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Assessment of Heterogeneous Road Traffic Noise in Nagpur

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The objective of the study is to assess the noise scenario and evaluate prediction model for heterogeneous traffic conditions. In the past few years, road traffic of Nagpur has increased significantly due to the rapid increase in the number of vehicles. Noise levels are monitored at six different squares, characterized as interrupted traffic flow due to traffic signals, high population density and heavy traffic where the major sources of noise are engines, exhausts, tires interacting with the road, horns, sound of gear boxes, breaks, etc. The A-weighted time-average sound levels ($L_{\mathrm{Aeq,\,T}}$) are measured at the different time of day during peak and off-peak traffic hours. To assess the traffic noise more precisely, the noise descriptors such as L_{10}, L_{50}, L_{90}, $L_{\mathrm{Aeq,\,T}}$, TNI (Traffic Noise Index), NPL (Noise Pollution Level) and NC (Noise Climate) are used. In the present study, the Federal Highway Administration (FHWA) noise prediction model is used for prediction of noise levels and it is observed that one-hour duration measured $L_{\mathrm{Aeq,\,T}}$ ranged from 71 to 76 dB(A) and 71.6 to 76.3 dB(A) during peak and off peak hours respectively. Due to the heavy traffic the peak hour Sound Exposure Levels (L_{AE}) at all locations are exceeding permissible limit of 70 dB(A) prescribed by the World Health Organization (W.H.O). Off-peak traffic hour noise levels are within permissible limit except at two locations, Jagnade and HB town square. Significant correlation was obtained when best fit lines generated between measured and predicted values gives R^2 of 0.455 for all time intervals. Chi-Square test (χ^2) was also computed to investigate the noise levels at different squares. The results show that the inhabitants of Nagpur city are exposed to high transportation noise during daytime.

Keywords: traffic noise; Federal Highway Administration (FHWA); Traffic Noise Model (TNM); Prediction Model; A-weighted time-average sound level ($L_{\mathrm{Aeq,\,T}}$); noise pollution.

1. Introduction

Various studies reveal that the road traffic noise is the major contributor of noise pollution in the urban areas. It is a predominant source of annoyance, in developed as well as in developing countries. High levels of traffic noise can adversely affect the health of the people living in close proximity to the road junctions or intersections. Road traffic noise is the major factor which affects the quality of life in urban areas; this is due to rapid increase in road traffic (Patel *et al.*, 2006; Alam *et al.*, 2001). Several studies from different countries have shown that the traffic noise has severe effects on the health of the public living in close vicinity of busy road highways (Calixto *et al.*, 2003; Cowan, 1994; Goines, Hagler, 2007). The various sources of noise that affect the quality of human life and potentially responsible for adverse health effects including physiological and psychological are air craft noise, commercial activities in residential areas, house hold noise etc. Increase in the community noise exposure is unpredictable and it may have direct as well as cumulative adverse health impacts. It also severely affects future generations and causes socio-cultural, aesthetic and economic damages (Tandel *et al.*, 2011).

Investigation of traffic noise prediction is more difficult in Indian cities due to heterogeneous traffic conditions such as mixed vehicles type, congestion, road type, weather conditions and inadequate traffic sense (PPTCOI, 2011; Rajakumara, Gowda, 2009). It can be seen that increasing number of vehicles and rapid growth in industrial and commercial sectors are responsible in a major way for road traffic noise. The major sources of noise are broadly classified as industrial, commercial and traffic, out of this the traffic or vehicular noise affects the human health most adversely (Jamrah *et al.*, 2006). As most of the transportation traffic passes within the boundaries of urban region where a large number of people are exposed to traffic noise as compared with industry noise level. Road traffic noise is the most widespread source of noise in all countries and the most prevalent cause of annoyance and interference. The road traffic noise not only depends on the volume of the vehicles, but also depends on several other factors such as traffic congestion, condition of the vehicle, speed of vehicle, type of road, road condition, honking and percentage of heavy vehicles. The road traffic contributes to about 55% of the total urban noise, most cities in India have been facing serious traffic noise problem in the last few years due to substantial growth in the number of vehicles, construction activity, industrialization and urbanization (Omidvari, Nouri, 2009; Banerjee, Chakraborty, 2006; Goswami, 2009).

