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Accuracy of Short-Term Noise Monitoring Strategy in Comparison to Long-Term Noise Monitoring Strategy

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The present study compares the accuracy in short-term noise monitoring strategies in comparison to the long-term monitoring strategies. The difference in short-term strategies from the annual average yearly sound levels is quantified as an error. The study extends the previous work reported exclusively for silence, industrial, commercial and residential zones in Indian scenario. The study re-affirms that random two months' strategy is the Best Practicable and Economic Option (BPEO), whereby an error of ± 2 dB is observed with a probability of 95% approximately. Adopting long-term noise monitoring strategy in larger parts of Indian cities is cumbersome and expensive process. Thus adoption of random two months' strategy adopted exclusively for silence, industrial, commercial and residential zones can be a practicable and economical option for noise mapping of larger parts of Indian cities.

Keywords: Long-term Noise Monitoring strategies, Short-term Noise Monitoring strategies, Random two months' strategy

1 Introduction

Noise pollution has become a serious concern not only in the Indian scenario, but across the globe. The alarming rate in the increase in vehicle population has created a hazardous problem of noise pollution. However, much research has emerged over the last decades linking environmental noise as a physiological and psychological stressor and have a negative impact on health such as annoyance, sleep disturbances, mental health, anger, disappointments, and anxiety[1-6]. Thus, there is a need for continuous noise monitoring of urban environment to understand the noise impact and take preventive measures for noise control. There had been some studies reported by researchers on the ambient noise levels assessment across the globe[7-11]. The Central Pollution Control Board (CPCB) has established a National Ambient Noise Monitoring Network in year 2011 with an objective of continuous long- term noise monitoring in 35 locations in seven major cities of India. The noise monitoring data observed from the network established has revealed that no site in residential and silence zone meet the ambient noise standards of India[12-15]. However, the network established is dedicated to only 10 sites in each city sites as such more noise monitoring stations are essentially required to completely map the cities. Przysucha and Batko[16] raised some concerns on uncertainty in noise measurements by focusing on the analysis of equivalent noise level by using numerical simulations.

The European Environmental Noise Directive, 2002/49/EC recommended all the member states to develop noise maps of the urban agglomerations in single noise parameters: L_{den} and L_{night} represented as equivalent level over a year. Thus, it is imperative in the Indian scenario to develop noise maps of cities for devising suitable effective measures for controlling the noise pollution. Following, the EU directive[17], much research has been done by the researcher's community to analyze and propose action plans for noise pollution in urban areas[18-21] which are road traffic [18], airport[19], railway traffic[20], as well as in industrial plants[21]. The availability of nationwide data for the metropolitan cities facilitates a precise understanding of the time-varying aspect of noise exposure in high-density population areas. This has some associated merits. Firstly, the statistical analysis facilitates a critical evaluation and analysis of noise exposure[22]. Secondly, a systematic approach across the population in many cases reduces the risk of bias and increases the generability[23]. A bootstrap approach was used for the estimation of uncertainty and determining the sound level pressure variability[24-26].

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There have been some studies repeated on long-term versus short-term strategies across different parts of the world. Gozalo *et al.*[27] studied about the categorization method across different sampling locations in the street of Plasencia, Spain using long-term measurement. For the time-series approach, DeVor *et al.*[28] used ARMA (auto regressive moving average) model to assess the level of autocorrelation through Dynamic Data System (DDS) approach in time series analysis. These models are then used to derive estimates of the sample mean variance and therefore to establish sampling strategies to obtain an estimate of the mean level within a 5 dB range. Gaza *et al.*[29] analyzed 24-h noise levels in order to evaluate the efficacy of random days strategy so as to represent the annual average equivalent noise levels. Romeu *et al.*[30] estimated the error using short-term noise measurements as interval length measurement. Morillas and Gajardo[31] measured the probability success of a 90% confidence interval to calculate L_{den} based on measurements for 9 days' data randomly throughout the year. Garg *et al*.[32] study revealed that short-term noise monitoring strategy gives a reliable accuracy levels with respect to continuous long-term monitoring[33]. The analysis showed that the error of ±3 dB(A) from annual equivalent level is calculated with a probability of 95%, following one-month noise-monitoring strategy. A recent study by Gerahty *et al*.[34] examined the year-long data set from permanent noise monitoring network in Dublin city, Ireland at different temporal levels: hour, day, week, and month. The study revealed long-term noise monitoring is necessary to define it as long term indicators. Table 1 summarizes the previous research studies conducted on long-term versus short-term noise monitoring strategies.

