.748994	77.120699
S9	SPS Classroom	28.751074	77.119260

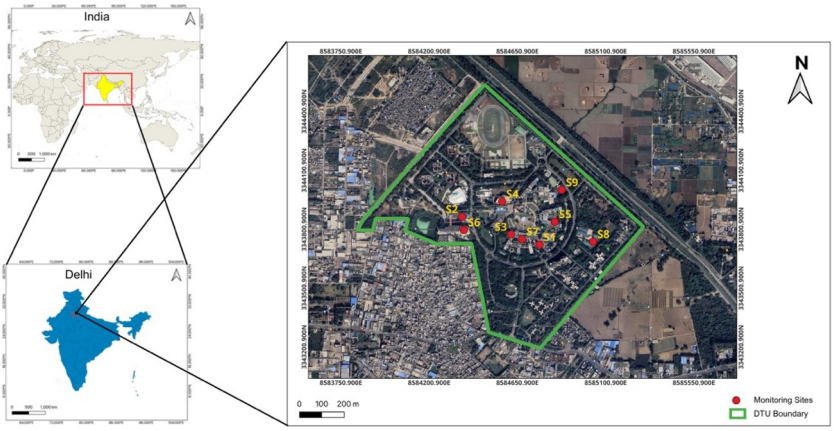

Fig. 1. Map of locations within the DTU campus selected for noise level monitoring

2.2 Methodology

2.2.1 Tools and Techniques

The study utilized a CESVA SC 310 sound level meter (or SLM) to measure noise level. This Class 1 Integrated SLM offers a frequency weighting of A, C, and Z, with a measurement range from 30 dBA to 137 dBA and an accuracy of ±0.6 dBA. Measurements were taken using the dBA scale, chosen for its suitability in assessing noise sources typical in educational settings and aligning with perceived speech levels. The SLM was calibrated according to IEC 61672-1 standard to ensure accuracy. The characteristics of the SLM [47] are provided in Table 2. The A-weighting scale was chosen due to its equal emphasis on all noise sources except for lower frequencies, aligning closely with speech levels perceived by listeners. Measurements were taken at each site as shown in Fig. **2**. During active classroom events such as discussions and presentations, as well as quiet activities like reading or writing, measurements of noise levels were taken. Furthermore, external sources of noise such as sounds from the corridor, construction work, and vehicle traffic were also observed and documented [11]. As a result, an

occupied state was defined when the classroom contained students, a teacher, furniture, and any functioning ventilation systems (e.g., heat blowers).

Table 2. Characteristics of CESVA SC 310

Product	CESVA SC 310
Type	Class 1 Integrating Sound Level Meter
Frequency Weighting	A, C, Z
Measurement Range	30 dBA to 137 dBA
Accuracy	± 0.6 dBA
Display	LCD screen
Communication	USB and RS-232 ports
Microphone	½ "condenser microphone

Fig. 2. Noise measurements taken at the monitoring site

2.2.2 Study Design

Noise measurements were conducted three times per day during the morning, noon, and evening periods. Morning measurements were taken from 09:00 to 11:00 hrs, afternoon measurements from 12:00 to 14:00 hrs, and evening measurements from 16:00 to 18:00 hrs. These measurements were carried out in classrooms S1 to S9 from Monday to Friday during study hours.

The measuring procedure was conducted according to the protocols given by the CPCB, in 2015 for ambient noise level monitoring [48]**.** The SLM was calibrated to concerning IEC 61672-1 standard [49]. Noise levels were measured in dBA scales at each location for 15:00 minutes [50,51].

The sound level meter provided the L_{eq}, L_{10}, $L_{50,}$ and L_{95} values for the entire monitoring. L_{eq} represents the equivalent continuous sound level over time. The L_{10} value indicates the peak noise component (noise levels equal to or exceeding 10% of the study duration), while the L_{50} value denotes the median noise (noise levels equal to or exceeding 50% of the study duration). Additionally, L_{95} signifies the background noise components (noise levels equalling or exceeding 95% of the study duration) [52].

LA_{eq}, the measurement used to describe the average sound level over a defined period was calculated for the period of 15 minutes and denoted by LA_{eq},15min. The formula here used is given in (1) [53].

$$LA_{eq} = 10 \log \sum f_i * 10^{Leq/10} \quad (1)$$

Where,
f_i = fraction of the total duration at a consistent level
L_{eq} = sound level in dBA.

The standard deviation (σ) was calculated for the 15-minute noise values. In statistics, the standard deviation measures the extent of dispersion or variation within a dataset. A small standard deviation suggests that the data points are clustered around the mean (or expected value) of the set, while a large standard deviation signifies that the data points cover a wide range of values.

