Effect of COVID-19 lockdown on noise pollution levels in an Indian city-A case study of Kanpur

Anirudh Mishra
HBTU: Harcourt Butler Technical University
Sanhita Das (sanhi.das25@gmail.com)
IIT Guwahati: Indian Institute of Technology Guwahati
Deepesh Singh
HBTU: Harcourt Butler Technical University
Akhilesh Kumar Maurya
IIT Guwahati: Indian Institute of Technology Guwahati

Research Article

Keywords: COVID-19, Noise pollution, Residential, Silence, India

Posted Date: March 9th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-221634/v1

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on April 22nd, 2021. See the published version at https://doi.org/10.1007/s11356-021-13872-z.

Abstract

Noise pollution is an emerging environmental threat, prolonged exposure of which can cause annoyance, sleep disturbance, hypertension, psychiatric disorders and also hormonal dysfunction. Among all the sources of noise pollution, the noise generated by road vehicle traffic significantly affects the quality of urban environments. Concerning the recent imposition of COVID-19 societal lockdown, this study attempts to investigate the impacts of COVID-19 lockdown on the changes in noise pollution levels before, during and after lockdown phase in different residential, commercial, industrial and silence zones of the city of Kanpur, India. Although a significant reduction in the noise levels was observed during lockdown, except for commercial zone all other monitoring stations had reported sound levels quite higher than the recommended noise limits set by the Central Pollution Control Board (CPCB) of India. Results further indicated that prominent improvements in health benefits could be observed in the lockdown period, much better than the pre-lockdown and unlock phase. Several noise mitigation strategies are also proposed, which may indeed pave the way for devising noise control measures in the local and regional level.

1. Introduction

Noise caused by increased urbanization and industrialization is recognized as environmental nuisance that affects human health and well-being (Mansouri et. al. 2006). The World Health Organization (WHO) has reported noise pollution as one of the major environmental contributors to public health challenges (WHO, 2018). Among all the sources of noise pollution, the noise generated by road vehicle traffic significantly affects the quality of urban environments (Méline et al., 2013; Paiva et al., 2019; Amoatey et al., 2020). It is recognized that increased exposure to noise can cause annoyance (Dratva et al., 2010; Babisch, 2002; Stansfeld and Matheson, 2003), sleep disturbance involving frequent awakening (Muzet, 2007; Guski et al., 2017), hormonal dysfunction (Said & El-Gohary, 2016), hypertension (Eriksson et al., 2012; Fuks et al., 2017; Oh et al., 2019) and also psychiatric disorders (Fyhri & Aasvang, 2010; Ongel & Sezgin, 2016).

Depending on the duration, intensity of noise and distance from noise source, the effects of noise on human health and comfort can be essentially divided into four groups: physical effects such as hearing and ear burning; physiological effects, such as increased blood pressure, irregularity of heart rhythms and ulcers; psychological effects, such as disorders, irritability, annoyance and stress; and finally performance effects, such as reduction of productivity and lack of concentration (Yilmaz and Ozer, 2005; Saadu, 1988; Tekalan, 1991; Singh and Dvar, 2004; Okah-Avae, 1996). In essence, the impact of noise pollution on public health outcomes has been a major concern worldwide (Abo-Qudais and Alhiary, 2004; Bhadram, 2003; Georgiadou et. al., 2004).

Concerning increased exposure to noise pollution in Indian cities, recent literature has underlined that the average noise level in different cities often exceeds the limits recommended by the Central Pollution and Control Board of India (Bhosale et al., 2010; Banerjee et al., 2008; Sagar and Rao, 2006; Kisku et al., 2006; Jamir et al., 2014). A study by Banerjee et al. (2008) reported that the maximum daytime and night time noise equivalent level in an industrial town of West Bengal exceeded the recommended noise limit by

14dB and 11.9dB respectively. Kisku et al. (2006) indicated that the maximum equivalent noise levels exceed by 23.9dB and 11.4dB in residential areas of the city of Lucknow during day and night time respectively, by 19.2dB and 19.9dB in commercial cum traffic areas, and by 2.2dB and 3.1dB in industrial areas. Thakre et al. (2020) further found an increment by 4.4dB and 5.2dB for morning and evening sessions respectively in the city of Nagpur from the year 2012 to 2019. In a recent study conducted in residential, commercial, industrial and silence zones of Mumbai Metropolitan Region, Kalawapudi et al. (2020) reported that silence zones were mostly affected by noise pollution, followed by residential, commercial and industrial zones. They further concluded that appropriate planning of city spaces could avoid exposure to rising noise pollution levels.

The emerging evidence suggests that most of the Indian cities are under potential threat of increased noise exposure that can have deleterious effects on physical and mental health of individuals. Howbeit, the recent imposition of COVID-19 societal lockdown has substantially reduced vehicular traffic volume and social events worldwide. In an attempt to delve deeper into the impacts of COVID-19 lockdown on noise pollution levels, this study investigates the changes in noise pollution levels before, during and after lockdown phase in different residential, commercial, industrial and silence zones of the city of Kanpur, India. The purpose of this study is to examine the changes in noise levels during different phases of lockdown, examine the noise exceedance levels in different zones, possible impact on health outcomes such as annoyance and sleep disturbance and propose efficient noise mitigation strategies to reduce the overall adverse health effects of noise.

2. Methodology

2.1. Characteristics of the study area

Kanpur is one of the most important cities in the northern region of India and is the main center of industrial and commercial activities. It is located in the state of Uttar Pradesh having latitude 26.4499° N and longitude 80.3319° E, 126m above the mean sea level. The population of Kanpur city is 29.2 lakh (2011 census) spread over an area of 403.7 km^2. The maximum and minimum temperature are observed to be 33.3°C and 3.7°C respectively, with an average rainfall of 820 mm, average relative humidity of 78.13% and wind speed of 0.936km/h.

To investigate the effects of noise exposure during different phases of lockdown, a total of six sampling locations were considered corresponding to residential, industrial, commercial and silence zones of the Kanpur city. Location details of the noise monitoring stations are presented in Table 1 and the geographic spread of the locations is outlined in Figure 1.

Table 1. Location details of the sound stations in Kanpur

Location ID	Zone	Sampling locations
1	Silence (Location I)	IIT Kanpur
2	Silence (Location II)	Mariyampur
3	Residential (Location I)	Kidwai Nagar
4	Residential (Location II)	Deep talkies
5	Commercial	Golchauraha
6	Industrial	Fazalganj

Collection of sound data was done from the environmental sensors established by Tech Mahindra under the project of smart city at each 1h time interval. Data on sound levels were gathered over a period of 24hours between November 2019 to September 2020, covering the complete phase of before lockdown, during lockdown and during unlock phase.

2.2. Noise assessment analysis

To analyze the noise pollution level, noise percentiles values (that is L10, L50 and L90) were calculated by using noise level data and these percentiles values were used to evaluate the noise pollution indices (Pathak et al., 2008; Robinson, 1971). Hourly noise data were analyzed to obtain the equivalent sound level (Leq) for all the days of a month corresponding to specific hour.

$$\mathrm{NC} = \mathrm{L10} - \mathrm{L90}$$

$$\mathrm{Leq} = \mathrm{L50} + (\mathrm{NC})^2/60$$

Where L10, L50, L90, NC, and represent the level of sound exceeding for 10%of total time of measurement, level of sound exceeding for 50%of total time of measurement, level of sound exceeding for 90%of total time of measurement, equivalent noise level and noise pollution level respectively. represents the equivalent effect of noise coming from different sources and of varying intensities (Robinson, 1971; Newman et. al., 1985).

