Ecological Questions 34 (2023) 3: 109–124 http://dx.doi.org/10.12775/EQ.2023.035

A Comprehensive Review of Noise Measurement, Standards, Assessment, Geospatial Mapping and Public Health

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Received: 30 November 2022 / Accepted: 8 March 2023

Abstract. Noise pollution is an emerging issue in cities around the world. Noise is a pernicious pollutant in urban landscapes mainly due to the increasing number of city inhabitants, road and aviation traffic, industrial and construction activities, and appliances or machinery used in daily life. The objective of this paper is to present a comprehensive review of noise measurement, guidelines/standards, and parameters used in noise monitoring; noise assessment associated with the area characteristics and the violations of guidelines/standards; noise geospatial mapping in urban planning; and physiological and psychological effects of noise exposure on public health.

The review results revealed that standard methodology was lacking in many of the reviewed studies for noise measurement in various land-use patterns, especially the duration of noise monitoring; noise levels exceeded the prescribed noise standards in almost every noise assessment study across the globe irrespective of land-use or designated zone, and are exhibiting rising trends particularly due to traffic-induced noise; the majority of the urban population has been exposed to the noisy environment and affected with significant physiological and psychological health impacts; noise geospatial mapping has demonstrated high potential in noise abatement and management; and marked drop in noise levels in an urban environment during COVID-19 lockdown period.

Based on the review results, the present study has suggested some future research perspectives of noise abatement and management that include a focus on – methodical noise assessment with prescribed guidelines of noise measurement and standards; geospatial noise mapping of urban areas, and real-time information system; universal database management software (DBMS) such as SQL and Improvado to compile data in single storage that will allow multiple users to access data despite different geographical locations; awareness programs using multi-media approaches in urban areas; and strict implementation of noise laws and regulations, that leads to the development of advanced technologies, integrated strategies, and sustainable environmental planning to mitigate the menace of noise pollution.

Keywords: Noise pollution, noise standards, noise assessment, traffic-induced noise, noise geospatial mapping, public health.

Abbreviations:

Arc GIS	Software name
CPCB	Central Pollution Control Board
COVID-19	Coronavirus Disease of 2019
DBMS	Database Management Software
dB	decibels
dB(A)	decibels with A-weighted frequency
GIS	Geographic Information System
IDW	Inverse Distance Weighting
ISO	International Standard Organisation
L_{10}	Ten percentile time surpassing sound levels during the observation time
L_{50}	Fifty percentile time surpassing sound levels during the observation time
L_{90}	Ninety percentile time surpassing sound levels during the observation time
L_{eq}	Equivalent continuous sound pressure level over a specified period
L_{Aeq}	Equivalent continuous sound pressure level with A-weighted frequency

L_{Amax}	Maximum time-weighted and A-weighted frequency sound pressure level
LAF, max	Maximum time-weighted and A-weighted frequency sound pressure level with a Fast response
LAS, max	Maximum time-weighted and A-weighted frequency sound pressure level with a Slow response
MCMC	Markov chain Monte Carlo
MDOE	Malaysian Department of Environment
NANMN	National Ambient Noise Monitoring Network
NC	Noise Climate
NEI	Noise Exposure Index
NPL	Noise Pollution Level
OSHA	Occupational Safety and Health Administration
QGIS	Software name
SLM	Sound Level Meter
SQL	Structured Query Language
TNI	Traffic Noise Index
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation

1. Introduction

Sound is omnipresent in daily life. The expression noise is nothing but a sound, which is an energy particle. The sound is converted to noise under its magnitude of appearance and becomes intolerable to human beings and the environment (Poddar, 2017). As per World Health Organisation (WHO) guidelines for community noise, unwanted sound has detrimental physiological and psychological effects on people, and noise is one such sound (Mamun et al., 2017). The harmful or annoying level of noise causes noise pollution. It is considered as the third most hazardous type of pollution to the environment and human health (Bouzir et al., 2017). According to Robert Lacey, a British historian, "of all the varieties of modern pollution, noise is the most insidious". The main source of noise pollution is human activity (Templeton et al., 2016). These statements serve as a reminder of the risk the noise poses as a slow-acting assassin. There are many different kinds of noise, including low-frequency noise, continuous noise, intermittent noise, and impulsive noise. If their safe limitations are surpassed, all of the aforementioned noise categories are harmful to both humans and animals (Liu et al., 2016). Although the impacts of noise are typically extremely brief and infrequently catastrophic; however, prolonged or repeated exposure can have harmful effects that build over time (Banerjee et al., 2008). Overexposure to noise causes time loss, stress at work, and job unhappiness in addition to lowering worker quality. The other negative impacts of loud exposure include hearing loss, irritation, disturbed sleep, and hypertension. Further, noise-induced stress chemicals like adrenalin and noradrenalin may increase the chance of developing ailments like cardiovascular disease (Ghotbi et al., 2011).

Noise pollution has risen at an alarming rate due to the explosive growth in industrialization, urbanization, transportation infrastructure, and population development over time. The problem of urban noise pollution is becoming more and more prevalent in non-industrialized countries as well, just as it has been in other metropolitan areas of technologically advanced nations. However, the issues here are far more intricate than in developed countries. There is a continuous migration from rural to urban areas, overcrowding in all major cities in emerging countries, poor city planning, and almost no solutions to limit the level of noise from various sources (Al-Mutairi et al., 2009). People in public places are subjected to noise from a variety of sources, including traffic, machinery, trains, and other sources, from dawn to dusk. The major factors contributing to increased traffic noise in metropolitan settings are honking, congestion, and a sharp rise in traffic flow. In fact, around two-thirds of the total noise pollution in a metropolitan area comes from traffic noise (Tandel & Macwan, 2011).

Presently, noise pollution has become a serious environmental issue in urban areas. If noise threat is identified during planning, it can be reduced; otherwise, it will be too expensive to control or optimize (Sahu et al., 2020). By measuring the noise level and analyzing the noise maps, studies in several countries have confirmed the increased noise exposure in urban areas (Domazetovska et al., 2020). The quality of noise maps can be improved by combining geographical data analysis, new mapping techniques, and mathematical modeling, all supported by a GIS (Akiladevi et al., 2015).

As noise pollution and its harmful effects are considered a topical issue, it becomes necessary to explore the extent of the studies in this area, encompassing all the relevant and related aspects of noise measurement, standards, assessment, geo-spatial mapping and public health.