Several research studies have indicated that a wider variation in sound distribution contributes to increased annoyance. The metric, noise pollution level (LNP) incorporates the diversity of sounds and is utilized for evaluating community noise impacts [53, 54]. Here LNP,15min was calculated and it is defined as

$$LNP = LA_{eq} + k\sigma \quad (2)$$

Where,
LNP = level of noise pollution in decibels (dBA)
LA_{eq} = average equivalent sound level (dBA)
σ = standard deviation of the sound level
k = constant with a value determined to be 2.56

To comprehend the overall noise exposure experienced by students at specific sites throughout the day, an average of the morning, afternoon, and evening LA_{eq},15min values were computed using the formula in equation 1 and labelled as LA_{eq}. Then similarly, LNP, LA_{10}, $LA_{50,}$ and LA_{95} were also calculated.

All the above-stated metrics in all nine locations were tabulated in **Error! Reference source not found.** and **Error! Reference source not found.**. Bar charts were prepared to represent the temporal and spatial noise variations. Fig**. 3** 3 depicts the spatial and temporal variation of the noise level in all 9 locations. A clustered chart was also made to represent the temporal variation in the LA_{eq},15min value, for all the nine sites during morning, afternoon, and evening periods. The values of noise standards prescribed by the ANSI [31], CPCB [33], and WHO [9] were also plotted alongside the LA_{eq}, 15-minute values.

Spatial maps of LA_{eq}, LNP, LA_{10}, $LA_{50,}$ and LA_{95} were developed using techniques like inverse distance weighted (IDW) interpolation on Quantum GIS. A version of QGIS 3.36.0-Maidenhead [7,55] was used to visualize the distribution of noise levels across different study spaces within the university. Alongside noise measurements, ambient conditions and factors that could influence the noise level in an indoor space were observed. Both quantitative and qualitative factors, which were both constant and varying in nature were identified and are listed in Table 3 and

Table **4**.

Table 3. Quantitative factors observed during monitoring

Quantitative Factors		
S.no	**Variable Name**	**Description**
1	Wind Speed	Wind speed in the classroom
2	Number of Students	Number of students in the classroom

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S.no	**Variable Name**	**Description**
1	Wind Speed	Wind speed in the classroom
2	Number of Students	Number of students in the classroom
3	Classroom Area	Size of the classroom
4	Ceiling Height	Height of the classroom to ceiling

Table 4. Factors noticed during monitoring that are qualitative in nature

Qualitative Factors		
S.no	**Variable Name**	**Description**
1	Internal Noise Origin/Sources	Noises within the classroom
2	External Noise Origin/Sources	Noises outside the classroom
3	Day Time	Time of day when the noise level was recorded
4	Acoustic Treatment	Implementation of acoustic treatment
5	Ceiling Shape	The shape of the classroom ceiling

The factors – classroom area, ceiling height, acoustic treatment, and ceiling shape are constant, while the remaining variables – wind speed, number of students, internal and external noise sources, and day time are the varying ones that were observed during the noise level monitoring at the nine sites. The data for the constant factors was obtained from the DTU Civil Office. Each factor has some effect on the noise levels. While some factors like classroom characteristics & acoustics, the number of students, and their behaviour, have major and noticeable effects, factors like time of the day and meteorological factors have a minor.

3 Results and Discussions

Noise levels at the nine chosen study areas were monitored and documented. The study outcomes are showcased through numerical tables, charts, and maps. Specifically, Table 5 displays the recorded fifteen-minute equivalent noise levels, the standard deviation in the readings over the fifteen minutes, and the computed noise pollution levels at these nine locations during morning, afternoon, and evening shifts.

Table 5. Spatial and Temporal Variation of Equivalent noise level (LA_{eq},15min), Standard Deviation (σ), and Noise pollution level (LNP,15min)

Site	Time Of The Day	LAeq,15min (dBA)	Standard Deviation (σ)	LNP,15min (dBA)
S1	Morning	51.0	2.5	57.4
	Afternoon	72.2	2.2	77.8
	Evening	51.2	2.1	64.0
S2	Morning	54.3	8.1	75.1
	Afternoon	52.6	3.9	62.5
	Evening	54.2	2.6	60.8
S3	Morning	61.1	4.6	72.8
	Afternoon	66.3	1.6	70.5
	Evening	65.6	4.7	77.6
	Morning	52.4	3.3	60.9

S4	Afternoon	49.8	1.8	54.5
	Evening	55.3	3.3	63.7
S5	Morning	57.6	3.6	66.9
	Afternoon	77.6	11.6	107.3
	Evening	49.7	6.0	67.1
S6	Morning	62.3	4.2	73.1
	Afternoon	66.0	1.3	69.3
	Evening	62.3	3.0	69.5
S7	Morning	61.0	4.1	71.5
	Afternoon	66.8	2.0	71.9
	Evening	61.0	2.0	71.5
S8	Morning	65.0	0.9	67.2
	Afternoon	57.9	2.0	63.0
	Evening	55.2	4.7	67.4
S9	Morning	61.0	2.7	68.0
	Afternoon	60.7	4.3	71.8
	Evening	65.6	2.0	70.6

The highest decibel levels (LAeq,15min**)** recorded during the morning, afternoon, and evening shifts were 65 dBA in S8, 77.6 dBA in S5, and 65.6 dBA in S3, respectively. Conversely, the lowest levels for the three shifts were 51 dBA in S1, 49.7 dBA in S4, and 51.2 dBA in S1, respectively. Overall, the noise levels fluctuated between 49.7 dBA and 77.6 dBA throughout the day, with the highest noise levels typically observed in the afternoon, followed by the evening and morning shifts.