A descriptive analysis is performed of the sound levels in the considered sound monitoring locations during different phases of COVID-19 lockdown. The changes in sound levels in the pre-lockdown, lockdown and unlock phase are assessed according to different land-use patterns (residential, industrial, commercial and silence zones). *t*-test for comparing two sample means and *F*-test for sample variances are applied to identify possible differences in the sound levels during lockdown phases and analysis of variance (ANOVA) test is conducted for more than two considered samples. All these analyses are performed at a significance level of 5%. Further, to examine noise impacts on public health, a possible estimate of the percentage of population at risk of high annoyance and sleep disturbance in all the considered zones are made based on the available literature.

3. Results And Discussion

3.1. Changes in sound levels according to different land-uses

A total of six locations were selected for sound level measurements corresponding to residential, industrial, commercial and silence zones. The equivalent continuous sound level data were averaged over 1hour (L_{eq}) and its monthly variation according to different land use types is presented in Figure 2.

Although a wide variation in the monthly sound levels can be observed according to different land use types, there exists a prominent trend in the overall sound levels during different phases of lockdown. In particular, data processed between March 25th to May 31st 2020 (nationwide lockdown declaration in India) can be related to 'during lockdown' phase, while the period before March 25th 2020 and after May 31st 2020 are defined as 'before lockdown' and 'unlock phase' respectively in this study. While the equivalent sound levels for all zones lie in the range of 42-87dB before lockdown period, it drastically reduced to 38-66dB during lockdown and then the range gradually increased to 41-76dB (Figure 2).

Concerning monthly differences in the equivalent sound levels, results of analysis of variance (ANOVA) test indicated no significant differences in between November and February (before lockdown) and between June and September (unlock phase) for both the residential zones. Moreover, due to unavailability of residential zone data during May, statistical tests could not be performed for the residential zones during lockdown period.   Before lockdown period, data of all the five months (November, December, January, February and March) revealed significant differences in for industrial [=8.56>=2.45, $p<0.001$], commercial [=15.82>=2.45, $p<0.001$], silence (location I) [=25.16>=2.45, $p<0.001$] zones, the only exception being location II of the silence zone where no statistical difference could be observed [=1.02<=2.45, $p=0.40$]. Further, statistical differences in the monthly data could be observed only for industrial [=23.35>=3.13, $p<0.01$] and location I of the silence zone [=3.13 > =2.71, $p<0.05$] during unlock phase, while *t*-test for sample means indicated statistical differences during lockdown phase for all land-use types.

Although differences in monthly data were observed for different zones, the equivalent sound level data were further grouped into three categories (according to before lockdown, during lockdown and unlock phase) for a better understanding of the changes in sound level as a result of nationwide lockdown in India. A summary of the statistical properties of during different phases of lockdown for all land-use types is presented in Table 2.

Comparing the mean values, a distinct reduction in sound levels is observed during lockdown, which gradually increased after lockdown phase. The same trend follows for all land-use types. The reduction in mean is found to be maximum for location I of residential zone (29%), followed by 23% reduction for location II of residential zone and location II of silence zone and 17% in location I of the silence zone. On the other hand, the reduction in is found be 8% and 14% for industrial zone and commercial zone respectively.

Table 2. Statistical summary of during different phases of lockdown

	Before lockdown				During lockdown				After lockdown			
	Min	Mean	Median	Max	Min	Mean	Median	Max	Min	Mean	Median	Max
Residential												
I	54.29	79.57	85.26	104.00	44.27	56.19	55.45	72.73	51.54	74.04	80.91	85.06
II	39.03	55.40	59.99	67.71	37.82	42.66	42.09	51.00	38.59	51.86	55.73	63.07
Industrial												
	48.26	70.27	72.23	88.56	53.45	64.19	62.12	76.64	54.02	74.71	79.80	86.44
Commercial												
	38.93	44.83	44.85	56.00	37.71	38.55	38.34	39.85	38.89	42.24	42.13	45.33
Silence												
I	38.94	46.57	46.07	54.41	37.71	38.55	38.35	39.85	39.80	46.49	47.11	51.61
II	45.71	75.71	83.13	101.27	40.75	57.79	56.65	78.11	43.37	69.07	76.05	85.52

Conversely, sound levels during unlock phase increased by 21% in the silence zones and location II of the residential zone as compared to sound levels during lockdown. It further increased by 32% in location I of the residential zone, while the increment was found to be lower in the industrial (16%) and commercial zones (9%) respectively. These results indicate that the reduction in sound levels during lockdown was considerably higher in residential (23dB and 13dB in location I and II respectively) and silence (8dB in location I and 18dB in location II) zones than that of industrial and commercial zones (6dB reduction in both the cases). This can certainly be attributed to the huge reduction in traffic, strict prohibition of individual's movement and closure of businesses, the impact of which could be observed in residential and silence zones. On the other hand, to expedite the operation of manufacturing units and avoid shortage of any essential commodities, inter-state and intra-state movement of trucks and other categories of goods vehicles were permitted as a result of which the reduction in sound level in the industrial zone was not found to be significant.

To further attain additional insights into the statistical significance of equivalent sound levels during different phases of lockdown, *t*-test was conducted for comparing two sample means (Table 3). As expected, significant differences in mean were obtained between data corresponding to before lockdown phase and during lockdown for all land use types. Similar observations were attained for data belonging to during lockdown and unlock phase in all the cases. This clearly indicates that the sound level in all the zones reduced significantly during lockdown. It is also interesting to note that no significant differences in the sound levels could be observed before lockdown and during unlock phase for residential, industrial, commercial and silence zones, which is an indication of normal traffic operations during unlock phase after the four phases of nationwide lockdown in India (starting from 25th March 2020 to 31st May 2020).

Table 3. *t*-stat results of during different phases of lockdown

		During		Unlock	
Residential (Location I)	Before	8.30 ($p<0.001$)	Significant	**1.98 ($p=0.09$)**	Not Significant
	During			-6.37 ($p<0.001$)	Significant
Residential (Location II)	Before	6.26 ($p<0.001$)	Significant	**1.40 ($p=0.08$)**	Not Significant
	During			-4.94 ($p<0.001$)	Significant
Industrial	Before	2.80 ($p<0.01$)	Significant	**-1.61 ($p=0.06$)**	Not Significant
	During			-4.43 ($p<0.01$)	Significant
Commercial	Before	10.17 ($p<0.001$)	Significant	1.57 ($p=0.09$)	Not Significant
	During			-9.05 ($p<0.001$)	Significant
Silence (Location I)	Before	13.13 ($p<0.001$)	Significant	**0.09 ($p=0.46$)**	Not Significant
	During			-12.65($p<0.001$)	Significant
Silence (Location II)	Before	4.73 ($p<0.001$)	Significant	**1.49 ($p=0.07$)**	Not Significant
	During			-3.00 ($p<0.01$)	Significant

Note: Bold features indicate no statistical difference between the samples

Furthermore, the distributions of equivalent sound levels (presented in Figure 3) for the residential zones indicate that 53% of the data were in between 80-90dB before lockdown in location I and 50% data in the range of 60-70dB corresponded to location II. During lockdown, the sound levels were mostly observed between 50-60dB and 40-50dB in location I and location II respectively. While most of the sound level data in the industrial zone were between 70dB and 80dB before lockdown, the mode increased to 80-90dB after lockdown. Also, 34%, 38% and 27.7% data corresponded to 50-60dB, 60-70dB and 70-80dB respectively during lockdown phase. In parallel, in the commercial zone lies in the range of 30-60dB before lockdown, the mode being observed at 40-50dB for data corresponding to both pre-lockdown and unlock phase.