The long-term noise monitoring strategy is a cumbersome and expensive exercise. It may not be possible to install and establish 24 h noise monitoring stations in each and every corners of metro-politician cities due to economical and infrastructural limitations. Thus, there is current need of devising short-term noise monitoring strategies for noise monitoring, assessment, identification of hotspots and considering suitable preventive measures for noise abetment and control. A recent study by Garg *et al*.[32] recommended random two months monitoring strategy to be the best practicable and economical option in Indian scenario based on the analysis of noise monitoring data acquired from 35 stations in 7 major cities of India. The present study is an extension to the previous work reported by Garg *et al*.[32] focused on analysing the accuracy and precision of short-term noise monitoring strategy with respect to the long-term strategy exclusively for silence, industrial, residential and commercial zones in Indian scenario. The study shall be helpful in devising short-term strategies of noise mapping of larger parts of metropolitan cities of India for controlling the noise pollution in Indian cities.

2 Methodology

2.1. Long-term noise monitoring strategy

The study utilizes the noise monitoring data acquired from 35 noise monitoring stations established by Central Pollution Control Board of India (CPCB)

Table 1 — Summary of previous research studies conducted on long- term versus short- term noise monitoring strategies.

Author	Location	Data source	Statistical method	Conclusions derived
Gaja *et al*., 2003	Valencia, Spain	Journal article[29]	Evaluated Error	Random days strategy is recommended with 99% accuracy. The study recommends 9 random days strategy for an error of ±1 dB with a probability of 87%.
Romeu *et al*.,2011	137 streets of nine cities, Spain	Journal article[30]	Evaluated Error	The study recommends 15 min.short- term measurement for estimating L_{d} with an error of ±2 dB(A) and % population coverage of 90% for main street
Morillas & Gajardo, 2014	Madrid, Spain	Journal article[31]	Evaluated standard deviation	The study recommended 32-35 random sampling days throughout a year for achieving a probability of 95% in estimation of L_{den}. For 90% confidence interval, it needs to take measurement for 9 days spread randomly throughout the year.
Garg *et al*., 2015	Seven metropolitan cities of India (35 locations)	Journal article[32]	Evaluated error	Random two months strategy
Geraghty *et al*., 2016	Dublin, Ireland	Journal article[34]	ANOVA	Long-term noise monitoring is necessary to accurately characterize long-term indicators

in seven major cities of India. The 35 noise monitoring stations spread in the seven major cities of India have been employed for round the clock (24hrs×365days) noise monitoring and assessment as discussed by Garg *et al*.[33]. Table 2 shows the details of 35 noise monitoring stations with the annual average ambient noise levels and the monthly standard deviation of day and night equivalent levels for the past four years for 35 sites under consideration. The average of L_{day} and L_{night} value were the average of monthly values. These stations have been deployed by Central Pollution Control Board in year 2011 under a prestigious project entitled as National Ambient Noise Monitoring Network. The details of the project, instrumentation and other infrastructural setup and analysis of acquired noise monitoring data has been mentioned in previous studies reported in references[12-13, 33].

The noise monitoring data so acquired from these stations is very helpful in understanding the noise

Table 2 — Annual average ambient levels, L_{day} and $L_{night}$for 35 noise monitoring stations installed across seven major cities in India for past four years[33].