1.1. Objective of the Review

The objective of the review is to present a comprehensive overview of the available knowledge on –

(i) Noise measurement and standards that include type/class of measuring instruments, units of measurements, weighting networks, prescribed exposure guidelines and standards by national and international agencies/organisations in specific environment to protect public health, and the noise parameters/terms used to express the measurements/results and, in turn, compare with applicable guidelines/standards;

(ii) Noise assessment of measurements/recordings associated to the area-characteristics, such as city noise, traffic noise, industrial zone, silence zone (hospitals, academic institutions, etc.), and the violations of guidelines/standards;

(iii) Techniques or software applicability in noise geospatial mapping for identifying and assessing the severity of noise levels, that can be useful in urban planning specific to area-characteristics and traffic information; and

(iv) Noise exposure and public health in diverse settings, such as city traffic, industrial workplace, educational institutes, etc.

The review also aims to demonstrate the gaps and/or constraints in studies and summarizes the future research prospective of noise control and management.

2. Methodology

The related research papers and articles were searched by string search in search engines [Google Scholar], database search [Web of Science Core Collection, SCOPUS (Elsevier), Taylor Francis, Springer, etc.] using the access rights of the National Institute of Technology Kurukshetra (India), conference proceedings search, and authors (organisation or agency) library search. String searches included few key words, such as noise pollution, noise assessment, noise guidelines standards, noise measurement, urban noise, traffic noise, industrial noise, noise in silence zone, noise in educational institutes, noise annoyance, impact of noise on health, noise and public health, and noise mapping. The searches were performed using exclusively English terms/words, and articles published in English were included in the present review.

After collecting the literature from the different sources, stated above, the relevant and identified articles/papers were read in full and being used for knowledge and/or information extraction. To interpret the status and quality of searched research works, the methodology described by Omlin et al. (2011) and Sordello et al. (2020) has been broadly followed with modifications to achieve the objectives of the present review. The norms adopted to evaluate the quality of the articles included the following:

(i) Declaration of type/class of SLM used, and frequency weighting adopted during measurements.

(ii) Type of exposure, that is – sources of noise or type of zone (viz.; traffic noise, industrial noise, neighbourhood noise, abstract noise, silence-zone, etc.) used for assessment.

(iii) Description of subjective exposure to noise (viz.; location, time, and duration of noise monitoring, traffic volume, etc.).

(iv) Comparison/violation of relevant noise guidelines/standards.

(v) Description of technique used for noise mapping.

(vi) Type of outcomes (impact of noise on public health).

Finally, some information (particularly related to noise guidelines and standards) was added manually from the agency/organisation website. In this review, a total of 55 articles (50 journal articles and 5 conference articles), 2 books and 3 organisation/agency websites (for noise guidelines/standards) were used for review. A narrative synthesis is being used in this review due to too much heterogeneity studies that impede any meaningful statistical summary.

3. Results of Literature Review and Discussion

The following sections and sub-sections deal the review and discussion in accordance with the objectives of the present study.

3.1. Noise Measurement and Standards

This section focuses the review and discussion on noise measurement and standards that include type/class and specifications of noise measuring instruments, guidelines and standards prescribed by national and international agencies in specific environment or classified zones, and the noise parameters/terms used in noise studies, as per objective (i) of the study.

3.1.1. Instruments for Measuring Noise

The most commonly used tool for measuring noise is a sound level meter (SLM) or noise dosimeter. SLM is used to monitor the noise level of a particular task or process, or how noisy a piece of machinery or area is; whereas, a noise dosimeter is a type of sound level meter used to assess an individual's exposure to noise during working hours (Debnath et al., 2012; Singh & Dadoriya, 2013; Das et al., 2014; Mamun et al., 2017; Hussein & Al-Sulttani, 2021). As the majority of research has been done on noise exposure in various environmental settings, SLMs have been widely used to measure noise levels; and only a limited number of researchers have used dosimeter. SLM is commonly a hand-held instrument with a microphone. The diaphragm of the microphone responds to changes in air pressure caused by sound waves. The movement of the diaphragm thus caused, i.e. the sound pressure deviation (in Pascal Pa), is then converted into an electrical signal (in volts V) and display the resulting sound pressure level (in decibels dB). A weighting network serves as the first step in the sound signal processing system. The sensitivity of this electronic circuit, which is rather straightforward, changes with frequency. Three different weighting kinds have been standardized internationally, namely A, B, and C. The A type weighing network is the most popular and has been adopted in national and international standards. The frequency response of the A-weighting filter is low which is similar to that of human hearing; whereas, B-weighting and C-weighting filter circuits approximate the signal to moderate and high sound pressure levels respectively (Katalin, 2018).

The International Electrotechnical Commission (IEC) 60651 standard specifies the directional characteristics, frequency weighting characteristics, time weighting characteristics, detector and indicator characteristics, and sensitivity to various environments of sound level metres (Katalin, 2018). Accordingly, the SLMs are divided into two performance categories / classes – Class 1 and Class 2. In general, the specifications for Class 1 and Class 2 SLMs have the same design objectives, but they differ mainly in tolerance limits and the range of operational temperatures. The level linearity error, extended by the expanded uncertainty of measurement, shall not exceed ±1.1 dB for class 1 and ± 1.4 dB for class 2 SLMs. The operational temperature range is from −10°C to +50°C for class 1 and 0°C to +40°C for class 2 SLMs. Having lower level of linearity error and wide range of operational temperature, Class 1 SLMs are used in research and calibration. Studies that followed WHO guidelines have generally used Class 1 type of SLMs, while studies as per International Standard Organisation (ISO) have used both types of SLMs (Alesheikh & Omidvari, 2010; Kumar et al., 2013; Singh & Choudhary, 2017; Konadath et al., 2019; Manojkumar et al., 2019).

3.1.2. Noise Guidelines and Standards

Noise regulation includes statutes, guidelines or standards relating to sound transmission established by global, regional, national, state or provincial and municipal levels of government and/or agencies. Accordingly, there are WHO guidelines for community noise at global level, OSHA (Occupational Safety and Health Administration) at regional level, and various national level agencies like USEPA (United States Environmental Protection Agency), CPCB (Central Pollution Control Board) in India etc. These agencies have different focus on noise limit as based on their individual functions, objectives and requirements.

WHO has given guidelines for noise in various environments including industrial, commercial and residential areas, public addresses, hospitals, schools etc., and it is basically concerned about the critical health effect of noise on people in the zones as mentioned in Table 1. For the safety of public health, USEPA has summarised noise levels with an adequate margin of safety to protect the public health. Table 2 shows the summary of the safe equivalent noise level and day- night average sound level for people in residential areas, schools etc. by USEPA. OSHA guidelines focuses only on the health of people in working environment and intend to lower the chance of hearing loss in workers. Table 3 depicts the permissible noise exposure of workers by OSHA to prevent noise-induced hearing loss. As the majority of studies in this review are conducted in India, it is inevitable to address Indian Standards prescribed by CPCB (Table 4). Among other agencies, CPCB standards seem to be more convenient as they have clearly categorised diverse city-areas in to four different zones/categories (industrial zone, commercial zone, residential zone and silent zone) as per land use, and prescribed different noise limit for these zones. It not only helps the researcher to easily identify the noisy areas, but also assist in analysis and planning.