However, all the sound level data were in between 30-40dB during lockdown in the commercial zone. Comparing the sound level distributions of the silence zones, the range of lies in between 30-60dB and 40-100dB before lockdown, the range being almost similar for data during unlock phase as well. While 100% of the data in location I corresponded to 30-40dB during lockdown, a wide variation in the data could be observed for location II of the silence zone. data during lockdown were observed in between 40-100dB, with 27% data corresponding to 60-70dB. This is because location II of the silence zone is near a rotary and is surrounded by hospitals and medical institutes. The wide variation in sound levels between 40 and 100dB even during lockdown is due to comparatively higher traffic volumes and also because of the operation of emergency medical services near that location.

These results signify that there has been a prominent decline in equivalent sound levels during lockdown. Comparing modes of the histograms, it can be observed that the range of reduces by approximately 10dB during lockdown as compared to the range before lockdown for location II of the residential zone, industrial, commercial and location I of silence zone. Conversely, the reduction is by almost 20dB for

location II of the silence zone and by 30dB for location I of the residential zone. This illustrates that nationwide lockdown has caused significant changes in the sound levels in different types of land-uses.

3.2. Time-wise variations in equivalent sound levels

The temporal variations of equivalent sound level during different phases of lockdown are further presented in Figure 4 with respect to different land use types. In all the cases, the reduction in L_{eq} during lockdown can be clearly visible although the range of sound levels are different for different zones. Moreover, the changing patterns in sound levels indicate two definite peaks- the first peak occurring in the morning and the second peak in the evening period. While distinct peaks in L_{eq} data are observed in the residential zones, industrial zone and location II of the silence zone during lockdown, no such pattern follows for commercial land-use and location I of the silence zone over different time periods. These zones (commercial and location I of silence land-use) show no significant changes in L_{eq} level even before the lockdown and during unlock phase as well.

Interestingly, the two distinct noisy periods are observed only during lockdown phase. The hourly pattern of sound before lockdown and during unlock phase shows an increase in sound levels, reaches peak, remains consistent for a longer time span till approximately 9pm and then follows a decreasing trend. However, the peak sound level in the morning during lockdown occurs between 8am and 9am for almost all the zones. Although there is an increase in L_{eq} in the evening period, the peak is much smaller and it does not reach morning levels.

The morning peaks in the residential locations can be due to continuous operation of essential services during the lockdown period, increased human mobility to meet household needs in the morning hours and also due to movement of stranded people to their own residences. Also, because some industrial establishments were functioning during lockdown, a small peak could be observed in the morning hours in the industrial area. On the other hand, the commercial and private establishments were shut down and as such no peak in the sound level was visible. Concerning both the locations of silence zone, location I (near IIT Kanpur) is a rural area near one of the institutes of national importance while location II (Mariyampur) is an urban area in the vicinity of a rotary and surrounded by hospitals and medical institutes. Comparing both these locations, comparatively higher level of sound could be observed in the Mariyampur area than that near IIT Kanpur. This can be attributed to higher traffic volumes in the Mariyampur area due to changes in speed, acceleration and deceleration along with honking near the intersection, and also due to the operation of emergency medical services near that location in the morning as well as evening hours.

The figure clearly illustrates that the sound patterns change considerably over different time periods possibly due to changes in traffic patterns as well as other human activities. In an attempt to provide a deeper understanding on the changing sound levels in the morning and evening period during different phases of lockdown, the 24h period is subdivided into two timeframes: day time (6am to 10pm) and night time (10pm to 6am). The average equivalent sound for daytime and nighttime are denoted as and respectively. Table 4 presents the average equivalent value during day and night time for all the zones.

The hourly average equivalent sound level for day and night time in the pre-lockdown, lockdown and after lockdown period indicates that the sound levels during daytime are considerably higher than night time in all the zones. This is in line with the observed peaks in sound level as presented in Figure 4. Also, changes in sound level clearly depict reduction in sound during lockdown which then increases after lockdown phase. While the equivalent sound levels were found to vary according to different land-use types, commercial zone and location I of silence zone exhibited approximately similar sound levels during day and night time in the pre-lockdown and lockdown period, a slight variation being observed during unlock phase.

Table 4. Statistical summary of average equivalent sound during day time and night time

Land use	Before lockdown		During lockdown		Unlock	
	Day time	Night time	Day time	Night time	Day time	Night time
Residential (I)	99.03	84.35	77.43	64.30	93.63	76.55
Residential (II)	74.11	57.28	57.81	50.07	70.24	52.98
Industrial	88.32	74.49	81.01	69.47	94.02	75.89
Commercial	58.79	51.18	50.59	47.65	55.37	49.64
Silence (I)	60.49	52.33	50.54	47.28	60.37	52.71
Silence (II)	98.92	76.67	78.54	64.05	93.06	68.33

The average reduction in sound levels in night time before lockdown and during unlock phase is almost 15dB, the maximum reduction being observed in location II of the silence zone (22dB and 25dB in pre-lockdown and unlock period respectively) and minimum is in the commercial zone (7dB in pre-lockdown phase); whereas the average sound level drops by 9dB during lockdown in all the zones. While the reduction in sound level during night (as compared to day time) before lockdown is in between 13% to 23%, the range is found to be 6-18% during lockdown and 10-26% during unlock phase. In the lockdown period, reduction in sound levels is found to be higher in residential areas, industrial zone and location II of the silence zone. Comparing daytime noise equivalents in the pre-lockdown and lockdown period, 22% reduction in sound equivalents is obtained for residential zones and location II of the silence zone, 15% for commercial and location I of silence zone and 8% reduction is obtained for the industrial zone. Also, reduction in night time sound equivalents before lockdown indicates that the reduction is maximum for location I of residential zone (24%), followed by location II of silence zone (16%), location II of residential zone (13%) and 7% for industrial and commercial zone.

The Central Pollution Control Board (CPCB) of India has recommended noise limits of 55dB and 45dB during daytime and nighttime in residential areas; 75dB and 70dB in industrial areas; 65dB and 55dB in commercial; and 50dB and 40dB during the day and night time in silence zones. Considering the prescribed limits, the percentage of times the hourly equivalent sound level exceeds the threshold values in the pre-lockdown, lockdown and unlock phase during day and night time are presented in Figure 5. Location I of the residential zone and location II of silence zone had recorded sound exceeding the

threshold 100% of the times during both day and night time in the pre-lockdown and unlock period. Except for commercial and industrial zone in the pre-lockdown period, all other zones showed more than 80% exceedance during daytime in pre-lockdown and unlock period. However, during night, location II of residential zone and industrial zone had exceedance levels comparatively lower than that in the daytime. Also, location I of the residential zone and location II of silence zone is not found to meet the noise standards at any time in the pre-lockdown and unlock period.

During lockdown, the percentage of times that sound exceeded the standard limits reduced considerably for most of the stations, the exceptions being residential (location I) and silence (location II) zones. More than 93% of the time the hourly equivalent sound exceeded 50dB during daytime in the silence zone (location II) and during night time, 100% exceedance was observed even during lockdown. For the residential zone (location I), the threshold was followed for only 25% of the time during day and 12% of the time the sound was within the night time threshold limit of 55dB. Conversely, commercial zone and location I of silence zone indicated that 100% of the times, sound was within the threshold limit during both day and night time. Location II of residential zone and industrial zone also showed lower percentage of exceedance. Although the reduction in equivalent sound levels can be clearly observed during lockdown for residential (location II), industrial and silence (location I) zones, location I of the residential zone and location II of silence zones showed no significant improvement. Only exception is with the commercial zone where sound level was observed to be lower than the recommended limit all the times in different phases of lockdown.