Name of Location	City	Area characteristics	2011		2012		2013		2014	
			*L*day	*L*night	*L*day	*L*night	*L*day	*L*night	*L*day	*L*night
Dilshad Garden	Delhi	Silence	52.4± 0.9	50.8±1.4	51.9±1.1	50.0±2.1	51.3±1.1	49.4±2.4	51.7±0.9	48.7±1.6
CPCB HQ.		Commercial	63.8± 2.0	53.9±1.4	62.2± 1.0	52.7± 1.3	63.2± 0.8	53.4± 1.0	65.9±1.7	54.4±1.6
DTU, Bawana		Silence	52.3±1.3	49.4± 2.1	51.3± 0.9	50.0± 3.2	52.3±1.7	49.8± 3.0	51.8±1.1	49.1±2.5
ITO		Commercial	73.1± 0.6	70.8± 1.0	72.0± 4.0	70.6± 5.3	73.6± 0.7	73.0± 0.4	74.2±1.0	72.9±1.4
NSIT Dwarka		Silence	56.6± 1.3	54.0± 0.8	56.6± 0.7	53.8±1.1	56.1± 0.5	53.4± 0.9	56.6±1.4	53.3±1.8
Gomti Nagar	Lucknow	Silence	61.3± 0.8	53.7± 1.5	62.9± 0.9	55.3± 1.1	67.0± 2.2	57.3± 1.6	69.5±1.4	61.2±2.0
HazratGanj		Commercial	72.0± 0.9	61.8± 1.0	72.4± 0.5	61.1± 1.0	72.5± 0.5	62.0± 1.3	72.5±0.5	61.7±1.5
Indira Nagar		Residential	54.2± 1.2	48.8± 2.9	53.6± 1.1	48.1± 3.0	54.2± 1.4	49.3± 3.6	57.0±0.9	50.6±4.7
PGI Hospital		Silence	55.3± 2.5	49.8± 2.8	58.2± 1.2	52.3± 3.6	60.5± 1.4	53.3± 3.0	62.4±1.3	55.8±3.5
Talkatora Industrial Area		Industrial	63.1± 0.4	55.7± 1.6	63.6± 0.7	55.9± 1.6	63.4± 0.5	56.1± 1.9	64.1±1.2	57.3±2.0
KasbaGole Park	Kolkata	Industrial	63.6± 1.2	59.6± 1.3	65.2± 1.6	62.0± 2.6	68.8± 3.5	66.2± 4.7	70.3±2.5	68.1±2.9
New Market		Commercial	67.3± 0.5	60.0± 1.4	67.0± 0.7	59.6± 1.4	67.6± 0.5	60.5± 1.6	70.2±2.3	67.5±5.2
Patauli		Residential	55.2± 1.0	49.4± 2.0	54.7± 1.0	50.2± 3.2	54.7± 1.6	54.3± 6.2	55.1±1.3	53.9±4.5
SSKM Hospital		Silence	61.4± 0.4	54.3± 0.9	62.0± 0.8	56.6± 1.8	62.3± 1.2	57.1± 1.9	62.4±1.1	56.7±1.7
WBPCB HQ		Commercial	61.9± 0.6	55.7± 1.3	61.0± 0.7	54.5± 1.1	62.1± 1.4	55.5± 1.4	63.9±0.6	57.7±0.9
AS HP	Mumbai	Silence	66.5± 1.2	59.7± 1.5	65.5± 1.0	58.7± 0.3	65.4± 0.8	60.6± 1.5	66.5±2.0	60.7±0.9
Bandra		Commercial	69.8± 0.5	67.4± 0.8	69.0± 0.7	67.9± 1.9	69.2± 0.4	66.5± 0.5	69.9±0.5	67±0.7
MPCB HQ.		Commercial	66.7± 0.6	62.8± 0.5	66.4± 0.5	63.1± 0.7	68.4± 1.6	65.3± 2.0	71.0±0.6	67.9±1.0
Thane MCQ		Commercial	62.6± 1.8	55.0± 2.3	61.7± 0.7	54.9± 1.9	62.5± 1.2	55.4± 1.4	64.5±1.0	56.4±1.3
Vashi Hospital		Silence	68.2± 1.7	58.7± 1.4	68.8± 0.9	59.3± 2.7	68.7± 0.8	57.0± 0.8	69.0±1.5	60.9±3.6
Abids	Hyderabad	Commercial	71.9± 0.5	63.1± 0.9	72.4± 0.9	63.7± 1.9	72.4± 0.8	64.0± 2.1	74.1±1.9	65.5±2.5
Jeedimetla		Industrial	62.3± 0.5	56.2± 1.4	63.0± 1.2	56.8± 2.1	63.0± 1.3	56.5± 1.6	65.0±0.6	58.6±0.8
Jubilee Hills		Residential	57.4± 1.0	50.7± 1.7	56.2± 0.7	48.6± 0.5	56.3± 0.6	48.9± 1.2	57.3±1.6	49.2±1.2
Punjagutta		Commercial	75.7± 0.6	71.0± 1.0	75.5± 0.5	70.3± 0.5	76.6± 1.7	71.1± 1.3	78.5±0.7	73.4±0.5
Zoo Park		Silence	53.8± 1.5	50.5± 2.8	54.2± 1.8	48.7± 2.0	54.4± 1.4	48.7± 1.1	56.1±1.2	51.0±2.2
BTM	Bengaluru	Residential	66.4± 0.4	56.5± 0.4	66.1± 0.5	56.0± 1.0	66.0	56.3± 0.8	66.4±0.7	57.1±1.1
Marathahalli		Commercial	56.9± 1.9	54.1± 1.8	54.5± 0.7	51.9± 0.6	57.3± 2.1	55.3± 2.8	59.5±0.7	56.6±0.8
NisargaBhawan		Residential	58.1± 3.0	48.4± 1.8	56.6± 2.0	47.7± 1.9	56.7± 1.9	48.0± 1.6	55.7±1.5	48.8±1.4
ParisarBhawan		Commercial	66.5± 1.1	58.2± 0.7	64.9± 0.3	57.0	65.0± 0.7	57.3± 0.8	64.8±0.8	56.6±0.5
Peeniya		Industrial	56.5± 1.6	55.0± 2.6	55.7± 1.2	49.2± 1.2	58.1± 1.1	53.1± 2.3	58.1±0.8	54.9±2.0
Eye Hospital	Chennai	Silence	64.2± 0.6	51.7± 1.2	62.5± 1.5	53.2± 3.1	64.3± 1.5	53.8± 2.2	61.7±3.9	53.5±1.2
Guindy		Industrial	76.1± 0.6	71.8± 1.1	75.5± 1.1	70.9± 1.3	75.2± 1.0	70.8± 1.5	76.9±1.9	72.2±1.2
Perambur		Commercial	68.5± 0.9	59.1± 0.8	68.8± 1.2	58.3± 1.2	68.3± 0.5	57.6± 0.7	69.1±1.3	57.9±0.8
T. Nagar		Commercial	72.4± 0.5	61.9± 1.1	73.1± 0.3	62.2± 1.0	73.9± 1.0	64.7± 2.0	75.0±0.9	66.9±1.6
Triplicane		Residential	67.8± 0.4	56.2± 1.0	67.6± 0.5	56.3± 0.8	67.7± 0.5	56.2± 0.7	68.4±1.4	57.6±2.0

