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Evaluation and Forecasting of Highway Traffic Noise in the City of Nagpur, India

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Abstract: The noise levels in Indian cities are largely affected due to increase in the number of vehicles and growth of the transportation sector in the past few years. Transportation is crucial owing to Nagpur's strategic location in central India. The City is linked with four metros Viz. Mumbai, Delhi, Kolkata and Chennai through roads, rails, and air. It's also a major conjugation for roadways as India's two national highways, Hajira-Kolkata (NH-06) and Kanyakumari-Varanasi (NH-07) are passing through the city. The main objective of this study is to assess and predict the traffic noise levels of uninterrupted traffic flow on prominent highways, and an attempt has been made to develop noise maps to represent an overall noise scenario of the city. Noise modelling and prediction are performed using a modified Federal Highway Administration (FHWA) model. Substantial correlation has been obtained between the measured and estimated noise levels, which gives R^2 of 0.503 having an error band of ± 3.8% with respect to the observed noise levels. Octave band spectral analysis reveals the dominance of noise emission levels in the medium and high-frequency range. This study perceives the observed equivalent noise levels at all the locations during the day and night hours exceeds up to 7.8 dB and 19.6 dB respectively, when compared with the permissible limits prescribed by National standard and signifies that the FHWA model is suitable for Indian road traffic conditions.

Keywords: *FHWA model, National Highway, Noise maps, Noise Prediction, Spectral analysis*

1. Introduction

Presently, all the rising nations like India are encountering the menace of vehicular noise due to continuous increase in highway traffic flow. Traffic noise is one of the environmental pollutants come across in our daily life and is a common reality in various Indian cities, including Nagpur. According to the 2001 census, the population of this city was more than 20 lakhs and since last 10 years, it has increased by 35% and subsequently personal vehicles were augmented by 45%. The Regional Road Transport (RTO), data reveals that about 400 vehicles comprising heavy, medium and light are registering every day. The research described in this study aims to assess and predict the noise impact on environment by applying numerous approaches. Many highways are going through the residential and commercial areas due to limited availability of land resources, which increase the vehicular noise in urban areas leading to environmental issues. It adversely affects the health of people physiologically and psychologically living in proximity to these highways [1, 2, 3 and 4]. Traffic noise along highways is inclined to be prevailing source of noise in urban areas contributing to 55% of the entire noise, most of the highways, there is mingled traffic with large variation in traffic volume, speed, road surface and other traffic related parameters [5, 6 and 7]. The Automobiles, industries, highway transport, airports, railways and public address system are major sources of noise pollution; it adversely affects the human being leading to irritation, loss of concentration and loss of hearing [8].

The public transport is the Primary mode of movement for most of the population in India and is among the most heavily used in the world, presenting the production of vehicles in this sector rapidly rising over 4.6 million annually and envisages the huge increase in the intensity of vehicles in future days. Many researchers have investigated the noise level for various Indian cities, some of these are mentioned in this study.

Vijay et al. (2015) analyzed the traffic noise in Nagpur city at three different roads and reported that the honking induced an extra 2 to 5 dB noise over and above traffic noise [9]. Rode et al. (2014) studied the traffic condition on the ring road of Nagpur city and observed the equivalent noise level at eight intersections, it perceives that the average noise level during the day and night interval is about 84.3 dB & 95.8 dB respectively [10]. Soni et al. (2012) examined that the traffic noise along a highway corridor on NH-28 going through Gorakhpur city [11]. and Mishra et al. (2014) Evaluates on NH222 passing near Kalyan City, Maharashtra at different sampling locations, both had analyzed the road traffic noise using the FHWA model and reported that the noise level exceeded the permissible levels and lie within an error band of ±10% compared to observed values [12].