These results indicated that the locations in the vicinity of Kidwai Nagar (location I of residential zone) and Mariyampur area (location II of silence zone) were profoundly affected by noise pollution and their levels were above the legal noise limits for 100% of the times in the pre-lockdown and unlock phase and more than 75% exceedance was during lockdown period. This can be due to the presence of nearby intersections in the vicinity of the monitoring stations where vehicles are more likely to generate higher levels of noise due to changes in speed, acceleration and deceleration patterns.

3.3. Noise impact assessment: annoyance and sleep disturbance

Continuous exposure to noise can have a long-term impact on person’s health and well-being. It can cause sleep disturbance and annoyance which may lead to psychological, attitudinal and physiological stress responses in some individuals (Babisch, 2002; Guski et al., 2017; Basner and McGuire, 2018). Except for commercial zone, all the monitoring stations considered in this work had reported sound levels quite higher than the recommended noise limits. In particular, location I of the residential zone and location II of the silence zone showed more than 87% exceedance of standard noise limits even during night time in the lockdown period. This is indeed a subject of serious concern which may directly question the well-being of the people residing in the nearby areas. In an attempt to assess the impact of noise exposure on individuals’ health, this section primarily aims at providing a possible estimate of the percentage of population at risk of high annoyance and sleep disturbance in all the zones.

Based on the equation developed by Miedema and Vos (1998), the percentage of population that is highly annoyed (%HA) due to exposure to road traffic noise can be estimated as a function of day-night average sound level (DNL). They considered that degree of annoyance is zero at a level of 42dB or for sound levels below that and the equation is formulated as:

$$\%HA = 0.24 * (DNL - 42) + 0.0277 * (DNL - 42)^2$$

The day-night average sound level is given by

$$DNL = 10\, log \frac{15 * 10^{L_d/10} + 9 * 10^{(L_n+10)/10}}{24}$$

where L_d and L_n are the 15-h daytime (7:00-22:00) and 9h night time (22:00-7:00) equivalent sound levels respectively. Similarly, the percentage of people with high level of sleep disturbance (%HSD) due to road traffic noise can be given by the equation formulated by Miedema et al. (2003):

$$\%HSD = 20.8 - 1.05L_n + 0.01486{L_n}^2$$

The possible impacts of road traffic on annoyance and sleep disturbance in all the considered zones during different phases of lockdown are presented in Table 5.

Table 5 Annoyance level and percentage of sleep disturbance during different phases of lockdown according to land use type

Land use type	Before lockdown			During lockdown			Unlock phase		
	DNL (dB)	HA (%)	HSD (%)	DNL (dB)	HA (%)	HSD (%)	DNL (dB)	HA (%)	HSD (%)
Residential I	97.80	86.23	37.96	76.50	41.25	14.72	92.07	81.47	27.50
Residential II	72.58	28.87	9.41	58.80	11.85	5.48	68.66	26.09	6.88
Industrial	87.24	87.44	25.04	80.49	50.28	19.57	92.36	82.34	26.70
Commercial	59.85	8.16	5.99	54.62	7.44	4.51	57.48	10.36	5.29
Silence I	61.27	13.76	6.55	54.33	7.17	4.37	61.40	15.08	6.74
Silence II	97.03	84.47	27.65	77.34	43.07	14.51	91.11	78.58	18.43

The results indicate that residents of Kidwai Nagar (location I of residential zone), Mariyampur (location II of silence zone) and people living near Fazalganj (industrial zone) were estimated to be at severe risk of being highly annoyed in the pre-lockdown and unlock phase and the risk of annoyance almost reduced to half during lockdown. Also, people living in the vicinity of these locations were at risk of having high levels of sleep disturbance. Compared with other zones, residents of Kidwai Nagar are considered to be the most negatively affected due to road traffic noise. This demonstrates the need to consider suitable noise reduction measures in the residential zone to protect the residents from any health disorder and psychological stresses.

The area near Deep Talkies (location II of residential zone) also showed impact of road traffic noise where 29% and 27% of people were anticipated to be highly annoyed in the pre-lockdown and unlock phase respectively, the percentage being reduced to 12% in the lockdown period. Although the risk of sleep disturbance was higher in the pre-lockdown period, it reduced to 5.48% during lockdown. Commercial zone exhibited lower risk of high annoyance and sleep disturbance among all the considered zones. Similarly, the percentage of highly annoyed people living near IIT Kanpur area (location I of silence zone) before lockdown was estimated as 13%, which reduced to 7% during lockdown and then increased to 15% in the unlock phase. Also, percentage of people who had high levels of sleep disturbance near IIT Kanpur during lockdown decreased from 6.55% before lockdown to 4.37% and then the percentage increased to 6.74% in the unlock phase.

Although the Kidwai Nagar and Mariyampur locations indicated sound levels exceeding the recommended noise limits most of the times during all phases of lockdown, the impact of road traffic noise on risk of high annoyance and sleep disturbance was found to be lower during lockdown as compared to that of pre-lockdown and unlock phase. In both these locations, the percentage reduced to half of that estimated in the pre- and post-lockdown period. In short, these results indicated that prominent improvements in health benefits could be observed in the lockdown period, much better than the pre-lockdown and unlock phase. This suggests that strict noise pollution mitigation strategies and suitable policy measures could provide public health benefits and provide an overall sustainable transport infrastructure.

3.4. Policy implications

The key empirical findings of this work indicated prominent reduction in noise levels during lockdown period in all the considered zones. Higher sound levels in the Kidwai Nagar and Mariyampur area can be attributed to the fact that the monitoring stations are located in close proximity to nearby intersections where changes in speed, acceleration and deceleration of vehicles contributed to higher sound levels. It is noteworthy to mention that the Mariyampur monitoring station is surrounded by hospitals and medical institutes which indeed showed sound exceeding the recommended noise limit most of the times. This prolonged exposure to excessive noise can detrimentally impact the safety and quality of healthcare and may delay the overall healing and recovering process of hospital patients. Recognizing that transportation noise can adversely impact people’s health, lifestyle, local economy and decreased participation on recreational areas, devising a noise control strategy can protect individuals from the ill-effects of noise pollution. Several possible policy implications obtained from this research are summarized below.

Promoting sustainable mode of transport- Results of this study demonstrate that significant reduction in noise levels can be achieved through stringent traffic reduction strategies. Although it is not feasible to impose lockdown or eliminate traffic from the cities, proper traffic management strategies can control the negative effects of noise pollution. Several interventions such as substitution of motorized private transport by active transport mode such as walking and cycling for short trips, parking management and restricting access for the noisiest vehicles can reduce noise pollution, improve road safety, provide recreational value to all the users and improve health of the communities. While cycling and walking offer health benefits, reduce noise, emissions and congestion, providing proper bicycle paths and walkways are equally important for the efficient mobility of cyclists and pedestrians.

Adoption of greener environment- The characteristics of the built environment such as view or access to green spaces in the neighborhood or having access to a quiet area can reduce annoyance (Gidlöf-Gunnarsson and Öhrström, 2010; van Renterghem and Botteldooren, 2012; Öhrström et al., 2006) and the negative response to road traffic noise. The construction of green belts around roads, vegetation, incorporation of green spaces in the cities or even green roof installations can be considered as several measures to help attenuate noise exposure especially in the residential, silence and industrial zones as considered in this research.

Road infrastructure- Consideration of noise-reducing pavements, traffic noise impedance walls, quieter vehicles, installation of natural or artificial noise barriers, no-horn sign and other traffic calming measures can reduce noise level at high sound level zones. Implementation of such measures in residential, silence and commercial zones can provide a livable, workable and healthy environment for the people residing in the nearby areas.

