Characterization of traffic noise for a typical Indian road crossing

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The present study attempts to characterize the traffic noise condition of a typical Indian city crossing. It uses a new methodology for characterization, giving importance to frequencies of sound primarily present in the noise. The characterization includes frequency-specific variation in the noise levels with time and location. The analysed data indicate existence of noises of two predominant frequencies, i.e. 63 Hz in the low frequency and 1 kHz in the high frequency domains. Sampled observations indicate the presence of fluctuations in the noise levels. The comparison of the observed noise levels with equivalent preferred noise criteria and noise rating curves suggests that the stipulated limits were not met particularly at 1 kHz frequency and thus it is associated with potential health hazards.

Keywords: Noise rating, predominant frequency, preferred noise criteria, sound pressure level, traffic noise characterization.

NOISE levels in the vicinity of a road corridor/crossing, railway track or airport can vary over a wide range due to the diversity of site conditions and activities occurring and has a major impact on physical and mental well-being of the population living nearby. This variation is extremely important to measure or interpret correctly. It is often a source of disagreement when applying standards and regulations, as there is no consensus about how to measure, estimate or present it[1]. Equivalent sound pressure level (L_{eq}) of 85 dB (A) measured at two places may have vastly different characteristics from the perspective of aural perception. Further, the adverse effects of noise, its impacts on the physical and mental well-being of people have been described by various researchers[2–8]. Most of the researchers have measured the average traffic noise level for assessment of adverse impact on human health[9–17]. In a recent study, characteristics (percussive and impulsiveness) of road traffic noise at 1/3 octave band frequency were monitored to evaluate the population response to an increasingly detrimental phenomenon[18]. The parameters 'preferred noise criteria' (PNC) and 'noise rating' (NR) were also used by few researchers to check whether the noise levels are below the specified limits for health hazards[19–21]. The literature stresses on the importance of studying frequencies of sound inherent to noise and/or its associated impacts to health. Generally, people ignore low-frequency noise, whereas literature reviews suggest that it is equally harmful to humans as high-frequency noise. In India, generally, the noise assessment studies have been done using average noise parameters (e.g. L_{avg}, L_{Aeq}, L_{max}, L_{min}, L_{dn}, L_{10}, L_{50}, L_{90}, etc.) without any frequency analysis[22–28]. Researches on road traffic noise pollution and its adverse impact on the community have been done in India[22–28]. Banerjee[29] has reviewed the impact of road traffic noise on human health.

The need is thus realized to develop a technique to represent the noise by using additional parameters to characterize it comprehensively. It essentially requires evolving a methodology to monitor and analyse the noise giving importance to frequencies. An attempt is thus made in the Indian context, using additional parameters to characterize typical Indian traffic noise. The characterization envisaged paying attention to locations and duration of sampling, parameters for sampling and the analysis of data using multiple criteria.

This communication attempts to overcome the weaknesses of previous studies by characterizing the traffic noise specific to frequencies and observing its variation over space (location) and time. This study aims to determine variation in sound pressure levels (SPLs) in predominant frequencies (PFs) with time and space; and to find its likely relationship with human health.

The study has been designed to characterize the traffic noise giving importance to frequency of noise, source of noise, time of noise generation and the possible harm to human health.

A small stretch of the national highway (NH-91) in Kanpur city was selected as the study area. The area is near the busy road crossing at the entrance of the Indian Institute of Technology Kanpur (IITK). Kanpur city is one of the largest industrialized cities in Uttar Pradesh (India) having a population of about 4.57 million (according to the 2011 census). The types of vehicles generally found on NH-91 are trucks (heavy/light), buses (normal/mini), cars/jeeps, three-wheelers (vikram), two-wheelers (motor cycles) and tractors. A broad-gauge railway track connecting Kanpur to Delhi via Kannauj also runs parallel (almost side by side) to NH-91 in the study area (Figure 1). The vehicular count in the study area was estimated simultaneously by manual counting of vehicles passing in both directions on NH-91 in front of IITK entrance (Figure 2). Two-wheelers and three-wheelers constitute a significant percentage of the vehicular population in the study area and the ratio of fast to slow moving vehicles on roads was 4 : 6. The large number of three-wheelers (vikram) which ply all over the city, contribute greatly to noise pollution because of inadequate

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traffic management and congestion. Poor road infrastructure and conditions of vehicles along with lack of public unawareness are some other reasons for noise pollution[30].

Eight sampling locations (A–H) were selected in the study area keeping in view the population of dwellers and vendors living and working in the institutional/commercial establishments and shops situated on the sides of NH-91 near the road/railway crossing at the IITK entrance (Figure 1). The description of noise sampling locations with coordinates (measured by global positioning system; GPS) and distances of various locations from the roads and railway track are given in Table 1.

Knowledge of frequency and distribution of sources is vital in understanding the traffic noise characteristics. The study of frequency-wise characterization of traffic noise was designed using the following strategies for noise characterization: (i) ascertaining PFs in octave bands contributing to noise levels; (ii) noise sampling at PFs; (iii) developing techniques for characterization of traffic noise using statistics or deviations in sampled data and (iv) relating the observed trend to human health. The above four goals have been addressed using the observed data. The scheme for observing (monitoring) and analysis of data is given below.

