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Impact of COVID-19 lockdown on ambient noise levels in seven metropolitan cities of India

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ARTICLE INFO

Article history:

Received 25 October 2020

Received in revised form 18 November 2021

Accepted 5 December 2021

Available online 18 December 2021

Keywords:

National Ambient Noise Monitoring Network (NANMN)

Day equivalent sound level, L_{day}

Night equivalent sound level, L_{night}

ABSTRACT

The paper analyzed the impact of lockdown on the ambient noise levels in the seventy sites in the seven major cities of India and ascertained the noise scenario in lockdown period, and on the Janta Curfew day in comparison to the pre-lock down period and year 2019 annual average values. It was observed that the majority of the noise monitoring sites exhibited a decrement in ambient day and night equivalent noise levels on the national Janta Curfew day and Lockdown period as compared with the normal working days attributed to the restricted social, economical, industrial, urbanization activity and reduced human mobility. A mixed pattern was observed at a few sites, wherein the ambient day and night equivalent noise levels during Janta curfew day and Lockdown period had been reported to be higher than that on the normal working days. The study depicts the noise scenario during the lockdown and pre-lockdown period for seventy sites in India and shall be instrumental in analyzing the consequences and implications of imposing lockdowns in future on the environmental noise pollution in Indian cities.

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1. Introduction

Noise pollution is evidently a serious health hazard apart from air and water pollution as analyzed in many research studies [1–3]. Thus, the continuous monitoring, reporting and analysis of the ambient noise levels in the urban scenario is necessary for devising and implementing suitable control and abatement measures for noise pollution prevention and control and reducing the associated health hazards. The entire world had been facing the wide spreading of Coronavirus (COVID 19) disease since the starting of the year 2020. The World Health Organization declared it as a 'global pandemic' on 11th March 2020. Subsequently, many countries imposed complete lockdown so as to prevent the spreading of this disease at an alarming rate. In India, a 14 h voluntary public curfew on 22nd March 2020 called as national 'Janta curfew' was observed followed by a much targeted nationwide lockdown initially for three weeks starting from 24th March to 14th April 2020, extended up to 3rd May 2020 followed by further extension till 31st May 2020. The government of India announced a 'Janta Curfew' from 7 am to 9 pm on Sunday, 22nd March to stop the spread of coronavirus disease, wherein people were urged not to step out of their homes except for those working in essential ser-

vices like healthcare, security or media. As a result, the lockdown rules were imposed by the Ministry of Home Affairs (MHA), India so as to prevent the rapid outbreak of pandemic. Also, all places of social gatherings, schools, colleges, offices, transportation systems including rail, road and air and industries were restricted with only few exceptions for necessary and essential services only. The details of all the consolidated activities permitted and prohibited during the Janta curfew day and in the national lock down period had been summarized in a recent Maharashtra Pollution Control Board (MPCB) report [4]. The studies had revealed that the air quality improved in India during the lockdown period due to considerable reduction in the concentration of particulate matter and gases like carbon monoxide as well as nitrogen dioxide [5–8]. A recent study conducted in Eastern India revealed that the particulate matter concentration reduced by three to four times, surface temperature reduced by 3–5 °C and noise levels (from 8 am to 4 pm) reduced from 85 dB(A) to 65 dB(A) amid lockdown [9]. There had been several studies reported on the effect of lockdown on air and noise pollution in many countries. A recent study in Dublin, Ireland observed a significant reduction in noise pollution at all the twelve noise monitoring stations [10] in the pandemic situation. The sound environment introduced by the lockdowns modified them not only in ambient noise levels, but also by the present sources and as such natural sounds were heard again [11]. Aletta et al., 2020 [12] reported an average reduction of

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5.4 dB(A) in the equivalent continuous sound levels for the eleven locations in London city, with reduction ranging from 1.2 dB to 10.7 dB. The imposition of quarantine closed all the commercial activities thus affected the environmental parameters directly associated to the human health [13]. A recent study presented by Somani et al., 2020 [14] also discussed about the reduced air and noise pollution in India in the pandemic period. These studies thus revealed the reduced air and noise pollution levels during the lockdown period due to restricted human activities.

Thus, it is imperative in national and international scenario to monitor and analyze the ambient noise levels in the cities and devise Noise Action Plans (NAPs) for the abatement and control of ambient noise levels so as to improve the health and quality of life. In India, the Central Pollution Control Board (CPCB), India established the National Ambient Noise Monitoring Network (NANMN) since the year 2011 with the prime objective of establishing the real-time continuous noise monitoring systems in the seventy sites in seven major cities of India [15–19]. This study analyzed the noise monitored data available from the seventy sites of seven major cities of India during the pre-lockdown period and lockdown period with an objective of:

- ascertaining the noise scenario and the annual average ambient noise levels of the seventy sites for the lockdown and pre-lockdown period and compare them with the ambient noise limits of India (Table 1 [18]),
- identify the noisy hot spots amongst the seventy sites and the requirements of implementation of Noise Action Plans,
- ascertain the status of compliance of the residential and silence zone sites with the ambient noise limits during the lockdown and pre-lockdown period, and
- analyze the severity of night equivalent noise levels in comparison to the day equivalent noise levels in lock down and pre-lockdown period.

Although the ten noise monitoring stations installed in one city can never describe the true picture of noise scenario in that city, yet the analysis of ambient noise levels acquired from the seventy sites in totality in this study shall be very helpful for understanding the noise scenario during different periods (annual average year 2019 values, Janta curfew day, pre-lockdown and lockdown period); planning for suitable noise control measures and analyzing the consequences and implications of imposing future lockdowns on the ambient noise levels in India.

2. Materials and methods

The permanent Noise Monitoring Terminals (NMTs) at the seventy sites reported in the study have been stationed in the seven major cities of India since year 2011 with each state having ten noise monitoring stations. The seven cities are: Bengaluru, Chennai, Delhi, Hyderabad, Kolkata, Lucknow and Mumbai. The seventy sites cover 25 commercial, 16 residential sites, 17 silence zone sites and 12 industrial sites. The network developed is a unique and one

Table 1
Ambient noise limits of India [18].

Category of area/ zone	Limits in dB(A)	
	Day time (6 a.m. to 10p.m.)	Night time (10p.m. to 6 a.m.)
Industrial Area	75	70
Commercial Area	65	55
Residential Area	55	45
Silence zone	50	40

of the largest noise monitoring network in the entire Asian continent reported so far. The explicit details of all the Noise Monitoring Terminals including the instrumentation employed and the methodology and procedure followed for ambient sound levels data acquisition, transmission, analysis and reporting had been discussed in details previously [15–17]. Fig. 1 shows the pictorial view on map of India of all the seven cities and seventy sites whereby these permanent NMTs had been installed and deployed for continuous noise monitoring throughout the year [20,21].

3. Results and discussion

The ambient day and night equivalent noise levels were measured for the seventy sites in the seven major cities of India during the following periods: annual average year 2019 day and night equivalent sound levels, pre-lockdown period, Janta curfew day and lockdown period. Tables 2 and 3 (a) and (b) enlists the details of the seventy sites and average day and night equivalent sound levels measured at the seventy sites in seven major cities of India during these different periods. These values were compared with the ambient noise standards for all the zones in order to ascertain their compliance and identify the noisy hot spots.

3.1. Annual average ambient noise levels in year 2019

The analysis of ambient day and night equivalent noise levels for the year 2019 revealed that eight sites including seven industrial and one residential site meet the ambient noise standards. Table 4 shows the frequency distribution of noise descriptors, day equivalent noise level, L_{day} ; night equivalent noise level, L_{night} ; 24 h equivalent sound level, $L_{Aeq,24h}$ and day-night average sound level, L_{dn} in dB(A) for seven major cities (70 sites) during the different periods. It was observed that majority of sites: 49 sites (70 %)

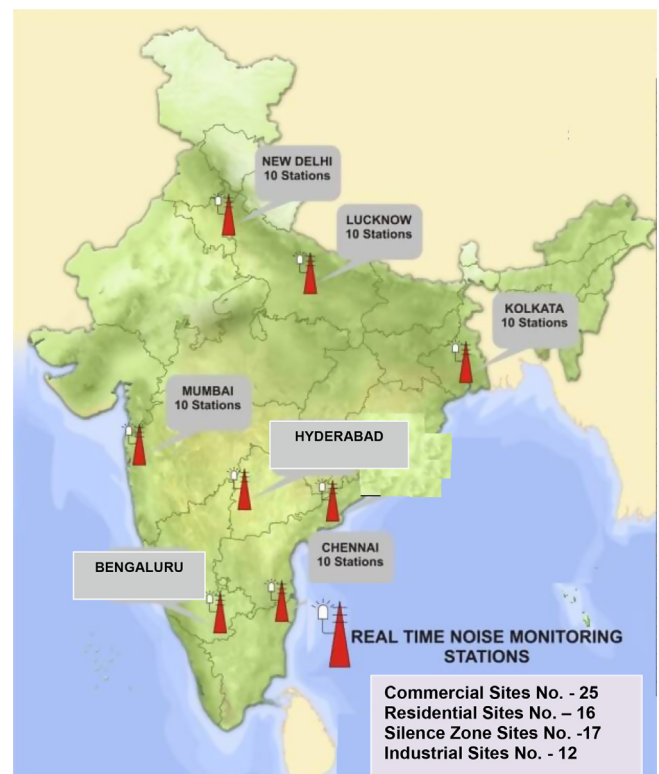


Fig. 1. Pictorial view on Map of India of seventy noise monitoring stations permanently situated in the seven major cities of India [20].

Table 2aAverage ambient levels, L_{day} and L_{night} for the twenty sites in the four major cities during normal days and lockdown period.