scenario, identifying the hotspots, and devising suitable remedial measures. The present study is primarily focused on utilizing this useful database to ascertain the accuracy of various short-term strategies in comparison to long-term strategies. Such an analysis shall be very helpful in the Indian perspectives to identify the optimized strategy. Four years (2011-14)[12-13] noise monitoring data is exclusively analyzed for 4 different zones *i.e* silence, industrial, commercial and residential zones. For instance, for the 14 sites lying in commercial zone, a monthly noise monitoring database of 672 (14×12×4) is utilized for present study. The day equivalent level is measured from the average sound level measurements acquired from 6.00 a.m to 10.00 p.m, while night equivalent level is measured from the average sound level measurement acquired from 10.00 p.m to 6.00 a.m.

The $L_{day,n}$ and $L_{night,n}$ values is calculated:

$$L_{day,n} = 10 \log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{0.1\left(l_{day,i}\right)}\right] \quad \ldots (1)$$

$$L_{night,n} = 10 \log\left[\frac{1}{n}\sum_{i=1}^{n} 10^{0.1\left(l_{night,i}\right)}\right] \quad \ldots (2)$$

where L_{day},i and $L_{night,i}$ are the A- weighted monthly averaged noise level while *n* represents the numbers of months (*n*=12) in long-term noise monitoring strategy.