Figure 1. Sampling locations (A–H) in the study area – IITK main entrance gate (source: Google Earth).

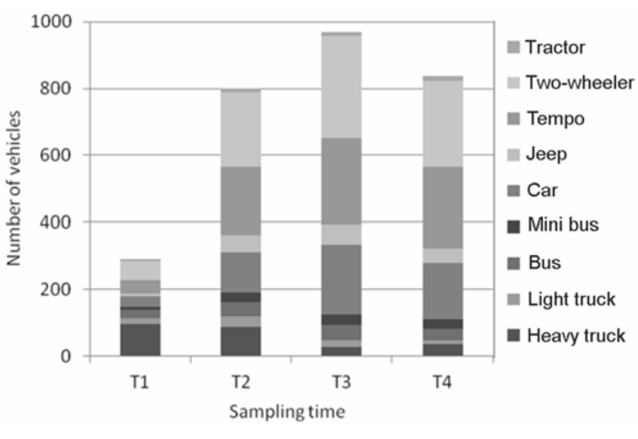

Figure 2. Average hourly vehicular distribution.

Sampling time slots were decided after giving due importance to background information and observed traffic pattern in the study area (see later in the text; Figure 2). Based on traffic volume on NH-91, four noise sampling time slots of 1 h each were selected for noise sampling at various locations in the study area: (i) early morning off-peak hour period $T1$ (5.30–6.30 am); (ii) afternoon peak-hour period $T2$ (1.30–2.30 pm); (iii) evening time peak-hour period $T3$ (5.00–6.00 pm) and (iv) morning peak-hour period $T4$ (10.00–11.00 am). Common noise parameters were monitored (i.e. L_{eq}, L_{90}, L_{max}, L_{min}, L_{in} ER 3 dB using frequency response, linear weighting (L), time response in fast mode and 1 s logging rate interval) using a sound-level meter (Model Quest-1900) equipped with filter unit (Model Quest OB-300), at a height of 1.2 m above ground, at an angle of 0° towards the source(s). The sound-level meter was calibrated regularly using a sound-level calibrator (Model QC-20).

To ascertain PFs of traffic noise in the study area, $L_{eq,30s}$ (L) datasets of noise samples in each 1/1 octave frequency at all sampling locations in different sampling slots were generated for a total duration of 1 h (Table 2). Frequencies of 1/1 octave band were classified as low (16–250 Hz) and high frequency ranges (500 Hz–16 kHz)[4,6,18]. The average sound pressure levels (L_p) were calculated using eq. (1) for all frequencies and the frequency corresponding to the highest L_p in each range was designated as the PF

$$L_p = 10 \log_{10} \frac{1}{N} \sum_{n=1}^{N} 10^{\frac{L_n}{10}}, \quad (1)$$

where N is the number of measurements in a particular octave frequency and L_n the nth observed $L_{eq,30s}$ (L) value in a particular octave frequency, $n = 1, 2, 3, \ldots, N$.

To understand behaviour/pattern of traffic noise characteristics, the results were analysed in two different study modes, i.e. (i) inter time slots study to understand variation of average $L_{eq,1h}$ (L) with space and time and (ii) intra time slots study to understand variation of instantaneous SPL (L) with space. Details of these analyses are given later in the text.

A traffic monitoring exercise was carried out to strengthen the available background information on the nature of vehicles generally found in the study area and the associated traffic movement patterns at different times of the day (Figure 2). The study indicated increase in total number of vehicles from $T1$ (morning) to $T3$ (evening) sampling time slot. Similar vehicular distribution was noticed in sampling time slots $T2$ and $T4$. Larger number of trucks were noticed in the morning sampling time slot $T1$, whereas the number of two-wheelers and tempos rose in the sampling time slots $T2$ and $T3$. Further, the exercise also provided the important information

Table 1. Details of noise sampling locations and their characteristics

Sampling location	GPS coordinates of sampling locations X (Easting)	Y (Northing)	Distance from centre line of noise source (m) NH-91	IITK main entrance road/crossing	Railway line	Description of sampling locations
A	80°14′48.7″	26°30′38.8″	8	3	50	Main entrance of IITK from NH-91.
B	80°14′47.6″	26°30′39.8″	10	40	80	Commercial shops on the sides of NH-91.
C	80°14′49.8″	26°30′39.5″	25	3	78	Commercial shops and NSI hostel on the sides of NH-91.
D	80°14′45.8″	26°30′39.0″	100	10	10	Near gateman and security guard room on the sides of the railway track and entrance of IITK road crossing.
E	80°14′47.7″	26°30′40.7″	10	60	97	Commercial shops on the sides of NH-91.
F	80°14′45.5″	26°30′39.7″	98	25	10	Near railway employee residence room on the sides of the railway track.
G	80°14′44.2″	26°30′39.3″	130	15	23	In front of the railway reservation centre, IITK campus boundary on the sides of the railway track.
H	80°14′44.1″	26°30′38.8″	135	5	25	Near security guard room, cycle stand.

