RESEARCH ARTICLE

Statistical and spatio-temporal analyses of noise pollution level and its health impact

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Abstract

Due to rapid urbanization and exponential growth in transportation; traffic noise has become a major area of concern. Noise not only disturbs our day-to-day life but also have severe adverse health effects over humans which further may lead to mortality. This paper focuses on the behavior of noise levels of Lucknow city over a decade and establishes its correlation with impact on human health in terms of annoyance and sleep disturbance. Apart from L_{eq}, different noise parameters like L_{10}, L_{50}, L_{90}, Traffic Noise Index (TNI), Noise Pollution Index (NPI), and Noise Climate (NC) have also been analyzed to understand the variation of noise. At all the locations, the noise level has been found exceeding their prescribed standards during day time and night time except at Amausi. Out of nine locations, TNI was found to be exceeding at three locations during day time and NPI exceeding at one location. However, during night time both values of TNI and NPL were observed within the limit at all the locations. From the noise map of the city during day time and night time, among all sampling locations, Charbagh has been found to be worst affected by noise pollution. A strong positive correlation has been observed among the total population, vehicular count, and day and night time noise data, which directly contribute to a higher percentage of sleep disturbance and annoyance among residents. Due to the increase in noise levels over a period of time, almost four times the population get affected by high annoyance and almost double the population get affected by sleep disturbance.

Keywords Noise pollution · Traffic Noise Index · Noise pollution index · Sleep disturbance · Annoyance

Introduction

Days are not far behind when the countries and their cities will be known by their pollutant levels. Environmental pollution has become a common problem for all cities

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irrespective of their geographical locations (Li et al. 2019; Gheibi et al. 2022). Among the various types of environmental pollution (air, water, and soil), noise pollution is one of them where human beings are living in an increasingly noisy environment (Grunst et al. 2021). Current city residents are experiencing elevated noise troubles as compared to earlier city residents from the past (Markandeya et al. 2021). Due to continuous population growth, technological advancement, and rapid urbanization, the extent, impact severity, and frequency of noise pollution are also growing (Tao et al. 2020b). Noise pollution is said to occur when unwanted disturbing or harmful sounds are encountered (Huang et al. 2021). Noise pollution is especially harmful because its immediate effects often go unnoticed (i.e., they build up gradually and the damage caused often cannot be reversed). Higher noise levels have been allied with severe effects on human health, varying from slight annoyance to physiological damage (Yin et al. 2020). The advancement of noise pollution in urban areas encompasses direct and accumulative severe health effects (mostly humans, animals, and birds); it is not only affecting our future generations by

debasing their residential, social, and learning surroundings but also responsible for corresponding financial loss (Tong et al. 2021). A clean environment is one of the indicators of valuable quality of life. In a recent USEPA classification, "noisy residential areas," average 58 dB(A), were rated as low socio-economic, while "quite residential areas," average 38 dB(A), were rated affluent neighborhoods (Mann and Singh 2022).

The presence of noise pollution beyond a specified limit under certain conditions in the atmosphere is injurious to humans. Psychological damage and annoyance can occur at much lower noise levels, e.g., sleep interference in human beings occurs at around 45 dB(A) (Ma et al. 2021; Wu et al. 2019). Some of the unpleasant physical and psychological side effects of prolonged exposure to noise pollution are loss of hearing (similar to what occurs naturally as a part of the aging processes), sleeplessness, severe migraine, and stomach problems that may occur at about 75 dB(A), and distinctly, a painful stomach ache at 180 dB(A) can prove fatal (Wang et al. 2020). Damage caused by noise can vary from damage to the eardrum, permanent hearing loss, headaches, stress, lack of concentration, fatigue, dizziness, cardiac and cardiovascular changes, irritation, nausea, inefficiency, etc. It can also disrupt the functioning of motor and psychomotor, can hamper work tasks and speech communication, can cause sleep disturbance, can affect room privacy, can cause insomnia and loss of appetite, and can cause some other damage to physical activities (Chang et al. 2014). It triggers the autonomic nervous system, which further stimulates the adrenal medulla to generate epinephrine and norepinephrine (Othman et al. 2017). It also triggers the pituitary gland which sequentially disturbs the thyroid, adrenal cortex, and gonads. The thyroid gland controls metabolism and its hormones are accountable for usual growth and development. Influences on gonad functioning can affect growth and maturation (Miller et al. 2018; Huang et al. 2021).

The sources of noise are many and varied, mainly from road and rail transport, factories, industries, aircraft, etc. Other sources of noise pollution are usage of high-volume horns (pressure horns) and leisure noise of amplifiers with high volume during celebration of festivals. The domestic noises from the radios, transistors, and television sets cumulatively enhance the dosage of noise in daily life (Othman et al. 2017). Noise levels are particularly severe near railway stations, road traffic junctions, bus terminals, and airports (Evans and Hygge 2007; Wang et al. 2020). Noise pollution can have several effects on human health varying from annoyance to hearing loss. Health effects of noise may be broadly classified as physiological, psychological, sociological, and psychoacoustical effects (Roozbahani et al. 2009; Ramazani et al. 2018). The major and most common effect of noise pollution is annoyance and sleep disturbance which

is assessed and correlated with other factors in the present study. This may further lead to mortality also.

In the current era of urbanization, the creation of smart cities is a major indicator of progress all around the world. The development of new road transportation has become a major indicator in smart city development which ultimately results in exponential vehicular growth. Since traffic noise is a major source of pollution, it needs time to develop new road networks with proper noise abatement mechanisms to avoid future health complexities due to noise pollution (Tiwari et al. 2014). In traffic, honking and rash driving and frequent acceleration and deacceleration are the major source of noise pollution, which are mainly caused due to congested road networks, irresponsible driving behaviors, and a lack of awareness among people. Low-frequency noise is also generated from the engine noise of different types of vehicles, it can be reduced with proper maintenance of vehicles (Tao et al. 2020a). The development of new roads with proper noise barriers is the need of the hour and must be implemented judiciously with the help of policy makers.