The error is calculated as the difference of short-term strategy (*e.g* one month or two consecutive months or random two months) with the annual average yearly value for a particular site for a particular year. The error in short-term noise monitoring strategies is calculated[32]:

$$L_{day,\ annual} = L_{day,\ monthly} \pm \varepsilon_{day} \quad \ldots (3)$$

$$L_{night,\ annual} = L_{night,\ monthly} \pm \varepsilon_{night} \quad \ldots (4)$$

where εday and εnight is the error observed in short-term monitoring strategy as compared to the long-term strategy.

2.2. Short- term noise monitoringstrategies

The four years' noise monitoring data from 2011-14 is exclusively analyzed for silence, industrial, residential and commercial zone out of the 35 locations under study, 9 locations lie in silence zone, 5 in industrial zone, 7 in residential zone and 14 in commercial zone. The following short-term noise monitoring strategies are adopted as follows:

- One-month strategy
- Consecutive two months' strategy
- Random two months' strategy
- Consecutive three months' strategy
- Random three months' strategy

The one-month strategy denotes the noise monitoring carried out for a particular site for continuous 30 or 31 days in a month consecutively. The two months' strategy denotes noise monitoring carried out for consecutively two months in a year, while random two months' strategy denotes noise monitoring conducted for any two months in a year and the same methodology is adapted for three months' strategy (consecutive and random).

The statistical data calculated is: mean error, standard deviation, probability range for 95%. The Histogram shows the frequency (in %) of the error observed in short-term noise monitoring strategy in comparison of long-term strategy. Fig. 1 shows the standard deviation in dB(A) for L_{day} and L_{night} for 35 locations in India in year 2014. It is observed that L_{night} levels had higher variability as compared to the L_{day}levels for many sites.

2.3. Statistical Parameters used for error evaluation in short-term strategy

Several statistical parameters like mean error, standard deviation in dB(A), 95% probability range in

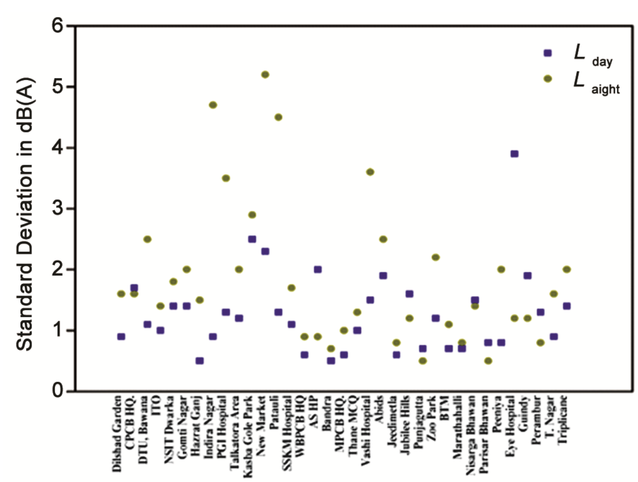

Fig. 1 — Standard deviation in dB(A) for *L*day and *L*night for 35 locations in India in year 2014.

dB(A) are calculated to ascertain the performance of short-term monthly noise monitoring strategy for silence, industrial, commercial and residential zone. The formula for the various parameter is given as follows:

$$\text{Mean Error} = \frac{1}{n}\sum_{i=1}^{n}\left|x_i - \bar{x}\right| \quad \ldots (5)$$

$$\text{Standard Deviation} = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\left|x_i - \bar{x}\right|\right)^2}}{n-1} \quad (6) \ldots$$

where, x_i is the noise level at a particular day and $\bar{x}$ is the monthly average of the noise level at particular site.

Probability of 95% is calculated based on data analysis for 95% of the data lying within a specified error range.

3 Results and Discussion

3.1. Zone wise parametric analysis

The error in short-term noise monitoring strategy for 9 sites out of 35 sites lying in silence zone, 5 sites out of 35 sites lying in industrial zone, 14 sites out of 35 sites lying in commercial zone and 7 sites out of 35 sites lying in residential zone is evaluated.