Table 2. Noise monitoring plan

Sampling stage	Sampling location	Monitoring days in different sampling time slots: $T1$, $T2$ and $T3$	$T4$	Sampling sound frequency	Sampling parameters and setting
Stage 1 PF determination	A	Day 1	–	All frequencies in 1/1 octave band	L_{eq}, L_{90}, L_{max}, L_{min}, L_{in}; fast; logging rate 1 s.
	B	Day 2	–		
	C	Day 3	–		
	D	Day 4	–		
	E	Day 5	–		
	F	–	Day 1		
	G	–	Day 2		
	H	–	Day 3		
Stage 2 Variation in L_{eq} at various PFs	A	Days 6–9	–	PF 1	
		Days 10–13	–	PF 2	
	B	Days 14–17	–	PF 1	
		Days 18–21	–	PF 2	
	C	Days 22–25	–	PF 1	
		Days 26–29	–	PF 2	
	D	Days 30–33	–	PF 1	
		Days 34–37	–	PF 2	
	E	–	Days 6–9	PF 1	
		–	Days 10–13	PF 2	
	F	–	Days 14–17	PF 1	
		–	Days 18–21	PF 2	
	G	–	Days 22–25	PF 1	
		–	Days 26–29	PF 2	
	H	–	Days 30–33	PF 1	
		–	Days 34–37	PF 2	

– shows no sample has been taken corresponding to monitoring time slot.

on choosing the four unique sampling time slots of 1 h duration (which can demonstrate the unique character of noise). The selected sampling time slots were $T1$ (5.30–6.30 am), $T2$ (1.30–2.30 pm), $T3$ (5.00–6.00 pm) and $T4$ (10.00–11.00 am).

At each sampling location, $L_{eq,30s}$ (L) in each 1/1 octave band frequencies was measured for 1 h to obtain the noise data specific to frequencies. The frequencies were changed manually one by one between 16 Hz and 16 kHz after every 30 s. Figure 3 shows the average sound pressure level (L_p) corresponding to each of the 1/1 octave frequencies.

The maximum value of L_p in the low frequency range (16–250 Hz) was 74.83 dB at 63 Hz, whereas in the high frequency range (500 Hz–16 kHz) maximum value of L_p was 70.52 dB at 1 kHz frequency (Figure 3). These

Table 3. Average values of $L_{eq,1h}$ (L)

Location	PF	Average $L_{eq,1h}$ (L) in dB in selected time slots			
		$T1$	$T2$	$T3$	$T4$
A	63 Hz	86.76 ± 0.90	89.90 ± 0.05	89.26 ± 0.36	–
	1 kHz	76.99 ± 0.87	85.48 ± 0.37	83.94 ± 2.17	–
B	63 Hz	87.35 ± 1.26	90.53 ± 0.66	89.42 ± 0.18	–
	1 kHz	80.58 ± 1.79	85.73 ± 1.31	82.67 ± 1.33	–
C	63 Hz	80.93 ± 0.82	82.85 ± 0.57	82.44 ± 0.51	–
	1 kHz	70.16 ± 1.76	75.98 ± 0.99	74.19 ± 0.68	–
D	63 Hz	77.89 ± 1.28	78.22 ± 1.06	79.61 ± 1.28	–
	1 kHz	65.49 ± 2.25	84.74 ± 3.19	79.81 ± 3.96	–
E	63 Hz	–	–	–	88.95 ± 0.80
	1 kHz	–	–	–	79.84 ± 0.77
F	63 Hz	–	–	–	76.38 ± 1.24
	1 kHz	–	–	–	83.08 ± 2.27
G	63 Hz	–	–	–	74.35 ± 0.56
	1 kHz	–	–	–	70.57 ± 2.26
H	63 Hz	–	–	–	78.98 ± 1.12
	1 kHz	–	–	–	72.97 ± 2.85

– shows no sample has been taken that monitoring time slot.
The value following the '±' sign indicates standard deviation in average L_{eq}.

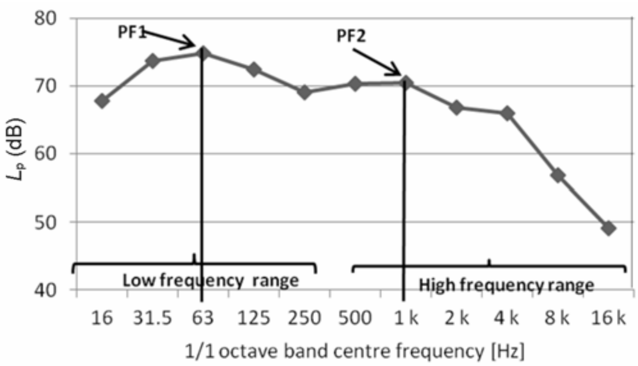

Figure 3. Variation of L_p in each 1/1 octave band frequency.

frequencies are designated as PF 1 (63 Hz) and PF 2 (1 kHz) and all further noise sampling for characterization of traffic noise has been performed at these two PFs.