Name of Site	City	Latitude	Longitude	Site characteristics	Annual Average equivalent sound levels for year 2019		Business-As-Usual (Pre-Lockdown days)		Lockdown period		Janta Curfew	
					L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}
Dilshad Garden	Delhi	28°40' 53.76" N	77°19' 6.2" E	Silence	68.7	68.4	66.9	67	66	66	66	66
CPCB HQ		28°39' 20.99" N	77°17' 39.91" E	Commercial	66.5	56.7	66.3	57.6	58.4	51.6	57	53
DTU, Bawana		28°44' 44.49" N	77°5' 1.56" E	Silence	62.2	57.9	58.9	57.3	59.7	57.6	59	58
ITO		28°37' 41.21" N	77°14' 27.22" E	Commercial	75.1	73.5	73.6	73.3	74.7	74.2	–	–
NSIT Dwarka		28°36' 14.46" N	77°2' 28.78" E	Silence	57.9	54.2	58.8	55	54.2	49.8	57	54
Gomti Nagar	Lucknow	26°52' 58.02" N	80°59' 58.02" E	Silence	66.9	60.2	64.9	58.6	60.9	54.1	55	53
Hazrat Ganj		26°51' 0.66" N	80°56' 51.59" E	Commercial	74.0	73.2	69.9	62.7	57.3	53.1	56	55
Indira Nagar		26°53' 25.08" N	80°59' 57.29" E	Residential	50.6	44.7	66.9	58.3	63.4	55.6	64	60
PGI Hospital		26°45' 17.68" N	80°55' 59.53" E	Silence	66.7	67	83.9	88.4	86.3	85.2	86	86
Talkatora Industrial Area		26°50' 2.44" N	80°53' 30.25" E	Industrial	63.7	62.3	66.7	58.4	59.8	55	62	64
Kasba Gole Park	Kolkata	22°31' 1.2" N	88°24' 15.8" E	Industrial	64.4	61.1	67.9	61.5	70.8	65.5	69	68
New Market		22°33' 41.4" N	88°21' 10.4" E	Commercial	72.9	76.3	64.1	62.4	61.8	62.5	63	66
Patauli		22°28' 21.07" N	88°23' 29.71" E	Residential	73.4	72.4	69.2	68.8	66.2	66.2	70	68
SSKM Hospital		22°32' 19.58" N	88°20' 35.29" E	Silence	70.4	69.6	43	–	42.3	44	43	75
WBPCB HQ		22°33' 42.67" N	88°24' 32.46" E	Commercial	63.4	57.0	62.3	56.4	53.6	49.5	54	56
AS HP	Mumbai	19°1' 15.83" N	72°51' 33.24" E	Silence	–	–	47.7	47.3	46.6	46.8	48	47
Bandra		19°3' 20.77" N	72°49' 49.41" E	Commercial	67.5	66.9	57.4	58	61.7	62.3	57	56
MPCB HQ		19°6' 42.73" N	73°0' 43.80" E	Commercial	70.2	67.3	68.5	67.4	62	59.7	58	60
Thane MCQ		19°0' 57.38" N	72°51' 29.24" E	Commercial	69.1	69.1	67.6	69.6	67.7	67.6	68	69
Vashi Hospital		19°4' 45.49" N	73°0' 0.12" E	Silence	75.8	74.2	66.2	66.4	57	57.8	67	62

Table 2bAverage ambient levels, L_{day} and L_{night} for the fifteen sites in the three major cities during normal days and lockdown period.

Name of Site	City	Latitude	Longitude	Site characteristics	Annual Average equivalent sound levels for year 2019		Business-As-Usual (Pre-Lockdown days)		Lockdown period		Janta Curfew	
					L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}
Abids	Hyderabad	17°23' 27.42" N	78°28' 25.59" E	Commercial	73.1	65.7	72.6	65.8	60.4	52.1	58	59
Jeedimetla		17°30' 44.12" N	78°28' 10.43" E	Industrial	72.6	73.2	65.7	65.9	70	69	68	69
Jubilee Hills		17°26' 22.08" N	78°23' 58.28" E	Residential	59.7	53.8	62.1	56.4	58.5	50.9	–	–
TSPCB		17°25' 27.77" N	78°27' 3.74" E	Commercial	69.8	62.9	69.2	63.3	61.7	55.2	60	61
Zoo Park		17°22' 8.44" N	78°28' 17.42" E	Silence	–	–	50.3	50.8	48.6	48.2	40	40
BTM	Bengaluru	12°54' 30.36" N	77°35' 10.96" E	Residential	64.7	64.7	64.5	65.2	63.2	62.8	63	67
Marathahalli		12°54' 45.45" N	77°34' 34.58" E	Commercial	73.1	72.7	78.6	77.1	76.2	75.3	79	77
Nisarga Bhawan		12°59' 0.54" N	77°35' 40.15" E	Residential	76.4	79.1	51.5	50.8	55.4	54.6	54	58
Parisar Bhawan		12°58' 32.18" N	77°36' 12.38" E	Commercial	67.2	62.1	65.6	61.5	57.2	51.3	57	57
Peeniyia		13°1' 4.28" N	77°30' 11.45" E	Industrial	63.4	58.4	62.1	59.5	58.7	59.3	61	61
Eye Hospital	Chennai	13°6' 16.13" N	80°17' 3.35" E	Silence	69.2	61.0	58.8	60.7	57.9	57.6	58	58
Guindy		13°0' 42.79" N	80°13' 9.46" E	Industrial	80.1	78.2	86.1	86.2	78.6	79.7	85	86
Perambur		13°6' 43.46" N	80°14' 16.85" E	Commercial	74.4	71.6	61.6	60	57.6	51	62	51
T. Nagar		13°2' 24.34" N	80°13' 57.44" E	Commercial	77.3	73.0	69.8	70.2	67	68.2	70	68
Triplacane		13°3' 17.91" N	80°16' 28.44" E	Residential	60.9	59.0	57.4	58.7	60.8	61.8	60	59

registered ambient day equivalent noise levels between 60 and 75 dB(A). 39 sites (55.7 %) registered night equivalent noise levels between 55 and 70 dB(A). 49 sites (70 %) registered $L_{\text{Aeq},24\text{h}}$ levels between 60 and 75 dB(A), while 40 sites (57.1 %) registered L_{dn} levels between 65 and 80 dB(A). Some of the sites showed very high ambient noise levels and thus immediately require the implementation of appropriate noise action plans. No commercial or the silence zone site complied with the ambient noise limits for the year 2019. The zone wise analysis showed that majority of sites lying in commercial zone (80%), residential zone (66.7%), silence zone (80%) and industrial zone (58.4%) registered day equivalent noise levels in range 60 to 75 dB(A). Also, the majority of sites lying in commercial zone (64%) and silence zone (66.7%) registered night equivalent noise levels in range 55 to 70 dB(A), while 66.7 % residential sites and 58.4 % of industrial sites registered night equivalent noise levels in range 50 to 65 dB(A). 2 residential sites, 2

silence zone sites, 2 industrial zone sites and no commercial zone site showed day equivalent levels up to 60 dB(A). Also, 3 residential sites, 2 silence zone sites, 2 industrial zone sites and no commercial zone site showed night equivalent noise levels up to 55 dB(A).

3.2. Ambient noise levels in pre-lockdown period

The analysis of ambient noise levels in pre-lockdown period (Business-As-Usual or normal) days were analyzed for the period of 7th March 2020 to 21st March 2020. Only ten industrial sites complied with the ambient noise standards in pre-lockdown period. It can be observed from Table 4 that 53 sites (75.7%) registered day equivalent noise levels between 55 and 70 dB (A) and 45 sites (64.3%) registered night equivalent noise levels between 50 dB(A) to 65 dB(A). 52 sites (74.3%) registered $L_{\text{Aeq},24\text{h}}$ levels between 60 dB(A) to 75 dB(A) and 49 sites (70%) registered L_{dn} levels

Table 3aAverage ambient levels, L_{day} and L_{night} for twenty new sites in the four major cities during normal days and lockdown period.

Name of Site	City	Latitude	Longitude	Site characteristics	Annual Average equivalent sound levels for year 2019		Business-As-Usual (Pre-Lockdown days)		Lockdown period		Janta Curfew	
					L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}
Civil Lines	Delhi	28°40' 55.97" N	77°13' 25.75" E	Commercial	61.7	58.3	60.8	57.5	58.3	54.3	57	54
R. K. Puram		28°33' 46.23" N	77°11' 12.4" E	Residential	66.8	61.6	60.9	58.7	59.7	54.7	–	–
Anand Vihar		28°38' 51.22" N	77°18' 57.02" E	Commercial	65.6	61.9	65.4	63	53.8	52.3	60	57
Mandir Marg		28°38' 11.41" N	77°12' 2.36" E	Silence	65.4	54.8	59.1	52.6	59.1	53.1	58.5	47.6
Punjabi Bagh	Lucknow	28°40' 12.83" N	77°7' 54.14" E	Residential	61.3	52.4	56.6	51	54.1	47.6	–	–
Chinhat		26°54' 17.09" N	81°03' 13.08" E	Industrial	67.3	60.0	67.7	51.2	62.6	50.4	56	50
IT College		26°52' 22.47" N	80°56' 30.28" E	Silence	64.7	59.5	65.5	59.1	59.6	52.4	54	53
CSS Airport		26°45' 55.41" N	80°53' 10.91" E	Commercial	76.3	67.0	62.8	57.6	61.6	50.9	68	50.6
RSC Aliganj	Kolkata	26°53' 21.89" N	80°56' 24.43" E	Commercial	65.1	57.6	65.5	60.9	58.8	53.9	78	–
UPPCB HQ		26°52' 6.75" N	81°00' 12.54" E	Residential	63.9	62.2	66.5	59.5	60.2	53.6	56	56
Birati N.		22°40' 13.99" N	88°26' 1.74" E	Residential	79.1	77.9	70.9	55.3	59.5	51.7	64	68
R G Kar		22°36' 16.18" N	88°22' 43.20" E	Silence	63.7	62.2	55.5	61.3	48.8	71.2	68	73.3
Tollygunge	Mumbai	22°29' 56.48" N	88°20' 43.79" E	Commercial	66.8	62.9	65.2	62.9	60.5	56.5	61	60
Bag Bazar		22°36' 4.61" N	88°22' 1.01" E	Residential	87.2	90.1	75.4	74.2	78	72.5	81	77
Tartala		22°30' 56" N	88°18' 19.2" E	Industrial	75.3	73.1	68.5	64.1	61.8	56.5	64	69
M&M Kandivali		19°12' 3.87" N	72°52' 12.14" E	Industrial	60.4	52.6	59.6	52.9	54	47.5	53	47
CST	Mumbai	18°56' 0.67" N	72°49' 29.61" E	Commercial	74.5	70.3	73.6	70	68	59.4	70	63
L&T Powai		19°7' 18.31" N	72°53' 34.27" E	Industrial	59.4	55.1	59.1	52.6	58.2	46.6	58	48
Pepsico Chembur		19°2' 52.89" N	72°54' 37.12" E	Residential	68.1	61.3	68.2	62.2	62.4	57.9	61	59
Andheri		19°6' 44.49" N	72°51' 20.71" E	Industrial	78.9	78.0	75.2	74.8	75.3	77.3	75	83

Table 3bAverage ambient levels, L_{day} and L_{night} for the fifteen new sites in the three major cities during normal days and lockdown period.