In comparison to the aforesaid researches, the current research objective is to investigate the decadal behavior of noise levels of Lucknow, an emerging smart city, using different statistical analyses. Lucknow, is a historical city earlier known as "Awadh" at the time of the Mughal era is culturally rich and has many archeological monuments and currently is a major emerging hub for industrialization and urbanization. The present study provides us with the details of the population getting affected by noise pollution in terms of annoyance and sleep disturbance which ultimately leads to different mental, psychological, and hearing disorders. It also focuses on the correlation and distribution of vehicular growth with an increase in noise pollution and its health impacts. This study will help policy makers to understand the interconnection of urbanization, vehicular traffic, noise pollution, and its health impacts on urban residents and plan accordingly to combat future challenges associated with it.

Methodology

Monitoring locations

The simultaneous random samples of noise level dB(A) of Lucknow city were taken by CSIR-Indian Institute Toxicological Research (IITR), Lucknow, during day time (6 AM to 10 PM) and night time (10 PM to 6 AM) for the period of 2010 to 2019 (10 years) (CSIR-IITR 2010–2019). Noise was monitored at nine (9) locations: Aliganj (S1), Vikas Nagar (S2), Indira Nagar (S3), Gomti Nagar (S4), Charbagh (S5), Alambagh (S6), Aminabad (S7), Chowk (S8), and Amausi (S9) (Fig. 1).

Fig. 1 Monitoring sites of the study area in Lucknow city
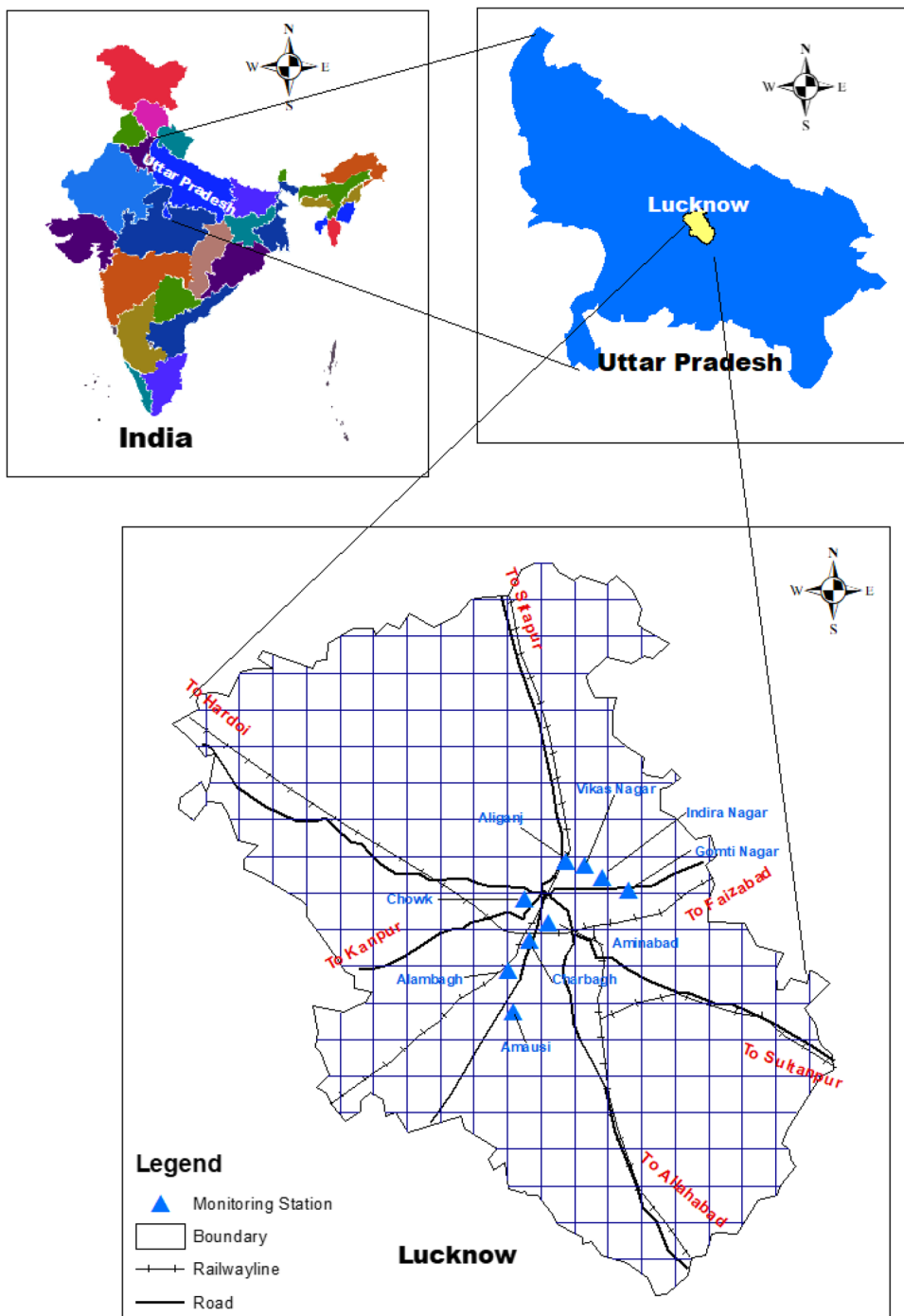
All nine monitoring locations are categorized under the following zones as given in Fig. 1. Frequency of monitoring is considered twice in a week for 2 months as pre-monsoon and twice in a week for 2 months representing the post-monsoon season. At each location, noise levels were recorded for day time (6 AM to 10 PM) and night time (10 PM to 6 AM). The monitoring was done with the help of CIRRUS Precision Data Logging Sound Level Meter CR-703B. All measurements were made with the "A" weighing filter at a height of 1.5 m above the ground level.