As mentioned earlier in the paper, numerous external and internal factors contribute to the noise levels within a given space. This variation of the varying characteristics often results in standard deviations in the measured values. For instance, abnormal standard deviations of 8.1in S2 during the morning and 11.6 in S5 during the afternoon were attributed to the utilization of noisy laboratory equipment and student discussions.

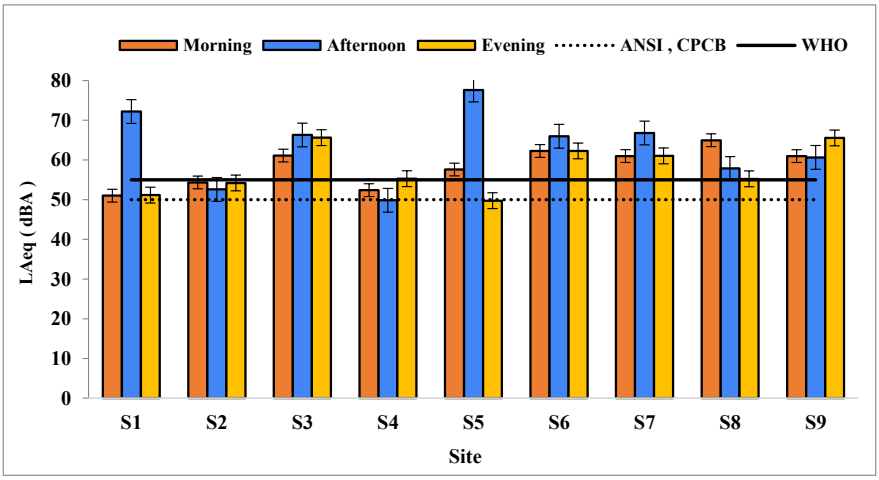

Fig. 3. Graphical representation of the spatial and temporal variation of LAeq,15min at the nine locations, and their comparison with noise standards

The findings from the objective measurements were juxtaposed against the noise limits recommended by ANSI, CPCB, and WHO for urban educational settings, which include schools and universities (Fig. **3**). The noise level assessments revealed that 96.29% of the recorded points surpassed the noise limit set by ANSI and CPCB (LA_{eq} = 50 dBA), while 62.96% of the measured points exceeded the standards outlined by the WHO (LA_{eq} = 55 dBA).

Table 6. Spatial variation of LA_{eq}, LNP, LA_{10}, LA_{50} and LA_{95}

	Noise Metrics (dBA)				
Site	**LA_{eq}**	**LNP**	**LA_{10}**	**LA_{50}**	**LA_{95}**
S1	67.5	73.2	70.3	67.4	63.7
S2	53.8	70.7	57.2	53.4	49.0
S3	64.9	74.6	68.4	64.4	60.1
S4	53.1	61.1	57.1	52.2	48.4
S5	72.9	102.5	74.1	73.0	72.3
S6	63.9	71.0	68.1	62.4	57.3
S7	63.9	71.6	68.4	64.8	57.8
S8	61.3	66.3	65.0	61.0	55.6
S9	63.0	70.4	66.5	62.7	57.9

The average noise level in the indoor spaces (average of 9 sites) was 66.1 dBA. To comprehend the overall noise exposure experienced by students at specific sites, an average of the morning, afternoon, and evening Leq values was computed and labelled as LA_{eq}. Table 6 presents the LA_{eq} values, ranging from 53.1 to 72.9 dBA. The most noise-polluted area was the mechanical engineering laboratory (S5), primarily attributed to the utilization of heavy and noisy instruments like the metal cutter. Following closely was the water engineering laboratory (S1), situated near a road, correlating the high noise levels to vehicular traffic movements and the operation of noisy lab equipment. Additionally, the high LA_{eq} in the Power Electronics

Laboratory (S3) was linked to the presence of electrical machines. Conversely, the Library and Computer Engineering laboratory were identified as the least noisy spaces. Despite this, the overall results exceeded permissible limits, as the university campus is situated in a silent zone, contrasting the recorded noise levels. Fig. **4** illustrates the map of LA_{eq} values across the sites, facilitating the identification of noise level hotspots and enabling the implementation of necessary measures to alleviate the issue.