Name of Site	City	Latitude	Longitude	Site characteristics	Annual Average equivalent sound levels for year 2019		Business-As-Usual (Pre-Lockdown days)		Lockdown period		Janta Curfew	
					L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}
Tarnaka	Hyderabad	17°25' 43.57" N	78°32' 15.83" E	Residential	81.4	81.7	63.7	50.6	71.4	67.9	69	66
Gaddapothram		17°36' 4.1" N	78°22' 19.8" E	Industrial	83.3	74.0	66.7	67.7	70.9	73.9	79	82
Gachibowli		17°27' 36.1" N	78°20' 3.3" E	Silence	60.0	58.2	60.9	58.7	60.3	56.9	59	55
Paradise		17°26' 36.7" N	78°29' 15.9" E	Commercial	81.4	80.3	79.4	76.3	71.3	66.5	68	72
Kukatpalli	Bengaluru	17°29' 45.3" N	78°23' 39" E	Commercial	69.9	66.7	69.2	67.4	63.1	58.4	62	63
Yeshwantpur		13°1' 5.04" N	77°33' 28.13" E	Commercial	72.1	64.0	71.4	65.1	65.8	59	63	61
R.V.C.E		12°55' 23.15" N	77°29' 58.5" E	Silence	67.4	65.9	56.2	52.5	50	48.7	49	49
Whitefield		12°58' 38.47" N	77°45' 5.18" E	Industrial	66.2	61.1	65.5	60.7	58.8	53.9	57	57
Dolmur	Chennai	12°57' 48.86" N	77°38' 17.78" E	Residential	64.3	59.3	62.2	57.7	60.9	53.5	57	55
Nihmans		12°56' 15.27" N	77°35' 32.95" E	Silence	72.0	74.1	66.6	72.8	62.3	70.7	75	81
Pallikarnai		12°56' 14.67" N	80°12' 55.27" E	Commercial	84.4	78.6	62.1	55.8	69.5	80.3	81	73
Velachery		12°58' 35.09" N	80°13' 15.27" E	Residential	65.5	59.7	62.6	55.7	58.1	50.9	58	51
Washermanpet	Chennai	13°7' 53.84" N	80°16' 43.95" E	Commercial	75.6	71.5	74.5	74.4	75.1	74.9	75	76
Anna Nagar		13°5' 21.45" N	80°13' 23.93" E	Silence	75.0	77.8	62.2	89.1	56.7	85.4	77	88
Sowcarpet		13°5' 42.4" N	80°16' 32.2" E	Residential	62.3	60.2	64.2	63.9	59.3	59	65	66

between 65 and 80 dB(A). No residential/commercial/silence zone site complied with the ambient noise limits for this period. Table 5 shows the zone wise analysis of frequency distribution of day and night equivalent sound levels for the different periods. The zone wise analysis (Table 5) showed that majority of sites in pre-lockdown period lying in commercial zone (87.4 %) registered day equivalent noise levels in range 60 to 75 dB(A), while 80 % of residential zone sites, 86.7 % of silence zone sites and 83.3 % of industrial zone sites registered day equivalent noise levels in range 55 to 70 dB(A). Also, the majority of sites lying in commercial zone (83.4 %) registered night equivalent noise levels in range 55 to 70 dB(A), while 87.5 % of residential zone sites, 60 % of silence zone sites and 66.7 % of industrial zone sites registered night equivalent noise levels in range 50 to 65 dB(A). 1 commercial zone site, 3 residential sites, 9 silence zone sites and 2 industrial zone sites showed day equivalent noise levels up to 60 dB(A). Also, 4 residential sites, 5 silence zone sites, 3 industrial zone sites and no com-

mercial zone site showed night equivalent noise levels up to 55 dB(A).

3.3. Ambient noise levels on Janta Curfew day

On the day of Janta Curfew i.e. 22nd March 2020, restricted vehicles on the roads and opening of only essential commercial units [7] was permitted by the authorities. Thus, fourteen sites including nine industrial sites, four commercial sites and one silence zone site complied with the ambient noise levels on day of Janta Curfew. It was observed (Table 4) that 45 sites (64.3 %) registered day equivalent noise levels between 55 and 70 dB(A) and 32 sites (45.7 %) registered night equivalent levels between 50 and 65 dB(A). 39 sites (55.7 %) registered L_{dn} levels between 65 and 80 dB(A), while 40 sites (57.1 %) registered $L_{Aeq,24hr}$ levels between 55 and 70 dB(A). No site lying in residential zone complied with the ambient noise standards. The zone wise analysis

(Table 5) showed that the majority of the sites on Janta curfew day lying in commercial zone (82.7 %), residential zone (84.7 %), silence zone (53.3 %) and industrial zone (66.7%) registered day equivalent noise levels in range 55 to 70 dB(A). Also, the majority of the sites lying in commercial zone (69.5 %) and residential zone (53.9 %) registered night equivalent noise levels in range 50 to 65 dB(A), while 53.3 % of silence zone sites registered night equivalent noise levels in range 45 to 60 dB(A). It was also observed that 5 residential sites, 11 silence zone sites, 4 industrial zone sites and 10 commercial zone sites showed day equivalent levels up to 60 dB(A). Also, 2 residential sites, 8 silence zone sites, 3 industrial zone sites and 5 commercial zone sites showed night equivalent noise levels up to 55 dB(A).

3.4. Ambient noise levels in lockdown period

The ambient noise levels in the lockdown period were analyzed for the period of 23rd March 2020 to 7th April 2020. It was observed that nineteen sites including nine industrial sites and ten commercial zone sites complied with the ambient noise standards. None of the silence or the residential zone sites surprisingly complied with the ambient noise limits. It can be observed from Table 4 that 49 sites (70 %) registered day equivalent noise levels between 55 dB(A) to 70 dB (A) and 41 sites (58.6 %) registered night equivalent noise levels between 50 dB(A) to 65 dB(A). 46 sites (65.7 %) registered $L_{Aeq,24h}$ levels between 55 dB(A) to 70 dB (A) and 44 sites (62.9 %) registered L_{dn} levels between 60 and 75 dB(A). 39 sites (55.7 %) met the target of 60 dB L_{day} in lockdown period, while 32 sites (45.7 %) met the target of 55 dB L_{night} in lockdown period. The zone wise analysis as shown in Table 5 showed that majority of sites in lockdown period lying in commercial zone (70.9 %) registered day equivalent noise levels in range 55 to 70 dB (A), while 80 % of residential zone sites, 66.7 % of silence zone sites and 58.3 % of industrial zone sites registered day equivalent noise levels in range 50 to 65 dB(A). Also, the majority of sites lying in commercial zone (66.6 %), residential zone (75 %) and silence zone (46.7 %) registered night equivalent noise levels in range 50 to 65 dB(A), while 58.4 % of industrial zone sites registered night equivalent noise levels in range 45 to 60 dB(A).

4. Comparison of the ambient noise levels for the different periods

The comparison of ambient day and night equivalent noise levels measured for the different periods were analyzed for the seventy sites in order to understand the noise scenario in the different periods and analyzing the change in noise scenario during the Janta curfew and lockdown in comparison to the pre-lockdown days and the annual average ambient day and night equivalent noise levels observed in the year 2019. The analysis of comparison of day and night equivalent noise levels for the different periods is presented in this section.

4.1. Comparison of ambient noise levels on the Janta curfew day with pre-lockdown period

Fig. 2 (a) and (b) show the difference between the day and night equivalent noise levels on the Janta curfew day and average ambient noise levels during the pre-lockdown period for the seventy sites. The analysis of ambient day and night equivalent noise levels in comparison to the pre-lockdown period shows that 33 sites (47.1 %) registered decrement in both the day and night equivalent noise levels. 41 sites (58.6 %) registered decrement in the day equivalent noise levels, while 43 sites (61.4 %) registered a decrement in the night equivalent noise levels. 24 sites registered decre-

ment in day equivalent level by ≥ 5 dB(A), while 15 sites registered a decrement in night equivalent noise levels by ≥ 5 dB(A). 9 sites registered decrement in day levels ≥ 10 dB(A), while only one site showed decrement in night level ≥ 10 dB(A). However, 9 sites showed an increment in the day equivalent noise levels by ≥ 5 dB(A), while 11 sites registered increment in night equivalent noise levels ≥ 5 dB(A). Overall, 16 commercial sites, 10 silence zone sites, 7 residential sites and 8 industrial sites showed reduction in day equivalent noise levels in the range of 0 to 15 dB(A). Also, 20 commercial sites, 13 silence zone sites, 5 residential sites and 5 industrial sites showed decrement in night equivalent noise levels in range 0 to 15 dB(A). It was observed that the majority of the sites lying in the commercial and silence zone registered decrement in the ambient day and night equivalent noise levels.

4.2. Comparison of ambient noise levels in lockdown period with pre-lockdown period

Fig. 3 (a) and (b) show the difference in average day and night equivalent noise levels of lockdown period with the pre-lockdown period for the seventy sites. The analysis of average ambient day and night equivalent noise levels in lockdown period in comparison to the pre-lockdown period shows that 50 sites (71.4 %) showed a decrement in both day and night equivalent noise levels. 53 sites (75.7 %) showed the decrement in day equivalent noise levels, while 55 sites (78.6 %) showed decrement in night equivalent noise levels. 30 sites (42.9 %) showed decrement in day equivalent noise levels ≥ 5 dB(A), while 29 sites (41.4 %) showed a decrement in night equivalent noise levels ≥ 5 dB(A). 4 sites showed a decrease in day equivalent noise levels ≥ 10 dB(A), while 6 sites showed a decrease in night equivalent noise levels ≥ 10 dB(A). Overall, 20 commercial sites, 14 silence zone sites, 11 residential sites and 8 industrial sites showed reduction in day equivalent noise levels in the range of 0 to 15 dB (A). Also, 20 commercial sites, 14 silence zone sites, 13 residential sites and 8 industrial sites showed decrement in night equivalent noise levels in range 0 to 15 dB(A). It was observed that the majority of the sites registered decrement in the ambient day and night equivalent noise levels.