Table 1. WHO noise quality guidelines for community noise with regard to specific environments and effects (Source: Birgitta et al, 1999; CPCB, 2017)

Specific Environment	Critical Health Effect(s)	L_{Aeq} [dB(A)]	Time base [hours]	L_{Amax} Fast [dB]
Outdoor living area	Serious annoyance, daytime and evening. Moderate annoyance, daytime and evening.	55 50	16 16	- -
Dwelling, indoors Inside bedrooms	Speech intelligibility & moderate annoyance, daytime & evening. Sleep disturbance, night-time.	35 30	16 8	- 45
Outside bedrooms	Sleep disturbance, window open (outdoor values).	45	8	60
School class rooms & pre-schools, Indoors	Speech intelligibility, disturbance of information extraction, message communication.	35	during class	-

Specific Environment	Critical Health Effect(s)	L_{Aeq} [dB(A)]	Time base [hours]	L_{Amax} Fast [dB]
Pre-school, bedrooms, indoors	Sleep disturbance.	30	sleep-ing-time	45
School, playground Outdoor	Annoyance (external source).	55	during play	-
Hospital, ward rooms, indoors	Sleep disturbance, night-time. Sleep disturbance, daytime and evenings.	30 30	8 16	40 -
Hospitals, treatment rooms, indoors	Interference with rest and recovery	#1	-	-
Industrial, Commercial shopping and traffic areas, indoors and outdoors	Hearing impairment.	70	24	110
Ceremonies, festivals & entertainment events	Hearing impairment (patrons<5 times/year).	100	4	110
Public addresses, indoors and outdoors	Hearing impairment.	85	1	110
Music and other Sounds through headphones/ earphones	Hearing impairment (free-field value).	85 #4	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults). Hearing impairment (children).	- -	- -	140#2 120#2
Outdoors in parkland and conservation areas	Disruption of tranquillity	#3	-	-

Note: #1: As low as possible.
#2: Peak sound pressure (not LAF, max) measured 100 mm from the ear.
#3: Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low.
#4: Under headphones, adapted to free-field values.

Table 2. Summary of noise levels identified as requisite to protect public health and welfare with an adequate margin of safety (USEPA, 1974; Fink, 2017)

Effect	Level	Area
Hearing Loss	$L_{eq}(24) \leq 70$ dB	All areas
Outdoor activity interference and annoyance	$L_{dn} \leq 55$ dB	Outdoors in residential areas and farms other outdoor area where people spend widely varying amounts of time and other places in which quiet is a basis for use.
	$L_{eq}(24) \leq 55$ dB	Outdoor areas where people spend limited amounts of time, such as school yards, playgrounds, etc.
Indoor activity interference and annoyance	$L_{dn} \leq 45$ dB	Indoor residential areas
	$L_{eq}(24) \leq 45$ dB	Indoor areas with human activities such as schools, etc.

Table 3. Permissible Noise Exposures (OSHA, 2022)

Duration per day, hours	Sound level dB(A) Slow response
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
¼ or less	115

Table 4. The Indian Ambient Air Quality Standards in respect of Noise (Das et al., 2014)

Area	Category of Area / Zone	Permissible Limits in L_{eq} dB(A)	
		Day Time 06:00 am to 10:00 pm	Night Time 10:00 pm to 06:00 am
(A)	Industrial Area	75	70
(B)	Commercial Area	65	55
(C)	Residential Area	55	45
(D)	Silence Zone	50	40

Note: 1. Silence zone is an area comprising not less than 100 metres around hospitals, educational institutions, courts, religious places or any other area which is declared as such by the competent authority.
2. Mixed categories of areas may be declared as one of the four above mentioned categories by the competent authority.

3.1.3. Noise Parameters

In most of the studies, the results, in terms of L_{eq} values in dB(A), have been compared with ambient air quality standards for noise as prescribed by and applicable in a region or country. Additionally, various noise parameters such as L_{10}, L_{50}, L_{90}, TNI (Traffic Noise Index), NPL (Noise Pollution Level), NC (Noise Climate) and NEI (Noise Exposure Index) have been used for analysis, mapping, and planning purposes (Banik et al., 2018; Shalini & Kumar, 2018; Sumit & Koshta, 2018; Titu et al., 2022).

Equivalent sound pressure level (L_{eq}) is designed to convert the time-varying characteristics of noise into an equivalent steady state noise level that, for a predetermined amount of time, has the same amount of acoustic energy as the time-varying noise. $L_{10,}$ L_{50} and L_{90} represents the time that exceeds 10%, 50% and 90% respectively of the entire observation time and are known as the ten, fifty and ninety percentile time surpassing noise levels respectively. L_{10} shows the highest degrees of intrusive noise, L_{50} denotes the typical noise level and L_{90} displays the level of background noise (Shalini & Kumar, 2018).

Traffic Noise Index (TNI) is a technique used to gauge responses to traffic noise irritation. The above threshold criterion is defined as the value of TNI over 74 dB (A), and is calculated using the formula below (Sumit & Koshta, 2018):

$$TNI = 4(L_{10}–L_{90}) + L_{90} – 30dB(A) \quad (1)$$

L_{eq} alone is an inadequate description of annoyance caused by fluctuating noise. So, the NPL (Noise Pollution Level) index is replaced particularly for the highly fluctuating road traffic noise and it is used to measure the unhappiness brought on by road traffic noise. It consists of two terms. The first is the amount of aggravation caused by variations in the equivalent continuous noise level (L_{eq}), and the second is a measurement of that increment. NPL can be expressed as follows for a distribution of noise levels that is Gaussian (Shalini & Kumar, 2018):

$$NPL= L_{eq} + (L_{10}–L_{90})\ dB(A) \quad (2)$$

Over some time, the volume of the sound will change. The following formula is used to evaluate the noise climate (NC), the range over which the fluctuations take place (Sumit & Koshta, 2018):

$$NC = (L_{10}–L_{90}) \quad (3)$$

Noise Exposure Index (NEI) determines whether or not the areas where noise is created are exposed to excessive levels of noise and is obtained by the following relationship (Banik et al., 2018):

$$NEI = (t_1/T_1) + (t_2/T_2) + \ldots\ldots + (t_n / T_n) \quad (4)$$

The permitted limit of exposure to a corresponding noise level is T_1 to T_n, while t_1 to t_n is the actual limit of exposure to a corresponding sound level. The noise exposure level is deemed excessive if the NEI value in any location during a certain hour is greater than 1.