Nagpur is among the cities with more than 2 million populations in India. It is located in the centre of the country with the ZERO MILE marker indicating the geographical centre of India. Nagpur is the second capital and the third largest city of the Indian state of Maharashtra after Mumbai and Pune. The population in Nagpur has increased by 35% since last 10 years and a number of personal vehicles have also increased by 45%, what becomes the main reason of insecurity of people while travelling on the road (INDO-USAID, June 2006). Nagpur is the third largest city in the Maharashtra having traffic congestion at different road intersections because of the continuous increase in the level of disparity in transportation demand (Rode, Shewales, 2014). Nowadays, monitoring of environmental parameters in metropolitan areas has become a serious issue due to combustion gases and particulates emitted by vehicles and excessive noise (Czyzewski, Dalka, 2007). The Regional Road Transport (RTO), Nagpur record shows that the increase in light, medium and heavy vehicles per year is 12%, 4.3% and 4% respectively, and that means an increase of nearly 0.146 million vehicles every year and over 400 vehicles, including four wheelers and two wheelers, are registered daily (Nandanwar *et al.*, 2013). Nagpur, being a developing city, has got a traffic density growing at rapid pace. The increasing number of two wheelers, four wheelers along with the public transportation and commercialization of residential areas put a serious question mark on the smooth and congestion free movement of traffic (Batra, Sarode *et al.*, 2013). The number of motor vehicles registered in the Nagpur region during 2005–2006 to 2010–2011 is shown in Fig. 1 (MTSM, 2010–2011).

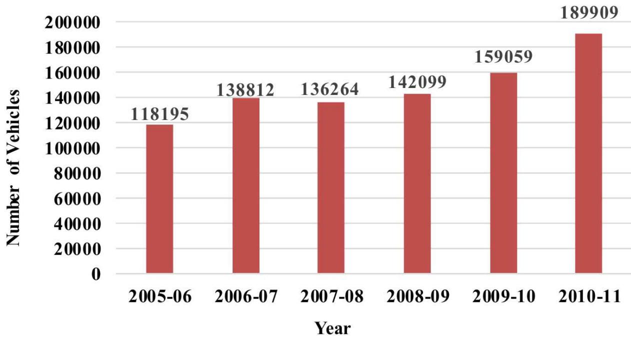

Fig. 1. Vehicles registered during 2005–2006 to 2010–2011 at RTO, Nagpur.

2. Noise prediction

To create a healthy and noise pollution free environment, measuring the L_{AE} and its prediction models are needed so that the noise level along crowded squares can be investigated and forecast in advance during the planning and design process (Ugbebor *et al.*, 2015). Traffic noise prediction models are required as an aid in the assessment of existing or envisaged changes in traffic noise conditions. Most countries have developed their own traffic noise prediction models according to their traffic and environmental conditions such as CoRTN (Calculation of Road Traffic Noise) model of the UK, the Federal Highway Administration (FHWA) model of the USA, the RLS90 model in Germany, the OLA model in Austria, the Statens Planverk 48 model in Scandinavia, the EMPA model in Switzerland, the ASJ model in Japan and the GIS model in China (Rajakumara, Mahalinge Gowda, 2008). However, these models are applicable to straight roads where the vehicular flow is considerably smooth, whereas Indian road traffic is heterogeneous in nature so the mentioned above models must be studied to ensure their validity in Indian traffic condition. In this study, an attempt has been made to investigate the A-weighted time-average sound level ($L_{\mathrm{Aeq,T}}$) at the squares broadly and conclusively by adopting an instrumental measurement technique and prediction modelling methods to represent our study more precisely. As there are no permissible limits prescribed for road traffic noise by the Central Pollution Control Board (CPCB), India, the measured noise levels are compared with tolerance limits for traffic noise prescribed by WHO (Berglund *et al.*, 1999).

3. Materials and methods

$L_{\mathrm{Aeq,T}}$ level was measured as per standard procedure using sound level meter CK: 172B Optimus Green (Cirrus, UK) (AGMAN, 1991). The instrument has an ability to measure the noise from 20 dB(A) to 140 dB(A) with resolution of 0.1 dB and up to 143 dB(C) peak in a single span.