4.3. Comparison of ambient noise levels on Janta curfew day with year 2019 annual average levels

Fig. 4 (a) and (b) show the difference in ambient day and night equivalent noise levels observed on the Janta Curfew day and year 2019 annual average day and night equivalent noise levels for the seventy sites. The comparison of the ambient day and night equivalent levels on the Janta Curfew day with year 2019 annual average noise levels revealed that 38 sites (54.3 %) showed a decrement in both day and night equivalent noise levels. 44 sites (62.9 %) showed decrement in day equivalent noise levels, while 43 sites (61.4 %) showed decrement in night equivalent noise levels. 28 sites (40 %) showed a decrease in day equivalent noise levels ≥ 5 dB(A), while 27 sites (38.6 %) showed a decrease in night equivalent noise levels ≥ 5 dB(A). Also, 19 sites (27.1 %) showed a decrease in day equivalent noise levels ≥ 10 dB(A), while 12 sites (17.1 %) showed a decrease in night equivalent noise levels ≥ 10 dB(A). However, it can be observed that 7 sites showed an increase in day equivalent noise levels by ≥ 5 dB(A), while 13 sites showed an increase in night equivalent noise levels by ≥ 5 dB(A). Overall, 20 commercial sites, 8 silence zone sites, 8 residential sites and 8 industrial sites showed reduction in day equivalent noise levels in the range of 0 to 15 dB(A). Also, 18 commercial sites, 9 silence zone sites, 8 residential sites and 6 industrial sites showed decrement in night equivalent noise levels in range 0 to 15 dB(A). It was observed that the majority of the

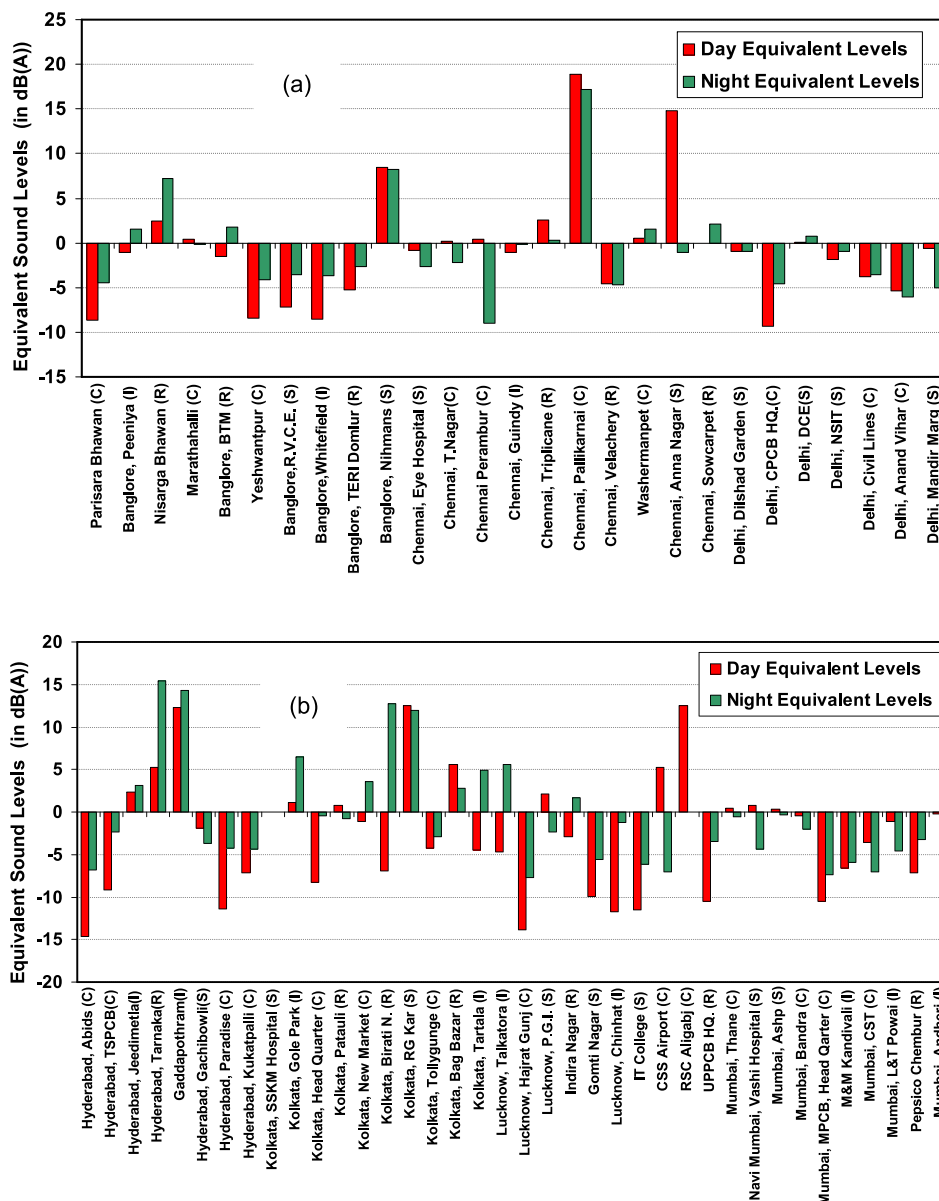


Fig. 2. (a) and (b). Difference in day equivalent noise levels, L_{day} and night equivalent noise levels, L_{night} in dB(A) on the Janta curfew day and the average day and night equivalent noise levels in Business As Usual (Pre-Lockdown) period in year 2020.

commercial zone sites registered decrement in the ambient day and night equivalent noise levels.

4.4. Comparison of ambient noise levels in lockdown period with year 2019 annual average levels

Fig. 5 (a) and (b) show the difference in ambient day and night equivalent noise levels observed during lockdown period with the year 2019 annual average day and night equivalent levels for the seventy sites. The comparison of the ambient day and night equivalent noise levels in lockdown period with the annual average year 2019 levels showed that 57 sites (81.4 %) showed a decrement in both day and night equivalent noise levels. 61 sites (87.1 %) showed a decrement in day equivalent noise levels, while 55 sites (78.6 %) showed decrease in night equivalent noise levels. 43 sites (61.4 %) showed a decrement in day equivalent noise levels ≥ 5 dB (A) and 38 sites (54.3 %) showed decrement in night equivalent

noise levels ≥ 5 dB(A). 22 sites showed a decrement in day equivalent noise levels ≥ 10 dB(A), while 18 sites showed a decrement in night equivalent noise levels ≥ 10 dB(A). Overall, 22 commercial sites, 8 silence zone sites, 12 residential sites and 11 industrial sites showed reduction in day equivalent noise levels in the range of 0 to 15 dB(A). Also, 18 commercial sites, 9 silence zone sites, 11 residential sites and 8 industrial sites showed decrement in night equivalent noise levels in range 0 to 15 dB(A). It was observed that the majority of the commercial and industrial zone sites registered decrement in the ambient day and night equivalent noise levels.

5. Overall noise scenario in different periods

The zone-wise analysis for the seventy sites under consideration as shown in [Table 5](#) revealed that the majority of sites lying in each zones showed the day equivalent noise levels ranging from 55 to 65 dB(A) in lockdown period and on the Janta curfew day,

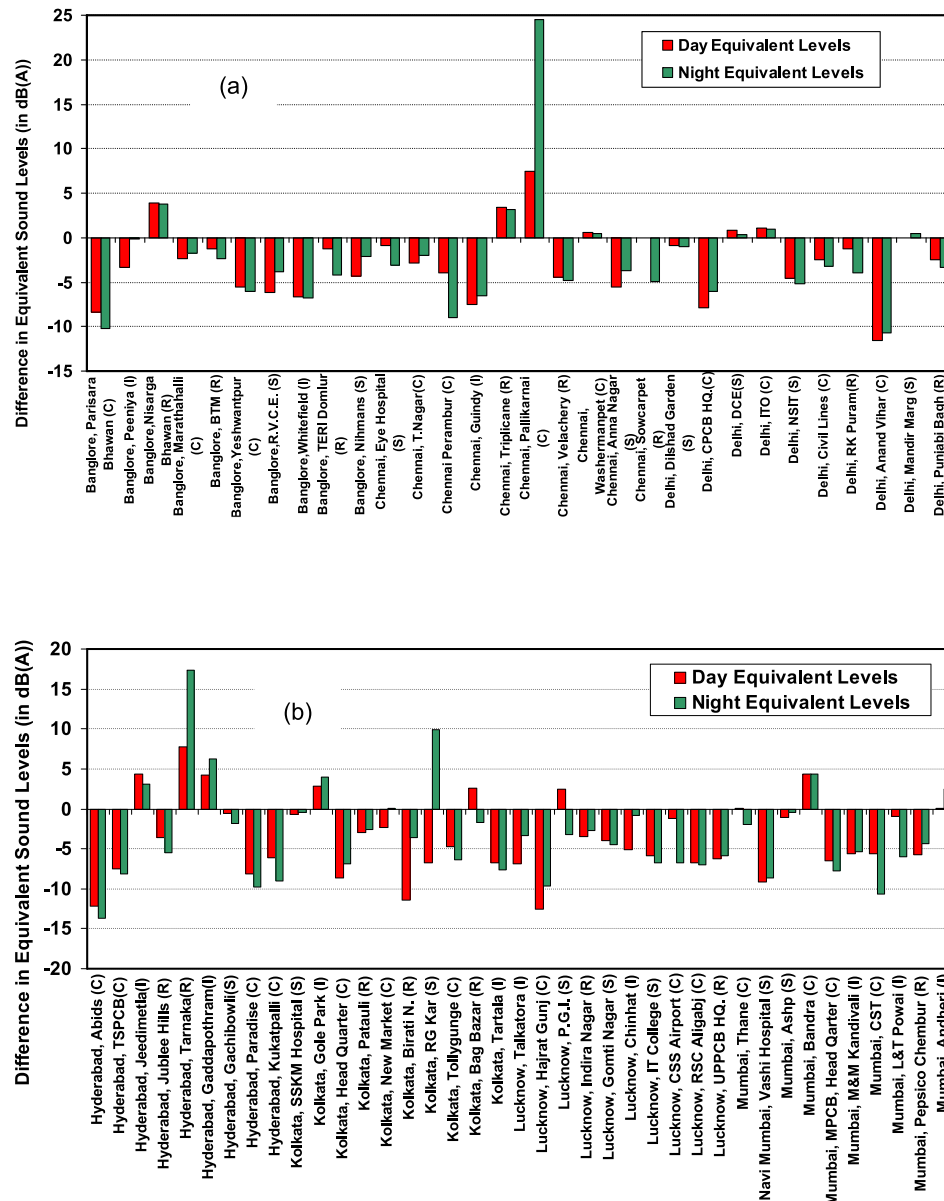


Fig. 3. (a) and (b). Difference in average day equivalent noise levels, L_{day} and night equivalent noise levels, L_{night} in dB(A) during Lockdown period and Business As Usual (Pre-Lockdown period) in year 2020.