3.2. Assessment of Noise

This section focuses the review and discussion on noise assessment studies associated to the area-characteristics or specified zones of an urban landscape, and the violations (if any) of prescribed guidelines/standards, as per objective (ii) of the study. As every aspect of human life, including public health, socio-economic and environmental had been severely affected all over the world, so the noise studies during the two-year period of COVID-19 have also been included to review the alteration of noise levels in urban areas.

Literature reviewed in related journals showed that noise measurement has varied according to the area-characteristics where it is conducted. It can be a heavy-traffic city area or an industrial or commercial or residential area, or areas coming under silent zones like schools, hospitals, courts or parks. However, most studies have focussed on noisy traffic congested urban areas – be it residential, commercial, industrial, mixed use or silent zone, and concluded that the majority of the sites have exceeded the limit prescribed by various national and international standards (Chauhan, 2008; Debnath et al., 2012; Obot & Ibanga, 2013; Mamun et al., 2017; Singh & Choudhary, 2017; Farooqi et al., 2019). Many contextual studies have revealed that noise pollution in cities is primarily caused by moving cars that emit about 55% of the overall noise in urban areas (Banerjee et al., 2008; Garg et al., 2017). It is particularly due to the tremendous increase in population causing rapid urbanization followed by uncontrolled use of vehicles. Various studies also reflect that noise emitted from vehicles is much greater than the permissible limit prescribed by various national and international standards (Banerjee et al., 2008; Al-Mutairi et al., 2009; Tandel & Macwan, 2011; Herzog et al., 2020; Domazetovska et al., 2020). For convenience, the noise assessment studies have been sorted and reviewed as city noise assessment (encompassing all representative land-use zones), industrial noise assessment, traffic noise assessment and noise assessment in silence zones, and also the impact of COVID-19 on noise pollution.

3.2.1. City Noise Assessment

In India, the National Ambient Noise Monitoring Network (NANMN) established by CPCB has been carrying out monitoring and analysing the ambient noise levels in metro cities since 2011. The monitoring is being carried out during the day (6:00 AM – 22:00 PM) and at night (22:00 PM – 6:00 AM) at various locations representing commercial, residential, industrial and silence zones. Based on the NANMN data for the period 2011–2014, Garg et al. (2017) analysed the status of noise pollution at 35 locations (14 commercial zones, 7 residential zones, 5 industrial zones, and 9 silent zones) in seven major noise-polluting metro cities (Delhi, Hyderabad, Kolkata, Mumbai, Lucknow, Bangalore and Chennai), and noted a slight increase in noise at 29 sites (82.9%) over the last four years. The day equivalent levels were greater than 65 dB(A) at 17 sites, and the night equivalent levels were greater than 60 dB(A) at 13 sites. The study concluded that silence zones and residential zones require effective noise abatement methods. Similarly, based on the NANMN data for the year 2018, Srivastava & Rai (2020) analysed the status of noise pollution at 10 sites on a monthly and yearly basis for Lucknow city and reported noise intensity in the city ranged from 37 dB(A) to 77 dB(A).

By analyzing monthly basis readings, it was observed that the industrial zone showed the values within the limit, the commercial zone exceeded the limit for night time and the limit exceeded for both day and night in the residential zone and silent zone. The average annual sound level was within the limit for the industrial zone, exceeded the CPCB limit for more regions in the commercial zone and residential zone, and a rapid noise level increase was noted in the silent zone. It was also found that vehicular traffic and markets are the main reason for noise in Lucknow city.

In the Indian state of Uttarakhand, two well-known cities, Haridwar and Dehradun, were studied for noise assessment by monitoring five residential, six commercials, three silent, and two industrial neighborhoods, and reported that the prescribed CPCB limits exceeded in every study region (Chauhan, 2008). Das et al. (2014) monitored noise levels at nine sites (including the commercial, residential, and silent zones) spread in-and-around in an Indian town, six different times throughout the day and night during a year, and observed that the noise levels far exceed the CPCB-established regulatory limits. The study reported that the main sources of noise in residential areas include home appliances, construction, children playing, daily activities, and so on; whereas, large crowds, use of loudspeakers, and hawkers-shouting have all been reported to occur in or close to places of worship. The most sensitive area, such as the hospital, also exceeded the CPCB-recommended permissible limit as a result of car horns, large crowds, backed-up traffic, etc. in Udaipur town. Kota city's industrial, commercial, and residential zones were studied, wherein a highly fluctuating Noise Climate (NC) was observed in the industrial area, and higher noise level upto 61 dB(A), higher than the authorised threshold of 55 dB, was observed in a residential area due to uncontrolled building activity (Singh & Choudhary, 2017). In an Algerian city of Biskra, a study on noise pollution was done for 47 places on weekdays and weekends. It was noted that more than 70.20% of the results obtained on weekdays and 55.30% of those on weekends showed noise intensity levels exceeding the level 70 dB(A) permissible by Algerian law and recommendations of WHO (Bouzir et al., 2017). In another study, eight out of ten locations in the industrial, commercial, residential, and silent zones of Lucknow city had L_{eq} values that varied widely and were above the CPCB limit (Bhushan & Shukla, 2018). A study in residential areas of Malaysia recorded TNI for the whole day and observed the noise level to be above 75 dB(A) during major times that were 20 dB(A) above the WHO and Malaysian Department of Environment (DOE) regulatory limits (Mutalib et al., 2018). The noise measurement study carried out in residential, commercial, sensitive, and mixed land-use patterns during morning and afternoon time frames for 15 minutes in the city of Mysore concluded that commercial locations had the greatest levels of noise, followed by mixed, sensitive, and residential regions indicating the influence of land-use types on noise levels in a city (Konadath et al., 2019). The study identified vehicular noise as the major noise source, with increasing number of private vehicles. The research in Vellore city reported a higher mean value of TNI during weekends than weekdays, and higher noise levels than the permissible limits prescribed by Indian and WHO standards for all zones (Manojkumar et al., 2019). High noise levels above the prescribed limit during weekends and vacation days have been reported for the residential and commercial zones in Dehradun because of high population density, the presence of bypasses, heavy traffic during weekends, etc. (Upreti et al., 2020).