Development of noise monitoring database- Empirical results of this study demonstrated higher sound levels exceeding the noise limits in the residential, industrial and silence zones. This can be directly associated with the heightened risks of individuals' well-being, health, psychological stresses, sleep disturbance levels and other heart diseases. The development of a wide sound monitoring network can help in assessing higher sound levels and also the effectiveness of noise pollution mitigation strategies. Installation of sound monitoring stations across the cities and development of a suitable noise monitoring database can direct towards the ill-effects of noise exposure in different areas, identify communities that could be at high risk of noise pollution, comprehensive health impact assessment can be examined and suitable policy measures can be devised in appropriate locations for protecting the health of the city and the environment.

Understanding the negative effects of noise exposure to the health and safety of individuals, it is important to closely monitor sound levels in the high-risk zones with a belief that the health and well-being of the communities can be protected only if appropriate actions and decisions are taken in due course of time.

4. Conclusions

This study attempted to investigate to what extent the coronavirus lockdown has impacted exposure to noise pollution levels and public health outcomes in the city of Kanpur, India. The behavioral shifts in transport sector and the societal lockdown has impacted positively on local and regional environmental pollution levels. In this regard, this study provided an understanding of monthly sound level patterns, time-wise variations in sound data, changes in sound levels during different phases of lockdown, and possible public health risks due to prolonged exposure to noise pollution. The magnitude of changes in sound levels in the residential, industrial, commercial and silence zones are examined in the pre-lockdown, lockdown and after lockdown phase.

Our results indicated a significant reduction in sound levels at all the six sound monitoring stations during lockdown phase as compared to that of pre-lockdown and unlock phases. The reduction was much higher in the residential and silence zones than that of industrial and commercial zones. Concerning day and night time sound equivalent levels, the sound levels during daytime were found to be considerably higher than night time in all the zones. The night time sound equivalent dropped by an average of 9dB during lockdown while the average reduction was by almost 15dB in the pre-lockdown and unlock phase in all the considered zones. Considering the limits recommended by the Central Pollution Control Board (CPCB) of India, except for commercial zone, all other monitoring stations had reported sound levels quite higher than the recommended noise limits. In particular, the locations in the vicinity of Kidwai Nagar (location I of residential zone) and Mariyampur area (location II of silence zone) showed more than 75% exceedance of standard noise limits even during lockdown period, while it reached 100% in the pre-lockdown and unlock phase. This is indeed a subject of serious concern as continuous exposure to noise can have a long-term impact on person’s health and well-being such as annoyance and sleep disturbance.

Although the Kidwai Nagar and Mariyampur locations indicated sound levels exceeding the recommended noise limits most of the times during all phases of lockdown, the impact of road traffic noise on risk of high annoyance and sleep disturbance was found to be lower during lockdown as compared to that of pre-lockdown and unlock phase. Results of this work indicated that prominent improvements in health benefits could be observed in the lockdown period, much better than the pre-lockdown and unlock phase. This suggests that strict noise pollution mitigation strategies and suitable policy measures could provide public health benefits and provide an overall sustainable transport infrastructure. In light of this, several possible noise mitigation strategies such as promoting sustainable mode of transport, adoption of green space, adequate road infrastructure and development of a sound monitoring network in the local and regional level were also indicated in this work.

Declarations

Ethics approval and consent to participate: Not Applicable

Consent for publication: Not Applicable

Availability of data and materials: The datasets generated and/or analysed during the current study are not publicly available because this data is collected as a part of the Smart Cities Mission of the

Government of India.

Competing interests: The authors declare that they have no competing interests.

Funding: No funding to declare.

Authors' contributions: Conceptualization: Anirudh Mishra, Deepesh Singh, Akhilesh Kumar Maurya; Investigation: Anirudh Mishra, Deepesh Singh; Methodology: Sanhita Das; Resources: Anirudh Mishra, Deepesh Singh; Formal Analysis: Sanhita Das; Writing-Original Draft: Sanhita Das, Anirudh Mishra; Visualization: Sanhita Das; Supervision: Deepesh Singh, Akhilesh Kumar Maurya; Validation: Deepesh Singh, Akhilesh Kumar Maurya; Writing-Review and Editing: Deepesh Singh, Akhilesh Kumar Maurya

Acknowledgements: Not Applicable

References

Abo-Qudais, S., & Alhiary, A. (2004). Effect of distance from road intersection on developed traffic noise levels. Canadian Journal of Civil Engineering, 31(4), 533-538.

Amoatey, P., Omidvarbona, H., Baawain, M. S., Al-Mayahi, A., Al-Mamun, A., & Al-Harthy, I. (2020). Exposure assessment to road traffic noise levels and health effects in an arid urban area. Environmental Science and Pollution Research, 27(28), 35051-35064.

Babisch, W. (2002). The noise/stress concept, risk assessment and research needs. Noise &Health 4 (16), 1–11.

Banerjee, D., Chakraborty, S. K., Bhattacharyya, S., &Gangopadhyay, A. (2008). Evaluation and analysis of road traffic noise in Asansol: an industrial town of eastern India. International Journal of Environmental Research and Public Health, 5(3), 165-171.

Basner, M., McGuire, S. (2018). WHO environmental noise guidelines for the European region:a systematic review on environmental noise and effects on sleep. International Journal of Environmental Research and Public Health 15, 519.

Bhadram, V. (2003). Noise pollution status in Visakhapatnam city. Nature, Environment and Pollution Technology, 2(2), 217-219.

Bhosale, B. J., Late, A., Nalawade, P. M., Chavan, S. P., & Mule, M. B. (2010). Studies on assessment of traffic noise level in Aurangabad city, India. Noise and Health, 12(48), 195.

Census India (2011) Retrieved from https://www.census2011.co.in/census/city/131-kanpur.html

Dratva, J., Zemp, E., Dietrich, D. F., Bridevaux, P. O., Rochat, T., Schindler, C., & Gerbase, M. W. (2010). Impact of road traffic noise annoyance on health-related quality of life: Results from a population-based study. Quality of life research, 19(1), 37-46.

Eriksson, C., Nilsson, M. E., Willers, S. M., Gidhagen, L., Bellander, T., & Pershagen, G. (2012). Traffic noise and cardiovascular health in Sweden: The roadside study. Noise and Health, 14(59), 140.

Fuks, K. B., Weinmayr, G., Basagaña, X., Gruzieva, O., Hampel, R., Oftedal, B., ... & Hoffmann, B. (2017). Long-term exposure to ambient air pollution and traffic noise and incident hypertension in seven cohorts of the European study of cohorts for air pollution effects (ESCAPE). European heart journal, 38(13), 983-990.

Fyhri, A., & Aasvang, G. M. (2010). Noise, sleep and poor health: Modeling the relationship between road traffic noise and cardiovascular problems. Science of the Total Environment, 408(21), 4935-4942.

Georgiadou, E., Kourtidis, K., & Ziomas, I. (2004). Exploratory traffic noise measurements at five main streets of Thessaloniki, Greece. Global Nestl International Journal, 6(1), 53-61.

Gidlöf-Gunnarsson, A., Öhrström, E. (2010). Attractive “quiet” courtyards: a potentialmodifierof urban residents’ responses to road traffic noise? International Journal of Environmental Research and Public Health 7, 3359–3375.

Guski, R., Schreckenberg, D., & Schuemer, R. (2017). WHO environmental noise guidelines for the European region: a systematic review on environmental noise and annoyance. International journal of environmental research and public health, 14(12), 1539.