while in the pre-lockdown period, majority of sites registered day equivalent noise levels ranging from 60 to 70 dB(A). Also, the majority of sites in each zone showed the night equivalent noise levels ranging from 50 to 60 dB(A) in lockdown period and on the Janta curfew day, while in the pre-lockdown period, majority of sites showed night equivalent noise levels ranging from 55 to 65 dB(A). It was observed that only 19 sites (27.1 %) complied with the ambient noise limits for the lockdown period. Table 6 shows the status of compliance of all the 70 sites with respect to the ambient noise standards for the year 2019 annual average values, Janta curfew day, pre-lockdown and lockdown period. It can be observed that no residential zone or silence zone site met the ambient noise standards in lockdown period. Table 6 also shows the status of compliance of day and night equivalent sound levels explicitly for the various sites with ambient noise standards of India. Interestingly, some of the sites partially complied with either

day or night noise limits. It can be observed that 33 sites (47.1 %) complied with day equivalent noise limits, while only 19 sites (27.1 %) complied with the night equivalent noise limits for the lockdown period. Similarly, on the Janta curfew day, 31 sites (44.3 %) complied with day equivalent noise limits, while only 14 sites (20 %) complied with the night equivalent noise limits. This is different to the scenario of the pre-lock down period, whereby 23 sites (32.9 %) complied with day equivalent noise limits, while only 10 sites (14.3 %) complied with the night equivalent noise limits. Thus, even in the lockdown situation, only 10 additional sites complied with day equivalent noise limits and 9 additional sites complied with night equivalent noise limits. 32 sites (45.7 %) only met the target of 55 dB L_{night} in lockdown period and 18 sites (25.7 %) on the Janta curfew day as 55 dB $L_{Aeq, outside}$ had been recommended as an interim goal by WHO [22]. In accordance with the U.S Department of Housing and Urban Development (HUD)

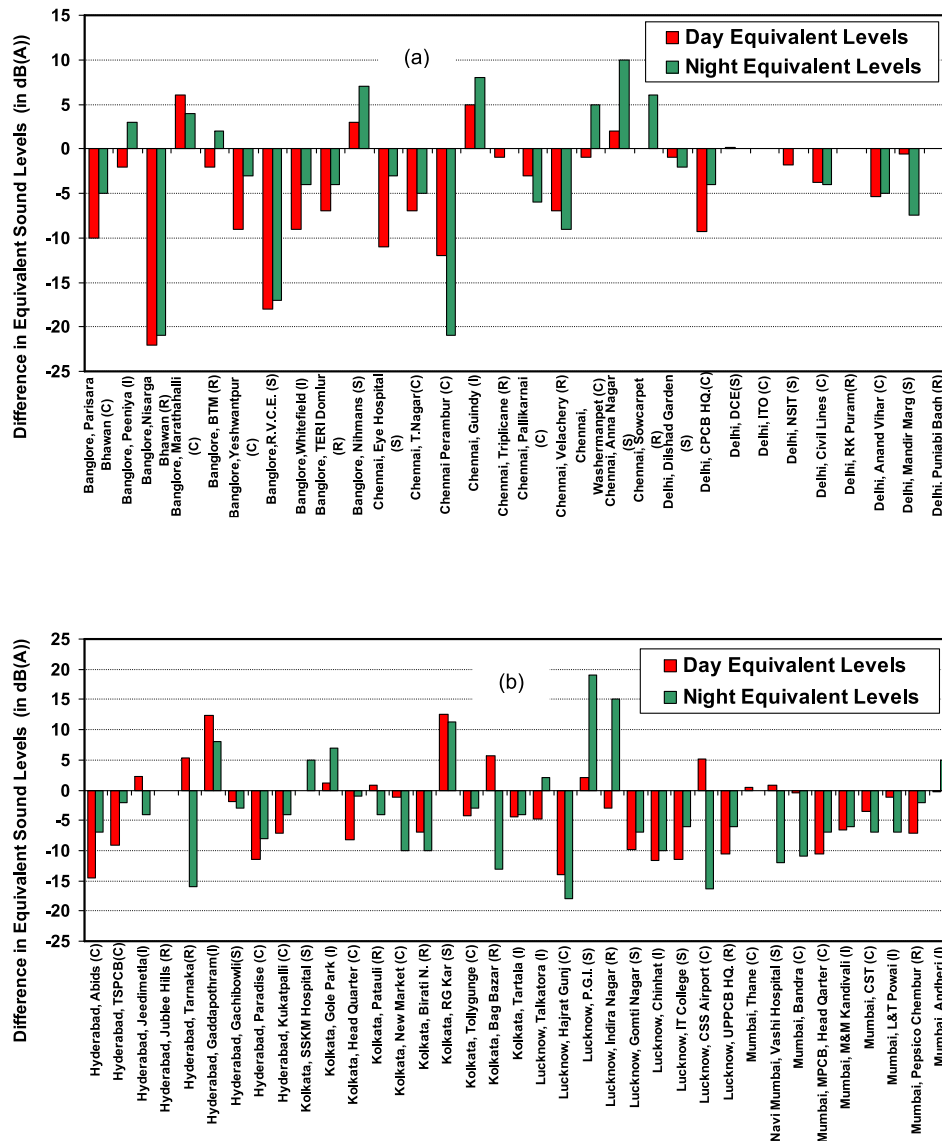


Fig. 4. (a) and (b). Difference in day equivalent noise levels, L_{day} and night equivalent noise levels, L_{night} in dB(A) on Janta Curfew day and annual average ambient day and night equivalent noise levels observed in year 2019.

recommended limits of the noise scenario of $49 < L_{Aeq} \leq 62$ dB(A) as normally acceptable [23]; 44 sites (62.9 %) met the criteria in lockdown period and 35 sites (50 %) on the Janta curfew day. Also, taking into account the criteria of $L_{dn} \leq 65$ dB(A) as acceptable, 42 sites (60 %) met the criteria in the lockdown period and 32 sites (45.7 %) on the Janta curfew day.

Table 7 shows the frequency distribution (in %) of difference of average ($L_{day} - L_{night}$) for the 70 sites. It was revealed that the majority of difference between the day and night equivalent noise levels in each period varied from -5 to 10 dB. Very few sites (<5.8 %) only showed the difference greater than 10 dB. It can be observed (Table 7) that the difference in the day and night equivalent noise levels within ± 5 dB(A) were observed for 42 sites (60 %) in pre-lock down period and 52 sites (74.3 %) in year 2019 as evident from the annual average values. However, during the lockdown period and on Janta curfew day, the difference between day and night noise levels within ± 5 dB(A) were observed for 40 sites (57.1 %) in lockdown period and 50 sites (71.4 %) on Janta curfew day. Thus, the night equivalent noise levels were not as severe

in the lockdown period as were observed in the year 2019 annual average values, while on the Janta curfew day, there was only a marginal impact on night equivalent noise levels in comparison to the year 2019 annual average values. Also, in order to ascertain the most severely affected zone, the noise limit exceedance factor for each zone and in each period was analyzed as shown in Table 8. The noise limit exceedance factor (NEF) was calculated as the ratio of the ambient noise level (day/night) observed at the site to the noise limit recommended by the ambient noise standards. The average of noise limit exceedance factor (NEF) for all the sites lying in one zone is called as the Average Exceedance Factor (AEF) as analyzed in Table 8 [24–26]. Some of the interesting observations analyzed from the analysis of ambient noise levels during pre-lockdown period, lockdown period and Janta curfew day as listed in Tables 6–8 are as follows:

- Overall, the percentage of stations complying with noise standards during day-time increased from 32.9 % during normal working days to about 47.1 % during lockdown period and