Mangeskar et al. (2012) noticed a rapid increase in equivalent noise level because of the bursting of loud firecrackers during a continued noise monitoring study for three days at ten different sites including industrial, residential, commercial, and silent zone during a festival in Kolhapur city in India. The range of noise was 49.13 dB (silent zone) to 104.51 dB (commercial zone), and found that all residential areas showed noise levels greater than the prescribed CPCB standards.

3.2.2. Industrial Noise Assessment

A few researchers have focused on the assessment of noise levels in industrial areas. The noise assessment, which lasted 12 hours and was done in five separate industries in Khulna city of Bangladesh indicated that the jute and power-generating industries exceeded the 90 dB regulatory limit of CPCB and OSHA (Banik et al., 2018). A noise survey conducted at 50 industrial locations in Gujranwala city (Pakistan) revealed that the noise levels were above the WHO's standard limit

(Maqsood et al., 2019). In another 24-hour noise monitoring study in two industrial zones of Pakistan reported noise at 102 dB, which was higher than the permissible limit of 75 dB (Farooqi et al., 2019). In an industrial study in Slovenia stated that the noise levels exceeded the upper exposure level of 85 dB (A) in the study area. The peak noise was from joiner's workshop where they work with machines (Herzog et al. 2020). A study in industrial zone in India found equivalent noise level within the limit as per CPCB.

The zone's monthly average sound pressure level ranges from 54 to 65 L_{eq} dB(A) at night and 62 to 69 L_{eq} dB(A) during the day (Srivastava & Rai, 2020). Another study with respect to CPCB in India during festival also showed the noise level in industrial zone within the limit (Mangeskar et al., 2012). Similarly, the study in five industrial locations concluded that four locations shows the noise level within the limit (Garg et al., 2017). The L_{eq} 74.3 dB(A) measured for a station in an industrial area of India is just a little bit below the 75 dB(A) daytime noise guidelines. The site displayed TNI and LNP values that were greater than allowed. This is due to the station being situated in an area where grain transportation by fully loaded trucks occurs too frequently (Singh & Choudhary, 2017).

3.2.3. Traffic Noise Assessment

A study of road traffic noise in various zones in an industrial town of Asansol (India) concluded that the population was exposed to road traffic noise that exceeded the permissible limits during day as well as night (Banerjee et al., 2008). The study also stated that topography, zones, landscapes, geographic features, etc. play a crucial role in the transmission of noise. Commercial areas and well-built-up residential areas have high noise levels due to apartments, shopping centers, vehicles passing alongside, etc.; whereas, open areas have fewer noise emissions due to the lack of human settlements, commercial establishments, vehicles, etc. More than 30% of the population in an Iranian city of Arak was greatly upset by road traffic noise, according to noise evaluation that was done at 18 places during the day and night from 7:00 AM to 22:00, as the daily average sound levels at all sites exceeded the Iranian regulatory standards by about 10 dBA (Mirhossaini & Pourzamani, 2008). In Kuwait, 47 roadway locations were subjected to a 20-minute assessment of urban traffic noise pollution repeated three to five times. Numerous noise characteristics were calculated, and it was shown that most of the time, especially on freeways and arterial roads, traffic noise levels exceeded the typical outdoor limit (Al-Mutairi et al., 2009). Another study conducted in Iran identified privately owned and inefficient automobiles as the major cause of traffic-related noise pollution in the Tehran city (Alesheikh & Omidvari, 2010). The study also observed that the background noise was higher than the standard limit. A traffic noise assessment study on the busiest corridors of Surat city for every 150-meter interval for 3 corridors during traffic peak time showed that the average noise limit was between 92 dB to 98 dB (Tandel & Macwan, 2011). The study found that population explosion, tremendous growth in industrialization, and a high number of vehicles lead to noise pollution. The study also observed that buildings near traffic areas were greatly affected by traffic. According to a noise survey conducted in a busy crossroads station in Tehran, all station sites had the same L_{eq} values, with the exception of the first section of the platform on both storeys and the entrance steps to the subway waiting platform (Ghotbi et al., 2011). It was stated that sound reflection in the older indoor system also was a case of noise pollution. A traffic noise study of Tirupur city during early morning hours and busy evening hours noted a considerable difference between morning and evening readings. In 90% of the regions, the noise level averaged around 85 dB, which was significantly higher than the regulatory limit. It was stated that personnel cars, public buses, etc. create high noise pollution due to old technology and poor maintenance (Keerthana et al., 2013). Movement of trains, buses, and other vehicles coupled with bad roads and other factors have been identified as the major cause of noise pollution in different zones of Morena city (Singh & Dadoriya, 2013). In a noise evaluation done in busy corridors in Chennai (India), it was reported that the noise intensity dropped with increasing distance and height from the carriageway (Akiladevi et al., 2015). It was observed that the building's first floor has a quieter noise level than its base floor. According to high-traffic streets' noise assessment study conducted in residential, commercial, industrial, and mixed areas in Birjand (Iran) during the morning, noon, evening, and night, the highest sound pressure level was recorded at noon due to heavy traffic vehicles, and the lowest was recorded at 77.23 dB in the evening, and having average sound levels at all stations higher than the standard level (Afshamia et al., 2016). Based on traffic noise assessment in different zones of Faisalabad city during the morning, noon, and evening at 85 sites classified as industrial, commercial, residential, traffic intersections, and silent zones, Farooqi et al. (2017) reported that majority of Pakistan's city areas (including structured and well-developed districts like commercial centres and residential neighbourhoods) have been subjected to unacceptable noise levels as high as 70 dB to 95 dB due to increased traffic noise on roadways. Singh & Choudhary (2017) reported the presence of a large number of automobiles contributed to the high TNI in the city of Kota (India). Every region of the study area had L_{eq} values higher than 80 dB; along with higher morning TNI and LNP than the respective allowed limits of 74 dB and 88 dB in most of the regions. In the morning, afternoon, and evening, four areas of Jabalpur, India, were the subject of a study on automotive noise pollution (Sumit & Koshta, 2018). A road traffic noise study conducted during peak hours in Varanasi – a commercial metropolis in India, identified a similar situation in which TNI and NPL exceeded the permissible limit. It has also been observed in the study that the L_{eq} value exceeded the permissible limit for the daytime, and the increase in vehicles was the main reason for noise pollution in Varanasi city (Shalini & Kumar, 2018). A study on noise measurement for six locations in Vellore (India) during morning, afternoon, and evening on weekdays and weekends concluded that locations having high traffic flow have L_{eq} values higher than 65 dB(A) (Manojkumar et al., 2019). Upreti et al., (2020) have also identified heavy traffic during weekends as the major cause of high noise levels above the permissible limits in Dehradun. A study conducted for 10-minute measurements at each location to investigate the influence of noise in metropolitan areas during the day, evening, and night on weekdays, along with a general survey in Skopje (Macedonia) for 96 inhabitants above 15 years old reported that 36% of the population responded that noise affects them constantly and 28% at night; and the traffic flow of vehicles and engines was the most vexing noise (Domazetovska et al., 2020). Following European regulatory standards, a measurement of residential urban traffic noise conducted in Pitesti (Romania) during peak hours at urban traffic crossings revealed that the noise level reached a high value of 73.5 dB due to braking and accelerating operations rather than the presence of heavier vehicles like a truck in traffic (Titu et al., 2022).