Sound pressure levels were measured for eight working days at the two PFs during the selected time slots according to the schedule mentioned in Table 2 for traffic noise characterization. For the first four days sound pressure levels were measured at PF 1 and during the remaining four days at PF 2 at all noise sampling locations during different sampling slots $T1$–$T4$. Generally, the observation at the sampling time slot $T2$ gave higher average equivalent ($L_{eq,1h}$) values for both the frequencies (Table 3). Thus the average equivalent noise levels generally maximized during the busy traffic hour (1.30–2.30 pm). Some rise was recorded in standard deviation (e.g. $L_{eq,1h}$ (L) in 1 kHz at location A in $T3$ time slot), which may be attributed to occasional excessive use of horns by vehicles or passage of trains near the crossing, etc.

Variation of average $L_{eq,1h}$ (L) was studied with time and space at two PFs in the study area (Figure 4). On the X-axis, the sampling locations are arranged in the order of increasing distance from the central line of the road (Table 1), as it is the main source of continuous noise. At 63 Hz frequency (PF 1), average $L_{eq,1h}$ (L) decreased with increasing distance of sampling points from the central line of the road. Similarly, at 1 kHz frequency (PF 2), average $L_{eq,1h}$ (L) decreased with increasing distance of sampling points except for sampling location D during sampling slots $T2$ and $T3$. The reason for higher value of $L_{eq,1h}$ (L) was the additional noise of train running on the nearby railway track (shown in Figure 1). More fluctuation in $L_{eq,1h}$ (L) at longer distances from the main road can be perceived from observing the standard deviation (Table 3). A somewhat different trend observed in point D may be likely due to contribution from the nearby railway noise and is corroborated from rail noise study (not reported here).

Figure 5 shows variation of average $L_{eq,1h}$ (L) with sampling time slots at locations A–D in PFs 1 and 2. Generally there was no marked variation in $L_{eq,1h}$ (L) in 63 Hz at any location. However, the value of $L_{eq,1h}$ (L) in 1 kHz frequency was maximum during time slot $T2$ due to increased traffic movement.

Fluctuation in instantaneous SPL is considered to be an important property of traffic which can be related to traffic pattern, traffic distribution and the socio-economic pattern for the locality. In order to study this, an intra time slots study was undertaken. Four days of average instantaneous SPL values in each noise sampling slot were compared for noise sampling locations situated very

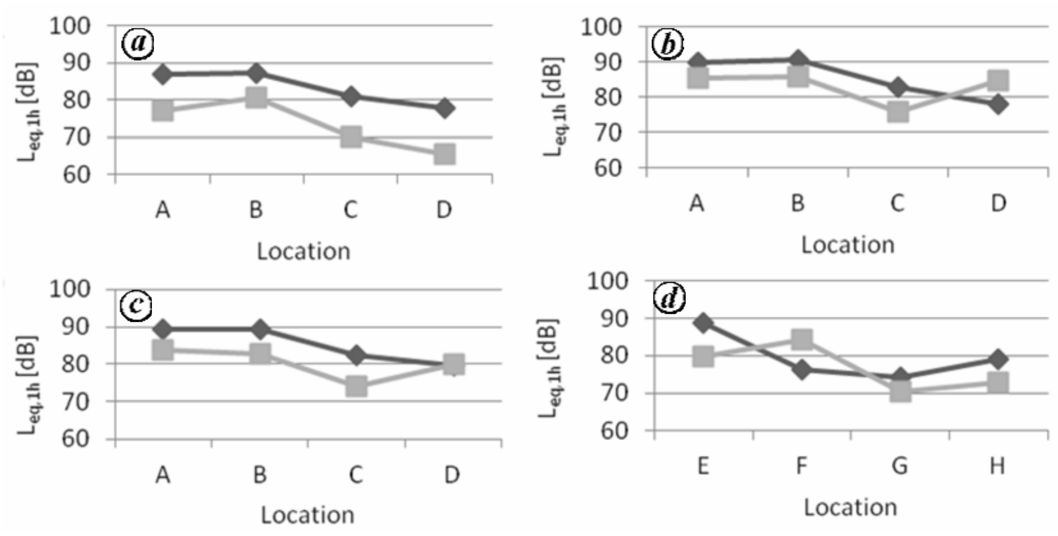

Figure 4. Variation of average $L_{eq,1h}$ (L) at different locations at sampling time slots: (***a***) *T*1; (***b***) *T*2; (***c***) *T*3 and (***d***) *T*4. ♦ 63 Hz (black line); ■ 1 kHz (grey line).