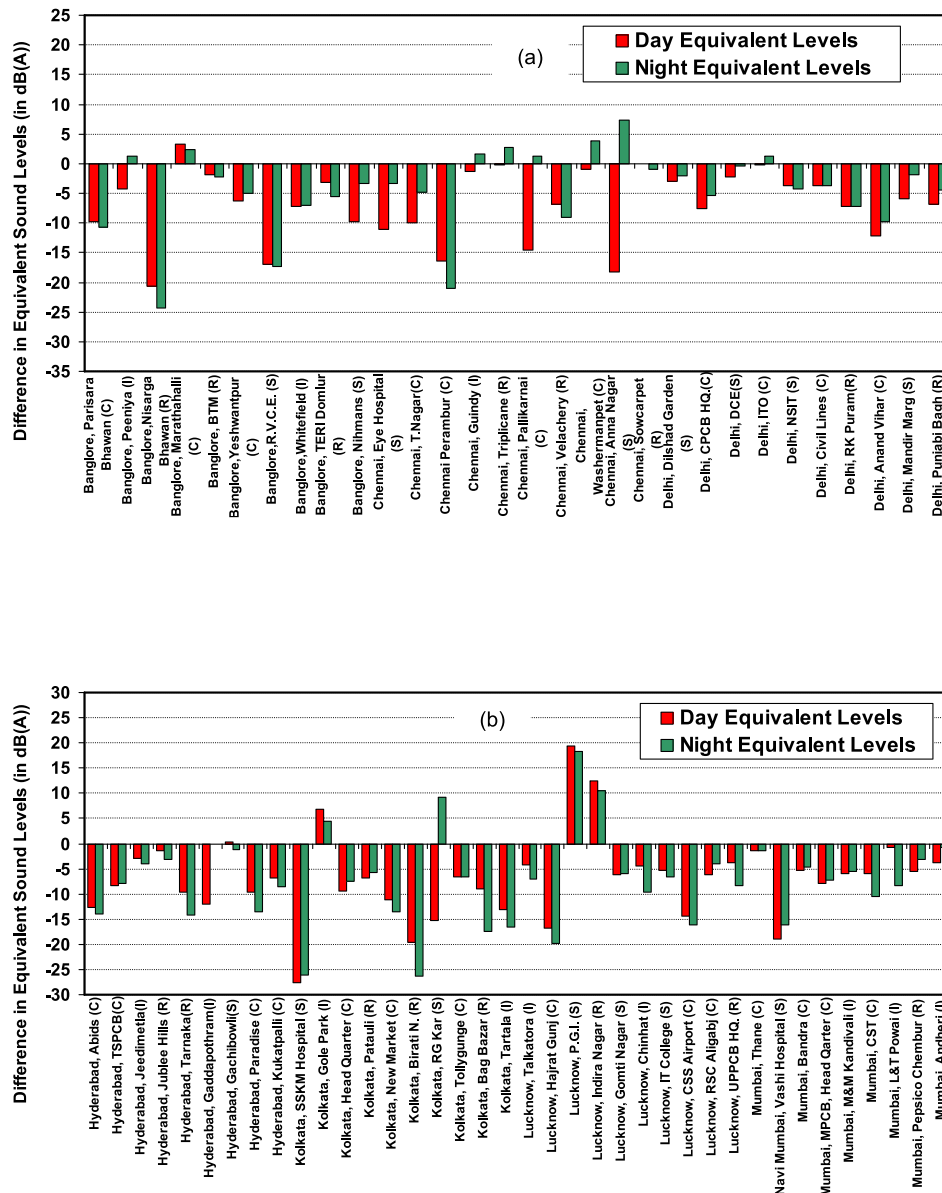


Fig. 5. (a) and (b). Difference in average day equivalent noise levels, L_{day} and night equivalent noise levels, L_{night} in dB(A) during the Lockdown period and annual average ambient day and night equivalent noise levels observed in year 2019.

44.3 % on the Janta curfew day. This can be attributed to restricted industrial/commercial activities as well as vehicular movements during the lockdown period. The highest increase in percentage of stations complying with day ambient noise standards was observed in commercial areas. It was observed that the percentage of stations complying with noise standards increased from 12.9 % to 21.4 % due to the lockdown restrictions imposed.

- 60 dB(A) L_{day} can be considered as *NOAEL* (no observed adverse effect level) for correlation between road traffic noise and myocardial infarction (MI); the risk of MI increases incessantly for noise levels higher than 60 dB(A) [22,27]. It can be observed that for the year 2019, only 8.9 % of the monitoring sites and during the pre-lockdown period, only 21.4 % of monitoring sites meet the 60 dB(A) L_{day} limit. However, during the lockdown period, 45.7 % of the monitoring sites and 41.4 % of the monitoring sites on Janta curfew day meet the 60 dB(A) L_{day} limit. The

WHO Regional Office for Europe recent guidelines recommended 53 dB L_{den} and 45 dB L_{night} as the threshold for road traffic noise [28,29]. A recent study by Garg (2019) recommended the use day-night average sound level and day-evening-night sound level descriptors without night time or evening time adjustments in Indian perspectives [30]. Thus, 53 dB(A) $L_{Aeq,24h}$ limit can be considered analogous value ignoring the 5 dB evening and 10 dB night time corrections. It was observed that only 8 sites during the lockdown period and 5 sites on Janta curfew day meet the 53 dB(A) $L_{Aeq,24h}$ limit. Also, only one site during the lockdown period and two sites on Janta curfew day meet the 45 dB(A) L_{night} limit.

- Marginal increase in percentage of stations complying with the ambient noise limits during day-time was observed in the residential areas. The percentage of complying stations increased from 1.4 % on the normal working day to 2.9 % during Janta curfew day and 7 % during Lockdown period in the residential

Table 4Frequency distribution of L_{day} , L_{night} , $L_{\text{Aeq,24h}}$ and L_{dn} in dB(A) for the seventy sites during year 2019 annual average, Business-As-Usual (Pre-Lockdown days), Janta curfew day and lockdown period.

Range of noise descriptors	L_{day}				L_{night}				L_{dn}				$L_{\text{Aeq,24h}}$			
	No of sites															
	Year 2019	Pre-Lockdown days	Janta curfew	Lockdown period	Year 2019	Pre-Lockdown days	Janta curfew	Lockdown period	Year 2019	Pre-Lockdown days	Janta curfew	Lockdown period	Year 2019	Pre-Lockdown days	Janta curfew	Lockdown period
$35 < L_{\text{eq}} \leq 40 \text{ dB(A)}$	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0
$40 < L_{\text{eq}} \leq 45 \text{ dB(A)}$	0	1	1	1	0	1	2	1	0	1	0	1	0	1	1	0
$45 < L_{\text{eq}} \leq 50 \text{ dB(A)}$	0	1	2	4	1	1	5	8	0	0	1	1	1	0	0	2
$50 < L_{\text{eq}} \leq 55 \text{ dB(A)}$	1	2	5	5	6	10	10	22	0	0	1	1	0	3	3	4
$55 < L_{\text{eq}} \leq 60 \text{ dB(A)}$	5	11	20	22	14	21	15	15	1	1	3	5	7	4	15	12
$60 < L_{\text{eq}} \leq 65 \text{ dB(A)}$	17	16	13	19	14	14	7	4	3	7	10	16	21	19	14	27
$65 < L_{\text{eq}} \leq 70 \text{ dB(A)}$	19	26	12	8	11	12	12	8	11	15	16	21	14	21	11	7
$70 < L_{\text{eq}} \leq 75 \text{ dB(A)}$	13	6	3	5	12	6	3	6	18	22	10	7	14	12	10	8
$75 < L_{\text{eq}} \leq 80 \text{ dB(A)}$	8	4	5	5	8	2	3	3	11	12	13	8	6	5	3	6
$80 < L_{\text{eq}} \leq 85 \text{ dB(A)}$	4	1	3	0	1	0	3	1	13	7	2	5	4	2	6	2
$85 < L_{\text{eq}} \leq 90 \text{ dB(A)}$	1	1	1	1	1	3	3	2	7	3	5	3	1	3	3	2
$90 < L_{\text{eq}} \leq 95 \text{ dB(A)}$	–	–	–	0	–	–	–	0	4	2	2	2	0	–	–	–

Table 5

Frequency distribution of day and night equivalent noise levels for the seventy sites during different periods: Pre-Lockdown period, Janta curfew day and lockdown period.

Variation of L_{day} and L_{night} values in dB	Percentage of noise monitoring locations in various zones																							
	Commercial						Residential						Silence						Industrial					
	Pre-lockdown		Janta curfew day		Lockdown		Pre-lockdown		Janta curfew day		Lockdown		Pre-lockdown		Janta curfew day		Lockdown		Pre-lockdown		Janta curfew day		Lockdown	
	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}	L_{day}	L_{night}
$40 < L_{\text{eq}} \leq 45$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	6.7	6.7	0.0	6.7	6.7	0.0	0.0	0.0	0.0	0.0	0.0
$45 < L_{\text{eq}} \leq 50$	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	6.2	0.0	0.0	6.7	13.3	13.3	13.3	0.0	0.0	0.0	25.0	0.0	25.0
$50 < L_{\text{eq}} \leq 55$	0.0	0.0	4.3	21.7	8.3	37.5	6.7	25.0	7.7	15.4	13.3	43.8	0.0	20.0	13.3	26.7	6.7	20.0	0.0	25.0	8.3	0.0	8.3	16.7
$55 < L_{\text{eq}} \leq 60$	4.2	29.2	39.1	30.4	25.0	20.8	13.3	43.8	30.8	38.5	33.3	18.7	40.0	26.7	33.3	13.3	46.7	26.7	16.7	16.7	25.0	8.3	33.3	16.7
$60 < L_{\text{eq}} \leq 65$	33.3	29.2	21.8	17.4	29.2	8.3	40.0	18.7	38.5	0.0	33.3	12.5	20.0	13.3	0.0	6.7	13.3	0.0	8.3	25.0	25.0	16.7	16.7	0.0
$65 < L_{\text{eq}} \leq 70$	33.3	25.0	21.8	13.0	16.7	12.5	26.7	6.2	15.4	38.5	6.7	12.5	26.7	13.3	20.0	6.7	6.7	6.7	58.3	16.7	16.7	25.0	8.3	16.7
$70 < L_{\text{eq}} \leq 75$	20.8	8.3	4.3	8.7	16.7	12.5	13.3	6.2	0.0	0.0	6.7	6.2	0.0	6.7	6.7	13.3	0.0	13.3	8.3	8.3	8.3	0.0	25.0	8.3
$75 < L_{\text{eq}} \leq 80$	8.3	8.3	4.3	8.7	4.2	0.0	0.0	0.0	0.0	7.7	6.7	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	8.3	0.0	8.3	16.7
$80 < L_{\text{eq}} \leq 85$	0.0	0.0	4.3	0.0	0.0	4.2	0.0	0.0	7.7	0.0	0.0	0.0	6.7	0.0	0.0	6.7	0.0	6.7	0.0	0.0	8.3	16.7	0.0	0.0
$85 < L_{\text{eq}} \leq 90$	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.3	6.7	13.3	6.7	6.7	8.3	8.3	0.0	8.3	0.0	0.0

areas. This can be attributed to the fact that noise emissions in the residential areas is mainly due to various factors such as the household appliances, vehicular movements etc. During the Janta curfew/lockdown period, although the vehicular movement was minimal; the background sound due to the household activities remained the same, and to some extent increased as most of the people were at home and hence marginal impact of Janata curfew/ lockdown observed in percentage of stations complying with noise standards. Also, on the Janta curfew day, the authorities encouraged common masses to clap and ring bells at 5 pm in evening as a show of appreciation for the doctors, nurses, policemen and staff deployed for fighting the pandemic, which may be a reason for escalated evening equivalent noise levels of the residential zone sites.