3.2.4. Noise Assessment in Silence Zone

Several studies have also been reported for the assessment of noise in noise-sensitive areas or silence zones. According to CPCB, a silence zone is described as "areas up to 100 meters around such premises as hospitals, educational institutions, courts." Also, many research papers have considered parks, universities, gardens, banks, etc. as silent zone (Chauhan, 2008; Kumar et al., 2013; Garg et al., 2017).

Indian studies have selected diverse types of silent zones which included parks, hospitals, and educational institutions. A study on ambient noise pollution in Assam's educational institutions in India found that noise levels were significantly higher than the CPCB-recommended limits in all the educational institutions, rendering them unfit for learning. The maximum noise level observed was 80 dB(A) in a college. Vehicle traffic (46%), students themselves (40%), people moving on the road (9%), construction workers, and other sources (5%), were the main causes of noise pollution (Debnath et al., 2012). According to a research on noise pollution in parks in Allahabad city (India), noise levels were reported to be higher than the recommended standard limit of 50 dB(A) during the day and 40 dB(A) at night during the busiest periods of the week at six locations (Kumar et al., 2013). The study indicated that traffic passing by the park showed high noise pollution levels.

According to Khaiwal et al., (2016), research conducted in and around 27 locations of an Indian tertiary hospital observed that sound levels in the study area ranged from 45 dB to 120 dB, which is over the recommended threshold. The study reported that hospital traffic noise predominates internal noise; whereas, cleaning equipment, television, phone ringing, trolley movement, etc. contribute to outdoor noise. It was also reported that weekend nights had higher levels of noise pollution than weekdays. Manojkumar et al. (2019) observed higher L_{eq} in educational zone in comparison to tourist and recreational zones in Vellore city, India. Another noise study at the school found that surrounding traffic and numerous student activities were the main sources of noise pollution. Teachers in the school discovered that corridors and practical workshops had the highest noise levels (Herzog et al., 2020). Yadav et al. (2021) in their study of noise sensitive areas noted high noise levels in the educational institution in India due to their location near traffic roads where a large number of human activities takes place. It was also noted that noise was less in temple areas compared to the hospital because the temple was located away from the road. The noise measurement study carried out for 15 locations coming under the silent zone (including schools, colleges, and hospitals) in Chennai (India) reported the noise levels with a range of 68.6 dB to 88.5 dB in the vicinity that ranged from moderate to extremely high as per the standard limits prescribed by WHO (Saritha & Subashini, 2021).

High noise levels in universities and schools, which come under the silent zone, have been reported in other countries as well. A noise study at a Nigerian university revealed a peak level of 89.5 dB(A), which was far higher than the acceptable value of 40 dB(A) to 50 dB(A) suggested by WHO for educational institutions (Obot & Ibanga, 2013). Electrical generating units that were significant for meeting the University's electricity needs were observed to be the main source of noise (42%). The study concluded that the environment was unsuitable for the teaching-learning process based on the high noise levels. According to a study on the influence of traffic noise conducted at urban schools over time, noise levels were reported higher in the horizontal and diagonal directions from the source of the noise than in the vertical direction. The average sound level was around 70 dB(A), which was very much higher than the 35 dB(A) suggested by Bangladesh National Building Code, 2006 for educational institutions (Mamun et al., 2017). The study conducted in busy locations in Pakistan recorded a maximum sound pressure level of 97 dB for educational institutes which was much above the permissible limit of 50 dB (Farooqi et al., 2019). A study based on noise data collected for 98 stations in a university observed that the highest noise was seen near the fence (94 dB) and the lowest was near the faculty center and green trees (Hussein & Al-Sulttani, 2021). The study concluded that the campus had been exposed to very high noise and does not match international standards – whether inside or outside the academic area.

3.2.5. Impact of COVID-19

The COVID-19 pandemic had severely affected every aspects of people's life globally for almost two years. Despite focus on the health and socio-economic studies during the pandemic period, few studies have also been reported in the field of noise level variations before and after COVID-19. Asensio et al. (2020) studied the alteration of noise levels in Madrid (Spain) during the COVID-19 shutdown in 2020. This study analysed oscillations in noise temporal patterns, which were closely associated to population activity and behaviour changes in response to environmental changes, and detailed the noise pollution reduction that had happened during the pandemic period. Mishra et al. (2021) assessed the impact of the COVID-19 lockdown on noise pollution exposure in Kanpur city (India). The data showed a considerable drop in sound levels during the lockdown period compared to the pre-lockdown and unlock phases at each of the six sound monitoring sites in the city. The average drop in night-time sound equivalent during lockdown was 9 dB across all zones studied; whereas, the average reduction between the pre-lockdown and unlock phases was roughly 15 dB. Caraka et al. (2021) employed several statistical techniques, including Wilcoxon and Fisher's tests, Bayesian Markov chain Monte Carlo (MCMC), and other prior selection comparisons in this article to determine whether noise pollution decreased while COVID-19. In Bayesian inference, the full posterior distribution was the result of interest for a parameter, whereas the posterior mean was roughly visible with point approximation. This study proved a reduction in noise pollution in Taiwan during COVID-19.

3.3. Noise Geospatial Mapping

The studies related to noise geo-spatial mapping and its potential have been reviewed and discussed in this section, as per objective (iii) of the study.

Noise mapping is an emerging technique and is being widely used in noise studies. Identifying and assessing the severity of noise problems at the local, regional, and national levels as well as providing information for traffic and urban planning are the main goals of noise maps (Akiladevi et al., 2015). The level of noise in a specific location at a set time can be depicted cartographically on a noise map (Srivastava & Rai, 2020). Noise pollution can be significantly reduced using spatial analysis and geostatistical GIS techniques as it helps the analyst to represent the noise measurement values using isopleth noise maps and to find out the noise hotspots in a given area easily at a glance (Farooqi et al., 2017; Farooqi et al., 2019; Konadath et al., 2019). Alesheikh & Omidvari, (2010) created and put into place a loosely-coupled architecture to use noise models from Geographic Information System software to combine observed noise from various places in a low-risk manner. Noise maps created in GIS can be employed for analysis and management; whereas, the noise effect can be computed in GIS by combining noise levels, population density, and noise sensitivity (Akiladevi et al., 2015).