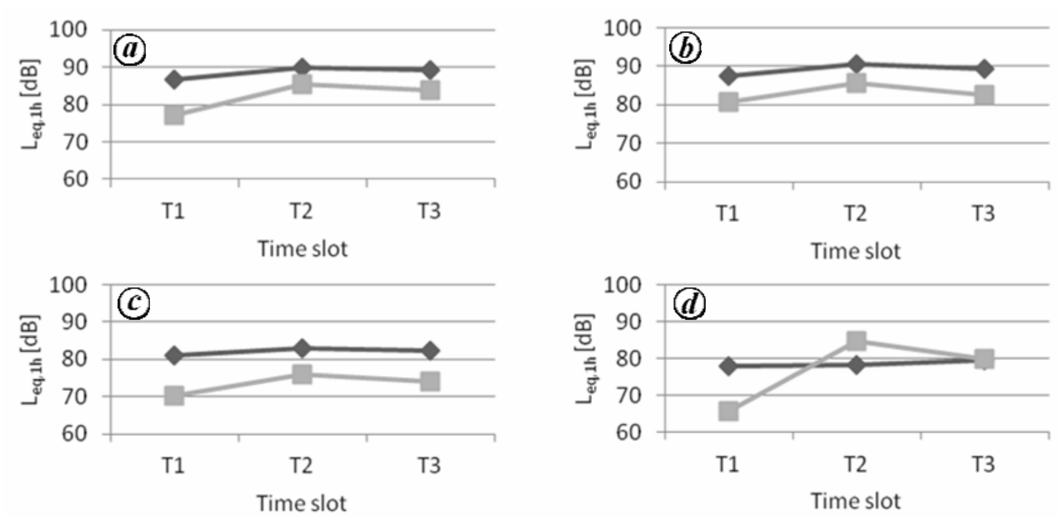

Figure 5. Four-days average $L_{eq,1h}$ (L) variation (in dB) for different time slots at locations: (***a***) A; (***b***) B; (***c***) C and (***d***) D. ♦ 63 Hz (black line); ■ 1 kHz (grey line).

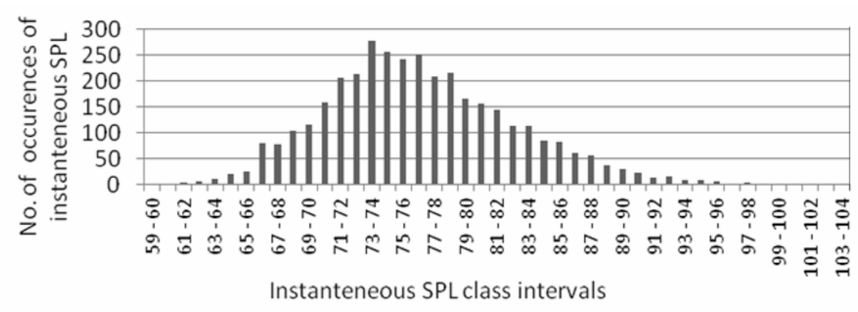

Figure 6. Histogram for location A in time slot *T*1 at PF 1.

near NH-91 (A, B and E) at the two PFs. Histograms were plotted to see the distribution of four-days average instantaneous SPL values at each of the three noise sampling locations in various noise sampling slots. It was found to follow normal distribution, indicating randomness and statistically significant number of observations

Table 4. Threshold value of average $L_{eq,1s}$ (in dB) at locations A, B and E

	Time slots/sampling locations/PFs													
	*T*1				*T*2				*T*3				*T*4	
	A		B		A		B		A		B		E	
Parameter	63 Hz	1 KHz	63 Hz	1 KHz	63 Hz	1 KHz	63 Hz	1 KHz	63 Hz	1 KHz	63 Hz	1 KHz	63 Hz	1 KHz
μ	75.0	62.9	74.2	62.5	81.3	72.5	80.7	70.2	81.0	71.5	80.5	69.3	79.0	68.6
σ	6.5	8.4	7.3	9.5	4.4	5.6	5.3	6.8	3.9	4.8	4.6	5.9	5.0	5.2
Th1	81.5	71.3	82.0	72.0	86.0	78.1	86.0	77.1	85.0	76.3	85.0	76.3	84.0	72.0
Occurrences from Th1	571	625	547	695	524	411	501	451	493	385	557	360	446	401
Th2	88.0	80.0	89.0	81.4	91.1	84.0	91.3	84.0	89	81.1	90.0	81.1	89.0	81.4
Occurrences from Th2	114	73	120	91	88	184	121	122	122	173	106	122	134	81
Th3	94.5	88.1	96.2	91	94.5	89.4	97.0	91.0	93.0	86.0	94.2	86.0	94.0	91.0
Occurrences from Th3	14	18	13	11	20	79	20	44	31	87	29	53	16	13

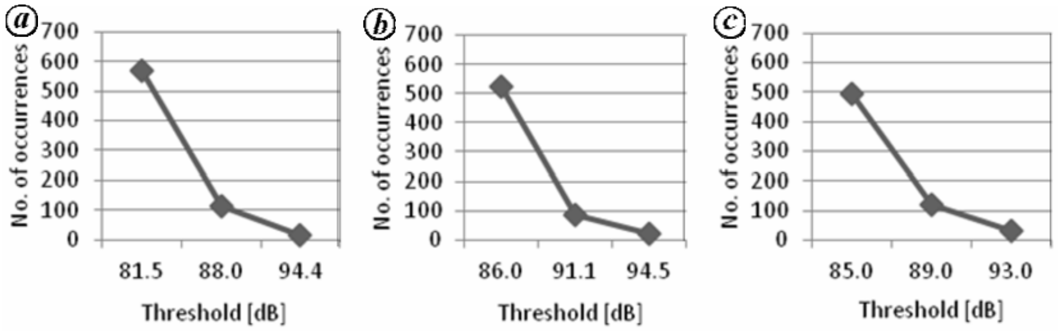

Figure 7. Average occurrences above thresholds for location A at time slots: (***a***) *T*1; (***b***) *T*2 and (***c***) *T*3 at 63 Hz.