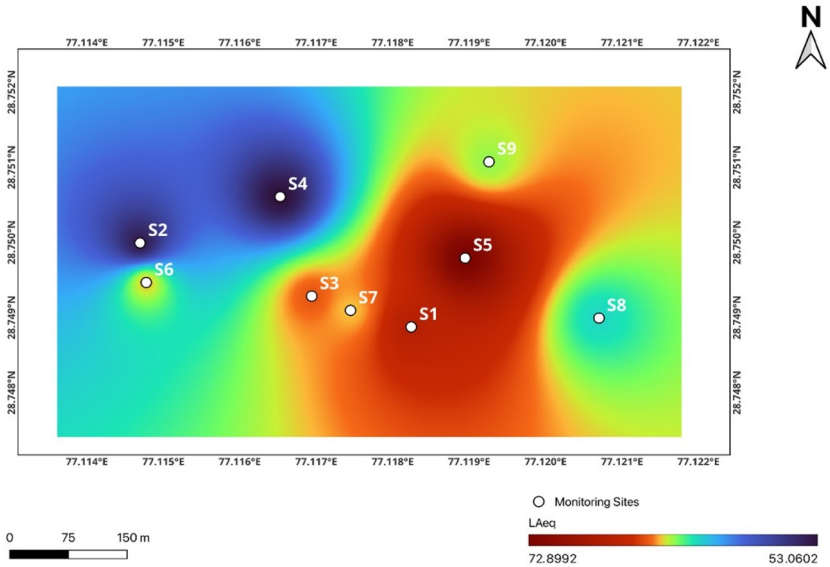

Fig. 4. Mapping of Equivalent Noise Level (LA_{eq}) in the nine sites across the DTU campus

The evaluation incorporated the Noise Pollution Level (LNP), which integrates LA_{eq} with a component signifying the noise variability, namely the standard deviation of instantaneous levels. This metric can be beneficial, particularly in scenarios where noise annoyance is a focal point. LNP is valuable for comparing noise levels in diverse environments with varying noise characteristics, as it provides a more comprehensive assessment than relying solely on LA_{eq}. Fig. **5** depicts the Mapping of Noise Pollution Level (LNP) within the nine sites across the DTU campus, visually representing the noise pollution levels present in each location. Here, we can infer that S5 is the most polluted due to the usage and stoppage of machines.

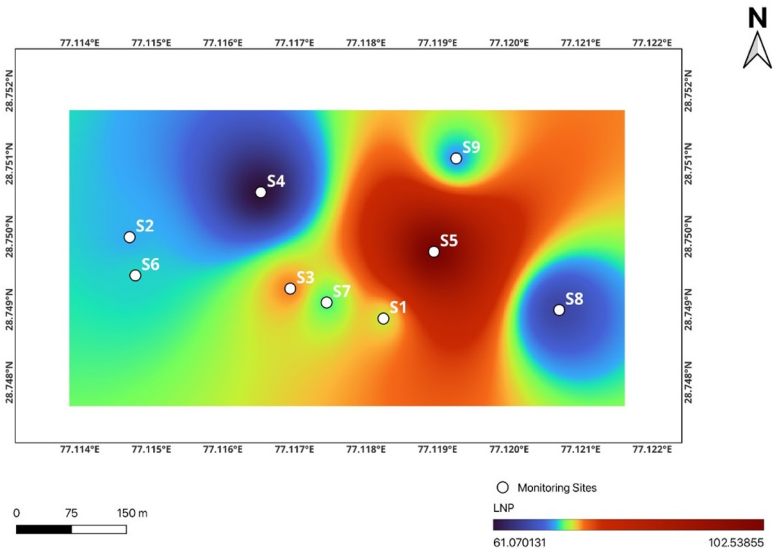

Fig. 5. Mapping of Noise Pollution Level (LNP) in the nine sites across the DTU campus

The noise metrics, i.e. the percentiles of noise level - LA_{10}, LA_{50}, and LA_{95}, were also discussed in this study. Values of these noise indicators are provided in Table 6. For example, looking at Fig. **6**, which shows the representation of LA_{10} (the ten percentile time exceeding noise level), it is observed that peak levels of intrusive noise exceed 10% of the total observation time with values ranging from 57.1 to 74.1 dBA across nine sites throughout the day. Additionally, based on Fig. **7**, showing the variation of LA_{50} (representing average noise level values), a span from 52.2 to 73 dBA indicates that only two classrooms adhere to ambient standards for about half of the time. Fig. **8** displays the background noise level (LA_{95}) and illustrates intense levels surpassing established guidelines or permissible values in three out of nine sites. Considering that the CPCB allows a maximum deviation of ±10 dBA from the noise standards, after adjusting for this range, it can be inferred that seven out of the nine sites maintain their noise levels within an acceptable range for 95% of the time.