Jamir, L., Nongkynrih, B., & Gupta, S. K. (2014). Community noise pollution in urban India: Need for public health action. Indian journal of community medicine: official publication of Indian Association of Preventive & Social Medicine, 39(1), 8.

Kalawapudi, K., Singh, T., Dey, J., Vijay, R., & Kumar, R. (2020). Noise pollution in Mumbai Metropolitan Region (MMR): An emerging environmental threat. Environmental monitoring and assessment, 192(2), 1-20.

Kisku, G. C., Sharma, K., Kidwai, M. M., Barman, S. C., Khan, A. H., Singh, R., ... & Bhargava, S. K. (2006). Profile of noise pollution in Lucknow city and its impact on environment. Journal of Environmental Biology, 37(2), 409-412.

Mansouri, N.,Pourmahabadian, M., & Ghasemkhani, M. (2006). Road traffic noise in downtown area of Tehran. Journal of Environmental Health Science & Engineering, 3(4), 267-272.

Méline, J., Van Hulst, A., Thomas, F., Karusisi, N., & Chaix, B. (2013). Transportation noise and annoyance related to road traffic in the French RECORD study. International journal of health geographics, 12(1), 1-13.

Miedema HME, Passchier-Vermeer W, Vos H. (2003). TNO Intro report2002-59: elements for a position paper on night-time transportationnoise and sleep disturbance. Netherlands, Delft; ToegepastNatuurwetenschappelijkOnderzoek, 2003. Pub. no. 02 5N 160 61241.

Miedema, H. M., & Vos, H. (1998). Exposure-response relationships for transportation noise. The Journal of the Acoustical Society of America, 104(6), 3432-3445.

Muzet, A. (2007). Environmental noise, sleep and health. Sleep medicine reviews, 11(2), 135-142.

Newman, J. S., & Beallie, K. R. (1985). Aviation noise effects, US Department of Transportation. R

Oh, M., Shin, K., Kim, K., & Shin, J. (2019). Influence of noise exposure on cardiocerebrovascular disease in Korea. Science of the Total Environment, 651, 1867-1876.

Öhrström, E., Skånberg, A., Svensson, H., Gidlöf-Gunnarsson, A. (2006). Effects of road trafficnoise and the benefit of access to quietness. Journal of Sound and Vibration 295, 40–59.

Okah-Avae, B. E. (1996). The science of industrial machinery and systems maintenance. Spectrum Books.

Ongel, A., & Sezgin, F. (2016). Assessing the effects of noise abatement measures on health risks: A case study in Istanbul. Environmental Impact Assessment Review, 56, 180-187.

Paiva, K. M., Cardoso, M. R. A., & Zannin, P. H. T. (2019). Exposure to road traffic noise: Annoyance, perception and associated factors among Brazil's adult population. Science of the Total Environment, 650, 978-986.

Pathak, V., Tripathi, B. D., & Mishra, V. K. (2008). Dynamics of traffic noise in a tropical city Varanasi and its abatement through vegetation. Environmental monitoring and Assessment, 146(1-3), 67-75.

Robinson, D. W. (1971). The concept of noise pollution level.Journal of Occupational and Environmental Medicine, 13(12), 602.

Saadu, A. A., Onyeonwu, R. O., Ayorinde, E. O., & Ogisi, F. O. (1998). Road traffic noise survey and analysis of some major urban centers in Nigeria. Noise Control Engineering Journal, 46(4), 146-158.

Sagar, T. V., & Rao, G. N. (2006). Noise pollution levels in Visakhapatnam city (India). Journal of Environmental Science and Engineering, 48(2), 139.

Said, M. A., & El-Gohary, O. A. (2016). Effect of noise stress on cardiovascular system in adult male albino rat: implication of stress hormones, endothelial dysfunction and oxidative stress. Gen Physiol Biophys, 35(3), 371-377.

Singh, N., & Davar, S. C. (2004). Noise pollution-sources, effects and control. Journal of Human Ecology, 16(3), 181-187.

Stansfeld, S. A., & Matheson, M. P. (2003). Noise pollution: non-auditory effects on health. British medical bulletin, 68(1), 243-257.

Tekalan, S. A. (1991). Effects of noise on hearing and other body systems. Ecology and Environment Journal, 2-11.

Thakre, C., Laxmi, V., Vijay, R., Killedar, D. J., & Kumar, R. (2020). Traffic noise prediction model of an Indian road: an increased scenario of vehicles and honking. Environmental Science and Pollution Research, 27(30), 38311-38320.

van Renterghem, T., Botteldooren, D. (2012). Focused study on the quiet side effect indwellings highly exposed to road traffic noise. International Journal of Environmental Research and Public Health 9,4292–4310.

Yilmaz, H., & Ozer, S. (2005). Evaluation and analysis of environmental noise pollution in the city of Erzurum, Turkey. International Journal of Environment and Pollution, 23(4), 438-448.