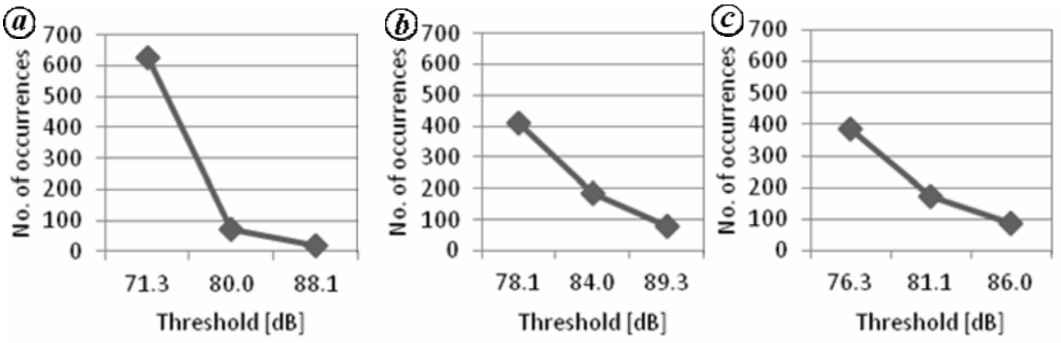

Figure 8. Average occurrences above thresholds for location A at time slots: (***a***) *T*1; (***b***) *T*2 and (***c***) *T*3 at 1 kHz.

have been used for analysis. One such histogram for sampling location A for noise sampling slot *T*1 at PF 1 is shown in Figure 6.

Mean (μ) and standard deviation (σ) were determined from the statistics and three threshold values were selected for determining average occurrences (noise fluctuations) around each threshold ('Th') for the study area: 'Th1' ($\mu + \sigma$), 'Th2' ($\mu + 2\sigma$) and 'Th3' ($\mu + 3\sigma$) (Table 4) were determined statistically. The attempt here was to find the extent of fluctuation around the mean values. The occurrences of instantaneous SPL exceeding the thresholds Th1–Th3 at location A at both PFs for various time slots have been determined and plotted in Figures 7 and 8. The occurrence of instantaneous SPL over threshold is importantly related to noise characterization as it indicates intensity of fluctuation of traffic noise and instantaneous variability of noise of a PF with time. Similar trends were also observed at other sampling locations B and E at the selected sampling time slots (related figures are not shown here).

From Figure 7 it is clear that occurrences above Th1 in 63 Hz are lesser in time slot *T*3 or *T*2 compared to *T*1, which may be due to decrease in heavy truck volume (Figure 1). No marked change in occurrences was observed at Th2 and Th3 in time slots *T*1, *T*2 and *T*3. Since a large number of times the fluctuations crossed different thresholds at 63 Hz, i.e. 500 (Th1), 100 (Th2) and 15 (Th3), the traffic noise demonstrated the character of throb or rumble, or hiss; this might be related to the tyres, axles, acceleration/deceleration of engines of tempos (vikram) and heavy vehicles as showcased by Leventhall[6]. Figure 8 reveals that at 1 kHz the number of occurrences of noise levels above Th1 was more in time slot *T*1 compared to other sampling time slots (*T*2 and *T*3) at location A. This might be due to more number of trucks, and their buzzing of horns while passing through the crossing. At sampling time slots of *T*2 and *T*3 the noise levels exceeded the thresholds of Th2 and Th3 more number of times than the similar thresholds under *T*1. The above observations are in line with the results of average $L_{eq,1h}$ (L) given in Table 3. It indicates that the average noise remained low in morning sampling time slot; however, it involved significant fluctuation, which is possible if there is a sudden passage of large noise followed by mild noise intervals, as was the case with more number of trucks passing through the crossing at high speed along with less intensity of other traffic. Further, generally the average noises increased significantly from morning to evening due to manifold increase in the number of vehicles. The large number (and types) of vehicles in the afternoons reduced the intermittent mild noisy period, causing rise in average noise level. Increase in occurrence of Th2 and Th3 may be related to the frequent use of horns at congested traffic. Thus, at 1 kHz, the traffic noise had an impulsive, intrusive and percussive character which may be related to frequent use of horns[18].