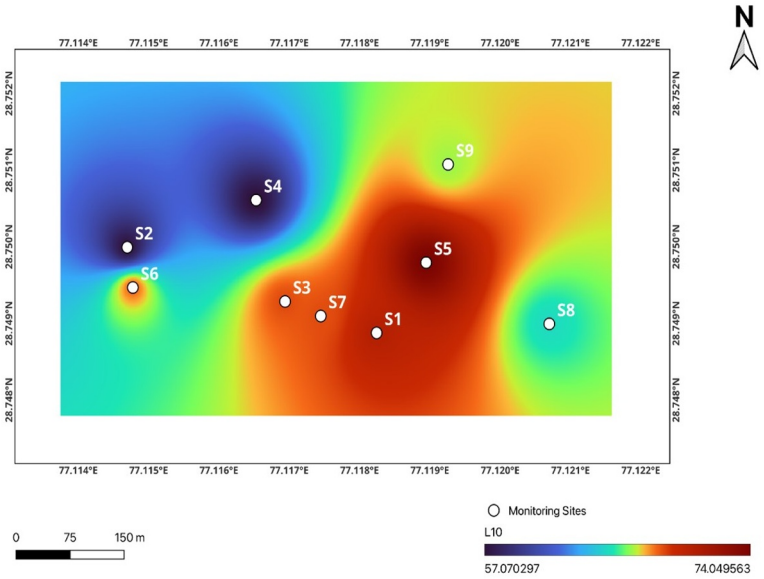

Fig. 6. Mapping of Peak Noise Level (LA_{10}) in the nine sites across the DTU campus

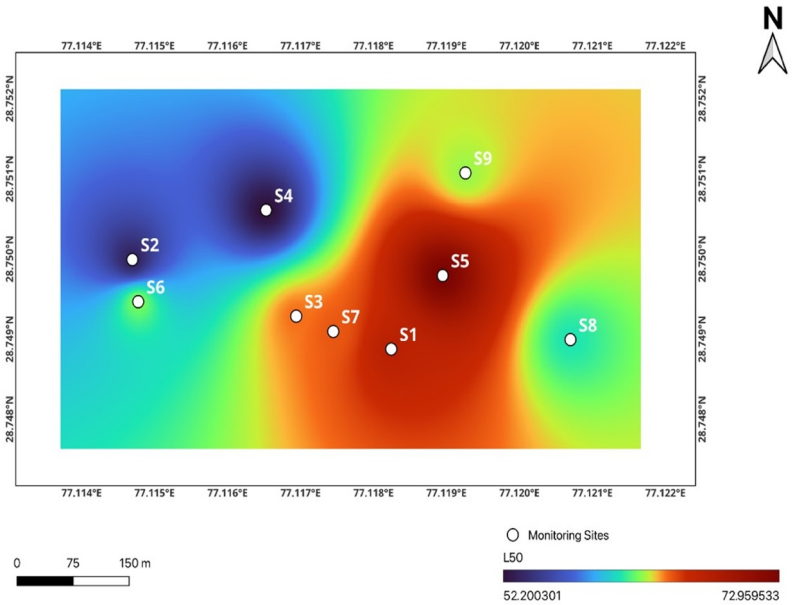

Fig. 7. Mapping of Mean Noise Level (LA_{50}) in the nine sites across the DTU campus

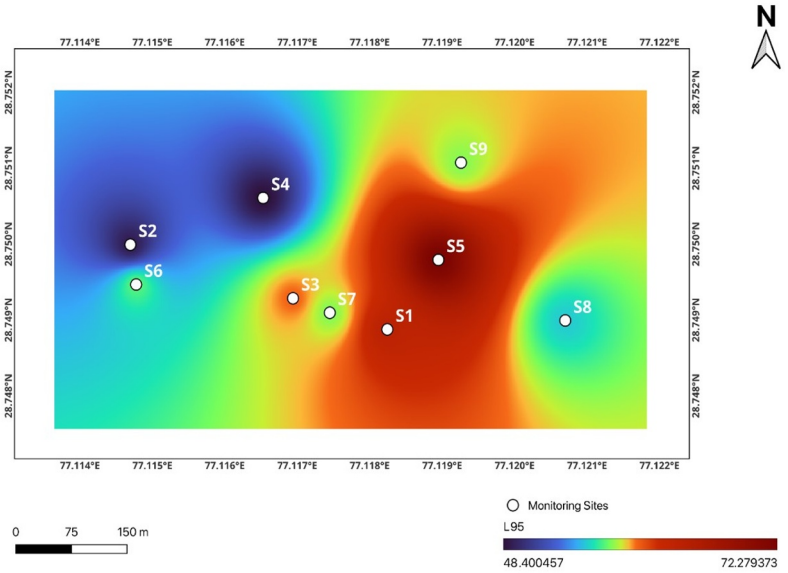

Fig. 8. Mapping of Background Noise Levels(LA95) at nine locations on the DTU campus4 Conclusions and recommendations

The research into the acoustic environment of university learning spaces has provided important insights into the impact of noise levels on student well-being and academic achievement. Various factors and their influence on classroom acoustics were also described thoroughly in the study. Objective measurements of sound pressure showed that most of the recorded points exceeded established university noise standards, highlighting the urgent need for active noise control measures in educational settings.

To effectively address noise concerns, it is recommended that educational institutions prioritize adhering to building design considerations laid down by the certified bodies, use soundproofing materials in classrooms and laboratories, as well as manually try to keep the decibels as low as possible. Student awareness programs and flexible classroom procedures should be followed to support a calmer and more productive learning environment. Keeping indoor plants is another way to reduce noise levels as they help absorb sounds. Research and development in noise mathematical modelling and acoustic simulation are encouraged to increase the effectiveness of noise abatement techniques and enhance student well-being. By integrating and applying these suggestions, universities can provide healthy learning environments to the students, boosting their academic performance and success.