Similar studies were performed by Mishra et al (2010), Shukla et al. (2009) and Shalini et al. (2014) for different cities in India using the FHWA model for prediction of traffic noise on (bus rapid transit system) BRTS corridor of Panchsheel enclave, South Delhi; Lucknow and Varanasi respectively and concludes higher noise levels than the prescribed limits [13, 14, and 15]. Agarwal et al. (2009) developed a noise prediction model for Jaipur city, a new factor tendency to blow horn was introduced in the conventional FHWA model and comparative study was done. In the study, modified FHWA model shows acceptable results with a deviation of 3 dB and gives significantly higher correlation coefficient value and therefore, resolved that the considered modified model can be applied under interrupted traffic flow conditions in urban areas [16]. The investigation of Balashanmugam et al. (2013) at Chidambaram town reported that the honking, flows of ill-maintained vehicles and poor road conditions that cause traffic congestion were found to be the reasons for high noise level [17]. Tandel et al. (2013) also reveal the exceeded noise levels in his study conducted for major arterial roads in Surat city of Gujrat [18].

Kalaiselvi et al. (2012) has established a new regression model conceiving different geometrical parameters and local metrological conditions to assess the traffic noise of Chennai city. The Study reveals that the horn noise will increase the Leq by 12 dB having frequency of 16 per minute [19]. Garg et al. (2014); (2015) performed the comparison study of the principal traffic noise models developed and adopted in several countries and concluded that a harmonized methodology along with a simple and less time consuming approach in conjunction with uncertainty calculations shall be more suitable for town planners and urban authorities for traffic noise predictions. Another study compares the multiple linear regression and Artificial Neural Network approach for their appropriateness for traffic noise modelling and predictions in Delhi city shows that *ANN* does better than the *MLR* models developed in terms of entire and equivalent traffic flow [20-21].

The above mentioned studies reveal the fact that heavy vehicles moving on the road have a substantial impact on noise. It was found that the FHWA model is relevant for the traffic noise prediction in India with a fair degree of accuracy. However, most of the preceding studies, particularly in Nagpur, noise assessments were conducted inside the city limit; nevertheless, the traffic flow distribution of major highways towards urban cities was so far neglected. Therefore, the main aim of the present study is to evaluate and predict the noise levels with the help of modified FHWA Model on highways for locations out of the municipal limit area, and attempt has been made to represent an overall noise scenario of the city in the form of contour maps by utilizing noise data from previous literatures [22].

2. Materials and Methods

2.1 Survey of Field

The detail summary was carried on various highways passing through the Nagpur city and based on maximal traffic flow, three major national highways were selected, namely NH-6 (Amravti road), NH-7 (Wardha road) and NH-69 (Chinwada road) which lies between 21°05' to 21°11' N latitude and 79°00' to 79°04'E longitude in Nagpur city. (Fig. 1).

2.2 Traffic Noise Measurements and Data Compilation

Noise measurement duration was 60 minutes for all sampling sites and performed using a sound level meter CK: 172B (cirrus, UK) complying to international standards. Before measurements, sound level meter was appropriately calibrated using a standard calibrator (CR:514).

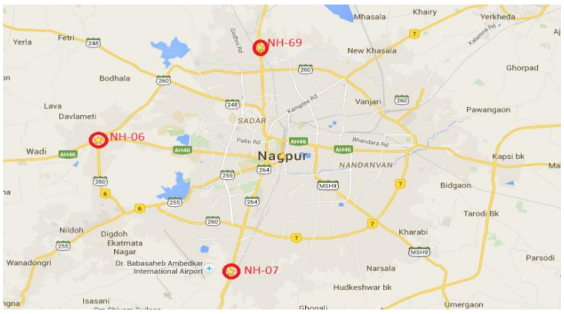

Fig 1: study map of selected national highways passing through the Nagpur city

When calibrating a microphone, a small correction of -0.3 dB may be necessary to compensate for the difference between the microphone free field response at zero degrees and the pressure level generated by the calibrator for making the effective calibration level of 93.7 dB. Windshield foam (90 mm) is utilized over the microphone capsule during measurements to minimize the noise level generated by turbulence. The standard range of the instrument for measurement of noise is from 20 dB to 140dB. Noise levels were estimated at 1.5m distance from the base by using a tripod with fast time weighting mode having 'A' frequency weighted and set the time history data rate 1 second as a default. Implementation of frequency analysis is carried out to determine the overall noise level distribution over a range of frequencies from 20 Hz to 20 KHz, as the human ear is capable of hearing a sound between these ranges. Parameters such as temperature, relative humidity and wind speed were also monitored during noise measurements to obtain a good estimation of noise levels. The Wind speed was below 5 m/s throughout the measurement. Vehicles were counted manually at all the locations during the measurement period. The spot speed measurement was acted physically by marking the two points on the road with a known distance and using a stop watch, a time was recorded for each selected class of vehicles to travel the distance between two points, dividing the distance with time, speed in km/h for each type of vehicle was calculated.