Figures

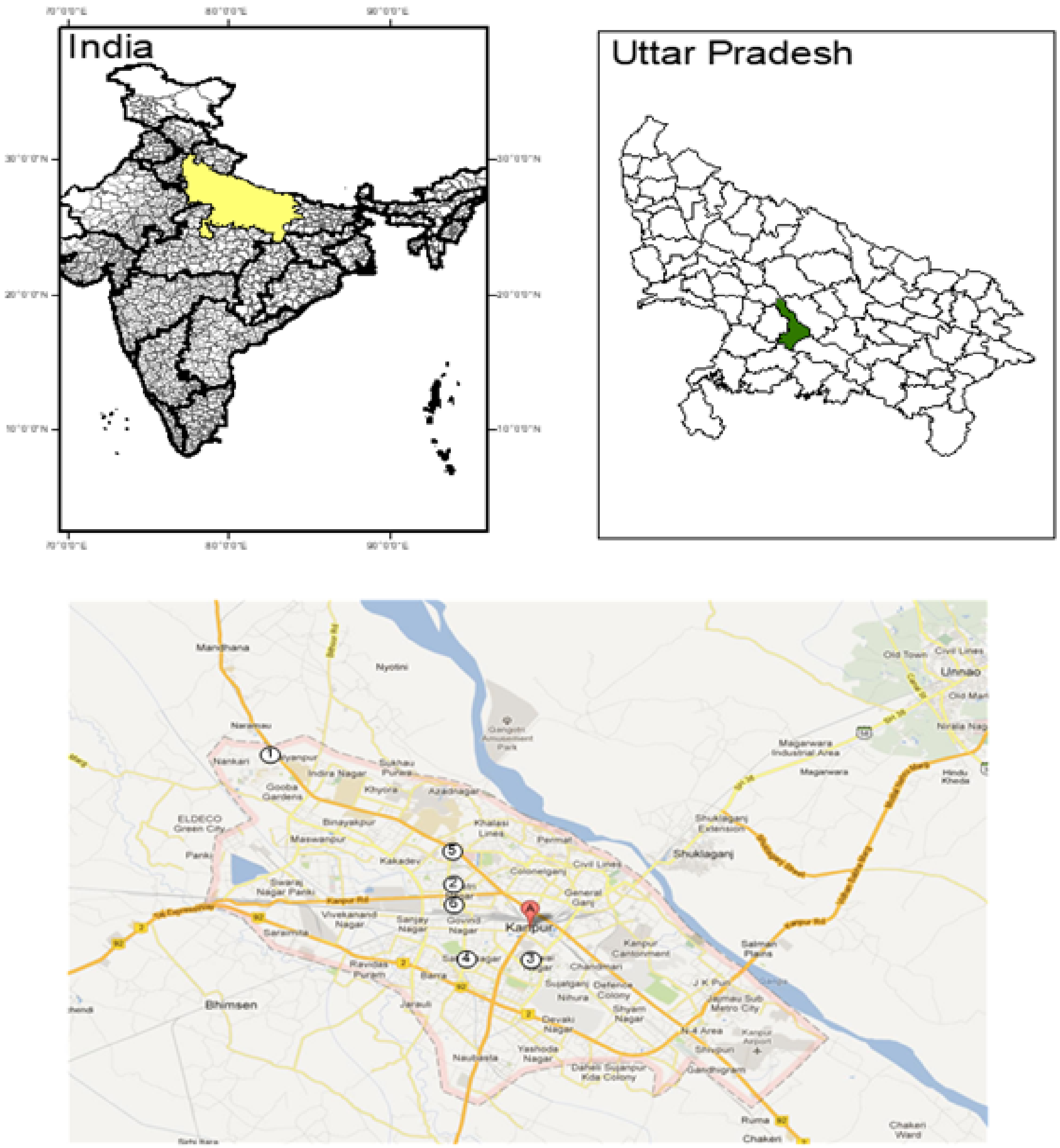


Figure 1

Map showing sampling locations. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

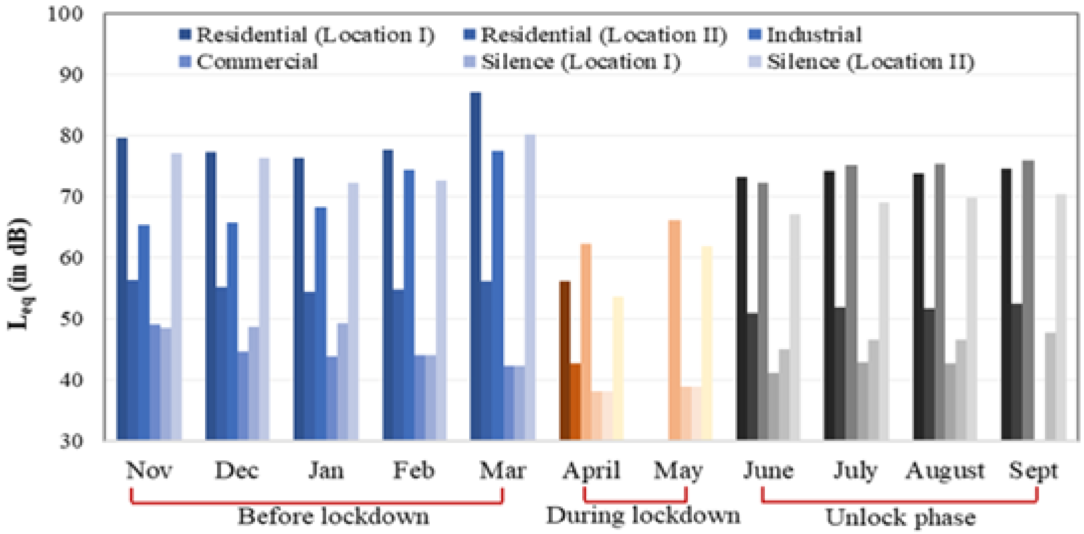


Figure 2

Monthly variation in L_eq according to different land use type

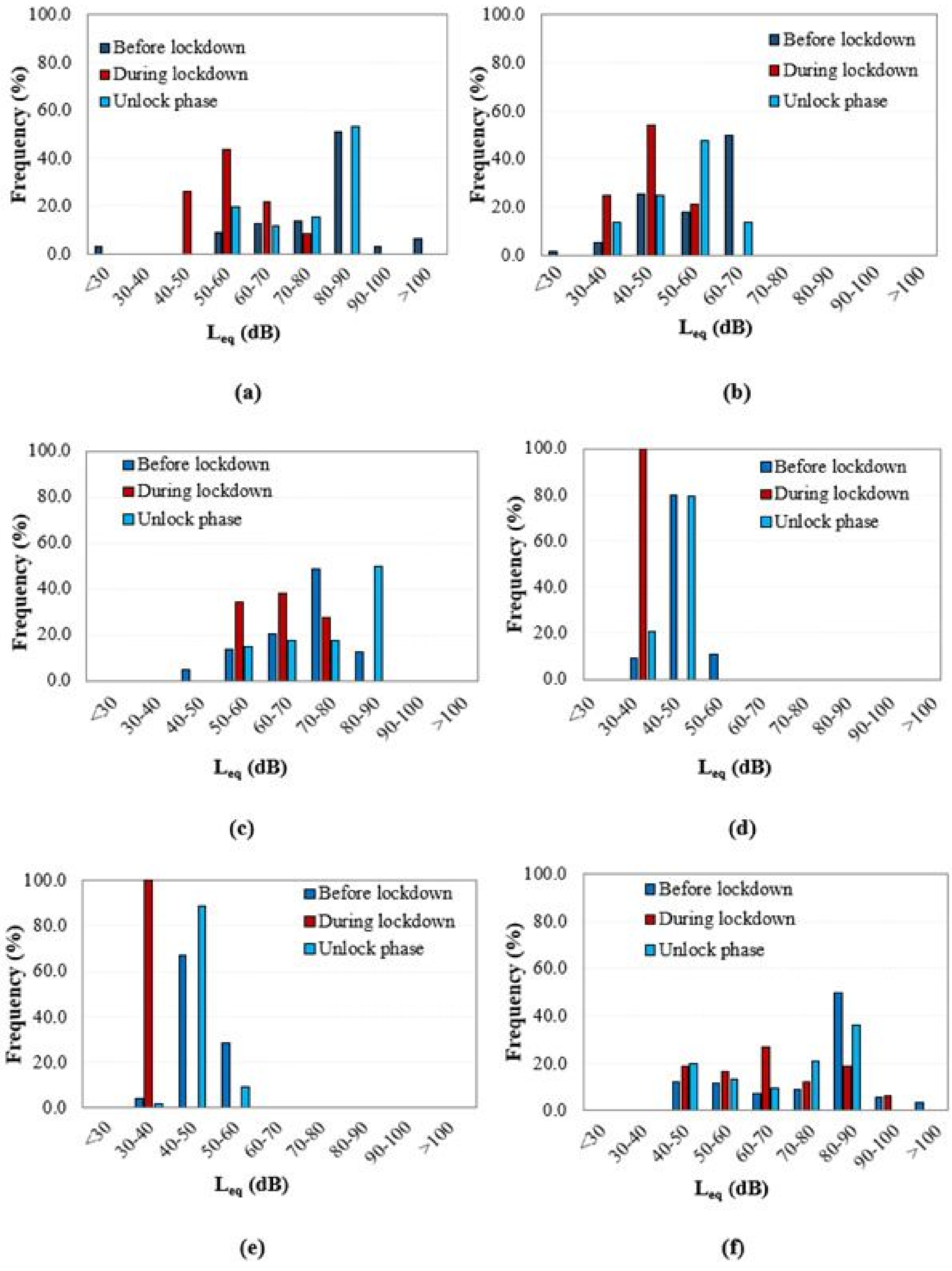


Figure 3

Frequency distribution of sound level before, during and after lockdown period at (a) residential (location I) (b) residential (location II) (c) Industrial (d) Commercial (e) Silence (location I) and (f) Silence (location II) zones