Figure 1 shows the parametrical standard deviation of all the 35 sites analyzed for short-term noise monitoring strategy. In Indian scenario, the ambient noise standards are recommended for four different zones: silence, industrial, commercial and residential zones. As such, a mixed type is observed for some sites wherein it is very difficult to classify the zone exclusively as silence, industrial, commercial and residential zones. The error mentioned in the study is basically the difference of annual average value and the short-term strategy (one month, two months, three months, both random and consecutive).

3.2. Statistical analysis of silence and industrial zone

the observations lying in a particular range of error. As such, a similar approach has been presented earlier [29, 32]. Table 2 gives the detailed description of all the 35 sites. References mentioned in introduction part discusses the details of these monitoring stations, guiding principles, strategy adopted and results obtained. It is difficult to explain the monthly variation for the 35 noise monitoring stations round the year in the present manuscript as different cities have different topography, meteorological conditions, traffic density etc. The following observations are as shown in Table 3 in silence and industrial zone as follows:

It was observed that adopting one-month strategy, an error of ±3 dB is evaluated with a probability

Table 3 — Statistics for short- term monthly noise monitoring strategy for silence and Industrial: one month, two and; three consecutive and random monthly strategies.

	Silence zone					Industrial Zone				
Parameter	Mean dB(A)	Standard deviation in dB(A)	Probability [-1;1]	Probability [-2:2]	95% Probability range in dB(A)	Mean dB(A)	Standard deviation in dB(A)	Probability [-1;1]	Probability [-2:2]	95% Probability range in dB(A)
One month monitoring strategy										
*L*day	-0.2	1.3	79.9	92.2	[-1.7;2.9]	-0.14	1.27	77.6	93.5	[-2.8;2.4]
*L*night	-0.5	1.7	60.3	84.7	[-2.6;2.5]	-0.20	1.62	66.7	84.5	[-2.4;3.3]
Consecutive two months monitoring strategy										
*L*day	-0.1	0.9	85.1	97.5	[-1.7;1.6]	-0.12	1.16	81.8	94.9	[-1.6;2.4]
*L*night	-0.2	1.6	66.8	82.6	[-1.9; -4.0]	-0.13	1.56	66.5	88.5	[-2.3;2.9]
Random two months monitoring strategy										
*L*day	-0.1	0.9	86.6	99.0	[-1.0;2.0]	-0.07	0.78	92.2	98.3	[-1.3;1.6]
*L*night	-0.3	1.3	78.7	93.9	[-2.2;2.6]	-0.13	1.08	84.6	96.4	[-2.1;1.7]
Consecutive three months monitoring strategy										
*L*day	0.1	0.8	87.9	97.6	[-1.2;1.7]	-0.09	1.04	86.6	95.9	[-1.6;2.1]
*L*night	0.1	1.5	69.8	89.1	[-2.2;2.1]	-0.02	1.33	72.4	91.2	[-1.7;2.8]
Random three months monitoring strategy										
*L*day	0.1	0.7	92.2	99.6	[-0.9;1.3]	-0.09	0.86	93.5	98.1	[-1.1;1.6]
*L*night	0.2	1.2	71.4	95.4	[-1.0;3.4]	0.10	1.01	77.2	98.6	[-1.9;1.6]

higher than 95% for both day and night equivalent noise level. It was also observed that an error of ±2 dB is evaluated with the probability more than 90% for day equivalent noise level

Figures 2(a-b) shows the histogram plot for random two months' strategy. The range of error observed for L_{day} is [-1.0; 2.0] dB and that for L_{night} is [-2.2; 2.6] dB for random two months' strategy and for random three months' strategy the range of error observed for L_{day} is [-0.9; 1.3] dB and that for L_{night} is [-1.0; 3.4] dB for 95% probability range. In silence zone the error range of random three months' strategy is less than one month, consecutive two and three months' strategy. The accuracy of random two months' strategy is observed to be less than random three months' strategy. In case of industrial zone, the range of error for random two months' strategy observed for L_{day} is [-1.3; 1.6] dB and that for L_{night} is [-2.1; 1.7] dB for 95% probability range as shown in Figs. 3 (a-b). It is inferred from the observation that accuracy of random two months' strategy is comparatively higher and thus serves as an optimal approach in comparison to the other approaches even though random three months' strategy has also higher probability with an error range for L_{day} is [-1.1; 1.6] dB and that for L_{night} is [-1.9; 1.6] dB.