Road geometrical dimensions in terms of road width, carriageway width, number of lanes, etc. were also measured for all the three highways NH-6, NH-7 and NH-69 to optimize the distance for recording noise levels.

Consequently, the distance of sound level meter is about 10.7, 15 and 15.8 meters respectively from the Centre line of the road and about 4 meters space from the building facades. The diagrammatic representation of typical road dimensions considered is as shown below. (Fig. 2).

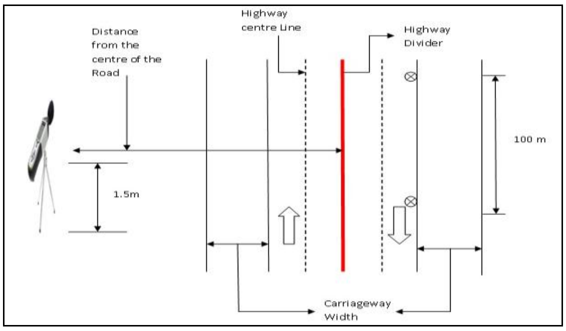

Fig 2: *Pictorial representation of noise monitoring*

3. Prediction using Modelling

The prediction of noise level is accomplished by using modified FHWA model as per Indian circumstances. Vehicles were separated into six classes; the Leq value for each class of vehicles is computed using the following expression [23].

$$Leqi = L_0 + A_{VS} + A_D + A_S \qquad (1)$$

Leqi = Hourly equivalent noise level for each vehicle type; L_0 = the reference energy mean emission level; A_D = Distance correction; A_{VS} = Volume and speed correction; A_S= Ground covers correction

The reference energy mean emission level for each of six vehicle classes was estimated, and these individual noise emission equations were used in the calculation for the prediction of equivalent noise levels. (Table 1).

The distance, volume and speed correction were determined by following formulae [24].

$$Ad = 10\log_{10}(D_0/D)^{1+\alpha}$$

Where, Do– 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.

$$A_{vs} = 10\log_{10}(D_0V/S) - 25$$

Where, V – volume of vehicles in each category in the veh/h; S – speed in km/h; Do – reference distance First Equivalent noise level for each vehicle class was computed. (Refer Equation 1); then logarithmically calculated, the total hourly Leq and finally combined Leq is calculated by logarithmic summation of the noise emission value of each vehicle class by following equation.

$$Leq = 10 \log \Sigma 10^{Leqi/10}$$

Table 1*: noise emission equation for each category of vehicle*

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

4. Results and Discussion

Table 2 & 3 summarizes various parameters collected at each selected location for different measurement periods. The study area was subjected to overflow of huge traffic throughout the day. The field observations and collected data are statistically analyzed and discussed in this section. The different effective noise parameters such as L_{eq}, $L_{max,}$ $L_{min,}$ and the noise levels exceeding 10%, 50%, and 90% in the measurement duration i.e L_{10}, L_{50} and L_{90} were recorded to determine the extent of noise pollution in the selected sites. While computing L_{eq}, succeeding parameters such as noise level fluctuation and level of variance in the traffic stream is substantially responsible and is evaluated by below expressions.

