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Evaluation and modeling of traffic noise in an urban area of Chhattisgarh, India

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ABSTRACT

Introduction: Traffic noise modeling is a rapidly growing field. Researchers are continually improving existing models and creating new ones that take into consideration complex aspects such as traffic flow patterns and the influence of geography. This study aims to test few models that may be suitable for the Indian scenario along with development of new model.

Materials and methods: In the present study, evaluation and modeling of traffic noise have been carried out. The study was carried out in 20 locations in Raipur city. Half of the locations were selected for validation of results, and half were selected for studying the best-suited model for our selected area. Six models best suited to our location were selected after performing the literature review in brief. Traffic data was collected, and models were tested.

Results: On comparing the data, it was found that out of six models, the Burgess model was found to be the most accurate, as its predicted noise levels are consistently closest to the measured noise levels across all ten locations. But the coefficient of correlation (R) for this model was found to be in the range of 0.31 to 0.64. Burgess model uses the framework of concentric zones to analyse how noise varies based on location within a city, taking into account factors such as land use, population density, and the types of activities prevalent in each zone. Further, we developed our own model by using the multiple regression method and validated our results. On performing the statistical analysis, highest value of R^2 (0.83 and 0.82) were found for locations PL1 and PL8 respectively. Mean Absolute Deviation (MAD) values ranged from 0.859 to 2.175, and Root Mean Squared Error (RMSE) values ranged from 0.884 to 2.203 for all locations.

Conclusion: The high R^2 values, close to 1, and the low RMSE values indicate that our model fits the data well. Therefore, we can conclude that the developed model is highly suitable for predicting noise levels at our location.

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Introduction

One of the major environmental problems in an urban area of a developing country is noise pollution. Road, rail, and air traffic cause noise pollution in large amounts. Road network development is very essential for the economic development of the country, but it also leads to the development of a noisy environment [1, 2]. Among these three major contributors to higher noise levels in the environment is road traffic. The registration of new vehicles on the road is large. Honking of vehicles, traffic congestion, and traffic flow cause noise generation in the ambient environment [3]. Mostly, we feel that noise pollution at the junction is found to be higher compared to the other portion of the road [4]. Noise pollution is a silent killer; very little attention is paid to it compared to other pollution. It affects the exposed population physiologically and psychologically [5, 6]. Due to noise exposure, the population suffers from dizziness, headaches, fatigue, and high blood pressure, which also affects the work performance of an individual [7]. The World Health Organization (WHO) estimates that environmental noise is a major contributor to the global burden of disease. In Europe, traffic noise ranks second only to air pollution as the leading environmental cause of health problems. According to the 2011 WHO report, traffic-related noise is responsible for the loss of over 1 million Healthy Life Years (DALYs) annually in Western Europe. The main contributors to this burden are sleep disturbances and annoyance, followed by cardiovascular diseases, cognitive impairments in children, and mental health issues.

In order to understand the impact of traffic on noise pollution levels in the ambient environment, monitoring of noise levels is a must. Many studies have been carried out globally to monitor and predict noise pollution and investigate its impacts. Many researchers completed a study in Jaipur city and concluded that road noise directly depends on the traffic flow present on the road [8]. From the traffic density data, they found that 72% of two-wheelers, followed by 15% of cars and Jeeps, 12% of three-wheelers, and 1% of the remaining vehicles, are the main sources of noise pollution on the roads. Hence, in the city, light motor vehicles are the main sources of noise. Similarly, other searchers conducted a study in Delhi and concluded that mismanagement of parking, congested roads, and a lack of awareness among the people are major causes of noise pollution in the city [9].

Generally, noise monitoring is done using an instrument called a Sound Level Metre (SLM). However, we can also predict the noise pollution so that proper traffic management can be done. In the era of modern technology, the prediction of noise will provide a better understanding for policymakers and traffic managers with less manpower and time consumption. Researchers performed a study in Curitiba and concluded that the German model RLS-90 fit well for calculating road traffic noise [10]. Also, by using linear regression, mathematical models can be developed for predicting equivalent noise levels. In a research, it was converted the UK calculation of Road Traffic Noise (CoRTN) model by trial and error and made it capable of calculating noise levels for Tehran Road [11]. In Malaysia, researchers proposed a noise model developed by a neural network for predicting and simulating traffic noise [12]. By using multiple regression analysis it was developed a model for predicting noise levels in the Sidney Metropolitan Area [13]. Other researchers carried out a study in Delhi and used the ANN method to develop a noise prediction model suitable for the city and capable of predicting noise levels [14]. Besides these, there are different traffic noise models available in developed countries, but for developing countries like India, there are no authorised models that can help in predicting noise pollution. Since the traffic conditions are different, the road network is different, and due to heterogeneity in the traffic, predicting noise is a tough task. On performing the literature study, we found a few models that may be suitable for the Indian scenario and tested the models that were best suited for our study area. Further, we also tried to develop a new model using the multiple regression method and validated the results between calculated and observed noise levels.