3.3. Statistical analysis of commercial and residential zone

Figures 4(a-b) shows the histogram plot for random two months' strategy for commercial zone. The range of error observed for L_{day} is [-0.9; 1.7] dB and that for L_{night} is [-2.0; 1.6] dB while the error range in random three months' strategy is observed for L_{day} is [-1.4; 1.0] dB and that for L_{night} is [-0.9; 1.5] dB for 95% probability range. It is evident that random three months' strategy outperforms random two months' strategy with marginal error accuracy. In residential zone the range of error for random two months' strategy observed for L_{day} is [-1.6; 1.8] dB and that for L_{night} is [-1.4; 1.9] dB for 95% probability range as shown in Figs. 5(a-b). The random three months' strategy has also higher probability for an error range for L_{day} as [-1.0; 1.5] dB and that for L_{night} as [-1.1; 1.9] dB. The standard deviation is calculated within a range of ±2 dB(A) for silence and industrial zones while it lies within ±1 dB(A) for commercial and residential zones in Table 4. It is evident that the range of error for L_{day} and L_{night} is comparatively less in consecutive two months' strategy in comparison to one-month strategy. Also, it was observed that random two months' strategy shows higher probability for an error of ±1, ±2, ±3 dB as compared to the consecutive two months' strategy.

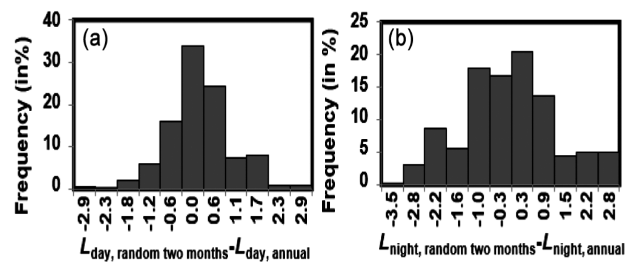

Fig. 2 — (a) & (b): Frequency histogram of calculated error from long- term annual average value for L_{day} and L_{night} for random two months' noise monitoring strategy for silence zone.

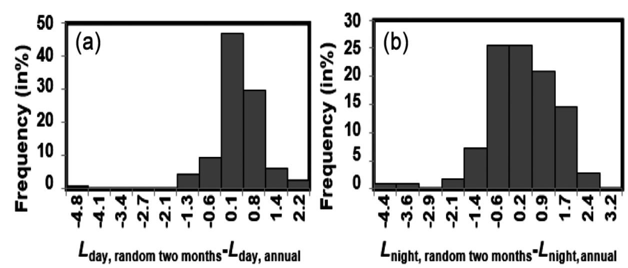

Fig. 3 — (a) & (b): Frequency histogram of calculated error from long- term annual average value for L_{day} and L_{night} for random two months' noise monitoring strategy for industrial zone.

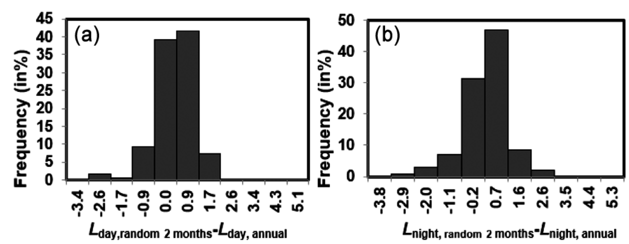

Fig. 4 — (a) & (b) Frequency histogram of calculated error from long- term annual average value for L_{day} and L_{night} for random two months' noise monitoring strategy for commercial zone.

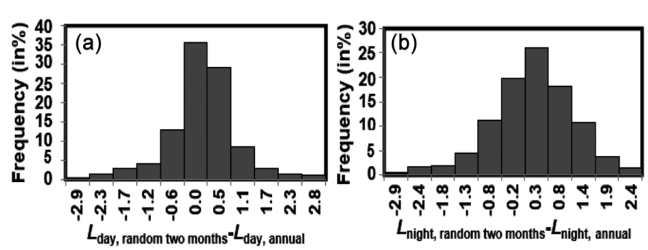

Fig. 5 — (a) & (b): Frequency histogram of calculated error from long- term annual average value for L_{day} and L_{night} for random two months' noise monitoring strategy for residential zone.