3.1. Study area and data collection

Extensive surveys were conducted at various squares in Nagpur city to optimize the nature of noise pollution, maximum traffic volume and crowded squares, and six strategic locations were identified: Medical square, Ram Nagar square, Indora square, RBI square, Jagnade square and HB Town square as highlighted in Fig. 2. One-hour duration measurements were taken during three different time intervals, i.e. peak hour 10 am – 11 am (morning), off-peak hour 2.30 pm – 3.30 pm (afternoon) and peak hour 6 pm – 7 pm (evening). L_{AE} level monitoring and measurements were performed in calm climate conditions for precise and accurate readings. Wind speed was invariably recorded during all the measurements at the interval of 15 minutes shown in Table 1. During L_{AE} level measurements the sound level meter was set to its slow response mode; frequency weighting "A"; data logging of the 1 second time interval and was placed 1.5 m above the ground level on a tripod. Road conditions were not the same due to variations in road lanes such as 6 lanes, 4 lanes and 2 lanes. All locations have footpaths on both sides and road divider separates the traffic flow except Ram Nagar Square. Consequently, the distance of a sound level meter from the centre of the road is about 17.5 m, 13 m, 14.5 m, 18 m, 13.5 m, and 15.5 m, respectively, and 3 to 4 m away from building facades of nearby roads. Parameters such as temperature, relative humidity and wind speed were also monitored and recorded during L_{AE} level measurements. Statistical analysis was performed to assess the impact of the diverse conditions of traffic noise based on the relationship between traffic volume, other noise descriptors and noise data. The vehicles were counted during the measurement period and were classified in six categories as Scooter/Motorcycle, Auto-Rickshaw, Car/Jeep/Van, Heavy Trucks and Bus as required in the FHWA model (Bhattacharya *et al.*, 2001).

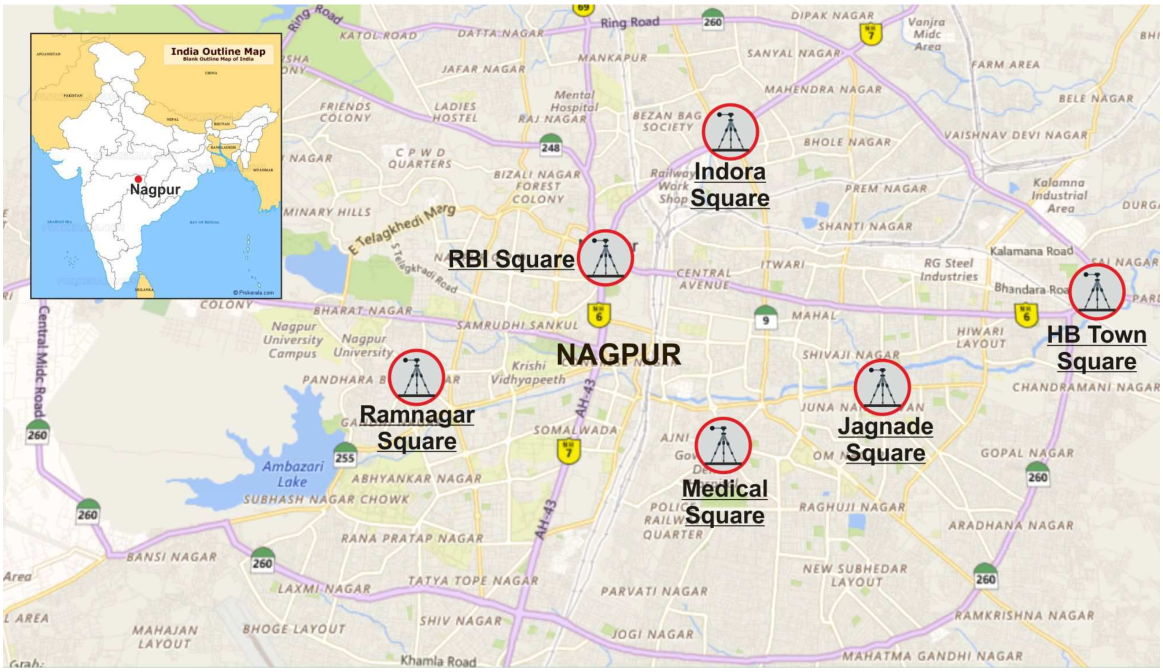

Fig. 2. Map of a study area sowing different monitoring locations in Nagpur.

Table 1. Weather conditions at the selected locations during measurement periods.

