Characterizing Traffic-Induced Noise Environments: Evidence from Urban Arterial Corridors

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ABSTRACT
Vehicular movement on roads generates noise noise-intensive environment posing potential risks. Environmental impacts due to traffic movements have been avidly studied. Few studies have dealt with noise variability. This paper presents an analysis of results for locations along grade separators for environmental noise measurements. The locations were grouped with similar attributes, and the noise impact of traffic was observed.

The A-weighted sound levels, ninety, fifty, and ten percent exceedance levels (L90),(L50),(L10), and derived noise descriptors: Noise climate (NC), Traffic Noise Index (TNI), and Noise pollution Levels (LNP) were higher at all locations. ANOVA single-factor and the Tukey criterion applied identified high-speed links generating noise-intensive environments. Analysis indicated a high correlation between vehicular speeds and noise. Also, Higher noise levels and minimal noise variability in free-flow conditions indicate more exposure. Results are significant for understanding implications for favouring measures for faster modes and aid in assessing trade-offs between sustainable and economically biased solutions and decisions

Keywords: Environmental noise ;Evaluation; Grade Separator; hazard ; Noise descriptors, Noise climate

INTRODUCTION:

The need to make a city potentially competitive by reducing travel times has prompted decision makers to opt for capacity additions mostly in the form of grade separators or other road widening schemes in cities, be it in the developed or the developing world.

Grade separators or flyovers, as they are popularly known, have been projected as a panacea to mitigate traffic issues. Their deemed value and functionality originate from their ability to segregate traffic and control access on dense routes thereby reducing the burden of traffic volume on many urban links. Such links are high traffic corridors or urban arterials located especially within or surrounded by densely populated areas. This reinforces the main purpose grade separator provision, which is to expedite the mobility of traffic minimizing travel times and avoiding congestion(Bonnilla and Urbanik, 1987; Liyanage, 2009; Suh and Yeo, 2016)

Many cities, therefore, boast of links with grade separators or flyovers, as they are known in developing countries, constructed of spans ranging from a few hundred meters to a few kilometers leaving slow moving traffic along with non-motorized traffic to move on the residual links below.

However, it is a recognized fact that mobility of traffic gives rise to impacts which are inadvertently felt by the users of the links and the surrounding neighbourhoods. Increased noise level is one such impact. The biggest contribution to the noise environment found in the contemporary urban environment is mostly due to the rise in urban mobility as a consequence of development and population growth as past studies have shown. Therefore noise as an externality of urban activity is a major concern affecting the quality of life of the urban dweller and especially that of the commuter (Alshobaki and Jamrah, 2008, Olayinka 2012, Qiu et al, 2017). Thus environmental noise is a phenomenon which needs to be investigated with respect to the road environment and is concomitant with its existence and usage.

LITERATURE REVIEW:

Noise pollution is a significant environmental problem and health hazard in most urbanized areas and is understudied compared to other pollutants and their effects in academic literature (Anomohanran, 2004, Stansfeld, 2015, Qiu et al..2017). Studies have been carried out to investigate and assess noise pollution levels in various cities across the world but are few in number in most of the developing world. Most studies are designed and dealt with the assessment of noise levels. Studies have typically focused on the prediction of noise levels due to predicted increase in traffic volumes on links , near facilities or restricted zones as also to test the effectiveness of noise prediction models in predicting them (Jamrah et al, 2006; Banerjee et al.2008; Olayinka, 2012, Salman, 2013, Lau et al,2014, Debnath and Singh, 2018). The literature has sporadic studies aimed at understanding perceptions of noise annoyance, soundscaping, noise prediction model application to possible scenarios, noise mapping of areas or segments, noise exposure, environmental costs (Goussous et al, 2014, Olayinka, 2012; Donovan and Janello, 2017). Most studies are location specific whether empirical or based on simulation outcome and model validation, for example, there are studies about the effect of distance from road intersection on developed traffic noise levels (Abo-Qudais and Alhiary, 2004; Olayinka and Saadu, 2010)

Almost all studies assessing environmental noise have concluded that noise levels were higher than permitted by local, national or global norms (Alshobaki and Jamrah, 2008). It is well established that noise is a potential hazard, carries a cost to human health and wellbeing as well as the quality of life in urban environments. Its impact and costs are only recently being regulated, standardized and researched (Lee and Fleming,1996, EPA, 1999; Berglund et al., 1999; Nijland et al., 2003; Government Of Australia, 2013).