Calculation of noise parameters

$L_{\text{day, 16 h}}$ It is defined as equivalent noise level for day time (6:00 AM to 10:00 PM).

$L_{\text{night, 8 h}}$ It is defined as equivalent noise level for day time (10:00 PM to 6:00 AM).

L_{den} It is defined as day evening night equivalent noise level.

L_{den} can be calculated using the following Eq. 1:

$$L_{\text{den}} = L_{\text{day,16h}} - 2 \times \ln \frac{(L_{\text{day,16h}} - L_{\text{night,8h}})}{22.4} \qquad (1)$$

Percentile noise levels

The noise level distribution can be assessed by evaluating noise level data with different statistical analysis. Following are the key percentile required for analysis of noise data (Pathak et al. 2008; Marks et al. 2008).

L_{10} Ten percentile time noise level can be defined as the noise level which is exceeding 10% of the total observation time. It can also be defined as peak noise level.

L_{50} Fifty percentile time noise level can be defined as the noise level which is exceeding 50% of the total observation time. It can also be defined as average noise level.

L_{90} Ninety percentile time noise levels can be defined as the noise level which is exceeding 90% of the total observation time. It can also be defined as background noise level.

Traffic Noise Index

Traffic Noise Index (TNI) can be acquired by combining different noise levels. It provides us a better correlation with dissatisfaction. While measuring, the A-weighted noise level outdoors, it is attained by contemplating, L_{10} as an average peak level interlopes with L_{90} as an average background noise level (Langdon and Scholes 1968). Mathematically it is stated as Eq. 2:

$$\text{TNI} = \left[4 \times \left(L_{10} - L_{90}\right) + L_{90}\right] - 30 \qquad (2)$$

TNI is consequent on the supposition that extensive fluctuation of noise levels over a particular period is the major prevailing factor in traffic noise annoyance. TNI also represents the degree of disparity in a traffic flow which results in noise variability, which is considered more annoying.

Noise Climate

Noise Climate (NC) can be defined as the range over which the sound level fluctuates for a particular interval. Mathematically it is presented as $L_{10} - L_{90}$ (WHO 1999; Miedema et al. 2011).

Noise Pollution Level

As per Robinson (1971) of the British National Physical Laboratory, L_{eq} is not a self-sufficient parameter to describe the annoyance caused by variable noise. Road traffic noise has always been considered fluctuating noise. Therefore, index NPL was evolved to assess the dissatisfaction instigated by road traffic noise. It comprises two terms: the first is the measurement of the equivalent continuous noise level (L_{eq}) and the second signifies the upsurge of annoyance produced by fluctuations in that level (Robinson 1971; Deshaies et al. 2011). Mathematically it can be expressed as given in Eq. 3:

$$\text{NPL} = L_{\text{eq}} + \left(L_{10} - L_{90}\right) \qquad (3)$$

Noise percentiles, e.g., L_{10} and L_{90}, NC, TNI, and NPL are calculated at all the locations for day time (LD), night time (LN), and day–night time (LDN) to understand the behavior of noise over time. A correlation plot has also been made to study the accuracy of monitored and predicted values.

Noise maps

In the present study, L_{eq} during day time and night time has been calculated over a period of 10 years at all the locations. All these location maps have been generated in Arc GIS and L_{eq} values during day time and night time have been inserted into the monitoring location database. Noise maps over L_{eq} (day) and L_{eq} (night) based on a spatial database has also been generated in Arc GIS.

Statistical analysis

Statistical analysis of noise data has been done using Jeffreys's Amazing Statistics Program (JASP: version JASP 0.17.1). In statistical analysis, one-way ANOVA has been done separately for residential and industrial areas. Apart from this, a descriptive statistic has been done for different components like vehicular count, total population, noise level during day and night, etc.

Health impacts

As per WHO, health is not only the absenteeism of diseases but also includes a state of complete physical, mental, and social well-being. Therefore, annoyance created because of noise is also considered one of the environmental health burdens (Robinson 1971).

Exposure–response relationship

The percentage of "highly annoyed" persons (HA) due to road traffic noise was calculated using Eq. 4:

$$HA\,[\%] = 0.5118 \times (L_{den} - 42) - 1.436 \times 10^{-2} \times (L_{den} - 42)^2 + 9.868 \times 10^{-4} \times (L_{den} - 42)^3 \qquad (4)$$

The percentage of "highly sleep disturbed" persons (HSD) as a function L_{night} was calculated using Eq. 5:

$$HSD[\%] = 20.8 - 1.05 \times L_{night} + 0.01486 \times L_{night}^2 \qquad (5)$$

Results and discussion

Results of noise quality data

L_{eq}, L_{10}, and L_{90} have been calculated at all locations during day time, night time, and day–night time over the period of 10 years. At all locations, L_{eq} varied from 66.4 to 79.3 dB(A), L_{10} from 70.5 to 84.8 dB(A), and L_{90} from 62.2 to 73.9 dB(A) during day time (Fig. 2 a). Shalini and Kumar (2018) studied the Varanasi location and found that L_{eq} varied from 70.2 to 92.0 dB(A), and in our study, the all-site average was found to be 72.2 dB(A) (Fig. 2 a). However, during night time, L_{eq} varied from 57.2 to 68.6 dB(A), L_{10} from 58.8 to 71.7 dB(A), and L_{90} from 55.5 to 65.6 dB(A) at all location (Fig. 2 b). Furthermore, L_{eq} varied from 64.9 to 77.7 dB(A), L_{10} from 68.7 to 82.8 dB(A), and L_{90} from 61.0 to 72.7 dB(A) at all locations during the day–night time (Fig. 2 c). The maximum average values of L_{10} for day, night, and day–night were 76.5 dB(A), 66.3 dB(A), and 74.8 dB(A) respectively (Fig. 2 a–c). The value of L_{10} was found to be 74.8 dB(A) for the all-site average during the day–night time. Shalini and Kumar (2018) have also found a similar result.