GIS tools come in many forms today, such as ArcGIS, QGIS, Hexagon GeoMedia, Cadcorp, etc.; however, different versions of ArcGIS software have been used by the majority of researchers. This software can be used to integrate the processed data, special analysis, and models. It has been found to be an adequate tool to address noise issues (Alesheikh & Omidvari, 2010). A road traffic noise study in the Skane region of Sweden used ArcGIS desktop software for doing noise mapping (Farcas & Sivertunb, 2012). In this study, seven tools were implemented to analyze noise level variation in the entire region. The study also created noise calculator software that can create noise maps based on the Nordic prediction method. Another study used inverse distance weighting (IDW) to map noise for both weekdays and weekends; wherein, the weighted average of the known point values was used to determine the unknown points (Manojkumar et al., 2019). In this study of Vellore city, the measured L_{eq} values at each location were imported to ArcGIS software. GIS mapping was carried out in noise mapping in Thiruvananthapuram city of Kerala (India) so as to improve the visibility and accuracy of the noise analysis by Maya & Sreedevi (2015). The study was conducted by dividing the city into different zones so that one can easily understand the noise intensity level at different zones using contour mapping. The noise maps were constructed based on the L_{eq} value of sound level for numerous sessions. The study reported that the maximum noise pollution was in the evenings; and compared to other zones, it was more prevalent in traffic zones. By modeling, Maya & Sreedevi (2015) were able to get the effect of noise pollution among people and therefore reduce it. By establishing buffer zones that serve as a tool for proximity analysis, the GIS approach has been utilized to define the degree of noise pollution by Maqsood et al., (2019) while studying the impact industrial noise on the hearing capacity of workers. In an academic environment, a similar contour mapping of Kufa University (Kufa River Campus) was carried out using GIS tools, and the spatial fluctuation of noise level was investigated using the Spline interpolation approach (Hussein & Al-Sulttani, 2021).

3.4. Noise and Public Health

The physiological and psychological impacts of noise on people in diverse settings such as city traffic, industrial workplaces, and educational institutions have been reviewed in this section, as per objective (iv) of the study.

Noise pollution has become a nuisance to people in general in recent decades. According to USEPA, there is a direct link between noise and health (Keerthana et al., 2013). People who are subjected to constant loud noise suffer harm and find it bothersome. Noise is a sign advising element for an individual's or society's overall physical and mental health. It is commonly recognized that noise exposure above a particular level – depending on its intensity, frequency, duration, and individual susceptibility, may harm human health; and, thus needs to be under control (Bhushan & Shukla, 2018; Srivastava & Rai, 2020).

Every noise study has reported that people living in cities are being exposed to the noisy environment, and traffic noise in particular has become a part of people living in urban areas. Noise pollution can significantly stress the auditory, non-auditory, and neurological systems of city dwellers (Mishra et al. 2021; Asensio et al., 2020). When homes were taken into account, the amount of outside noise produced by human activity is high (Hunashal & Patil, 2012). According to a noise survey conducted in Skopje city of Macedonia, 41% of the population experienced anxiety and 35% has sleep disturbances as a result of noise (Domazetovska et al., 2020). A survey conducted in Morena city in India reported that shopkeepers and vendors spending most of their time in the commercial zone were exposed to high noise levels and therefore had physiological and psychological problems due to it (Singh & Dadoriya, 2013). The noise measurement carried out in various land use patterns in Chennai (India) also revealed that noise pollution harmed city dwellers' health (Konadath et al., 2019). Sahu et al. (2020) reported headache, high blood pressure, light-headedness, weariness, and others effects on body's structure due to traffic noise in a city. The study conducted a poll that looked at the current state of aggravation caused by traffic noise, 34% of people experienced irritability, 26.2% experienced insomnia, and 22% performed poorly at work after being subjected to noise from traffic for more than six hours every day. Physical and psychological impacts on persons were frequently measured in this way.

Another crowd of people who are under the threat of noise pollution are the workers working in large industrial sectors. Many studies on industrial noise pollution and effects using advanced technologies have also been reported. Loudness variations can cause both temporary and permanent hearing loss in the inner ear of human beings. Short-term noise exposure is not harmful to the body, but chronic exposure to 83 dB noise causes hearing loss. Aygul et al. (2017) reported that continuous exposure to more than six hours of noise will be hazardous to humans. In the entire world, it is estimated that 16% of workers had hearing impairment brought on by noise pollution at work. According to a survey of 200 workers in an industrial area of Pakistan regarding the effect of noise pollution on their ability to hear, 66.36% of the workforce was exposed to very high noise levels. The serious physical and mental health issues that these factory workers were susceptible to include annoyance, hypertension, irritation, speech impediment, insomnia, depression, headaches, and even hearing loss (Maqsood et al., 2019). Another investigation, performed among 20 to 80-year-old textile loom labourers in a Pakistani industrial area, reported that all respondents suffered from health problems caused by noise. Responders also reported headache (94%), lack of sleep (76%), hypertension (74%), psychological stress (74%), high blood pressure (64%), vertigo (60%), and hearing loss (56%) (Farooqi et al., 2019), as shown in Fig. 1a. A survey of five different industries in Khulna city, Bangladesh indicated that 68% of respondents suffered from headaches, 50.67% found the noise bothersome, 29.33% had difficulty in sleeping, and 33.33% felt dizzy as a result of the noise (Banik et al., 2018), as shown in Fig. 1a. Further, 74.67% of them desired to be relocated to a more peaceful area. Additionally, it was noted that all industries, except one, were located extremely close to residential areas. The occupational health consequences of noise were investigated in a survey of 58 industrial workers aged 46 to 55 years with 21 to 30 years of industrial experience by Herzog et al., (2020). The study reported that 95% of the workers experienced noise at their workplace daily, 78% experienced noise during the whole week, and 81% knew co-workers with hearing impairment.