Methodologically studies on noise annoyance mostly lean towards subjectivity as they rely largely on questionnaires as data generating tools and therefore are prone to limitations and biases (Misdarris et al, 2014). Statistical analysis is also favoured for environmental noise assessment but it has rarely been used to establish a relationship or causation between the generated noise descriptors and other factors in a given location. Since the causality of noise and its associative factors is not easy to prove compared to air and water due to its very short decay time (Davis and Masten, 2004) Studies have also used multiple regression analysis techniques (Salman, 2013). Assessment of noise levels amongst researchers has invariably been used with noise prediction models or simulation tools to highlight future impacts of projects or development thus becoming a part of environmental impact assessment ex ante as most countries have made the Environmental Impact Assessment (EIA) studies mandatory whenever projects are being upgraded or new planned developments coming up with generated noise levels being a major component to be assessed (Dravitzsky and Jackette, 2011, Biddle et al. 2014)

Studies are also based on capturing the data, mapping, model applications and validation of existing models such as CRTN, for noise prediction in a future scenario. However there are few studies dealing with the variability in environmental noise and its analysis and interpretations along road links or explanation of the interrelationship amongst factors inducing the phenomena (Berglund and Nilsson, 1998 ; Balachander et al.,2004 ; Alberola et al.,2015 ; Socoro et al.,2017; Donovan and Janello , 2017)

While academic literature abounds with studies which deal with the assessment and analysis of noise levels in different urban zones due to traffic movement, variability of noise levels occurring along road segments and their significance for identifying risk zones which may affect commuters or neighbourhoods adversely due to traffic movement or other traffic characteristics as contributory factors has rarely been studied (Braj and Jain ,1995;.Ebozoje and Umoh, 2013;Chanderprabha and Laura;2013)

The contention of the study is that variability in noise environments exists on urban arterials with fast-moving traffic and by comparing similar locations the study can help in identifying major contributors to noise generation. This would be significant in not only defining risk-prone areas along segments but also for undertaking mitigation or preventive measures to reduce noise exposure in urban areas.

This study aims:- 1)) to examine whether there is variability in common noise descriptors between locations 2) to determine whether there is a significant difference in noise environments due to traffic segregation along arterials and 3) to assess and identify which locational or traffic attributes are producing a highly intense noise environment.

THE STUDY AREA:

For the empirical study, the selection criteria which were applied to identify case studies were**:** 1) the urban arterials which passed through similar development and land use zones 2) the urban arterials having parallel links with segregated traffic 3)the urban arterial belonged in the same climatic zone and city and lastly 4) where road users were likely to exhibit similar driving behaviour. This was done to ensure comparability of surveyed results in real situations so that data generated is as realistic, achievable and hence reliable.

The study included urban arterials with parallel grade separators which satisfied the above criteria. This was done to characterize locations based on only traffic and physical attributes and to minimize the possible influence of other extraneous variables on the outcome of the study viz. type of land use and urban development, traffic composition or pattern of movement, topography, climatic composition micro and macro (climatic conditions are an important criteria since humidity levels; high winds are variables which have considerable influence on noise measurements) etc. The study used statistical tools for extensive analysis. Thus 24 survey locations were identified where mix traffic and segregated traffic conditions co-existed along the same arterial for the environmental impact study.

The city selected was Nagpur which is a fast-growing tier two city in central India with a current population of 24 lakh. Although the city seems atypical for the developed world it shares common development traits with cities in the Indian subcontinent as well as many others belonging to the developing world. The generic aspects of the city are organic development for the most part of its existence, radial growth trajectories, a demographic growth rate of 1.9, mixed traffic conditions typically having similar driving environment characteristics. The city has mixed land uses abutting its major arterials with most buildings having 2-4 floors, parking on roads, a mix of signalized and non-signalised methods of traffic management. Nagpur also belongs to the tropical wet and dry zone or one which is otherwise classified as a tropical savannah climate as per Köppen climate classification with dry conditions prevailing for most of the year.

METHODOLOGY:

The study was designed to test the hypothesis that locational attributes which create favourable conditions for fast movement of traffic have higher noise levels as compared to those locations where only slow moving or stop and go traffic conditions prevail. The null hypothesis therefore for the study is $H_{o:}$ $\mu_1=\mu_2=\mu_3$; where μ= group mean.

For assessing and analyzing the noise levels, noise measurements were taken at grade on residual links and above grade i.e. on the flyover links and were compared. Twenty four locations along four flyovers, at and above grade were selected and measurements were taken during peak hour's morning from 10.00 am to 12.00 pm and evening from 5.45 pm to 7.45 pm during normal weekdays along with volume count of motorized and non-motorized traffic. The locations above and below grade were further grouped based on the following attributes: 1) speeds 2) percent of motorized traffic 3) a number of lanes available

Table 1: Criteria For Grouping Locations

	LOCATION ATTRIBUTES	GROUP I	GROUP II	GROUP III
1	SPOT SPEEDS (MEAN)	23.24	25.28	47.93
2	PERCENTAGE OF MOTORIZED TRANSPORT (hourly mean)	60.00	78.00	98.00
3	MODE SEGGREAGATION	NO	NO	YES
4	NUMBER OF LANES USED	6 TO 8	10 TO 14	4
5	TRAFFIC CONDITIONS	free flow / stop and go	free flow / stop and go	free flow
6	ROAD LINK	AT GRADE	AT GRADE	ELEVATED 9.00 Ms
7	SURFACE FINISH (ROAD LINK)	BITUMEN	BITUMEN	CONCRETE