Traffic Noise Index, Noise Climate, and Noise Pollution Level

TNI was calculated for day time, night time, and day–night time at all the locations for equivalent noise levels over the period of 10 years. Similarly, NC and Noise Pollution Level (NPL) have also been calculated over the period of 10 years at all locations.

From TNI (Fig. 3 a), it can be observed that during day time out of nine locations, the value of TNI is exceeding the threshold values of 74 dB(A) at three locations. However, during night time, it is within permissible limits at all locations. From day-night equivalent noise levels, it can be observed that the TNI value is exceeding its threshold at two locations, namely Aliganj and Charbagh. Similar TNI results are reported by Manojkumar et al. (2019) for the Vellore sampling location.

Noise climate (NC) depicts the range over which the sound levels fluctuate for a particular time interval. It can be observed (Fig. 3 b) that in most of the locations during day time, values of NC are high as compared to night time due to less variance of noise during time. But at three locations, namely Aminabad, Chowk, and Amausi, NC values are higher at night time as compared to day time. It shows that in these areas during night time, noise fluctuation is more than that during day time. This may be due to plying of heavy vehicles, e.g., trucks and buses in this area during night time. Munir et al. (2021) have also observed that the NC value during day time was more than that during night time. A similar observation for NC value has also been reported by Pathak et al. (2008).

In residential areas, at Vikas Nagar, a significant reduction has been noted for values of TNI and NC during night time as compared to day time; it represents that during night time, there is a significant reduction in traffic noise and its variation. It also depicts that traffic noise is a major source of pollution in this area. Charbagh is a railway station and Alambagh is a bus stop in Lucknow. During night time, both the values of TNI and NC are getting significantly reduced at these locations in comparison to those during day time. Traffic noise is a major source in these areas, and during night time, due to a significant reduction in traffic, both TNI and NC values get reduced significantly. A study reported by Nazneen et al. (2020) found a reduction trend during night time due to less traffic movement. Moreover, the maximum day–night equivalent NC has been observed at Aliganj, i.e., 11.5, and the minimum day-night equivalent NC has been observed at Aminabad (Fig. 3 b).

Figure 3 c of Noise Pollution Level (NPL) at different locations of Lucknow depicts that during day time at Charbagh, the NPL value is exceeding the prescribed standard of 88 dB(A). Night time and equivalent day–night NPL at all the locations is well within the prescribed standard of 88 dB(A) at all locations. Min and Min (2018) studied the cumulative exposure to night time environmental noise and

Fig. 2 Variation of L_{10}, L_{eq}, and L_{90} for day (**a**), night (**b**), and day–night (**c**) at different sites of Lucknow city
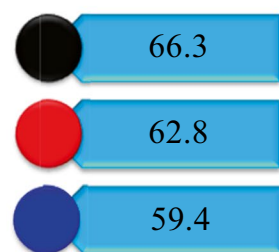
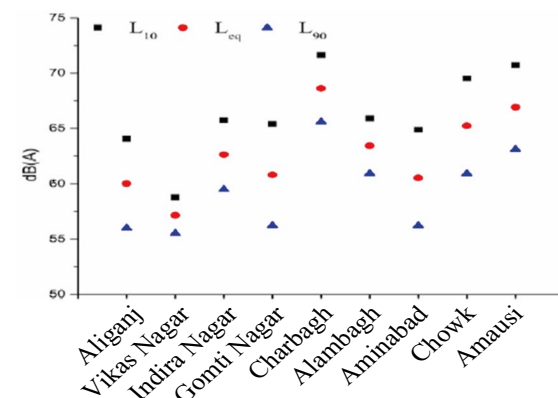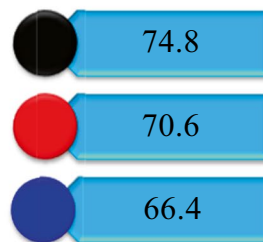**All Site (L_{10}, L_{eq} and L_{90}) dB (A)**
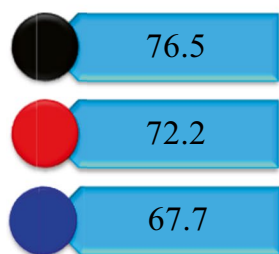
(a)
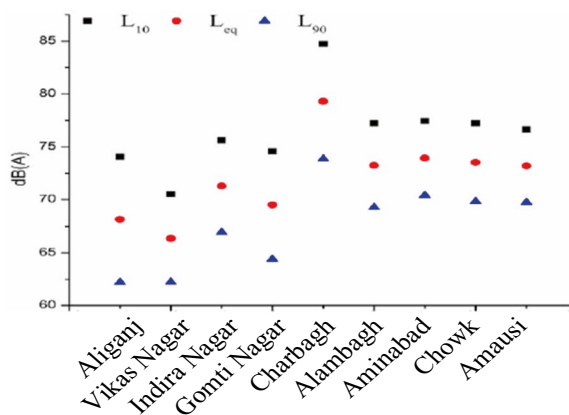
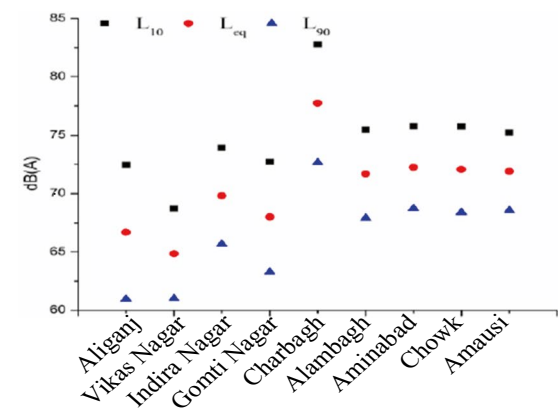**All Site (L_{10}, L_{eq} and L_{90}) dB (A)**

(b)

All Site (L_{10}, L_{eq} and L_{90}) dB (A)

(c)

the incidence of peptic ulcer and concluded that night time noise levels are less in all cases.