5 References

[1] M. M. Damián-Chávez, P. E. Ledesma-Coronado, M. Drexel-Romo, D. I. Ibarra-Zárate, and L. M. Alonso-Valerdi, "Environmental noise at library learning commons affects student performance and electrophysiological functioning," *Physiol Behav*, vol. 241, Nov. 2021, doi: 10.1016/j.physbeh.2021.113563.

[2] K. Mealings, "A Scoping Review of the Effects of Classroom Acoustic Conditions on Primary School Children's Physical Health," *Acoust Aust*, vol. 50, no. 3, pp. 373–381, Sep. 2022, doi: 10.1007/s40857-022-00271-8.

[3] C. El Yamlahi Chahdi, B. El Wahbi, Y. El Madhi, and A. Soulaymani, "Noise pollution in school institutions: Study case at Sidi Yahya Zaer middle school in Temara, Morocco," *Social Sciences and Humanities Open*, vol. 9, no. March, 2024, doi: 10.1016/j.ssaho.2024.100877.

[4] M. H. Masum, S. K. Pal, A. A. Akhie, I. J. Ruva, N. Akter, and S. Nath, "Spatiotemporal monitoring and assessment of noise pollution in an urban setting," *Environmental Challenges*, vol. 5, Dec. 2021, doi: 10.1016/j.envc.2021.100218.

[5] M. Cai, J. Zou, J. Xie, and X. Ma, "Road traffic noise mapping in Guangzhou using GIS and GPS," *Applied Acoustics*, vol. 87, pp. 94–102, 2015, doi: 10.1016/j.apacoust.2014.06.005.

[6] L. S. Deconto, M. B. S. Novelli, D. J. da S. Lima, and E. L. A. Monteiro-Filho, "Influence of natural and anthropogenic sound sources on the soundscape of the Cananéia estuary, southeastern Brazil," *Mar Pollut Bull*, vol. 169, Aug. 2021, doi: 10.1016/j.marpolbul.2021.112502.

[7] P. Das, S. Talukdar, S. Ziaul, S. Das, and S. Pal, "Noise mapping and assessing vulnerability in meso level urban environment of Eastern India," *Sustain Cities Soc*, vol. 46, Apr. 2019, doi: 10.1016/j.scs.2019.01.001.

[8] S. Tet Leong and P. Laortanakul, "MONITORING AND ASSESSMENT OF DAILY EXPOSURE OF ROADSIDE WORKERS TO TRAFFIC NOISE LEVELS IN AN ASIAN CITY: A CASE STUDY OF BANGKOK STREETS," 2003.

[9] Organización Mundial de la Salud., *Environmental noise guidelines for European Region*. WHO Regional Office for Europe, 2018.

[10] I. Enmarker and E. Boman, "Noise annoyance responses of middle school pupils and teachers," *J Environ Psychol*, vol. 24, no. 4, pp. 527–536, Dec. 2004, doi: 10.1016/j.jenvp.2004.09.005.

[11] G. Sundaravadhanan, H. Selvarajan, and B. McPherson, "Classroom Listening Conditions in Indian Primary Schools: A Survey of Four Schools," *Noise Health*, vol. 19, no. 86, pp. 31–38, Jan. 2017, doi: 10.4103/1463-1741.199240.

[12] A. Y. Alqahtani, A. A. Makki, and H. M. Alidrisi, "Revealing factors influencing classroom noise in the universities teaching and learning environment: A design of experiments approach," *Journal of Engineering Research (Kuwait)*, vol. 11, no. 1, p. 100009, 2023, doi: 10.1016/j.jer.2023.100009.

[13] C. Visentin, M. Pellegatti, M. Garraffa, A. Di Domenico, and N. Prodi, "Individual characteristics moderate listening effort in noisy classrooms," *Sci Rep*, vol. 13, no. 1, Dec. 2023, doi: 10.1038/s41598-023-40660-1.

[14] R. F. Guidini, F. Bertoncello, S. Zanchetta, M. Lúcia, and S. Dragone, "Correlations between classroom environmental noise and teachers' voice Correlações entre ruído ambiental em sala de aula e voz do professor," 2012.

[15] A. Jaramillo, M. Ermann, and P. Miller, "The teachers perspective on noise in the classroom," *Proceedings of Meetings on Acoustics*, vol. 19, no. 2013, 2013, doi: 10.1121/1.4799985.