**Details of Attributes listed above : 1) Spot mean speeds taken for all motorized modes only , values are means ± 4.78 SD for grp I and grp II and ± 2.5 SD 2) motorized modes includes Light Motor Vehicles and Heavy Motor Vehicles in the traffic stream 3) Mode Segregation i.e. Having limited or no access to certain mode types.4) total no. of Lanes in both directions 5) signalised and non-signalised segments have stop and go and free flow traffic.6) link existed on ground or elevated above ground.

for movement 4) traffic condition 5) mode segregation 6) surface of the link and 7) link elevation (Table 1). Figure 1 shows the modal split for the three groups of links.

Based on the above criteria survey locations were divided into three separate groups and all having the same number of samples. Data collected were analyzed and compared using ANOVA single factor to test whether there was any significant difference between them. Correlation coefficients were also found for speed and noise descriptors. Noise levels were registered using a tripod mounted SLM type 2 device. Volume counts and speeds of vehicles were recorded using two video cameras and recorded hourly.

The SLM was mounted on a tripod at a height of 1.2 m. and a distance of 1.5 and 2 m. from

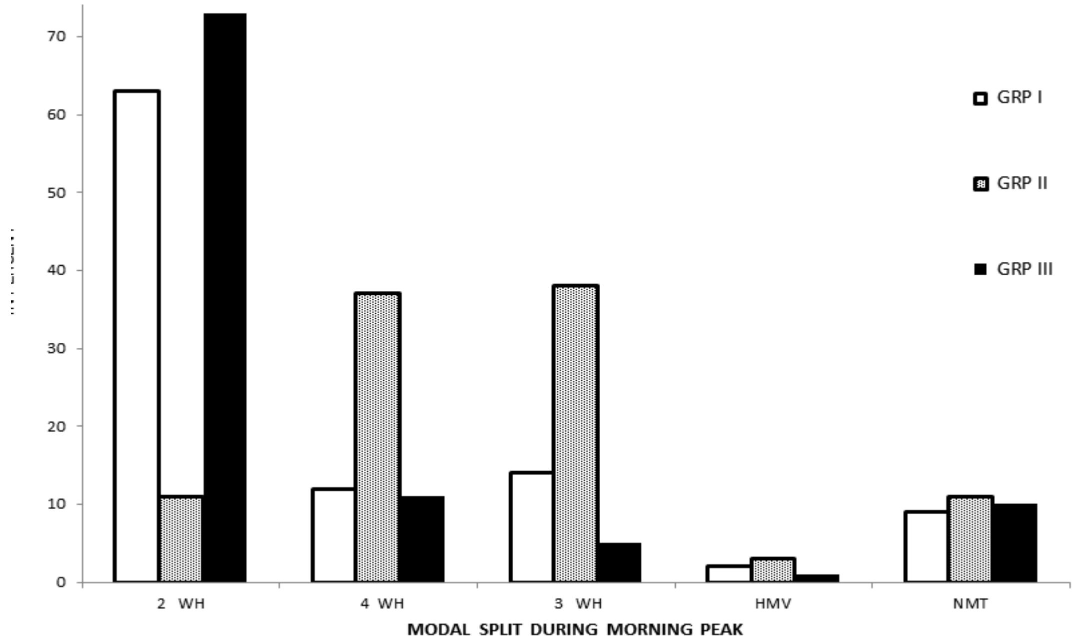

Figure 1: Modal split on the three types of links.

the kerb side of the road as per spatial availability above grade at certain sections of the links. (EPA 1999, CPCB 2000; FHWA, 2010; Olayinka, 2012).The tripod was used to minimize the effect due to body reflection of sound waves of the surveyors.
Instruments used in the survey are 1) Sound Level Meter (SLM): A Sound Level Meter fast type, A-weighted, and complying to following standards:
----A. International electrician committee standard: IEC PUB 651 TYPE 2.
----B. US national standard: ANSI S1.4 Type 2 was used having a measuring range 30~130 dB(A) with ±1.5 dB accuracy and frequency response of 31.5Hz to 8.5KHz , with a sampling rate of 2 times per second and Digit & Resolution: 4 digits & 0.1 dB. The microphone is 1/2 inch polarization capacitance microphone.
2) Anemometer: Anemometer GM8908, to measure Air velocity, Air temperature with a Resolution: 0.2º C, 0.2m/s and measurement range: for ----Air velocity: 0~30m/s, 0~90km/h, 0~5860ft/min, 0~55knots, 0~65mph (± 5%) ,----Air temperature range : -10~45º C, 14~113º F (± 2º C)
3) Thermo-hygrometer : Humidity Range 20 → 90 % , temperature Range -50 → +70 °C with a accuracy (for humidity) Accuracy ±5% (25 → 80%) ±10% elsewhere and % (for temperature) Accuracy ±1°C (0 → 40 °C) ±2 °C elsewhere, resolution 0.5°C/RH %.
Noise levels were taken on two random working days when relatively calm climatic conditions prevailed in the region. The temperature, wind velocity, humidity levels were noted and were between prescribed levels to avoid any discrepancies in measurements (EPA 1999, CPCB, 2010; Olayinka and Saadu,

2010). Noise measurements were made over a period of 60 minutes (1 hr.) with a sampling of Lmax levels at a rate of 5per / min i.e. one in 12 seconds. The locations were selected along the links on the following criteria:1) they were situated along the links where grade separators existed and were in use throughout the day 2) they were either mid segments or at intersections of the links.