Table 2: *Noise level gathered at all the National highways during the morning hours in dB*

Locations	Lmin	Lmax	Leq	L10	L50	L90	TNI	NPL	NC
NH-06	53.4	100.5	73.7	76.8	69.9	63.1	87.9	87.4	13.7
NH-07	51.8	103.8	74.6	77.5	70.2	63.1	90.7	89	14.4
NH-69	45.3	105	73.1	76.3	65.9	58	101.2	91.4	18.3

Table 3: *Noise data gathered at all the National highways during the night hours in dB*

Locations	Lmin	Lmax	Leq	L10	L50	L90	TNI	NPL	NC
NH-06	55.7	93.5	69.3	71.4	66.4	62.3	68.7	78.4	9.1
NH-07	55	98	72.8	74.8	68.1	62.3	82.3	85.3	12.5

NH-69	51.9	96.3	71.5	74.6	65.6	58.6	92.6	87.5	16

Noise Pollution Level (NPL) = L_{eq} + a (L_{10} – L_{90})

Where,

a = 1.0 (constant in the equation)

Traffic Noise Index (TNI) = 4 (L_{10}-L_{90}) + L_{90} - 30 dB.

Noise Climate (NC) = L_{10}-$L_{90.}$

Based on the obtained results for morning hours L_{min} and L_{max} ranges is from 45.3 to 105 dB; the parameters $L_{10,}$ $L_{50,}$ L_{90} are ranged from 76.3 to 77.5 dB; 65.9 to 70.2 dB and 58 to 63.1 dB respectively. The noise indicators like TNI, NPL, NC ranges from 87.9 to 101.2 dB; 87.4 to 91.4 dB and 13.7 to 18.3 dB respectively. However, during the night, range of minimum and maximum noise level is from 51.9 to 98 dB; the parameters $L_{10,}$ $L_{50,}$ L_{90} are ranged from 71.4 to 74.8 dB; 65.6 to 68.1 dB and 58.6 to 62.3 dB respectively. The noise descriptor, like TNI, NPL, NC ranges from 68.7 to 92.6 dB; 78.4 to 87.5 dB and 9.1 to 16 dB respectively.

It was observed that Leq during the morning and night hours at NH-69, NH-06 and NH-07 range between 73.1 & 71.5 dB, 73.7 & 69.3 dB and 74.6 & 72.8 dB respectively. The Significant difference is not observed between the morning and night noise levels. TNI values were higher than Leq signifies the effect of any single noise event causes an increase in different percentile values and therefore, TNI increases. This is also the indication of deteriorated road condition and vehicular honking effect. Highest measured noise levels observed at NH-06 followed by NH-07 and NH-69 during all measurements. The average noise levels exceeded the permissible noise limit prescribed by National standard for the day (65 dB) and night time (55dB).

Estimated traffic flow for different category of vehicles and their speed have been analyzed using the FHWA model, and it is concluded that the estimated noise levels were underestimated than that of observed values at all the selected highways except NH-07, This may be attributed to the higher vehicle count at NH-07 as compared to other highways. The graphical representation between the predicted, measured and permissible noise level is shown in Fig. 3.

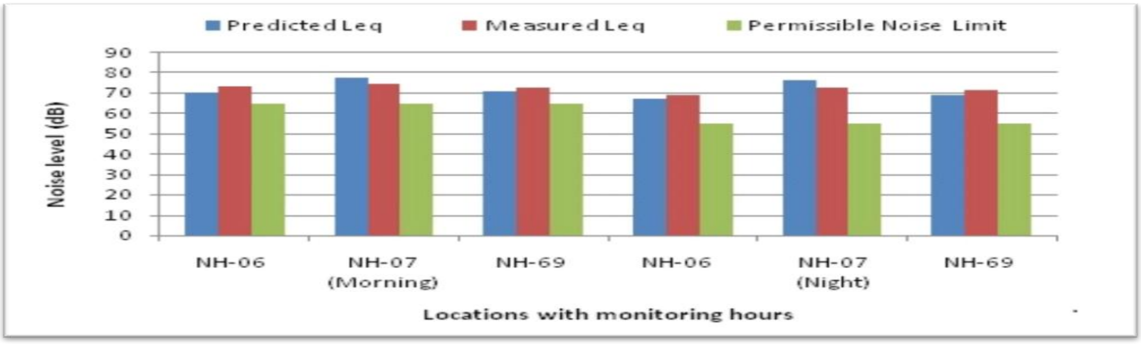

Fig 3: *Comparison graph for measured, predicted and permissible noise limit*

5. Scrutinization of Frequency Spectrum

Octave band analysis is performed to extract detailed information from a complex sound. This is done by recording the octave band sampling data from all the three national highways and estimates the frequency distribution of the noise levels electronically with a sound level meter. Traffic noise spectra during the daytime.