Spatial distribution of Noise Level

A noise map has been created for L_{eq} day time and night time data over the decades by the IDW method in Arc GIS. From the noise maps, it can be observed that at an industrial area, i.e., Amausi, during day time, the noise level varies from 72.2 to 77.2 dB(A) which is a little bit higher

than the prescribed standard of 75.0 dB(A); however, during night time, it varies from 62.2 to 67.2 dB(A) which is well within the prescribed standard of 70.0 dB(A) (Fig. 4). At all commercial locations except Charbagh during day time, the noise level varies from 72.2 to 77.2 dB(A), and during night time, it varies from 62.2 to 67.2 dB(A) which is higher than the prescribed standards of 65.0 dB(A) and 55.0 dB(A) respectively for day and night. Gupta and Ghatak (2011) have also found the L_{eq} is higher than that of the standard value. However, among all sampling locations

Fig. 3 **a** Variation of Traffic Noise Index (TNI) at different locations ▶ of Lucknow city. **b** Variation of Noise Climate (NC) at different locations of Lucknow city. **c** Variation of Noise Pollution Level (NPL) at different locations of Lucknow city

at Charbagh, the maximum noise level has been observed during day and night time, i.e. 77.2 to 79.3 dB(A) and 67.2 to 72.2 dB(A) respectively. This may be due to the presence of a railway station which contributes to additional noise level burden to this point.

At all residential locations during day time, the noise level varies from 67.2 to 72.2 dB(A), and during night time, it varies from 57.2 to 62.2 dB(A) which is quite higher than the prescribed standards of 55.0 dB(A) and 45.0 dB(A) respectively for day and night (Fig. 4).

Statistical analyses

For residential location

One-way ANOVA has been done among four residential locations during day time and night time for noise monitoring over the decades (Table 1).

During day time as per statistical analysis, no such variance of noise has been observed among all locations in the last decade $F_{(3, 36)} = 1.549$ and $p = 0.219$. Similarly, during night time, one-way ANOVA has been done, and as per statistical analysis, no such variance of noise has been observed among all locations in the last decade $F_{(3, 36)} = 2.772$ and $p = 0.055$.

For commercial location

One-way ANOVA has been done among four commercial locations during day time and night time for noise monitoring over the decades (Table 2).

During day time, there was a significant difference among different commercial locations, $F_{(3, 36)} = 3.24$ and $p = 0.03$. Again, to verify the variation among different locations, a post hoc test was conducted (Table 3).

It can be observed that except for Charbagh, the rest of the locations' noise values are significantly similar at all locations during day time. Similarly, during night time, there was a significant difference observed among different commercial locations, $F_{(3, 36)} = 11.073$ and $p < 0.01$.

Again, to verify the variation among different locations, a post hoc test was conducted (Table 4). From the post hoc test, it has been observed that except for Alambagh and Chowk, a significant difference in noise level has been observed among all others.
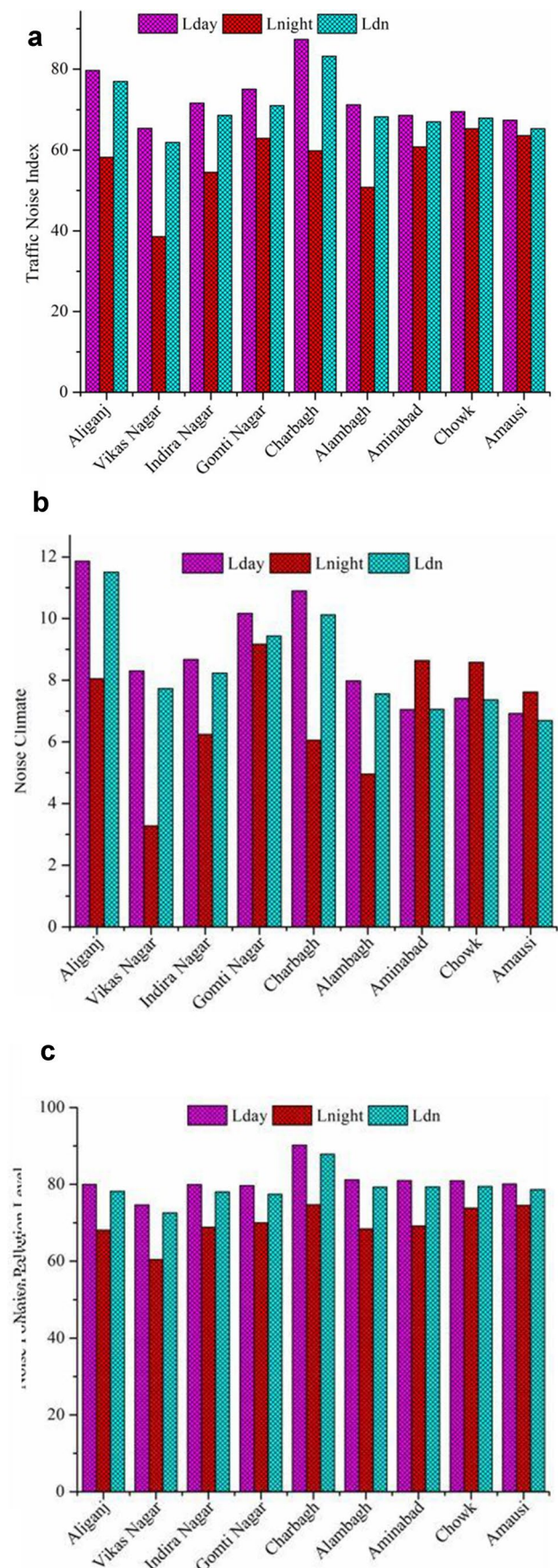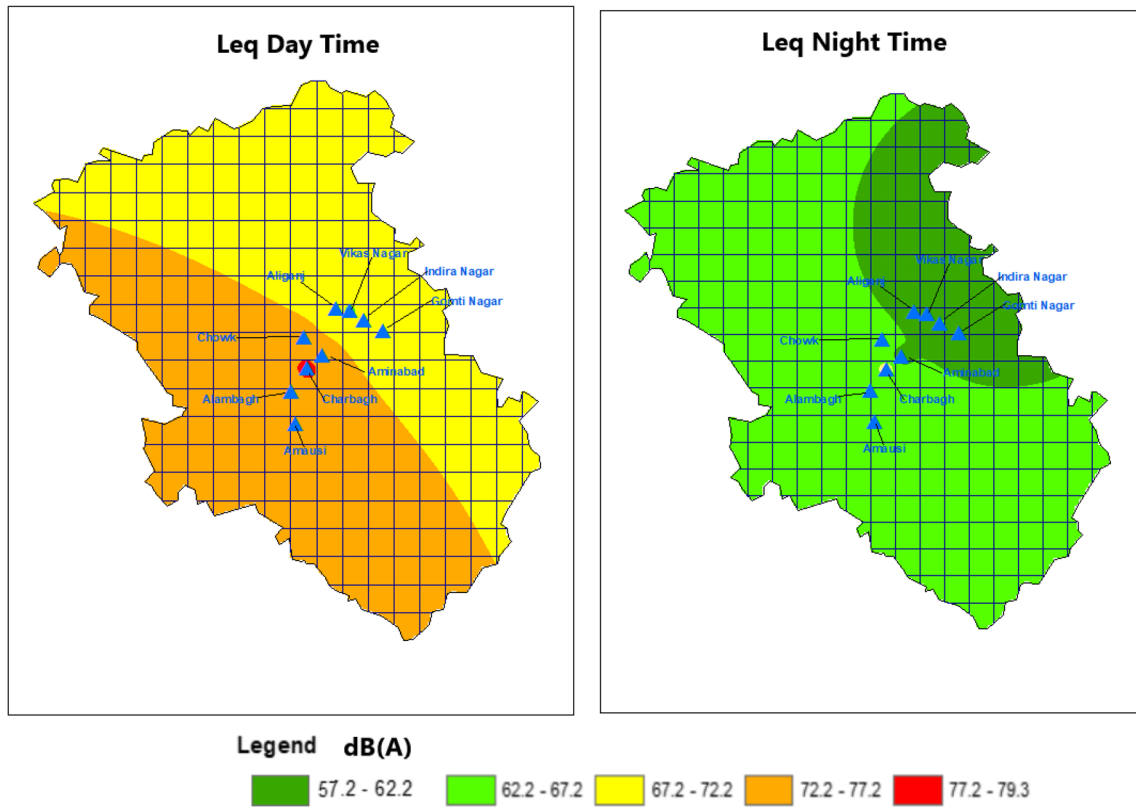
Fig. 4 Variation of noise levels at different areas of Lucknow city