From these recorded readings noise descriptors which are the percent exceedance levels commonly used, the L10, L50, and L90 were calculated from hourly samples. The other noise descriptors were derived using formulae explained below:

The noise descriptor Leq (equivalent continuous sound level), is defined as the steady sound pressure level which over a given period of time has the same total energy as the actual fluctuating noise. Thus, the Leq is, in fact, the RMS sound level with the measurement duration used as the averaging time.

$$LAeq = 10LOG\left[\frac{1}{N}\sum_{i=1}^{N}\left(Antilog\left(\frac{LAi}{10}\right)n_i\right]\right. \quad \ldots(1)$$

The noise climate NC is the range over which sound levels fluctuate in a given interval of time and is given by,

$$NC = (L_{10} - L_{90}) \quad \ldots(2)$$

Traffic noise index, TNI takes into account the amount of variability in observed sound levels in an attempt to improve the traffic noise measurements

$$TNI = 4(L_{10} - L_{90}) + L_{90} - 30dB \quad \ldots(3)$$

Noise pollution levels, L_{NP} employs the equivalent continuous (A weighted) sound levels Leq and the magnitude of time fluctuations in levels. It attempts to account for the increased annoyance due to temporal fluctuations in noise. (Harris, 1991; Olayinka and Saadu, 2010)

$$L_{NP} = L_{Aeq} + (L_{90} - L_{10}) \quad \ldots(4)$$

ANOVA single factor was conducted to compare the noise levels and descriptors for all groups. The Post hoc comparisons for noise descriptors LNP, TNI and L10 levels were done using the Tukey criterion (HSD), Honest Significant Difference), which is a conservative test and controls the alpha level overall and is based on studentized range distribution.

RESULTS AND DISCUSSION

From the noise measurements commonly used noise descriptors such as the 10 percent exceedance levels, 50 percent exceedance levels, 90 percent exceedance levels , the A-weighted equivalent sound pressure level LAeq and the A-weighted equivalent continuous sound pressure level , Leq of the sample time T also known as 'time average sound pressure level' were computed (Australian Noise manual 2013)

Also the TNI -Traffic noise index, LNP –the noise pollution levels and the NC – the noise climate were also derived for all (Fig 2-4).

With computed noise levels from recorded measurements for all locations, it is observed that L90 mean levels are the highest in group 3 (Tables 2 - 4).