The present study did not attempt to identify the exact human health hazards. Rather, it tried to identify the presence of any low or high frequency sounds/noises of high level in a typical Indian road crossing, which can cause hazards to human health. PNC and NR curves have been used by various researchers[19–21] for estimating the adverse impact of traffic noise to human health by applying correction factors (addition of 5 dB (A) for variations in outdoor urban residential and commercial areas). In the study area, a large population is being exposed to hazardous noisy traffic conditions due to typical socio-economic constraints. The acceptable values in dB (A) are given in Table 5 (ref. 19). PNC and NR test curves at two PFs are shown in Figure 9 along with the $L_{eq,1h}$ (A) values observed at noise sampling locations at various noise sampling time slots.

For all selected sampling slots (*T*1–*T*4), PNC 25 and NR 30 standards are not met always for locations A, B, C and E at 63 Hz. $L_{eq,1h}$ (A) values at all sampling locations exceeded the permissible limits of PNC 55 and NR 55 at 1 kHz. These observations indicate that the population exposed to traffic noises in the study area will likely experience high levels of high frequency noise (1 kHz) and in some cases high levels of low frequency noise (63 Hz), which are likely to cause health hazards. Some of the problems of high-frequency noise are hearing impairments, hypertension, high blood pressure, speech interface, annoyance and disturbance to daily activities[2,11,17] whereas low-frequency noise can lead to annoyance, sleep deprivation, physiological disorders, etc.[6,7,16].

Traffic noises generally present in typical Indian city environment show lot of variability. The levels of noise vary over time, space and inherent frequency spectra. Highly variable nature of noise is difficult to address. Available researches primarily used the equivalent or average SPL-based technique to study noise, which largely failed to represent noise from the frequency perspective. This communications discusses the technique to characterize traffic noise using frequency-based approach. In the absence of a well-defined technique to handle the spectrum of sound waves present in noise, the authors suggest a new technique.

A comprehensive noise sampling plan was applied keeping in mind the background information of traffic pattern and monitoring of types of vehicles plying at the

Table 5. Acceptable SPL based on corrected preferred noise criteria (PNC) and noise rating (NR) curves values

Standard	Acceptable SPL values in dB (A) at PFs		Environmental situation
	63 Hz	1 kHz	
PNC 25	57	35	Residential area
NR 30	60	30	
PNC 55	75	60	Commercial area
NR 55	84	60	

*Standard value extracted from Kosten and Van[19].

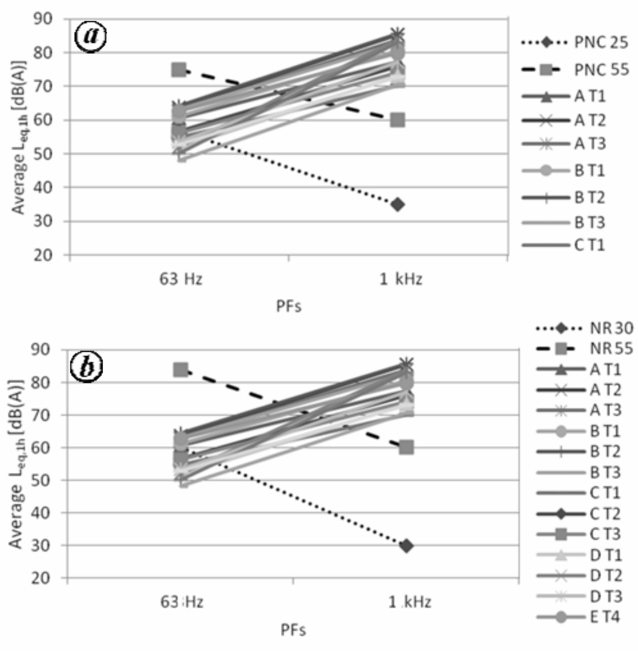

Figure 9. Comparison of $L_{eq,1h}$ (A) in PFs with standard (***a***) PNC and (***b***) NR.

traffic crossing throughout the day. Considering the strong relationship that the character of noise can have with its inherent frequencies, the initial study or analysis was targeted to ascertain the frequencies which were contributing significantly to high average or equivalent noise levels. Interestingly two frequencies, i.e. 63 Hz and 1 kHz were identified in the low and high frequency domains causing noise pollution in the Kanpur city crossing.

The next phase of study was focused to find variability in noises at the above two frequencies. Variability was judged on the basis of: (i) hourly average equivalent SPL (average $L_{eq,1h}$) and (ii) variability between instantaneous SPLs within a sampling period. The average $L_{eq,1h}$ was observed to show some variation with time and location. Expectedly, the places closer to the main road, i.e. A, B, and E and the busy afternoon traffic hour, i.e. 1.30–2.30 pm recorded higher noise levels. In terms of frequency there was not much variation between noises of 63 Hz at different time slots, however, noise of 1 kHz was found to increase during 1.30–2.30 pm because of excess traffic and frequent use of traffic horns.