[16] E. Sala and L. Rantala, "Acoustics and activity noise in school classrooms in Finland," *Applied Acoustics*, vol. 114, pp. 252–259, Dec. 2016, doi: 10.1016/j.apacoust.2016.08.009.
[17] C. Burke and I. Grosvenor, "School buildings," *The School I'd Like*, pp. 31–44, 2020, doi: 10.4324/9780203439074-10.
[18] B. Shield, R. Conetta, J. Dockrell, D. Connolly, T. Cox, and C. Mydlarz, "A survey of acoustic conditions and noise levels in secondary school classrooms in England," *J Acoust Soc Am*, vol. 137, no. 1, pp. 177–188, 2015, doi: 10.1121/1.4904528.
[19] B. Shield and J. E. Dockrell, "External and internal noise surveys of London primary schools," *J Acoust Soc Am*, vol. 115, no. 2, pp. 730–738, Feb. 2004, doi: 10.1121/1.1635837.
[20] A. Kaarlela-Tuomaala, R. Helenius, E. Keskinen, and V. Hongisto, "Effects of acoustic environment on work in private office rooms and open-plan offices - Longitudinal study during relocation," *Ergonomics*, vol. 52, no. 11, pp. 1423–1444, 2009, doi: 10.1080/00140130903154579.
[21] C. E. Mediastika, L. Kristanto, J. Anggono, F. Suhedi, and H. Purwaningsih, "Open windows for natural airflow and environmental noise reduction," *Archit Sci Rev*, vol. 61, no. 5, pp. 338–348, Sep. 2018, doi: 10.1080/00038628.2018.1502151.
[22] M. K. Kim, C. Barber, and J. Srebric, "Traffic noise level predictions for buildings with windows opened for natural ventilation in urban environments," *Sci Technol Built Environ*, vol. 23, no. 5, pp. 726–735, Jul. 2017, doi: 10.1080/23744731.2016.1262708.
[23] A. Kaarlela-Tuomaala, R. Helenius, E. Keskinen, and V. Hongisto, "Effects of acoustic environment on work in private office rooms and open-plan offices - Longitudinal study during relocation," *Ergonomics*, vol. 52, no. 11, pp. 1423–1444, 2009, doi: 10.1080/00140130903154579.
[24] C. Y. Choi and B. McPherson, "Noise levels in Hong Kong Primary Schools: Implications for classroom listening," *Intl J Disabil Dev Educ*, vol. 52, no. 4, pp. 345–360, Dec. 2005, doi: 10.1080/10349120500348714.
[25] P. Cech, "Smart Classroom Study Design for Analysing the Effect of Environmental Conditions on Students' Comfort," *Intelligent Environments*, vol. 21, pp. 14–23, 2016, doi: 10.3233/978-1-61499-690-3-14.
[26] D. Singh, A. Prakash, A. K. Srivastava, K. Kumar, and V. K. Jain, "The effects of meteorological parameters in ambient noise modelling studies in Delhi," *Environ Monit Assess*, vol. 185, no. 2, pp. 1873–1882, Feb. 2013, doi: 10.1007/s10661-012-2674-1.
[27] G. Clausen and D. P. Wyon, "The combined effects of many different indoor environmental factors on acceptability and office work performance," *HVAC and R Research*, vol. 14, no. 1, pp. 103–113, 2008, doi: 10.1080/10789669.2008.10390996.
[28] A. Y. Alqahtani, A. A. Makki, and H. M. Alidrisi, "Revealing factors influencing classroom noise in the universities teaching and learning environment: A design of experiments approach," *Journal of Engineering Research*, vol. 11, no. 1, p. 100009, Mar. 2023, doi: 10.1016/j.jer.2023.100009.
[29] T. B. de Souza, K. C. Alberto, and S. A. Barbosa, "Evaluation of noise pollution related to human perception in a university campus in Brazil," *Applied Acoustics*, vol. 157, Jan. 2020, doi: 10.1016/j.apacoust.2019.107023.
[30] B. Szeremeta and P. H. T. Zannin, "Analysis and evaluation of soundscapes in public parks through interviews and measurement of noise," *Science of the Total Environment*, vol. 407, no. 24, pp. 6143–6149, 2009, doi: 10.1016/j.scitotenv.2009.08.039.
[31] "ANSI-ASA_S12.60-2010_PART_1_with_2011_sponsor_page".
[32] "Acoustics in Educational Settings: Acoustics in Educational Settings: Technical Report ASHA Working Group on Classroom Acoustics." [Online]. Available: http://www.asha.org/members/deskref-journals/deskref/default