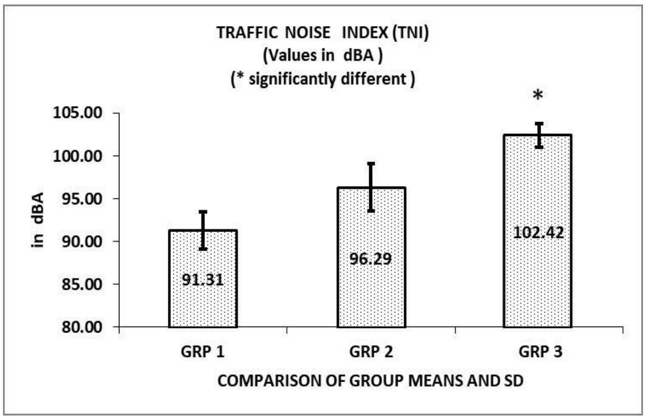

Figure 2: Traffic Noise Index

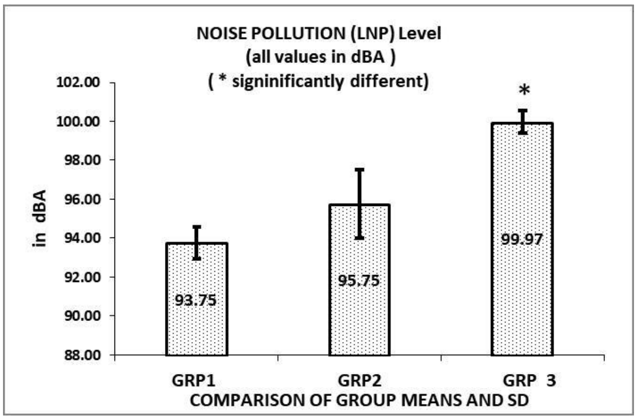

Figure 3: Noise Pollution Level

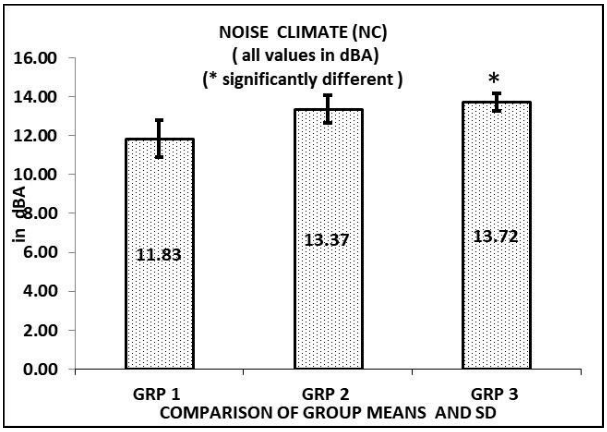

Figure 4: Noise Climate

All these are locations are above grade and elevated from the ground with vehicles with spot speeds ranging from 40- 65 km/hr. Whereas at grade locations of Grp.1 and 2 with lower spot speeds ranging from 20-40 km/hr. have lower L90 mean levels. In Group 3 it is further observed that the locations have the highest values of noise descriptors L10, L50, Leq and Laeq with smaller standard deviations ranging from ±0.90 for L10 to ± 1.68 dB(A) for L90; whereas Grp 3 and have larger standard deviations. For Grp.1, L10 has a standard deviation of ±3.35 dB(A) and for L90 it is ±5.61 dB(A) while in Grp 2 L10 has a standard deviation ±4.77 dB(A) and for Leq it is ±4.83dB(A) (Fig. 5). The narrow range of deviation implies that the noise levels are found nearer to their mean and therefore values stabilize. , hence the environment remains charged with intense environmenta l noise. From these observed differences , it is evident that the null hypothesis H_o be rejected which was based on assumption that there is no difference between noise levels at all locations and alternate hypothesis H_a to be accepted.

TABLE 2: NOISE DESCRIPTORS AT GRADE (GRP I LOCATIONS)

LOCATION	L10(in dBA)	L50(in dBA)	L90 (in dBA)	Leq (in dBA)	Laeq (in dBA)
1	83.70	75.10	70.49	78.01	80.17
2	83.01	74.00	68.60	77.46	80.32
3	85.01	77.65	71.39	80.74	80.84
4	80.9	73.15	66.99	76.37	77.28
5	87.80	84.10	80.70	84.94	85.06

6	**87.21**	**81.45**	**77.69**	**82.96**	**84.23**
7	**87.20**	**80.20**	**73.90**	**83.15**	**84.30**
8	**91.60**	**85.90**	**82.00**	**87.44**	**87.66**
MEANS	**85.80**	**78.94**	**73.97**	**81.38**	**82.48**
MAX	**91.60**	**85.90**	**82.00**	**87.44**	**87.66**
MIN	**80.90**	**73.15**	**66.99**	**76.37**	**77.28**
STD DEV	**3.35**	**4.74**	**5.61**	**3.91**	**3.37**

* Values in the Table are in dBA

TABLE 3 : NOISE DESCRIPTORS AT GRADE (GRP. II LOCATIONS)

LOCATION	**L10**(in dBA)	**L50**(in dBA)	**L90 (in dBA)**	**Leq** (in dBA)	**Laeq (in** dBA)
9	**80.51**	**73.50**	**67.40**	**76.36**	**77.15**
10	**84.72**	**78.00**	**71.79**	**80.79**	**81.70**
11	**84.11**	**76.50**	**69.19**	**80.21**	**79.72**
12	**80.90**	**73.60**	**68.49**	**76.17**	**77.30**
13	**87.30**	**81.30**	**75.49**	**83.62**	**84.01**
14	**90.30**	**84.30**	**79.80**	**86.14**	**86.50**
15	**93.22**	**86.60**	**79.09**	**89.93**	**88.77**
16	**88.50**	**80.40**	**71.39**	**85.28**	**84.36**
MEANS	**86.20**	**79.28**	**72.83**	**82.31**	**82.44**
MAX	**93.22**	**86.60**	**79.80**	**89.93**	**88.77**
MIN	**80.51**	**73.50**	**67.40**	**76.17**	**77.15**
STD DEV	**4.47**	**4.77**	**4.77**	**4.83**	**4.23**

* Values in the Table are in dB(A)

TABLE 4: NOISE DESCRIPTORS AT GRADE (GRP III LOCATIONS)