Table 1 ANOVA analysis for residential location during day and night time

Cases	Sum of squares	df	Mean square	F	p	η^2
ANOVA—day time						
Location	103.549	3	34.516	1.549	0.219	0.114
Residuals	802.030	36	22.279			
ANOVA—night time						
Location	117.893	3	39.298	2.772	0.055	0.188
Residuals	510.377	36	14.177			

Type III sum of squares

Table 2 ANOVA analysis for commercial location during day and night time

Cases	Sum of squares	df	Mean square	F	p	η^2
ANOVA—day time						
Location	172.449	3	57.483	3.240	0.033	0.213
Residuals	638.699	36	17.742			
ANOVA—night time						
Location	447.925	3	149.308	11.073	<.001	0.480
Residuals	485.430	36	13.484			

Type III sum of squares

Table 3 Post hoc comparisons—location wise

Locations		Mean difference	95% CI for mean difference		SE	t	p_{Tukey}
			Lower	Upper			
Alambagh	Aminabad	−0.980	−6.053	4.093	1.884	−0.520	0.954
	Charbagh	−5.140	−10.213	−0.067	1.884	−2.729	0.046
	Chowk	−0.270	−5.343	4.803	1.884	−0.143	0.999
Aminabad	Charbagh	−4.160	−9.233	0.913	1.884	−2.208	0.140
	Chowk	0.710	−4.363	5.783	1.884	0.377	0.981
Charbagh	Chowk	4.870	−0.203	9.943	1.884	2.585	0.064

P-value and confidence intervals adjusted for comparing a family of 4 estimates (confidence intervals corrected using the Tukey method)

Table 4 Post hoc comparisons—location wise

Locations		Mean difference	95% CI for mean difference		SE	t	p_{tukey}
			Lower	Upper			
Alambagh	Aminabad	4.470	0.047	8.893	1.642	2.722	0.047
	Charbagh	−4.990	−9.413	−0.567	1.642	−3.039	0.022
	Chowk	−0.220	−4.643	4.203	1.642	−0.134	0.999
Aminabad	Charbagh	−9.460	−13.883	−5.037	1.642	−5.761	<.001
	Chowk	−4.690	−9.113	−0.267	1.642	−2.856	0.034
Charbagh	Chowk	4.770	0.347	9.193	1.642	2.905	0.030

P-value and confidence intervals adjusted for comparing a family of 4 estimates (confidence intervals corrected using the Tukey method)
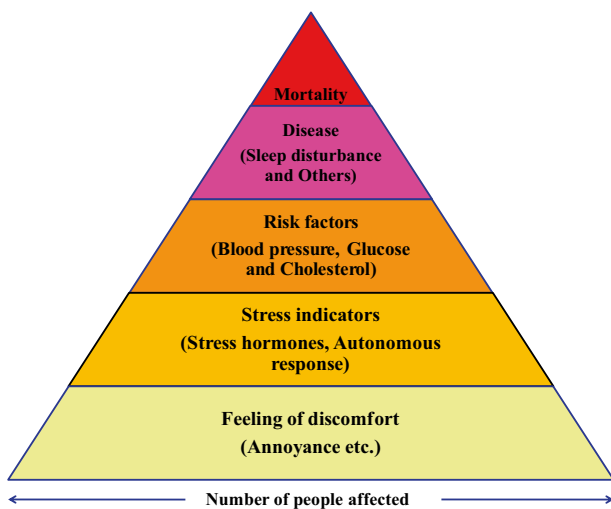
Fig. 5 Severity of health effects of noise and number of people affected