Location	10.00 am – 11.00 am			2.30 pm – 3.30 pm			6.00 pm – 7.00 pm		
	Wind speed [m/s]	Temp. [°C]	Relative humidity [%]	Wind speed [m/s]	Temp. [°C]	Relative humidity [%]	Wind speed [m/s]	Temp. [°C]	Relative humidity [%]
Medical Sq.	2.5	46	15	3.6	47	14	1.9	39	24
Ram Nagar Sq.	3.1	46	16	3.6	47	15	2.5	39	24
Indora Sq.	3.1	40	29	1.9	46	15	1.7	45	15
RBI Sq.	2.5	43	25	3.1	46	15	2.2	44	16
Jagnade Sq.	3.1	42	18	3.1	47	12	0.6	34	17
HB Town Sq.	2.5	45	14	2.5	47	14	1.1	46	16

3.2. Prediction of traffic noise levels based on modelling

In this study the modified version of the Federal Highway Administration (FHWA) model proposed for L_{AE} prediction as per Indian condition (Bhattacharya *et al.*, 2001)is used. The FHWA model predicts the L_{AE} level by making adjustments to the reference sound level. The reference sound level is A-weighted time-average sound level ($L_{\mathrm{Aeq,\,T}}$) of sound which is received from each type of vehicles passing the road side (Bhattacharya *et al.*, 2001). After taking on field measurements the adjustments are made in $L_{\mathrm{Aeq,\,T}}$ level of the sound on the basis of traffic movements, varying distance of receivers from the road, finite length of roadways and shielding effects. The equation for the predicted $L_{\mathrm{Aeq,\,T}}$ as per this model is given as (1)

$$L_{\mathrm{Aeq,\,T}} = 10 \log \sum 10^{L_{\mathrm{eq}i}/10}, \tag{1}$$

where $L_{\mathrm{eq}i}$ is hourly equivalent noise level for each vehicle type given by (2):

$$L_{\mathrm{eq}i} = L_0(E_i) + A_{VS} + A_d, \tag{2}$$

where L_0 is the reference energy mean emission level for each category of vehicle as given in Table 2, and A_d = distance correction which is given by

$$A_d = 10 \log_{10} \left(\frac{D_0}{D}\right)^{1+\alpha}, \tag{3}$$

where D_0 – reference distance taken as 15 m in FHWA model, D – distance from the centre of the line to the measurement point, α – ground cover coefficient taken as '1'. A_{VS} – volume and speed correction given by

$$A_{VS} = 10 \log_{10} \left(\frac{D_0 V}{S}\right) - 25, \tag{4}$$

where V is volume of each category of vehicle in per hour (vehicle/h), S – speed of each category of vehicles (km/h) and A_S – ground covers correction.

After taking the measurement on the field the adjustments are made and finally the combined $L_{\mathrm{Aeq,\,T}}$ is calculated by logarithmic summation (1) of the noise emission value of each vehicle class.

Table 2. Reference energy mean emission level for each category of vehicle.

Category of vehicle	Reference energy mean emission equation (L_0)
Scooter/motorcycle	$L_0 = 59.364 + 0.9317 \log(\mathrm{S})$
Auto-rickshaw	$L_0 = 88.527 - 4.8433 \log(\mathrm{S})$
Car/jeep/van	$L_0 = 68.992 - 0.0796 \log(\mathrm{S})$
Light commercial vehicle	$L_0 = 54.908 + 4.9153 \log(\mathrm{S})$
Heavy truck	$L_0 = 39.012 + 10.074 \log(\mathrm{S})$
Bus	$L_0 = 10.253 \log(\mathrm{S}) + 37.867$

4. Results and discussion

Data collected from six different monitoring locations at three time intervals showed a wide variation of sound exposure levels as depicted in Table 3. Various noise parameters were recorded at different time intervals in order to assess statistical variations in traffic flow conditions. Prevailing weather conditions, wind speed, temperature and relative humidity, were recorded during measurement at all selected locations, as shown in Table 1.

4.1. Data analysis of observed and predicted $L_{\mathrm{Aeq,T}}$

Figures 3, 4 and 5 show the comparative analysis of observed, predicted and permissible limit (of WHO) $L_{\mathrm{Aeq,\,T}}$ during the peak and off-peak hours. It clearly illustrates that the observed and predicted $L_{\mathrm{Aeq,\,T}}$ exceed the permissible limit at all the six locations. In the morning and evening peak hours, the maximum observed $L_{\mathrm{Aeq,\,T}}$ is at Jagnade Square (76 and 76.3 dB(A)) and the minimum is at Medical Square (71 and 71.5 dB(A)). Estimation of $L_{\mathrm{Aeq,\,T}}$ using the FHWA model is well with the error margin of ±2.1 dB(A) for peak hours, whereas for off-peak hours it is ±1.6 dB(A). During the off-peak hours, the maximum observed $L_{\mathrm{Aeq,\,T}}$ is at Jagnade Square (73.9 dB) and the minimum is at Medical Square (69.3 dB(A)).