LOCATION	**L10(in** dBA)	**L50**(in dBA)	**L90 (in dBA)**	**Leq (in** dBA)	**Laeq (in** dBA)
17	**90.20**	**80.50**	**75.80**	**83.96**	**86.32**
18	**90.64**	**79.60**	**75.38**	**83.48**	**87.16**
19	**91.64**	**82.40**	**77.18**	**85.88**	**88.27**
20	**90.61**	**81.80**	**76.59**	**85.08**	**87.23**
21	**91.91**	**83.05**	**80.00**	**85.41**	**89.03**
22	**91.06**	**82.55**	**79.49**	**84.78**	**87.72**
23	**90.92**	**82.50**	**77.19**	**85.64**	**87.67**
24	**93.00**	**83.80**	**78.57**	**87.27**	**90.56**
MEAN	**91.25**	**82.03**	**77.53**	**85.19**	**88.00**
MAX	**93.00**	**83.80**	**80.00**	**87.27**	**90.56**
MIN	**90.20**	**79.60**	**75.38**	**83.48**	**86.32**
STD DEV	**0.90**	**1.37**	**1.68**	**1.18**	**1.31**

* Values in the Table are in dB(A)

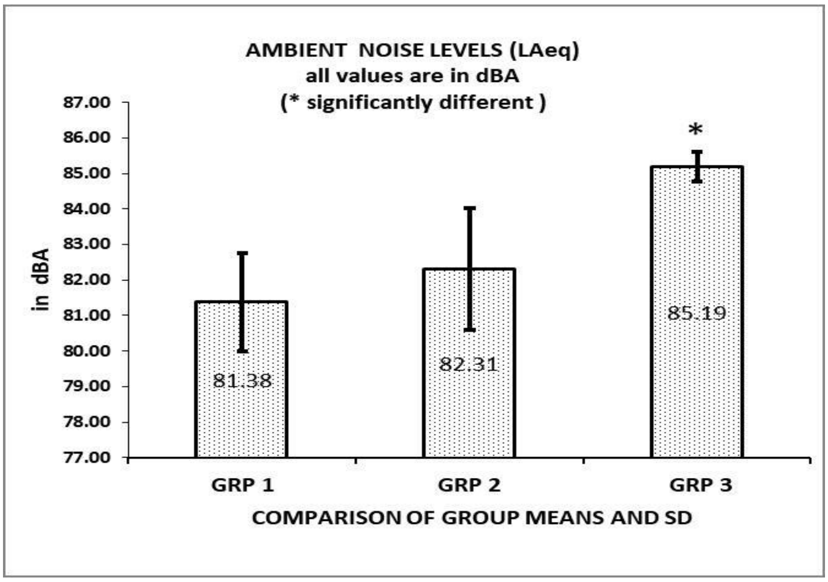

Figure 5: Ambient Noise Levels

The L90, which are the ninety percent exceedance levels or the background range of noise levels were found to be as follows :- for group I they are between 66.99-82 dB(A) , for Group 2 they are between 67.40-79.80 dB(A) and for Group 3 they are between 75.38 – 80 dB(A). Hence variance is the smallest for Group III. However at all locations regardless of other parameters, the noise levels are clearly in excess of the permissible standards for daytime in commercial land use zones as given by the central pollution control board, India which is 65 dB(A)(CPCB, 2010)

ANOVA single factor was conducted to compare the noise levels and descriptors for above and at-grade locations. The ANOVA test was done to test for similarity of means and determine whether there was any significant difference between the three groups. The null hypothesis tested was H_0: $\mu_1=\mu_2=\mu_3$. Statistically, a significant difference was obtained for LNP, TNI and L10 levels.But for L50,L90 levels the null hypothesis was accepted as there was no statistically significant difference at the alpha < 0.05 level for which the test statistics were [$F(2, 23) = 2.52$, $p = 0.104$] and [$F(2, 23) = 1.45$, $p = 0.255$ respectively (Table 5 and Table 6).

TABLE 5: ANOVA SUMMARY FOR ALL GROUPS (L90 LEVELS)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	95.9484	2	47.9742	2.52324	0.104217	3.4668
Within Groups	399.2716	21	19.01293			
Total	495.22	23				

TABLE 6: ANOVA SUMMARY FOR ALL GROUPS (L50 LEVELS)

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F-crit*
Between Groups	45.77688	2	22.88844	1.458538	0.255192	3.4668
Within Groups	329.5472	21	15.69272			
Total	375.3241	23				

The Post hoc comparisons for LNP, TNI and L10 levels was done using the Tukey criterion (HSD), Honest Significant Difference., which is a conservative test and controls the alpha level overall.
The Tukey criterion (HSD) "T "is given in equation 5;