Health impacts

The very first impact of noise over human health is the feeling of discomfort which results in annoyance. This disturbance and annoyance activate the stress hormones of our body which leads to different risk factors, e.g., problems in blood sugar, cholesterol, etc. (Mohammed et al. 2020). This further leads to sleep disturbance, which itself is a root cause of different life-threatening diseases which ultimately moved to mortality (Fig. 5). The population suffering from annoyance due to exposure to environmental noise is a major area of concern. Therefore, to figure out the percentage of the population getting annoyed due to noise exposure, L_{den} was calculated at all the sampling sites. Exposure–response relationship equations were used to calculate the percentage of the highly annoyed population of Lucknow over the period of 2010 to 2019. The percentage of the population getting sleep disturbance at night time has also been estimated over the decades.

Annoyance and sleep disturbance

It can be observed that during the years from 2011 to 2019, a significant increase has been observed in the percentage of people getting affected by high annoyance and high sleep disturbance (Fig. 6). From 2011 to 2019, the percentage of the population affected from high annoyance is increased from 16.6 to 42.0% and the percentage of the population affected from high sleep disturbance
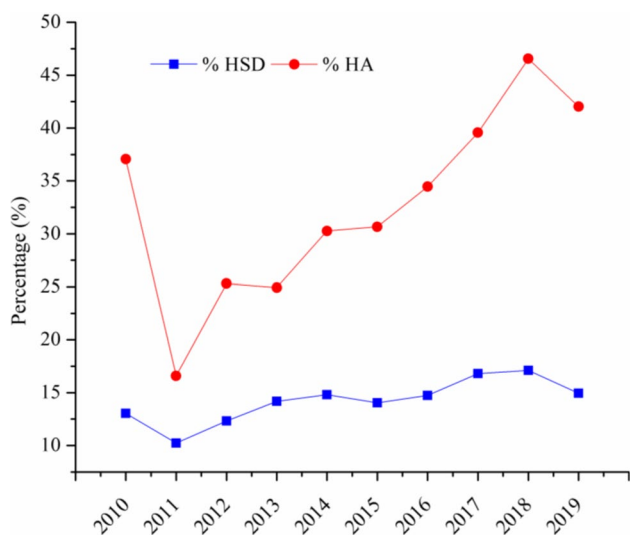
Fig. 6 Trends of high annoyance and high sleep disturbance due to noise over the past decade

increased from 10.22 to 14.94%. Douglas and Murphy (2016) studied source-based subjective responses to sleep disturbance from transportation noise and observed that a significant number of people are affected with annoyance and sleep disturbance due to noise.

From Table 5, it is clear that night noise pollution levels correlated better between observed and calculated values followed by day–night and day values. The determination coefficient (R^2) was found to be 0.985 (for night), 0.981 (for day–night), and 0.976 (for day).

A descriptive statistic has been applied over different components and a strong correlation has been observed among them, which signifies that day and night noise is directly correlated with the increase in the population as well as vehicular count, which directly contribute to a higher percentage of sleep disturbance and annoyance among residents (Table 6 and Fig. 7).

Table 5 Comparison between observed and calculated values of day, night, and day–night noise

Day			Night			Day–night		
Observed	Calculated	R^2	Observed	Calculated	R^2	Observed	Calculated	R^2
68.14	70.66	0.976	60.05	61.21	0.985	66.71	69.07	0.981
66.37	67.60		57.18	57.37		64.87	65.93	
71.29	72.63		62.65	63.34		69.82	71.03	
69.49	71.34		60.85	62.35		68.02	69.61	
79.31	81.43		68.64	69.29		77.73	79.56	
73.25	74.38		63.45	63.89		71.71	72.73	
73.93	74.81		60.57	61.90		72.26	73.15	
73.53	74.51		65.26	66.57		72.08	73.05	
73.20	74.05		66.94	67.98		71.92	72.72	