- In the silence zones, the percentage of stations complying with noise standards during the day-time even reduced during the lockdown period. The percentage of complying stations decreased from 4.3 % during normal working days to 2.9 % during the lockdown period in silent zones. This can be attributed to the fact that it is mainly the hospitals which are located in silence zones and activities contributing to noise generation remain unchanged in an around hospital area during lockdown period, some sites even witnessing an increase in these activities.
- A marginal increase in percentage of stations complying with noise standards during day- time was observed in the industrial areas. In the industrial areas, the percentage of complying stations increased from 14.3 % during normal working days to 15.7 % during the lockdown period. A marginal increase in the percentage of stations complying with ambient noise standards was observed in industrial area as some of the sources of noise pollution such as vehicular movements etc. had been prevailing even during the Janta curfew and the lockdown period.
- Analysis of night equivalent noise levels showed a marginal increase in the percentage of stations complying with noise standards during the night-time. The percentage of complying stations increased from 14.3 % during normal working days to 27.1 % during the lockdown period and 20 % during the Janta curfew day. In the residential, silence and industrial zones, the number of stations complying with the ambient noise limits were the same, which can be attributed to the fact that the activities carried out during night-time remained unchanged in all three categories viz. normal working day, Janta curfew and lockdown period. It was observed that for the commercial areas, the percentage of stations complying with ambient limits increased to 12.9 % in lockdown period and 5.7 % on Janta curfew day. This can be attributed to the closure of some of the commercial activities such as malls, banquet halls, restaurants, markets, shops etc.
- An important observation on the average exceedance factor (AEF) analyzed during the different periods (Table 8) was that the silence zone is the most affected zone and showed excessive violation of the limits, wherein the night equivalent noise levels were observed to be 1.5 to 1.6 times the ambient night noise limits. The day equivalent noise levels were observed to be 1.2 to 1.3 times the ambient day noise limits for silence zones. The residential zone experienced an average exceedance factor of 1.3 to 1.4 times the ambient night noise limits during each period, while the commercial zone experienced an average exceedance factor of 1.2 to 1.4 times the ambient night noise limits during each period. The average exceedance factor for the day-time for commercial zone was observed to be in range of 1.0 to 1.1 in lockdown, pre-lockdown period, while that for the residential zone AEF value was in range of 1.1 to 1.2. As

obvious, the industrial zone registered the lowest average exceedance factor of 0.9 in each case for day and night equivalent noise levels. It was observed that the silence zones with AEF 1.2–1.6 were the noisiest zones followed closely by residential (AEF 1.1–1.4) and commercial (AEF 1.0–1.1) zones and industrial zones, the least (AEF 0.9–1.0). A similar findings pertaining to the range of AEF values for the four zones had been presented earlier by Kalawapudi et al., 2020 [26] study for the Mumbai Metropolitan Region (MMR) of India. It may be noted that mixed category zone is prevalent in some of the sites. Some sites lying in residential and silence zones have close proximity to the road/metro train networks, markets and other commercial and industrial establishments, vehicular movements, honking noise, loudspeaker noise and even prone to aircrafts noise, which is the prime cause for the accentuated ambient noise levels.

It is evident that although lockdown had a prominent effect on the reduction of the day and night equivalent noise levels, yet only few sites complied with the ambient noise limits. The silence zone witnessed an increase in the activities which resulted in marginal effect of Janta curfew/lockdown. None of the residential zone or silence zone sites met the ambient noise standards even in the lockdown period. These observations also suggest a retrospective and prospective view on the ambient noise limits for the residential and silence zones in India. It is rightly pointed out in the European Night Noise Guidelines (2009) report that the limits could be a reasonably high value, but firmly imposed or a stringent limit with no legal obligation whatsoever [22].

Fig. 6 suggests the flow chart of reducing the noise pollution in the residential and silence zone sites in Indian cities. Demarcation of all the silence zone and residential zone sites in cities, and non-honking zones and the implementation of land-use planning especially for the new developments in Master Plan Document shall be some of the pivotal steps for reducing the ambient noise levels. Planning and execution of various Noise Action Plans (NAPs) such as erection of noise barriers, restricted movement of heavy vehicles in residential and silence zones, prohibiting honking noise, traffic management and control, installation of green belts, vegetation and trees, enhancing the sound insulation of windows and facades and developing enhanced acoustic balcony [31,32] especially in the sites witnessing high traffic, road surface improvement or replacement [33] can substantially reduce the ambient noise levels as recommended in various studies [34–37]. However, while devising the suitable noise control measures, the economic considerations, cost-benefit analysis plays an important role and thus the initiation of the Best Practicable and Economical Option (BPEO) must be considered. Also, an action plan should define the actions in a 'smart' way (specific, measurable, achievable, realistic, time related) and should not merely be a policy statement, but should be accountable and clearly define the estimated noise level reductions to be accomplished [38]. Noise mapping of various sites in the cities, identification of the noisy hotspots and periodic review and assessment of noise scenario after fixed intervals (say three years) by the concerned authorities shall be indispensable to analyze, understand, devise and execute suitable long-term and short-term noise action plans [39]. Also, the enactment of some legal measures such as type approval noise testing of vehicles, horns, noise labeling of domestic appliances, machines and construction equipments [40], strict enforcement of National Building Codes, land-use planning and management policy, improving the urban soundscapes by vegetation, musical water fountain etc. shall be instrumental in noise control in residential and silence zones [41–43]. Thus, the analysis of ambient noise levels during the lockdown and pre-lockdown period presented in this study shall be

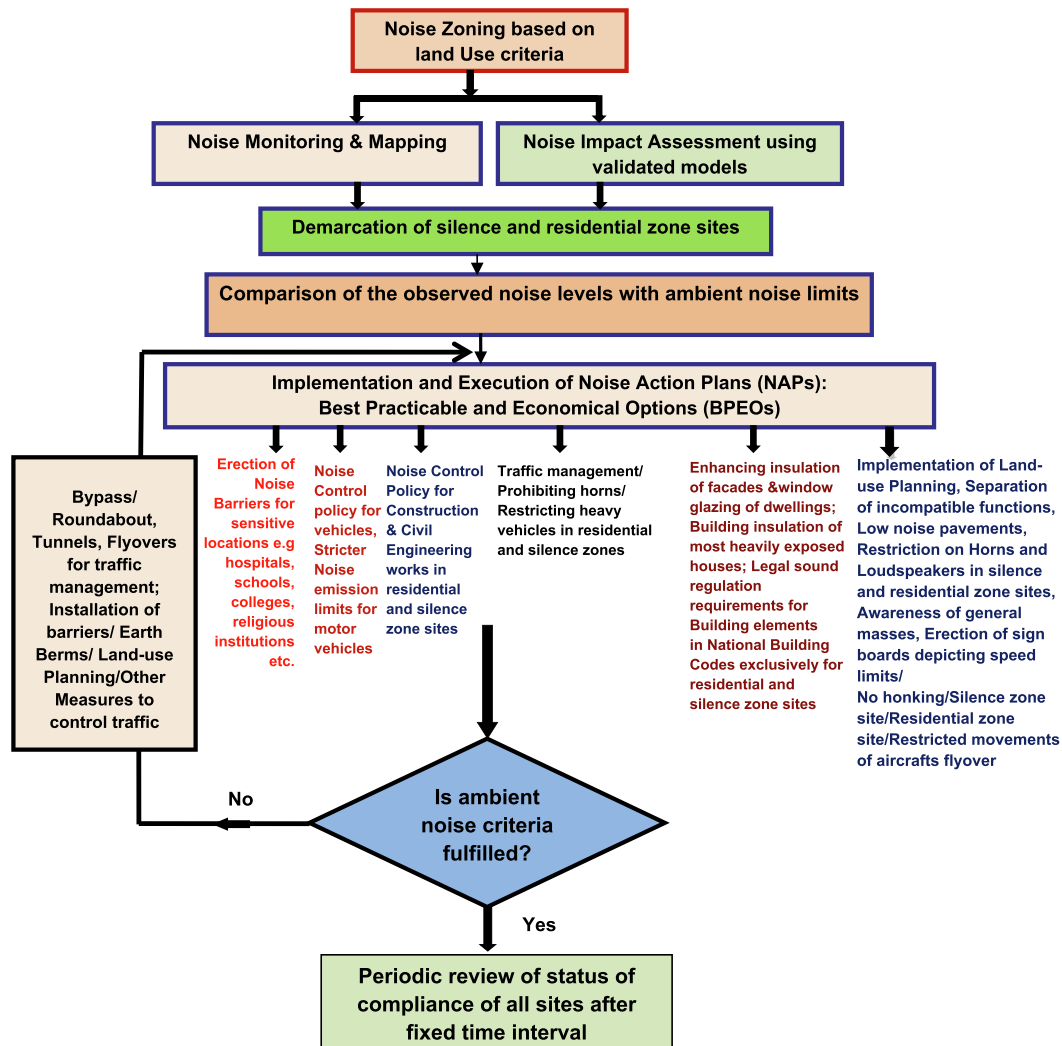


Fig. 6. Flow chart of recommended noise pollution control strategy in silence and residential zone sites in the metropolitan cities of India.

Table 6
Status of compliance of various sites with the ambient noise limits.