$$T = q_{\alpha(c,n-c)}\sqrt{\frac{MSE}{ni}} \qquad \dots\dots(5)$$

Where $q_{\alpha(c,n-c)}$= Studentized range distribution based on c and (n-c) df.
c= no of treatments /columns
And n = total sample size
MSE= mean square error (from ANOVA table) (within groups).
n_i =sample size of the treatment group with the smallest no. of observations.
For TNI at a significance level of 5% and Studentized range for df1 = 2 and df2 = 21 is 2.941, All Groups have the same number of samples. Tukey Honestly Significant Difference (HSD) is 6.404; Mean of Groups 1 and 2 are similar: 4.98500 <= 6.40408; ** Mean of Groups 1 and 3 differ: 11.11000 > 6.40408 and Mean of Groups 2 and 3 are similar: 6.12500 <= 6.40408.
For LNP at significance level of 5% and Studentized range for df1 = 2 and df2 = 21 is 2.941; All Groups have the same number of samples. Tukey Honestly Significant Difference (HSD) is 3.453., Mean of groups 1 and 2 are similar: 1.99375 <= 3.45265; ** Mean of Groups 1 and 3 differ: 6.21875 > 3.45265 and ** Mean of groups 2 and 3 differ: 4.22500 > 3.45265.
For LNP levels, Group 1, Group 2 and Group 3, F=8, p=0.003. As p<0.05, we reject the null hypothesis as there was no significant difference between groups. But when we look at the difference within groups (1 vs 2, 2 vs 3, 1 vs 3), only Group 1 and Group 3 are significantly different by Tukey's (HSD).
For L10 at significance level of 5% and Studentized range for df1 = 2 and df2 = 21 is 2.941. Tukey Honestly Significant Difference (HSD) is 3.394. Means of Group 1 and 2 are similar: 0.39125 <= 3.39380; ** Means of Groups 1 and 3 differ: 5.44375 > 3.39380 AND ** Means of Groups 2 and 3 differ: 5.05250 > 3.39380.
The Tukey result clearly indicates that Group 3 is different from Group 1 and 2. This further suggests that locational attributes like controlled access lanes, which are Grp. 3 locations where movement of fast moving traffic is possible, register higher noise levels as compared to mixed mode medium and slow traffic locations viz., Grp 1 and Grp 2
It is also evident from figure 3. that while the computed Noise Climate values of Grp 3 and 2 are similar all other noise descriptors are higher for Grp 3 as compared to Grp1 and 2 by 3 to 6 dB(A). This again corroborates the findings that traffic with higher speeds contributes to environmental noise more significantly than traffic with lower speeds.
The other locational attributes had a weaker correlation with all noise descriptors with only "speed" exhibiting the most positive and strong associations with them. Observed spot speeds were found to correlate positively to TNI (+0.56), NC (+0.46), LNP (+0.38). Traffic Noise Index (TNI) also correlated positively with Heights (+0.54) of the locations. The study showed that at the confidence interval of 95%, (p>0.05), two-tailed test and Pearson's r, (when all noise measurements were a free field) the analysis indicates that "speed" as a causative factor is more distinct than any other locational attribute.
The mean noise descriptors viz. TNI, Leq, and LNP for all locations are plotted on a radar graph to explain the variability among locations as well as the exceedance above prescribed levels of CPCB noise standards (Fig 6). From the radar graph which gives a visual summary of the performance of locations, it is clear that Grp. 3 locations record the highest values among all groups.

The ANOVA and Post Hoc Test ($p < 0.05$) corroborate/confirm that higher vehicular speeds, a higher percent of motorized traffic and free flow conditions of mobility are the main contributors to a higher noise energy-charged environment in particular as all of these are distinguishing attributes of Group 3. The Group 3 locations are above grade, have lesser number of lanes with high-speed vehicles plying on them at near free flow conditions by Indian standards.