Table 3. Sound exposure level (dB (A)) variations at different squares at different time intervals.

Location	Levels of noise [dB(A)]																	
	10.00 am – 11.00 am						2.30 pm – 3.30 pm						6.00 pm – 7.00 pm					
	$L_{\min}$	$L_{\max}$	$L_{\mathrm{Aeq,\,T}}$	L_{10}	L_{50}	L_{90}	$L_{\min}$	$L_{\max}$	$L_{\mathrm{Aeq,\,T}}$	L_{10}	L_{50}	L_{90}	$L_{\min}$	$L_{\max}$	$L_{\mathrm{Aeq,\,T}}$	L_{10}	L_{50}	L_{90}
Medical Sq.	63.4	96.8	71.0	72.6	68.2	65.9	60.9	88.4	69.3	71.6	66.9	64.3	64.5	87.7	71.5	74.2	69.7	66.8
Ram Nagar	56.7	96.4	72.3	73.6	68.2	64.8	56.7	93.1	69.4	70.6	65.7	62.5	62.7	96.5	75.2	77.5	70.8	67.6
Indora Sq.	64.2	102.9	75.3	77.1	72.1	68.8	60.5	93.5	70.7	73.1	68.7	64.9	61.1	90.3	71.6	74.0	69.5	66.0
RBI Sq.	54.7	96.3	71.5	73.0	68.5	63.6	56.2	95.8	70.1	72.3	67.5	62.7	59.3	91.9	71.6	73.5	69.1	64.7
Jagnade Sq.	61.4	103.1	76.0	76.6	69.9	66.7	59.6	105.8	73.9	75.1	69.4	65.6	61.4	106.5	76.3	77.2	70.7	67.4
HB Town Sq.	59.8	97.2	73.7	75.3	69.3	65.1	57.9	101.4	73.4	74.0	67.9	63.8	58.2	99.5	73.2	74.8	69.5	65.6

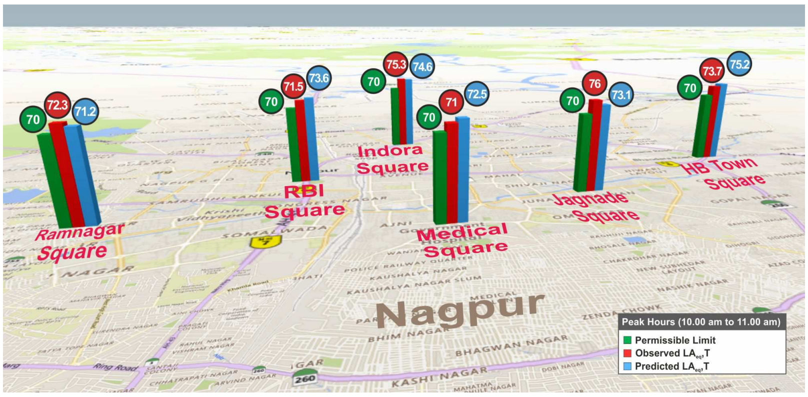

Fig. 3. Comparative analysis of permissible limit, observed and predicted L_{Aeq} during peak hours (10.00 am to 11.00 am).

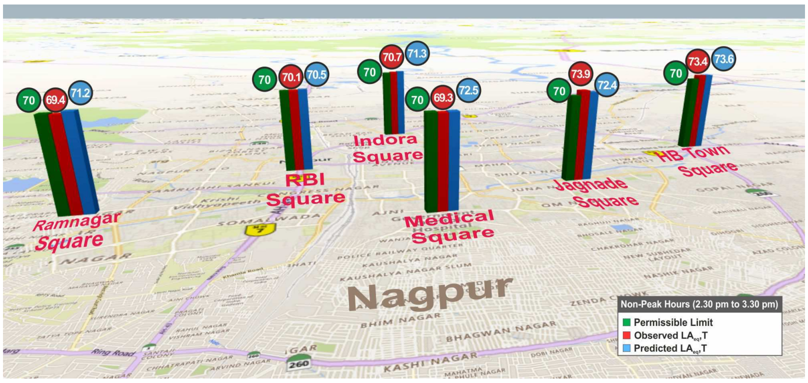

Fig. 4. Comparative analysis of permissible limit, observed and predicted L_{Aeq} during non-peak hours (2.30 am to 3.30 am).