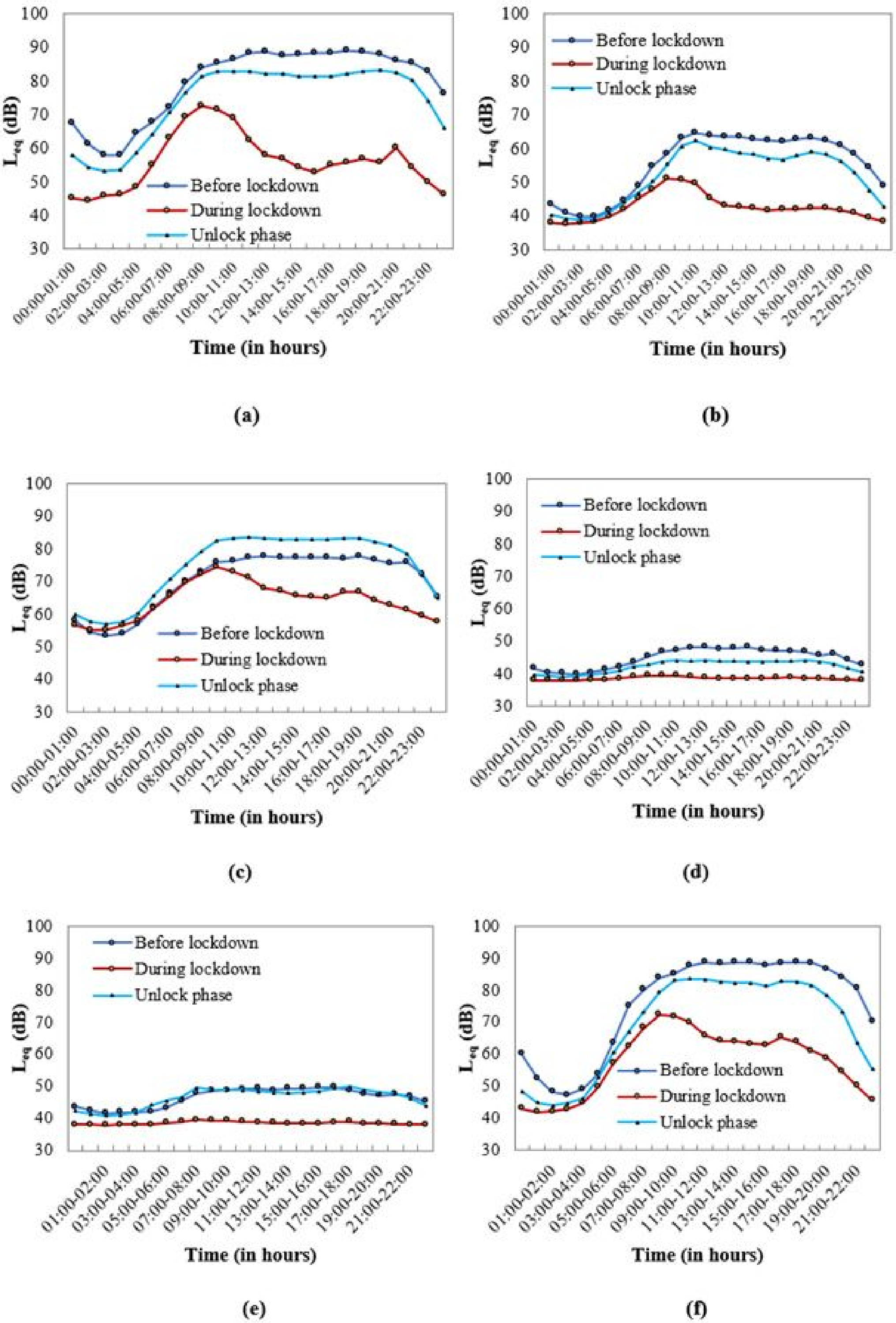
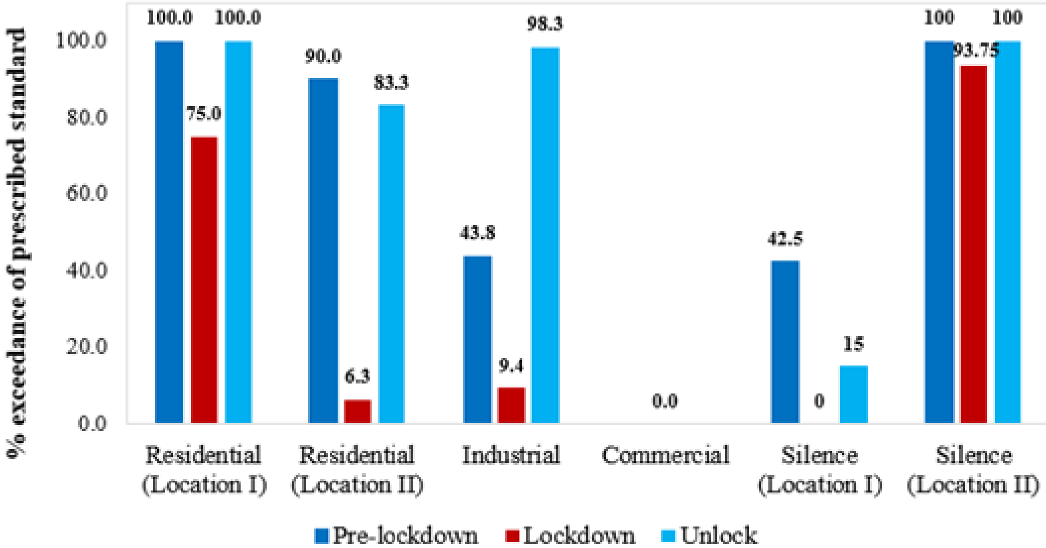


Figure 4

Time-wise variation in L_eq during different phases of lockdown for (a) residential land use (location I) (b) residential (location II) (c) Industrial land use (d) commercial land use (e) silence zone (location I) and (f) silence zone (location II)



(a)

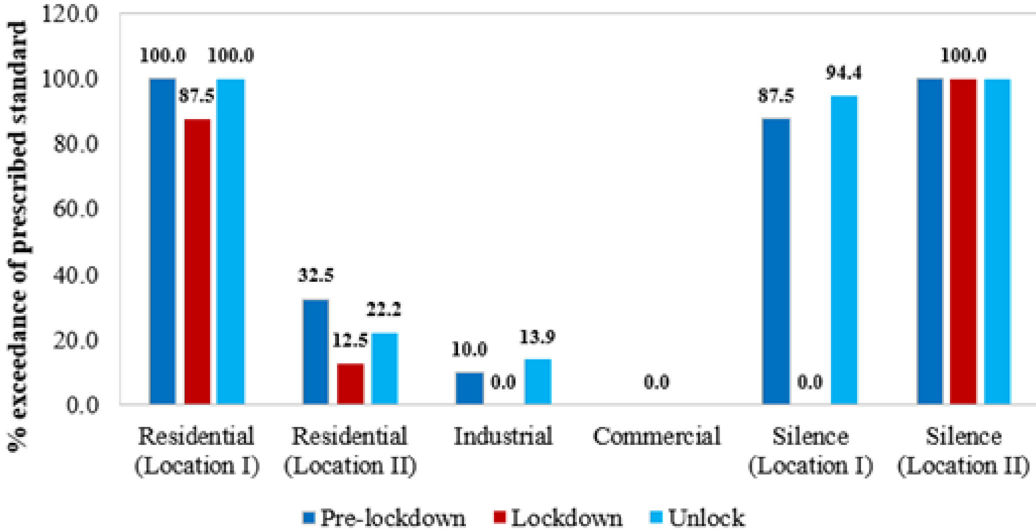


Figure 5

Percentage of time the hourly equivalent sound exceeded the standard noise limits in all the phases of lockdown during (a) daytime and (b) nighttime