[33] "THE NOISE POLLUTION (REGULATION AND CONTROL) RULES, 2000."
[34] R. R. Mcneer, C. L. Bennett, D. B. Horn, and R. Dudaryk, "Factors affecting acoustics and speech intelligibility in the operating room: Size matters," *Anesthesia and Analgesia*, vol. 124, no. 6. Lippincott Williams and Wilkins, pp. 1978–1985, Jun. 01, 2017. doi: 10.1213/ANE.0000000000002118.
[35] S. Lapp, "Noise in Classrooms: Its Impact on Students and How to Cost Effectively Manage It."
[36] Y. Liew, "The effectiveness of using furnishings to improve the housing acoustic of low-cost flats in Malaysia," *Journal of Building Performance*, vol. 11, no. 1, pp. 107–116, 2020.
[37] C. M. Mak and Y. P. Lui, "The effect of sound on office productivity," *Building Services Engineering Research and Technology*, vol. 33, no. 3, pp. 339–345, 2012, doi: 10.1177/0143624411412253.
[38] J. F. Culling, R. Gocheva, Y. Li, and N. Kamaludin, "The effects of ceiling height and absorber placement on speech intelligibility in simulated restaurants," *Acoust Sci Technol*, vol. 41, no. 1, pp. 223–228, 2020, doi: 10.1250/ast.41.223.
[39] J. F. Culling, R. Gocheva, Y. Li, and N. Kamaludin, "The effects of ceiling height and absorber placement on speech intelligibility in simulated restaurants," *Acoust Sci Technol*, vol. 41, no. 1, pp. 223–228, 2020, doi: 10.1250/ast.41.223.
[40] E. Arvidsson, E. Nilsson, D. B. Hagberg, and O. J. I. Karlsson, "The Effect on Room Acoustical Parameters Using a Combination of Absorbers and Diffusers—An Experimental Study in a Classroom," *Acoustics*, vol. 2, no. 3, pp. 505–523, 2020, doi: 10.3390/acoustics2030027.
[41] P. J. Lee, Y. H. Kim, J. Y. Jeon, and K. D. Song, "Effects of apartment building façade and balcony design on the reduction of exterior noise," *Build Environ*, vol. 42, no. 10, pp. 3517–3528, Oct. 2007, doi: 10.1016/j.buildenv.2006.10.044.
[42] E. P. Obot, R. C. Okoro, D. E. Oku, C. N. Nwosu, and M. U. Onuu, "Acoustical Analysis of Insertion Losses of Ceiling Materials," vol. 60, no. September, pp. 15–25, 2023.
[43] M. Kamal, R. A. El-Rahman, and S. Tawfiq, "Evaluation of noise levels affecting Schools in Cairo - Egypt," *Proceedings of ISMA 2010 - International Conference on Noise and Vibration Engineering, including USD 2010*, pp. 1811–1820, 2010.
[44] H. Boucher and T. Moisey, "An Experiential Learning of a Philosophy of Music Education Inspired by the Work of Canadian Composer R. Murray Schafer," *Creat Educ*, vol. 10, no. 10, pp. 2111–2131, 2019, doi: 10.4236/ce.2019.1010153.
[45] Q. Bian, C. Zhang, C. Wang, L. Yin, W. Han, and S. Zhang, "Evaluation of Soundscape Perception in Urban Forests Using Acoustic Indices: A Case Study in Beijing," *Forests*, vol. 14, no. 7, Jul. 2023, doi: 10.3390/f14071435.
[46] K. T. Tsai, M. Der Lin, and Y. H. Chen, "Noise mapping in urban environments: A Taiwan study," *Applied Acoustics*, vol. 70, no. 7, pp. 964–972, Jul. 2009, doi: 10.1016/j.apacoust.2008.11.001.
[47] "sc310_en".
[48] "Protocol for Ambient Level Noise Monitoring," 2015.
[49] International Electrotechnical Commission., International Electrotechnical Commission. Technical committee 29 : Electroacoustics., and International Organization of Legal Metrology., *Electroacoustics : sound level meters. Part 1, Specifications*.
[50] R. Vijay, A. Sharma, T. Chakrabarti, and R. Gupta, "Assessment of honking impact on traffic noise in urban traffic environment of Nagpur, India," *J Environ Health Sci Eng*, vol. 13, no. 1, Feb. 2015, doi: 10.1186/s40201-015-0164-4.

[51] J. Romeu, M. Genescà, T. Pmies, and S. Jiménez, "Street categorization for the estimation of day levels using short-term measurements," *Applied Acoustics*, vol. 72, no. 8, pp. 569–577, Jul. 2011, doi: 10.1016/j.apacoust.2010.09.012.

[52] A. K. Guha and S. Gokhale, "Urban workers' cardiovascular health due to exposure to traffic-originated PM2.5 and noise pollution in different microenvironments," *Science of the Total Environment*, vol. 859, Feb. 2023, doi: 10.1016/j.scitotenv.2022.160268.

[53] M. Long, "Acoustic Measurements and Noise Metrics," in *Architectural Acoustics*, Elsevier, 2014, pp. 129–174. doi: 10.1016/b978-0-12-398258-2.00004-0.

[54] "Assessment and Mapping of Environmental Noise Levels in Chandigarh City: A Case Study," *Indian Journal of Pure & Applied Physics*, 2023, doi: 10.56042/ijpap.v61i10.2588.

[55] V. K. Patil, S. P. Lunawat, B. Student, K. Wagh, and S. N. Dharankar, "Noise Mapping Using Q-GIS: A Case Study of Nasik City," *International Journal for Research in Engineering Application & Management (IJREAM)*, vol. 04, p. 3, 2018, doi: 10.18231/2454-9150.2018.0377.