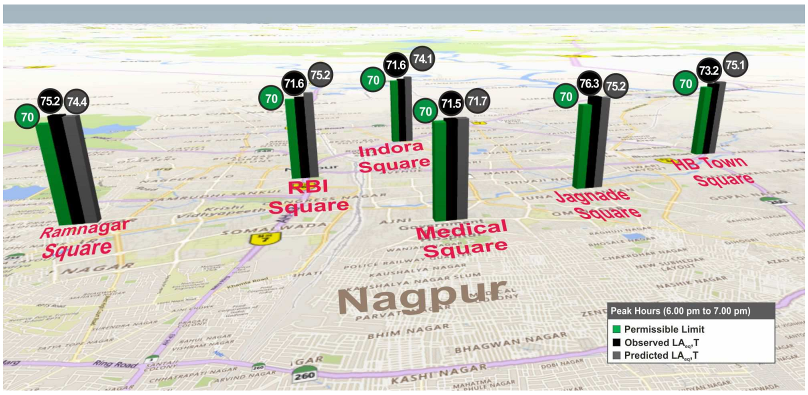

Fig. 5. Comparative analysis of permissible limit, observed and predicted L_{Aeq} during peak hours (6.00 pm to 7.00 pm).

4.2. Analysing noise pollution parameters

$L_{\mathrm{Aeq,\,T}}$ is the measure of the average sound pressure level during a period of time, but it is not a sufficient descriptor of the annoyance caused by fluctuating noise. While estimating noise pollution, apart from the variation in sound levels and degree of variation in a traffic flow, following descriptors are equally significant and are calculated as given in Eqs. (5)–(7) (ENM-B&K, n.d.).

$$\mathrm{NPL} = L_{\mathrm{Aeq,\,T}} + a\,(L_{10} - L_{90})\,, \tag{5}$$

where $a = 1.0$ (constant in the equation),

$$\mathrm{TNI} = 4\,(L_{10} - L_{90}) + L_{90} - 30\ \mathrm{dB(A)}, \tag{6}$$

$$\mathrm{NC} = (L_{10} - L_{90}). \tag{7}$$

The Sound Exposure Level variations $L_{\min}$ and $L_{\max}$ for each location, during peak hours (10 am –

11 am) ranged from 54.7 to 103.1 dB(A). The measured L_{AE} for L_{10}, L_{50}, and L_{90} ranged from 72.6 to 77.1 dB(A); 68.2 to 72.1 dB(A); 63.6 to 68.8 dB(A) respectively as shown in Table 3. The measured $L_{\mathrm{Aeq,T}}$ ranged from 71 to 76 dB(A) while predicted $L_{\mathrm{Aeq,T}}$ ranges from 71.2 to 75.2 dB(A). The noise descriptors such as NPL, TNI and NC ranged from 77.7 to 85.9 dB(A); 62.7 to 76.3 dB(A) and 6.7 to 10.2 dB(A) respectively as shown in Fig. 6.

During off-peak hours (2.30 pm – 3.30 pm), minimum and maximum Sound Exposure Level ranged from 56.2 to 105.8 dB(A). Noise parameters L_{10}, L_{50}, and L_{90} ranged from 70.6 to 75.1 dB(A); 65.7 to 69.4 dB(A); 62.5 to 65.6 dB(A) respectively as shown in Table 3. The $L_{\mathrm{Aeq,T}}$ measured ranged from 69.3 to 73.9 dB(A) and predicted values were between 69.9 to 73.6 dB(A). The noise descriptors such as NPL, TNI and NC ranged from 76.6 to 83.6 dB(A); 63.5 to 74.6 dB(A) and 7.3 to 10.2 dB(A) respectively as shown in Fig. 7.

Similarly, during peak hours (6.00 pm – 7.00 pm), minimum and maximum Sound Exposure Level ranged from 58.2 to 106.5 dB(A). Measured Sound Exposure Level for L_{10}, L_{50}, and L_{90} ranged from 73.5 to 77.5 dB(A); 69.1 to 70.8 dB(A); 64.7 to 67.6 dB(A) respectively. The measured $L_{Aeq,T}$ ranged from 71.5 to 76.3 dB(A) while predicted $L_{\mathrm{Aeq,T}}$ ranged from 71.7 to 75.2 dB(A). The noise descriptors such as NPL, TNI and NC ranged from 78.9 to 86.1 dB(A); 66.4 to 77.2 dB(A) and 7.4 to 9.9 dB(A) respectively as shown in Fig. 8.