Period	Number of sites meeting legal limits for both day and night time	Name of the sites	Number of Compliant Stations: Day and Night Time exclusively
Year 2019 annually	Eight (Seven industrial and One residential) sites	Whitefield, Gole Park, Talkatora, Peeniya, Indira Nagar, Chinhat, Kandivali and L&T Powai	Day time limits: 12 sites (1 residential, 1 commercial and 10 industrial sites) Night time limits: 8 sites (1 residential and 7 industrial sites)
Business-As-Usual (Pre-Lockdown days)	Ten (Ten industrial sites)	Peeniya, Whitefield, Jeedimetla, Gaddapothram, Gole Park, Tartala, Talkatora, Chinhat, Kandivali and L&T Powai	Day time limits: 23 sites (3 silence, 1 residential, 9 commercial and 10 industrial sites) Night time limits: 10 industrial sites
Janta curfew	Fourteen (Nine Industrial sites, Four commercial sites and One silence zone site)	Peeniya, Whitefield, Parisar Bhawan, Perambur, CPCB headquarters, Civil lines, Jeedimetla, Zoo, Gole Park, Tartala, Talkatora, Hazrat Gunj, Chinhat, Kandivali and L&T Powai	Day time limits: 31 sites (4, silence, 2 residential, 15 commercial and 10 industrial sites) Night time limits: 14 sites (1 silence, 4 commercial and 9 industrial sites)
Lockdown period	Nineteen (Nine industrial and Ten commercial zone sites)	Peeniya, Whitefield, Parisar Bhawan, Perambur, CPCB Headquarters, Civil Lines, Anand Vihar, Abids, TSPCB, Jeedimetla, Gole Park, Kolakata Head Quarter, Tartala, Talkatora, Hazrat Gunj, Chinhat, CSS Airport, Kandivali and L&T Powai	Day time limits: 33 sites (2 silence, 5 residential, 15 commercial and 11 industrial sites) Night time limits: 19 sites (9 commercial and 10 industrial sites)

Table 7
Frequency distribution (in %) of difference of average ($L_{\text{day}} - L_{\text{night}}$) values in dB for the 70 sites.

Range of ($L_{\text{day}} - L_{\text{night}}$) in dB	Year 2019 annually		Business-As-Usual (Pre-Lockdown days)		Janta curfew		Lockdown period	
	No. of sites	No. of sites (in %)	No. of sites	No. of sites (in %)	No. of sites	No. of sites (in %)	No. of sites	No. of sites (in %)
$-20 < (L_{\text{day}} - L_{\text{night}}) \leq -15$ dB	0	0	0	0	1	1.4	1	1.4
$-15 < (L_{\text{day}} - L_{\text{night}}) \leq -10$ dB	0	0	0	0	1	1.4	0	0
$-10 < (L_{\text{day}} - L_{\text{night}}) \leq -5$ dB	0	0	2	2.9	3	4.3	2	2.9
$-5 < (L_{\text{day}} - L_{\text{night}}) \leq 0$ dB	15	21.4	14	20.0	25	35.7	13	18.6
$0 < (L_{\text{day}} - L_{\text{night}}) \leq 5$ dB	37	52.9	28	40.0	25	35.7	27	38.6
$5 < (L_{\text{day}} - L_{\text{night}}) \leq 10$ dB	18	25.7	21	30.0	6	8.6	23	32.9
$10 < (L_{\text{day}} - L_{\text{night}}) \leq 15$ dB	0	0	2	2.9	1	1.4	4	5.7
$15 < (L_{\text{day}} - L_{\text{night}}) \leq 20$ dB	0	0	2	2.9	0	0	0	0

Table 8
Average Exceedance Factor (AEF) for different zones in year 2019, pre-lockdown period, lockdown period and Janta curfew day.

Year 2019 annual average values						
Category	L_{day}			L_{night}		
	Maximum value	Minimum value	AEF	Maximum value	Minimum value	AEF
Industrial Area ($n = 12$)	1.1	0.8	0.9	1.1	0.8	0.9
Commercial Area ($n = 25$)	1.3	1.0	1.1	1.5	1.0	1.2
Residential Area ($n = 16$)	1.6	0.9	1.2	2.0	1.0	1.4
Silence zone ($n = 17$)	1.5	1.2	1.3	2.0	1.4	1.6
Pre-Lockdown period						
Category	L_{day}			L_{night}		
	Maximum value	Minimum value	AEF	Maximum value	Minimum value	AEF
Industrial Area ($n = 12$)	1.1	0.8	0.9	1.2	0.7	0.9
Commercial Area ($n = 25$)	1.2	0.9	1.0	1.4	1.0	1.2
Residential Area ($n = 16$)	1.4	0.9	1.2	1.6	1.1	1.3
Silence zone ($n = 17$)	1.7	1.0	1.2	2.2	1.2	1.6
Lockdown period						
Category	L_{day}			L_{night}		
	Maximum value	Minimum value	AEF	Maximum value	Minimum value	AEF
Industrial Area ($n = 12$)	1.0	0.7	0.9	1.1	0.7	0.9
Commercial Area ($n = 25$)	1.2	0.8	1.0	1.5	0.9	1.1
Residential Area ($n = 16$)	1.4	1.0	1.1	1.6	1.1	1.3
Silence zone ($n = 17$)	1.7	0.9	1.2	2.1	1.2	1.5
Janta curfew day						
Category	L_{day}			L_{night}		
	Maximum value	Minimum value	AEF	Maximum value	Minimum value	AEF
Industrial Area ($n = 12$)	1.1	0.7	0.9	1.2	0.7	0.9
Commercial Area ($n = 25$)	1.2	0.8	1.0	1.8	0.9	1.2
Residential Area ($n = 16$)	1.5	1.0	1.1	1.7	1.1	1.4
Silence zone ($n = 17$)	1.7	0.7	1.2	2.5	0.9	1.5

beneficial for consideration of imposing lockdowns, traffic control plans (odd-even rule) etc. for noise pollution prevention and control in the metropolitan cities in India [44–50].

6. Conclusions and recommendations

The study presented the noise scenario during the lockdown period, pre-lockdown period and on the day of Janta curfew. The impact of lockdown on the ambient noise levels for the seventy sites in the seven major cities of India was analyzed. The lockdown imposed to curtail the spread of COVID-19 pandemic was unique and never witnessed in past in India. The study revealed that the reduction in noise levels was more pronounced during the day-time for majority of the sites as compared to night-time due to reduced economic activities. 50 sites (71.4 %) registered a decrement in both day and night equivalent noise levels in lockdown period when compared to the pre-lock down period. 30 sites

(42.9 %) showed a decrement in day equivalent noise levels ≥ 5 dB(A), while 29 sites (41.4 %) showed decrement in night equivalent noise levels ≥ 5 dB(A) in lockdown period in comparison to the pre-lockdown period. The analysis of ambient day and night equivalent noise levels on Janta curfew day in comparison to the pre-lockdown period shows that 33 sites (47.1 %) registered a decrement of both day and night equivalent noise levels. 24 sites (34.3 %) registered decrement in day equivalent level by ≥ 5 dB(A), while 15 sites (21.4 %) registered a decrement in night equivalent noise levels by ≥ 5 dB(A) on Janta curfew day. The reduced ambient noise levels at majority of the sites was primarily due to the restricted social, economical, industrial, urbanization activity, reduced human mobility, low traffic volumes on the roads and reduction in honking noise. However, the accentuated day equivalent noise levels at some sites in lockdown period and on the day of Janta curfew may be attributed to the execution of some specific activities like policing, increased activities near the

hospital areas in pandemic situation, announcements on the loud-speakers, vehicular movements and other domestic noise due to restricted human mobility. Thus, suitable noise control action plans are required to be implemented and executed for such sites for bringing the ambient levels below the limits.

An interesting observation in the present study on ascertaining the compliance of the ambient day and night equivalent noise levels in the lockdown period and on the Janta curfew day in comparison to the ambient noise standards showed that only nineteen sites comprising of nine industrial and ten commercial zone sites complied with the ambient noise limits in the lockdown period. Also, on the day of Janta curfew, Fourteen sites including nine industrial sites, four commercial sites and one silence zone site met the noise limits. No site lying in silence zone and residential zone complied with the ambient noise standards during the lockdown period. 33 sites (47.1 %) complied with day-time noise limits, while 19 sites (27.1 %) complied with night-time noise limits in lockdown period. On the day of Janta curfew, 31 sites (44.3 %) complied with day-time noise limits, while 14 sites (20 %) complied with night-time noise limits. It is thus evident that even imposition of lockdown in some sites is not enough in bringing the ambient day and night equivalent noise levels within the limits. The analysis of ambient noise levels observed for the different zones revealed that a marginal increase in percentage of stations complying with noise standards during day-time was observed in industrial and residential zones. The highest increase in percentage of stations complying with day ambient noise standards was observed in commercial areas due to the restricted social and economical activities. However, for the silence zones, the percentage of stations complying with the ambient noise limits during day-time even reduced during the lockdown period. The percentage of complying stations decreased from 4.3 % during normal working days to 2.9 % during the lockdown period in silence zones. This may be attributed primarily due to increase activities near the hospital areas in pandemic situation. The analysis of night equivalent noise levels showed a marginal increase in the percentage of stations complying with noise standards during the night-time. The percentage of complying stations increased from 14.3 % during the normal working days to 27.1 % during the lockdown period and 20 % during the Janta curfew day.

The non-compliance of the ambient noise limits for the residential and silence zone sites in the lockdown period revealed that even such measures are in-effective in reducing the ambient noise levels below the limits. This is primarily due to the mixed category zone prevalent for the majority of these locations. Thus, the implementation of Best Practicable and Economical Options amongst the different noise action plans (NAPs) as described in Fig. 6 can be very helpful in reducing the ambient noise levels below the recommended limits. Thus, future developments on Smart Cities and townships should consider these aspects at the conceptualization and designing stages for reducing the noise pollution and developing sustainable cities promoting good health and quality of life.

CRediT authorship contribution statement

N. Garg: Conceptualization, Methodology, Writing – review & editing. **V. Gandhi:** Investigation, Writing – review & editing. **N. K. Gupta:** Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Authors express sincere gratitude towards the Central Pollution Control Board, India authorities for their consent to publish this work. The content of the papers is solely to present a prospective view on the effect of COVID-19 lockdown on noise pollution scenario at seventy sites in seven major cities of India and may not be used for disputes redressal in legal frameworks. The views and opinions expressed are those of author's own and do not necessarily reflect the official policy or position of any agency of the Government of India.

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