Noise pollution in educational institutions affecting the teaching-learning processes has been reported in many studies. Due to poor job performance, rising errors, declining motivation, etc., noise pollution has grown to be a significant issue in educational settings. Noise negatively impact reading-concentration, problem-solving, and memory (Keerthana et al., 2013). It has also been reported that noise pollution in colleges results in annoyance, lack of concentration, speech interference, stress, low productivity, increased absenteeism, and other negative effects (Obot & Ibanga, 2013). Students learning outcomes have been significantly impacted by their learning environment; and noise has been observed to be one of the main factors that distracted pupils, impaired their ability to pay attention and concentrate, and caused headaches and anxiety (Farooqi et al., 2020). A noise pollution survey conducted in an educational institute observed that 62% of people had a disturbance in the teaching-learning process, 18% for classroom discussion, and 20% had health problems and mental stress (Debnath

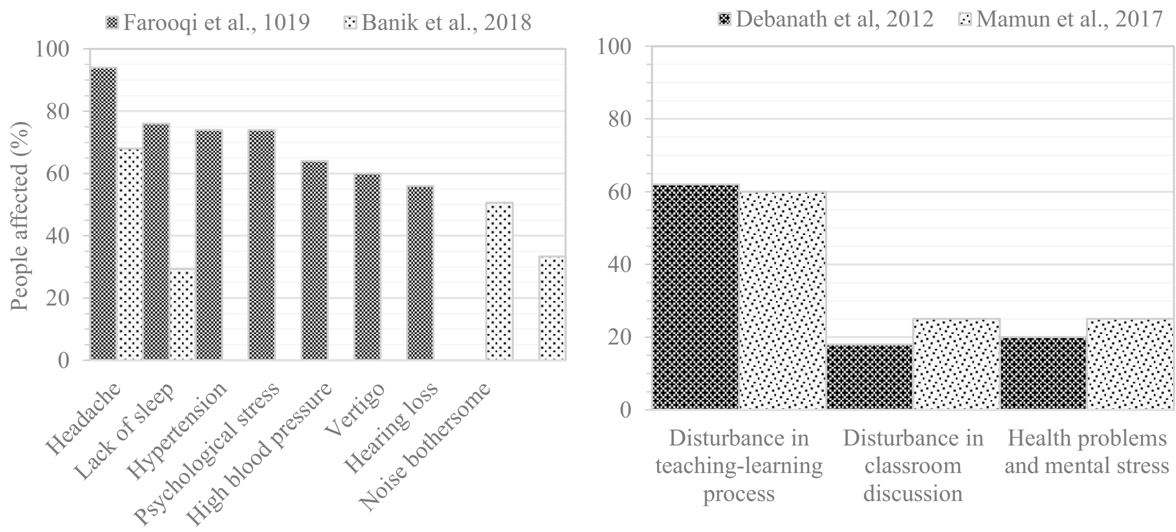

Figure 1. Health effects in noisy environment: **a** – Industry; **b** – Educational institute

et al., 2012), as shown in Fig. 1b. Another survey of 100 individuals, including teachers and students, identified that 60% had a disturbance in the teaching-learning process, 25% had difficulty in classroom discussion and 25% had health-related issues (Mamun et al., 2017), as shown in Figure 1b. The results of a study, based on the questionnaire and the interviews with 210 students in different age groups from four schools, made it abundantly evident that noise in educational settings has a detrimental effect on children's ability to study and accomplish academically (Gilavand & Jamshidnezhad, 2016). In a similar study, during a poll of 38 instructors at another school, it was observed that 74% encountered noise in the workplace on a daily basis, with 17% experiencing the most noise on Friday and 14% experiencing the most noise on Monday (Herzog et al. 2020). Noise's detrimental impacts on instructors were observed in increased food intake (50%), and smoking (42%). Further, almost 75% of illnesses requiring medical attention among teachers were stress-related. It is significant to note that in both the studies related to educational institutes, the impact of noise is spread among people similarly, whether students or instructors.

4. Conclusion

The review of research papers revealed that studies carried out in accordance with WHO guidelines have generally used Class 1 types of SLMs, while studies as per ISO and national guidelines have used both – Class 1 and Class 2 types of SLMs; and mostly compared the results with applicable national standards that are broadly consistent with WHO guidelines. In most of the studies, the results have been expressed and compared with standards in terms of Leq values in dB using A-weighted frequency network, and additionally reported results in derived parameters (such as TNI, NPL, NC and NEI) for better description of noise exposure in specific environment. However, it is reflected in the review that standardized methodology, especially the duration of noise monitoring, was lacking in many of the studies for noise measurement in various land-use patterns (i.e., areas or zones). Further, studies have reported noise assessment in a variety of locations or urban landscape, including city traffic, residential areas, industrial areas, silence zones (schools and universities, hospitals, parks, etc.), and compared them with national and international standards to analyse and check whether the noise levels are within the permissible limits, but noise levels exceeded the prescribed limits in almost every study across the globe irrespective of land-use or designated zone, and exhibited rising trends particularly due to traffic induced noise. Almost every study has reported that urban population has been exposed to the noisy environment and has significant physiological and psychological impacts on public health that include headache, high blood pressure, anxiety, sleep disturbances, hearing loss, insomnia, depression, hypertension, vertigo, weariness, speech impediment, lower work efficiency, disturbance in teaching-learning process and other effects on body's structure. Despite few recent studies on noise geo-spatial mapping, the potential of noise mapping techniques has been well demonstrated in noise abatement and management. However, one of the main constraints while analysing and/or reviewing a study area for current noise mapping is the non-availability of ambient noise level data of other already monitored areas/cities.

The marked drop in noise equivalent during day as well as night time across all zones/landscape of urban environment during COVID-19 lockdown period, even in residential areas, is an encouraging sign in the sense that improved conduct can be an effective tool in noise abatement. As the ultimate goal of a research is to identify a solution to mitigate noise pollution, so based on the demonstrated gaps and/or constraints the following future research perspectives of noise abatement have been suggested:

- The upcoming studies must methodically carry out the noise assessment with prescribed guidelines of measurement and standards, particularly with respect to duration of monitoring.
- Use of advanced tools like SPSS software for quantitative analysis of complex data should receive attention as it utilizes both descriptive and inferential statistics.
- Future investigations need to focus on geospatial noise mapping of urban areas and real-time information system that can lead to proper urban landscape planning, and to take precautionary and regulatory measures in advance.
- Universal database management software (DBMS), such as – SQL (Structured Query Language) and Improvado, can be adopted by national and international noise monitoring agencies to compile data in a single storage area that will allow multiple users to access data despite different geographical locations.
- Awareness programmes about the negative impacts of noise pollution should be carried out using multi-media approaches, especially in urban areas. This can be augmented by city-wise noise pollution mitigation plan focussing on noise hotspots and specific sources.
- The laws and regulations should be properly implemented for the abetment of noise pollution.

It is high time that the researchers, and national and international agencies come up with the development of advanced technologies, integrated strategies and sustainable environmental planning to mitigate the menace of noise pollution.

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