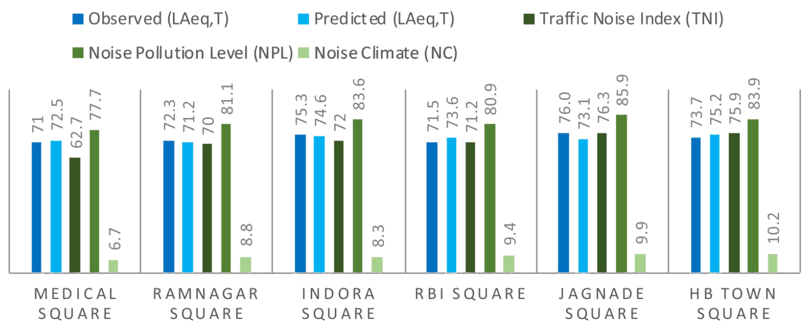

Fig. 6. Comparative analysis of observed and predicted $L_{\mathrm{Aeq,T}}$ with noise pollution parameters during peak hours (10.00 am to 11.00 am).

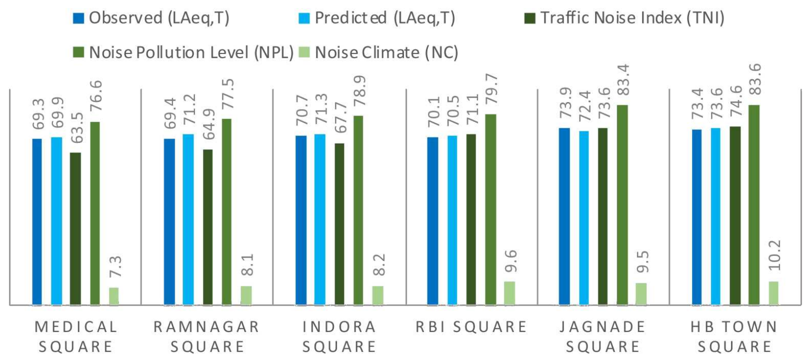

Fig. 7. Comparative analysis of observed and predicted $L_{\mathrm{Aeq,T}}$ with noise pollution parameters during non-peak hours (2.30 am to 3.30 am).

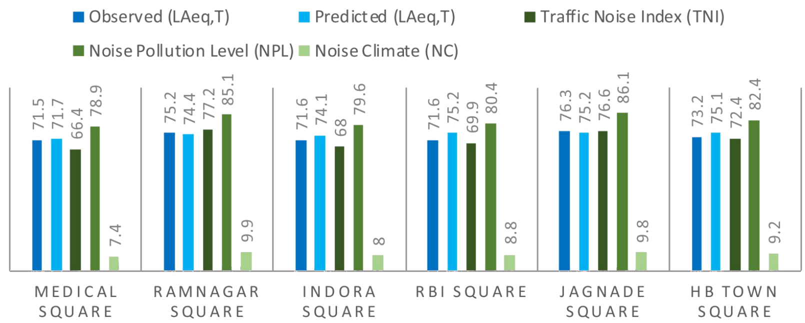

Fig. 8. Comparative analysis of observed and predicted $L_{\mathrm{Aeq,T}}$ with noise pollution parameters during peak hours (6.00 pm to 7.00 pm).

Table 4. Measured and predicted equivalent noise levels L_{Aeq} at different squares at different time intervals.

Locations	10.00 am – 11.00 am		2.30 pm – 3.30 pm		6.00 pm – 7.00 pm	
	Predicted	Observed	Predicted	Observed	Predicted	Observed
Medical Sq.	72.5	71.0	69.9	69.3	71.7	71.5
Ram Nagar Sq.	71.2	72.3	71.2	69.4	74.4	75.2
Indora Sq.	74.6	75.3	71.3	70.7	74.1	71.6
RBI Sq.	73.6	71.5	70.5	70.1	75.2	71.6
Jagnade Sq.	73.1	76.0	72.4	73.9	75.2	76.3
HB Town Sq.	75.2	73.7	73.6	73.4	75.1	73.2