Table 6 Descriptive statistics analysis for all the locations

|	Vehicle_no	Day	Night	T_P	P_HA	P_HSD	%HA	%HSD
Valid	10	10	10	10	10	10	10	10
Missing	0	0	0	0	0	0	0	0
Std. deviation	371,335.128	4.040	2.478	387,803.870	557,049.273	148,736.862	9.034	2.031
Variance	1.379e + 11	16.318	6.138	1.504e + 11	3.103e + 11	2.212e + 10	81.605	4.125
Skewness	0.022	− 0.758	− 0.744	0.101	0.118	− 0.155	− 0.244	− 0.500
Std. error of skewness	0.687	0.687	0.687	0.687	0.687	0.687	0.687	0.687
Kurtosis	− 1.394	0.433	1.008	− 1.187	− 0.565	− 0.674	− 0.351	0.599
Std. error of kurtosis	1.334	1.334	1.334	1.334	1.334	1.334	1.334	1.334
Shapiro–Wilk	0.955	0.957	0.940	0.969	0.975	0.973	0.984	0.953
P-value of Shapiro–Wilk	0.730	0.751	0.558	0.885	0.935	0.919	0.985	0.698
Range	1.087e + 6	13.480	8.460	1.153e + 6	1.792e + 6	469,502.000	30.000	6.890
Minimum	1.107e + 6	64.080	58.490	4.474e + 6	761,458.000	469,239.000	16.600	10.220
Maximum	2.194e + 6	77.560	66.950	5.627e + 6	2.554e + 6	938,741.000	46.600	17.110
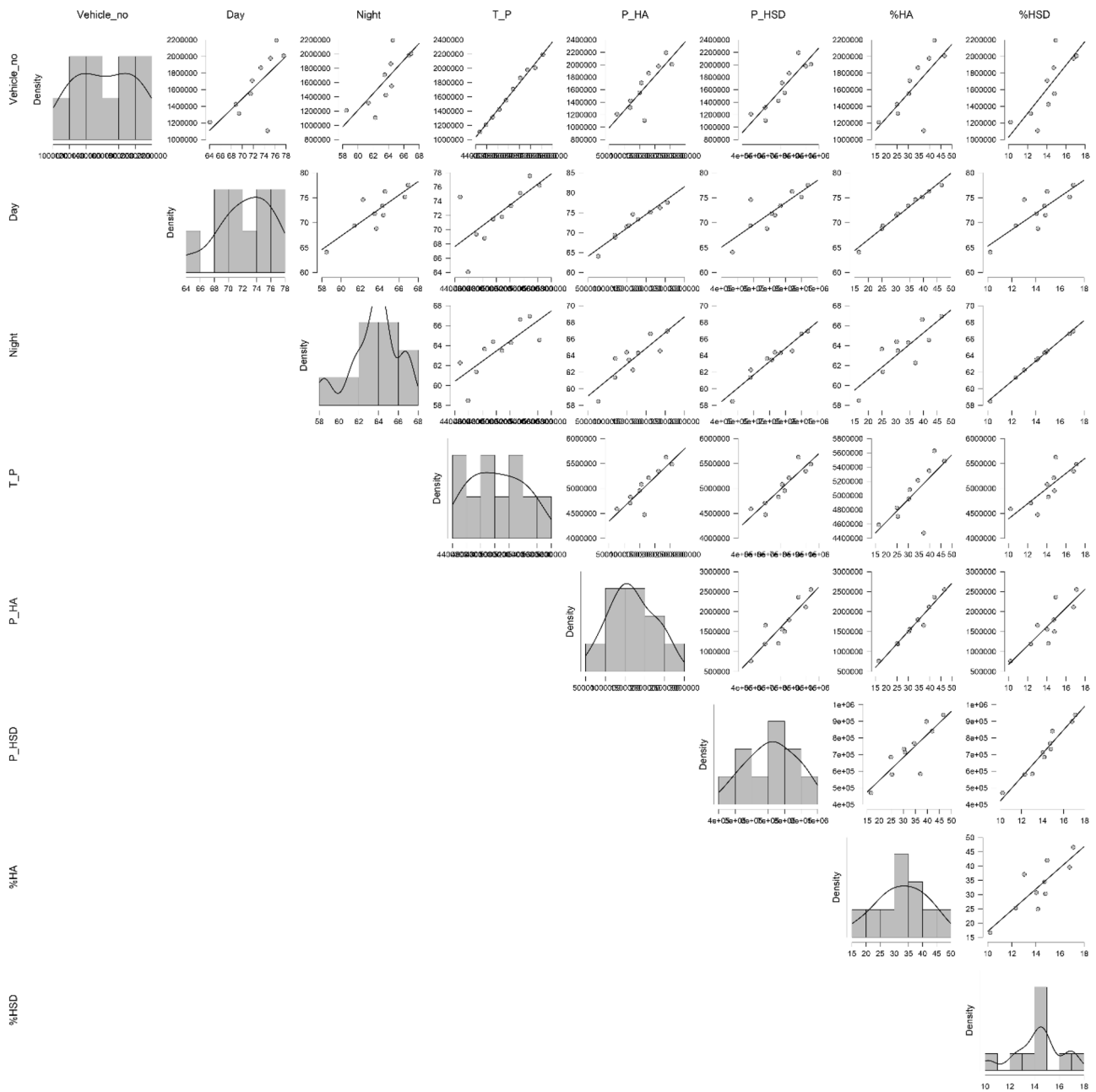
Fig. 7 Correlation and trend plot of noise over the past decade

Conclusions

The present research concluded that at all the residential and commercial locations, not only equivalent sound levels during day time and night time was far above the prescribed standards but also background noise, i.e., L_{90}, were also exceeding the prescribed standards. However, at industrial locations, equivalent sound levels during day time and night time were within the prescribed standards. In residential areas, during day time, TNI values at two locations, i.e., Aliganj and Gomti Nagar were found to be above the prescribed standards, whereas in industrial and commercial areas at Charbagh, the TNI value was above standard during day time. During day time at Charbagh, the NPL value was also exceeding the prescribed standard. It has also been observed that at Aliganj and Charbagh, the day–night equivalent TNI was above the prescribed standards. The higher values of TNI represent a major contribution to traffic noise at these locations. The noise map of Lucknow also suggested that except in industrial areas, the noise level was far above

the prescribed standards all over the city. Using one-way ANOVA statistical analysis, it has been observed that among residential locations, there is no such variation of noise during day time and night time. However, among commercial locations, variations of noise were observed both during day and night time. Annoyance is the very first impact of noise over human health, which further leads to sleep disturbance and finally to mortality. From this study, it can also be concluded that over the past period from 2011 to 2019, the percentage of people getting highly annoyed has increased from 16.6% (7,61,458 persons) to 42.0% (23,65,163 persons). Similarly, the percentage of the population affected by HSD has also increased from 10.22% (4,69,239 persons) to 14.94% (8,40,998 persons). In a decade, it can be perceived that almost four times the population get affected by high annoyance and almost double the population get affected by sleep disturbance, which is an alarming situation and requires the immediate attention of the authorities and policy makers for better mitigation measures. In future studies, we can plan the modeling and impact of traffic noise by introducing electric vehicles for public and personal transportation and plan new road networks with proper noise barriers and the impact of smart traffic networks over noise pollution in smart cities.

Declarations

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