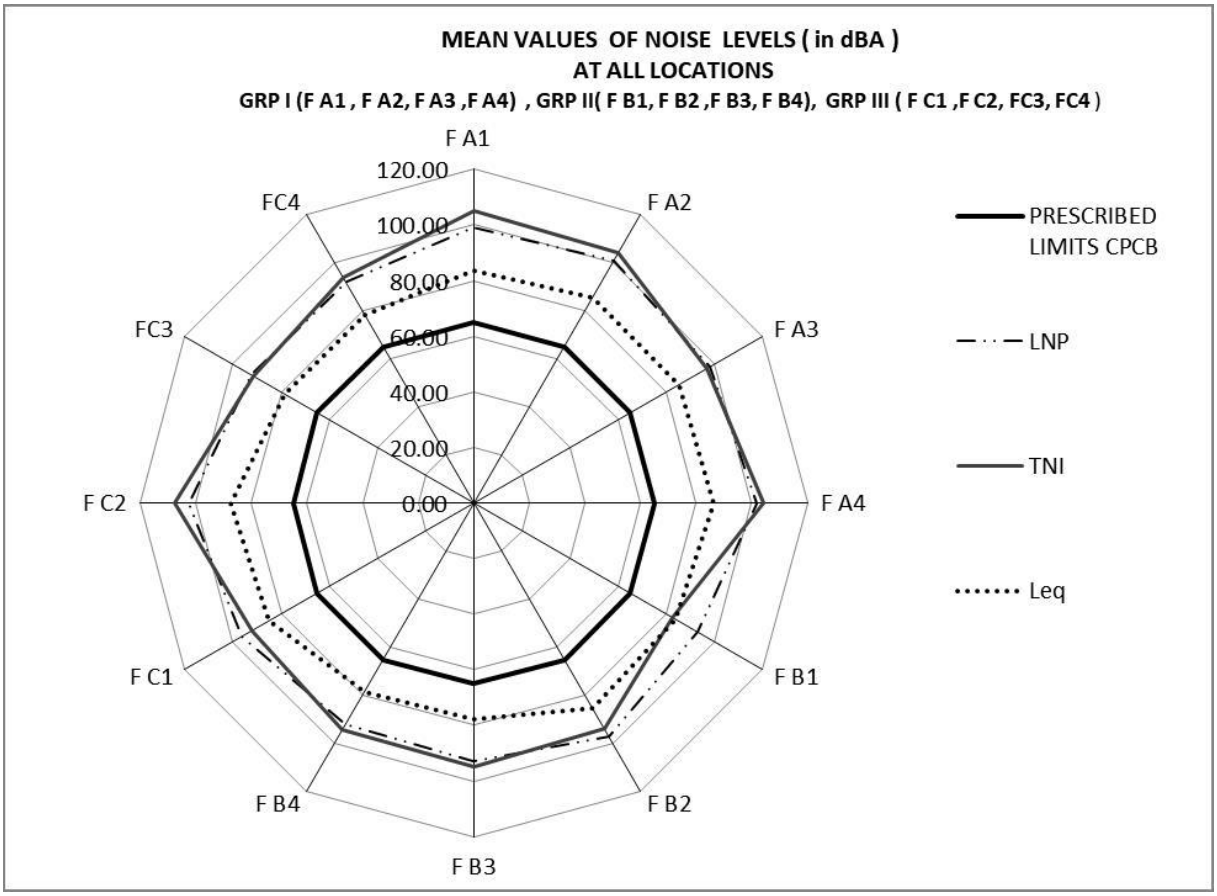

Figure 6: Prescribed limits and mean values of Noise descriptors

The study suggests that the noise environment fluctuates or changes along arterial routes since noise descriptors increase or decrease whenever traffic stream speeds and not necessarily traffic volumes at those locations tended to be higher or lower. In the study volumes at Grp 1 and 2 locations were definitely higher with thrice the number of lanes as compared to Group 3 as they comprised of slow and medium speed modes using them.

Traffic speeds also exhibited a positive correlation with the noise descriptors NC, TNI, and L10. Therefore it can be inferred further that arterials with locations conducive to high speeds would give rise to an environment which is highly noise energy charged and contains more sound energy levels which are potentially risky. The findings further imply that corridors where higher speeds are allowable, like Grade separators, could become high-risk zones throughout their lengths affecting immediate surroundings and mainly vulnerable commuters.

The study demonstrated that environmental noise pollution is a risk that neighborhoods are exposed to, along routes/links abutting fast moving traffic lanes For commuters frequenting these links the risk is more pronounced as the exposure could be almost on a daily basis. Noise as an externality of traffic movement is well established but the role of locational aspects and attributes have rarely been dealt with. The study's main focus was on the arterial segment characteristics which were speeds, the percentage of motorized modes, number of lanes, and access control, a condition conducive to faster mobility.

CONCLUSION

This study was designed to evaluate the environmental noise and elicit common noise descriptors for select locations. The stated study hypothesis was that on arterial links with fast moving traffic noise levels will be higher and vice versa. For comparability in the study urban arterials with grade, separators were selected to establish whether access controlled links were different statistically. ANOVA single factor test was run on observations and computed values of noise descriptors. Three noise descriptors of the groups were critically important and they were also found to be statistically significant hence Turkeys' post hoc test was run to verify and establish group difference. Two results showed that Grp.3 locations were indeed different. The study infers that along urban arterials higher noise levels well above the permissible limits prevail posing a potential risk to road users and its immediate neighbourhoods (CPCB 2010, Berglund et al 1999). Such links are in potential danger of reaching thresholds of intolerance, even pain and therefore would warrant reconsideration before proposing capacity additions such as dedicated lanes. The study corroborates the findings of similar studies which conclude that risk assessment is a major aspect before projects are approved. Hence ex-ante evaluation for impact assessment should be mandatory for new capacity additions being proposed for higher speed modes.

The study has implications and significance for Urban Local Bodies (ULB) or Governments while planning high mobility corridors wherein high speeds are allowed. The impact of noise which is definitely an unwanted externality is rarely taken into consideration since its effects although severe seems to be short-lived as noise levels degenerate as distance increases from the source, unlike other pollutants. ULB's need to plan for and consider encouraging non-motorized transport more they also should conduct thorough environmental evaluations whenever capacity additions are envisaged. Currently, planning capacity additions and grade separators are a trend in most cities in the developing world. Hence for ULBs' planning for improving mobility by contemplating capacity additions or access controlled lanes for faster modes, then there need to be requisite mitigation measures planned as well to minimize exposure of active or passive users to these detrimental noise externalities.

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