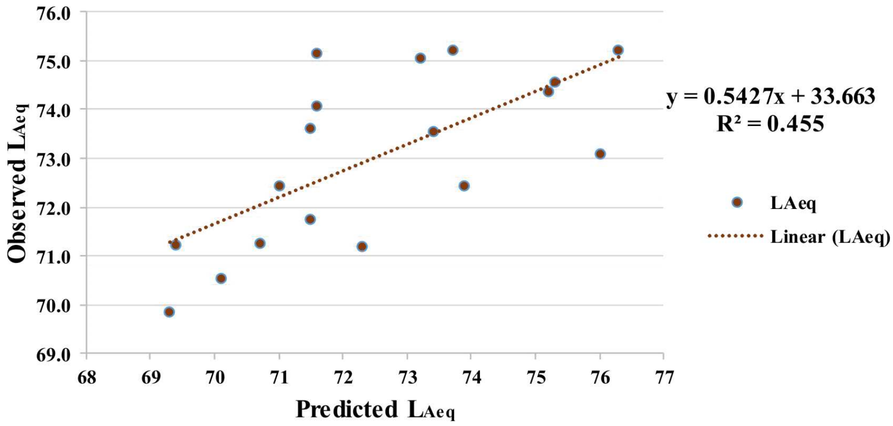

Fig. 9. Correlation between observed and predicted $L_{\mathrm{Aeq,\,T}}$ for morning, afternoon and night hours.

After analysing the above, it clearly shows that the measured $L_{\mathrm{Aeq,\,T}}$ level, for all the locations, was more than the permissible prescribed limit (70 dB(A) for road traffic noise of WHO) during all peak and off-peak time intervals except at Medical and Ram Nagar square during non-peak hour (Swain *et al.*, 2012). In most of the measuring sites, there were more vehicles in peak hours, especially during evening hours (6.00 pm – 7.00 pm) (Figs. 4–6). It is also observed that the $L_{\mathrm{Aeq,\,T}}$ level was high when the numbers of vehicles was higher, which was predominantly found in the morning and evening peak hours. TNI levels were lower when compared with the $L_{\mathrm{Aeq,\,T}}$ for all selected locations which reveals the presence of wider roads leads smooth traffic flow, implying the fact that event fluctuations affect less the values of different noise percentile levels and consequently the TNI (Krishna Murthy *et al.*, 2007) (Figs. 6–8).

4.3. Chi-square test for goodness of fit

The Chi-square (χ^2) test was conducted for goodness of fit between observed and predicted values. The calculated χ^2 is 0.13, 0.04 and 0.12 for different time interval, 10 am – 11 am; 2.30 pm – 3.30 pm and 6.00 pm – 7.00 pm. The alpha level (a) was considered as 0.05 for this experiment and degrees of freedom is 5.

- The P (Cumulative probability) value for a time interval, 10 am – 11 am is 0.003.
- The P (Cumulative probability) value for a time interval, 2.30 pm – 3.30 pm is 0.
- The P (Cumulative probability) value for a time interval, 6.00 pm – 7.00 pm is 0.003.

Since all the calculated P values are less than the alpha level, the null hypothesis can be rejected and it can be concluded that there is a relationship between observed values and predicted values. The predicted and observed L_{Aeq} during all the measurement period at all the selected sites are as shown in Table 4. Figure 9 shows the best fit lines generated between observed and predicted values for this model, and gives correlation coefficients R^2 as 0.455, for all time intervals.

5. Conclusion

The present study has attempted to implement and evaluate the validity of the FHWA model for heterogeneous road traffic, as most of the Indian cities have interrupted traffic flow conditions. Estimation of $L_{\mathrm{Aeq,\,T}}$ using the FHWA model is well with the error margin of ±2.1 dB(A) for peak hours, whereas for off-peak hours it is ±1.6 dB(A). Based on the data it can be concluded that the FHWA regression model can be used for traffic noise prediction on Indian road conditions. Although its accuracy may vary with respect to the level of accuracy obtained while computing the basic simulation parameters like traffic volume, distance between source and receiver as well as the type of ground surface. The data recorded during all the measurement sites explicitly revealed that sound exposure levels are high as compared to the WHO prescribed limits, the average continuous noise level is increased up to the 4 dB(A) except at Medical and Ram Nagar square during non-peak hours. It also clearly depicts that the transportation sector is one of the major contributors of urban community noise. Measured and calculated noise parameters show higher levels for all investigated locations in the study area. Mostly squares are surrounded by many educational institutes, commercial complexes, hospitals and residential areas, thus the inhabitants of these areas are exposed to high noise levels. With the growing economic activity, it is necessary to plan for the infrastructure development so as to support the growth of the city; one of the major impacts of economic development will be increased traffic on the city roads. Hence, the noise control policies are necessary to control the vehicular congestion in the Nagpur city to avoid the negative effect of noise pollution on the environment and on the human being. Control measures can include conducting public awareness programmes, installation of noise barriers between the noise transmission paths to attenuate noise levels. Other measures such as implementation of vegetation belt at appropriate places can prove as effective noise barrier.

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