Interesting observations were noticed for variability between instantaneous SPLs within a sampling period. The fluctuations occurred at significant number of times above the average L_{eq} at 63 Hz (500 times at threshold 1 and 100 times at threshold 2). Occurrence of such a large number of rapidly changing noise levels at low frequency gave the noise the character of throb or rumble, or hiss; which may be attributed to noise originated from the tyres, axles and acceleration/deceleration of engines of tempos (vikram) and heavy vehicles generally found at the Kanpur city crossing. At 1 kHz increased movement of trucks at the morning sampling time slot (along with low density of other vehicles) and the frequent use of high-pitched horns caused frequent fluctuations in instantaneous SPL (although average $L_{eq,1h}$ remained low for the slot). From morning to evening, the number of trucks decreased but the number of slow-moving vehicles (tempo, scooter, etc.) increased. It was also associated with the frequent stoppage in traffic and extensive use of horns, causing increase in average $L_{eq,1h}$, although fluctuations around the average decreased. On the whole extensive use of horns gave the noise an impulsive, intrusive and percussive character. Further, the observed hourly average $L_{eq,1h}$, values at 1 kHz at all sampling locations over different sampling periods did not meet PNC and NR limits making it hazardous for health, which may lead to hearing impairments, hypertension, high blood pressure, speech interface, annoyance, etc. On some occasions the observed hourly average noise levels at 63 Hz did not meet the required standard, which can also have harmful implications.

The study thus revealed the important frequencies (63 Hz and 1 kHz) of sound present in traffic noise at Kanpur city contribute more for noise pollution. Further the observed noise values and their variation over time and space can largely be related to available traffic patterns. Further, studies using a frequency-based approach indicate probable sources, location and time of generation of noise, which can be hazardous to human health. Thus, it can be used to devise specific remedial measures to noise pollution.

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Received 7 October 2011; revised accepted 25 September 2012

Assessment of impact of climate change with reference to elevated CO_2 on rice brown planthopper, *Nilaparvata lugens* (Stal.) and crop yield

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Impact of elevated CO_2 on the rice brown planthopper (BPH), *Nilaparvata lugens* (Stal.) population and rice yield was assessed in open-top chambers during kharif 2010 and 2011. Brachypterous females laid more eggs (324.3 ± 112.3 eggs/female) on the rice plants exposed to elevated CO_2 (570 ± 25 ppm) than 380 ppm ambient CO_2 (231.7 ± 31.8 eggs). Elevated CO_2 exhibited positive effect on BPH multiplication and resulted in more than a doubling of its population (435.4 ± 62.0 hoppers/hill) at peak incidence compared to ambient CO_2 (121.4 ± 36.8 hoppers/hill) during kharif 2010; corresponding populations being 113.0 ± 11.5 and 47.0 ± 8.1 hoppers/hill during kharif 2011 respectively. Besides, honeydew excretion was observed to be 74.41% more under elevated CO_2 (187.6 ± 44.8 mm^2/5 females) than ambient CO_2 (48 ± 20.1 mm^2/5 females). On the other hand, high CO_2 exhibited nutritive effect on uninfested rice crop through 21.6%, 15.3% and 14.1% increase in the number of tillers, reproductive tillers and seeds/panicle respectively, and as a consequence increased grain by 11.1% compared to ambient CO_2. However, despite the nutritive effect, crop under elevated CO_2 suffered higher yield loss (26.5%) due to higher BPH population as well as sucking rate compared to ambient CO_2 (12.4%).

Keywords: Brown planthopper, climate change, elevated CO_2, rice.

RICE (*Oryza sativa* L.) is the world's most important staple food for two-thirds of the human population[1]. In India, rice is grown on an area of 41.85 m ha with a production of 102 m tonnes[2]. However, rice productivity in India remains on the lower side due to many abiotic and biotic constraints[3]. Among the biotic factors, the brown planthopper (BPH), *Nilaparvata lugens* (Stal.) is one of the most important sucking pests of rice, causing huge crop losses during certain years[4]. Global climate change, the current burning issue around the world, poses a multitude of threats to biodiversity, and human life and livelihood. According to projections, the Earth's temperature has already increased by 0.74°C between 1906 and 2005 and CO_2 is expected to increase up to 445–640 ppm by 2050 due to increase in anthropogenic emissions of greenhouse gases[5].

In the context of climate change, temperature directly affects insects and CO_2 affects them through host plants[6]. Increase in atmospheric CO_2 will have a significant impact on plant growth and development primarily due to changes in photosynthetic carbon assimilation patterns[7,8]. Increase in growth and yield under elevated CO_2 has been reported in many species including rice[9]. Changes in atmospheric CO_2 affect not only the plant quality but also the herbivore performance[10]. The C : N ratio of the plant foliage generally increases when plants are grown in elevated CO_2 than in ambient CO_2. As a result, insect larvae of castor semilooper increased leaf consumption under elevated CO_2 to compensate for lower nitrogen in plant foliage[11]. However, certain pests such as wheat aphids were not affected by elevated CO_2 (ref. 12). Therefore, rise in CO_2 might impact the foodgrain production directly as well as indirectly through its effect on crop pests[13]. Owing to differential effects of elevated CO_2, it becomes imperative to assess the effect on different crop pests. As BPH is an important pest of rice, it was thus deemed

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