Table 4 — Statistics for short- term monthly noise monitoring strategy for Commercial and Residential zones: one month, two and; three consecutive and random monthly strategies.

Commercial Zone					Residential Zone				
Mean dB(A)	Standard deviation in dB(A)	Probability		95 % Probability range in dB(A)	Mean dB(A)	Standard deviation in dB(A)	Probability		95% Probability range in dB(A)
		[-1;1]	[-2:2]				[-1;1]	[-2:2]	
One month monitoring strategy									
-0.2	1.1	82.7	94.5	[-2.4;2.2]	-0.2	1.2	78.3	94.6	[-1.9;2.4]
-0.2	1.3	76.6	91.7	[-2.4;2.2]	-0.1	1.4	70.1	91.2	[-2.5;2.4]
Consecutive two months monitoring strategy									
-0.1	0.9	87.9	97.5	[-1.6;1.8]	-0.1	1.1	78.3	96.4	[-1.8;2.3]
-0.1	1.1	81.3	97.2	[-1.7;2.3]	0.1	1.3	71.1	93.2	[-1.8;2.4]
Random two months monitoring strategy									
-0.1	0.7	91.9	98.7	[-0.9;1.7]	-0.1	0.8	90.1	99.3	[-1.6;1.8]
-0.1	0.9	87.2	98.1	[-2.0;1.6]	-0.1	0.9	85.9	98.7	[-1.4;1.9]
Consecutive three months monitoring strategy									
-0.1	0.8	91.1	98.3	[-1.7;1.7]	-0.1	0.9	83.2	98.4	[-2.3;1.6]
-0.1	0.9	84.6	98.2	[-1.8;1.9]	0.1	1.2	72.8	93.6	[-1.8;2.3]
Random three months monitoring strategy									
-0.1	0.7	95.5	99.6	[-1.4;1.0]	0.1	0.8	92.1	99.8	[-1.0;1.5]
0.1	0.9	88.9	99.2	[-0.9;1.5]	0.1	1.3	82.7	99.0	[-1.1;1.9]

4 Conclusions

The present study ascertains the accuracy of short- term noise monitoring strategies in comparison to the long-term noise monitoring. A case study of all the silence, industrial, commercial and residential zone sites out of the 35 sites wherein noise monitoring stations have been established under *NANMN* project is presented. The noise monitoring data for the past four years (2011-14) has been analyzed to quantify the error in short-term strategy in comparison to the long-term as previously reported by Garg *et al.*[32]. However, the present study differs on the aspect of analysis reported exclusively for silence, industrial, commercial and residential zones from the noise monitoring data acquired from all the sites under consideration for past four years. The following conclusions are drawn from the present study:

- The one-month noise monitoring strategy offers a reliable approach for achieving an error of ±3 dB for all the four different zones. In case of sites lying in residential zones, the probability of error of ±3 dB for L_{day} and L_{night} with respect to annual average value is more than 95%. It is observed that probability of error in night equivalent noise levels is less as compared to the day equivalent noise levels. This may be due to higher standard deviation values observed for night equivalent noise levels as compared to day equivalent noise levels as shown in Table 2.
- Random two months' strategy offers an optimized and cost-effective approach. An error of ±2 dB with a probability of 95% is observed for day and night equivalent noise levels for all the four zones.
- Adapting random three months' strategy shows higher probability of ±2 dB error when compared to random two months and consecutive three months' strategy. In case of sites lying in commercial and residential zones, a probability of ±2 dB error is 99%. The uncertainty in an error of ±3 dB in random three months' strategy is almost negligible. Thus, these observations suggest that random two months' strategy is an optimized approach and may be employed for noise mapping of layer parts of Indian cities. These observations are consistent with previous research work reported by Gaza *et al.*[29] and Morillas and Gajardo[31] studies pertaining to the recommendation of random sampling, but differs on the aspect of monthly strategy rather than temporal sampling strategy. Future work shall focus on analyzing the optimal temporal sampling strategies for silence, industrial, commercial and residential zones in Indian perspectives.

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