Composed of a mix of vehicle having dominance for the 315Hz- 3.15 KHz except at NH-06 is of 400Hz to 3.15 KHz. However, dominance noise spectra during the night is 315 Hz- 2 KHz at NH-69 whereas at NH-06 and NH-07 highways the frequency distribution for dominance noise levels obtained at 1 KHz- 3.15 KHz and 800 Hz to 3.15 KHz respectively, pointed in Fig. 4. & Fig. 5.

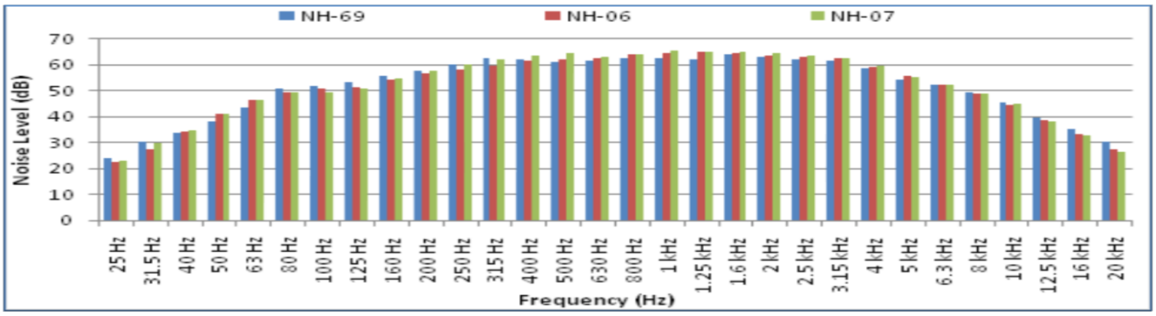

Fig 4: *Spectrum analysis for morning hours*

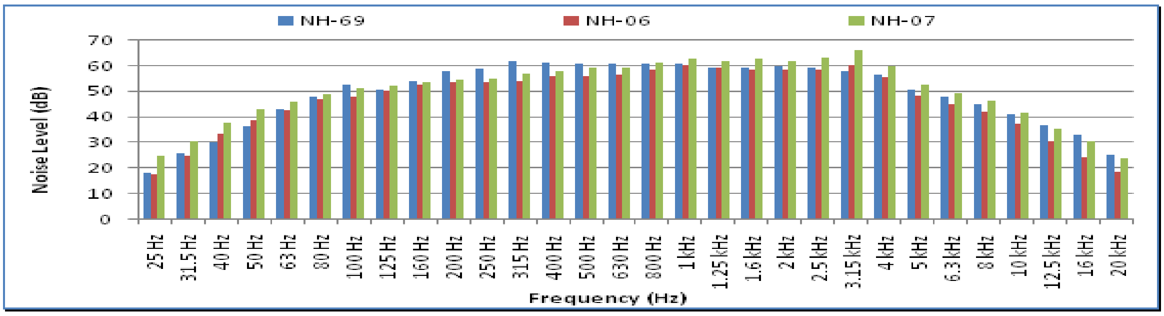

Fig 5: *Spectrum analysis for night hours*

6. Comparative Study

As per reviewed literature, noise is directly proportional to traffic volume, which means that traffic noise rises with an increase in traffic volume [25]. In contrast, at NH-06 conflicting result was obtained for night hours where obtained noise levels are low even though traffic volume was higher compared to daytime as shown in Fig. 6. This may be due to considerably less percentage of vehicle flow found in the category of car/jeep, auto rickshaws and busses as compared to other highways during night hours.

Comparison of forecasted results delineates that the estimated noise levels are nearer to the assessed values, and the best fit line generated between the measured and computed values has a correlation coefficient of 0.503 for this model as shown in Fig. 7. The percentage error is about ± 3.8% between the observed and predicted Leq computed using correlation plot for assuring the stability of this model.

6.1 Contour Maps Depicting Noise Status of Nagpur City

In the present study, an attempt has been made to represent the overall noise scenario of Nagpur city for which recent data from previous studies are utilized and with the help of Surfer software, contour maps were developed as depicted in Fig. 8,9**.** This software model is built on gridding method commonly used in the field of environmental science in which each measured noise level is considered as point source and based on the number of point sources it predicts intermediate values to show their exposure levels**.** The Contour map represents the distribution of noise exposure having contour lines through points of equal elevation. In the noise map, noise levels were classified into four categories, i.e. lower ≤ 65 dB; permissible ≤ 70dB; higher ≤ 80dB and critical > 80dB. It clearly reveals that, the noise levels in Nagpur city for most of the areas, including national highways have reached at higher and critical levels.

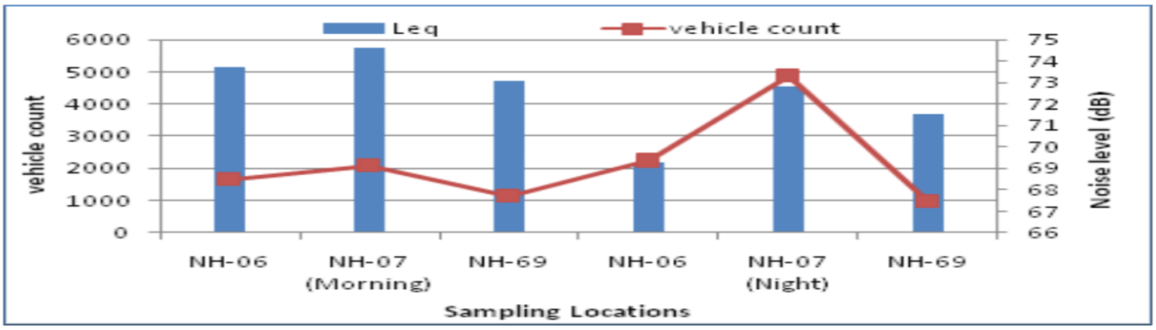

Fig 6: *Vehicle count versus noise level during morning and night hours*

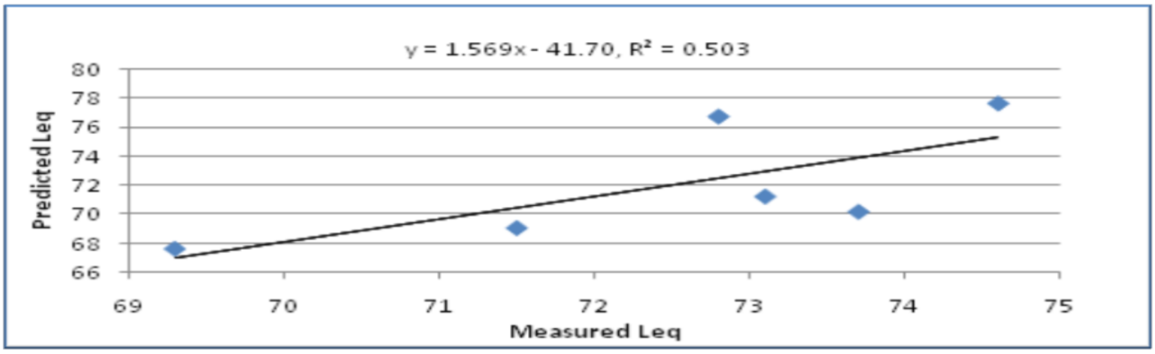

Fig 7: *Correlation plot between predicted and measured equivalent noise level*

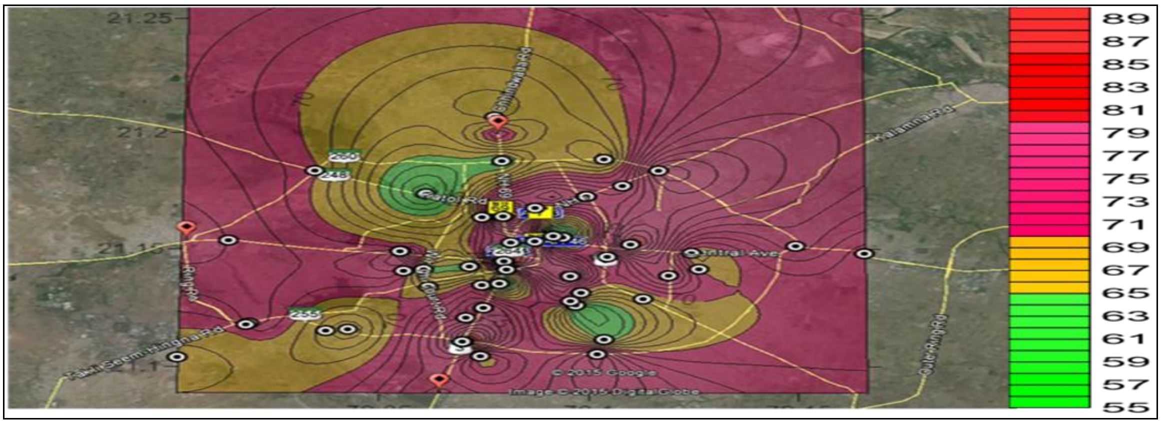

***Fig 8:** Noise map of Nagpur city (morning hours 10 am. - 12 am.)*

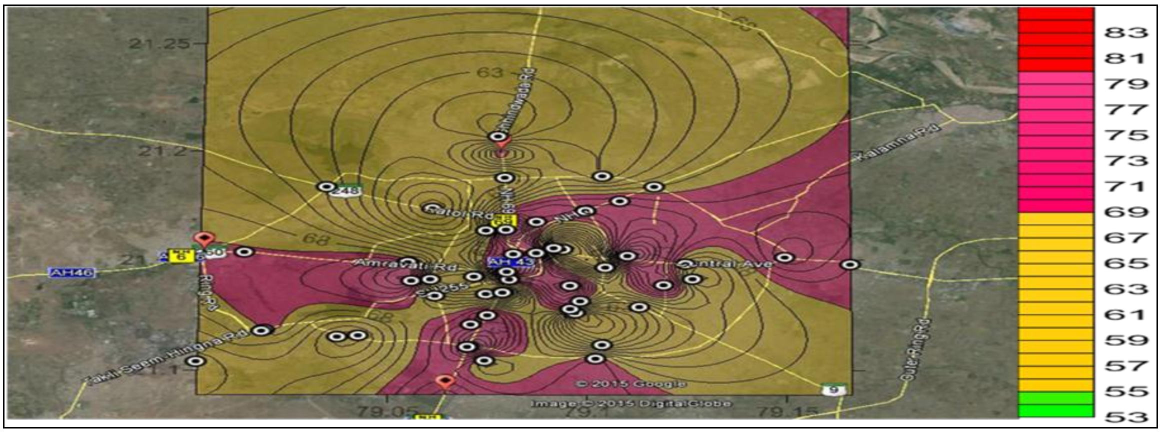

***Fig 9:** Noise map of Nagpur city (night hours 8 pm. – 10 pm.)*

7. Conclusion

Based on such extensive report, the study revealed that the noise level reached at an alarming level in Nagpur city, and it is resolved that the heavy traffic having greater velocity vehicles on these highways and majority of the transportation sector is responsible for the noise level exceeding the national standards. The outcome of the noise map depicted that the noise levels at most of the places in the city reached to critical levels and requires efficient noise control measures to avoid negative effects of noise pollution. The results estimated from the FHWA model are very close to the observed values, hence it can be concluded that this model is applicable for predicting the noise levels in Indian cities with an acceptable limit of accuracy. The recorded noise spectrum for national highways shows the large variation of noise level exists between the medium and high-frequency range. For controlling this undesirable noise, restrictions on the fast running vehicles and continuous stream of traffic flow can be planned as early as possible, especially those highways which are passing through the residential and commercial areas to prevent the adverse effect on the public health and on the environment. Enforcement of more effective regulations are urgently required to reduce the vehicular congestion and its associated noise impacts in the Nagpur city.

8. Acknowledgment

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