Materials and methods

Study area

Raipur, a city in Chhattisgarh state in India, was selected to perform this study. The city is located in the central part of India at 21° 11’22” N, 21° 20’02” N, and 81°” E, 81°41’50” E and is well connected with rail and road [15]. The expansion of the city is going on very fast; hence, construction activity is going on a large scale. It is also a major commercial hub for trade and commerce in the central region. 10 important locations mostly busy roads with movement of heavy vehicles in the city were considered for the evaluation and 10 different locations were used for validation of developed model. The study area map is shown in Fig. 1.

Data collection

A field survey was carried out to determine the characteristics of traffic in the city. 10 different locations were selected for data collection and 10 different for validation. SLM (BSWA 308 Class 1) was mounted on a tripod stand 1.5 m above ground level, and as per the standard mentioned in ISO 9613, the instrument was installed 7.5 m away from the centre of the road and 3 to 3.5 m away from the reflecting objects [16]. The study was done for 20 days and the noise levels were measured for 1 h at each location, and data was logged every 1 second. These noise levels were used in further data analysis as observed noise levels. Along with this, traffic volume was measured at each location by using a video camera. The road width at each location was measured using a measuring tape. After collecting all traffic data and noise levels, further analysis was carried out in our Environmental Engineering Laboratory at the National Institute of Technology, Raipur (NITRR). Noise levels measured using SLM was retrieved, and the data was exported in Excel format. The process of retrieval of data is shown in Fig. 2.

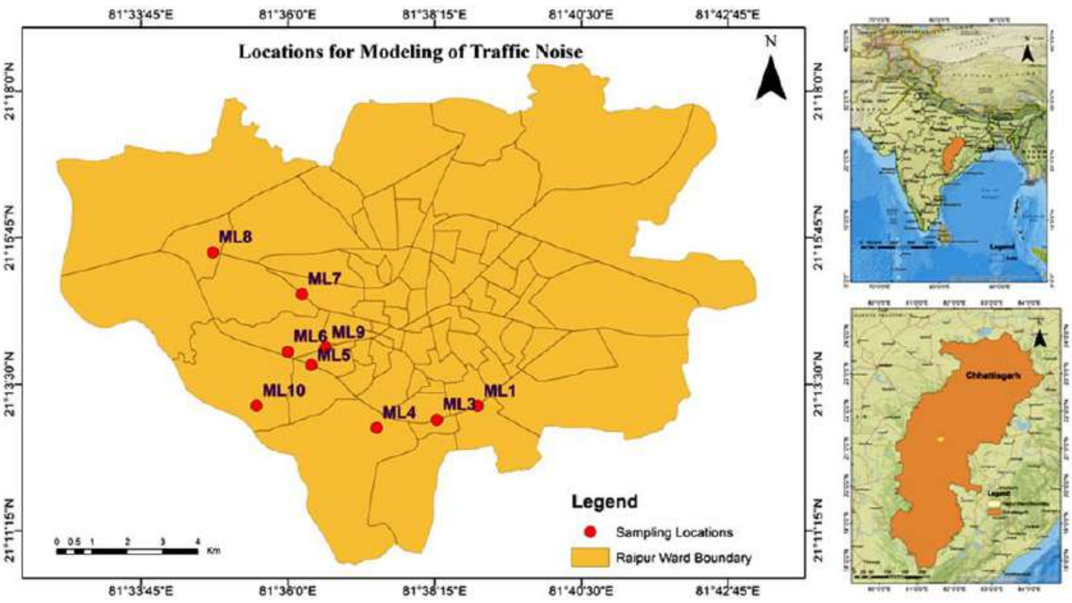
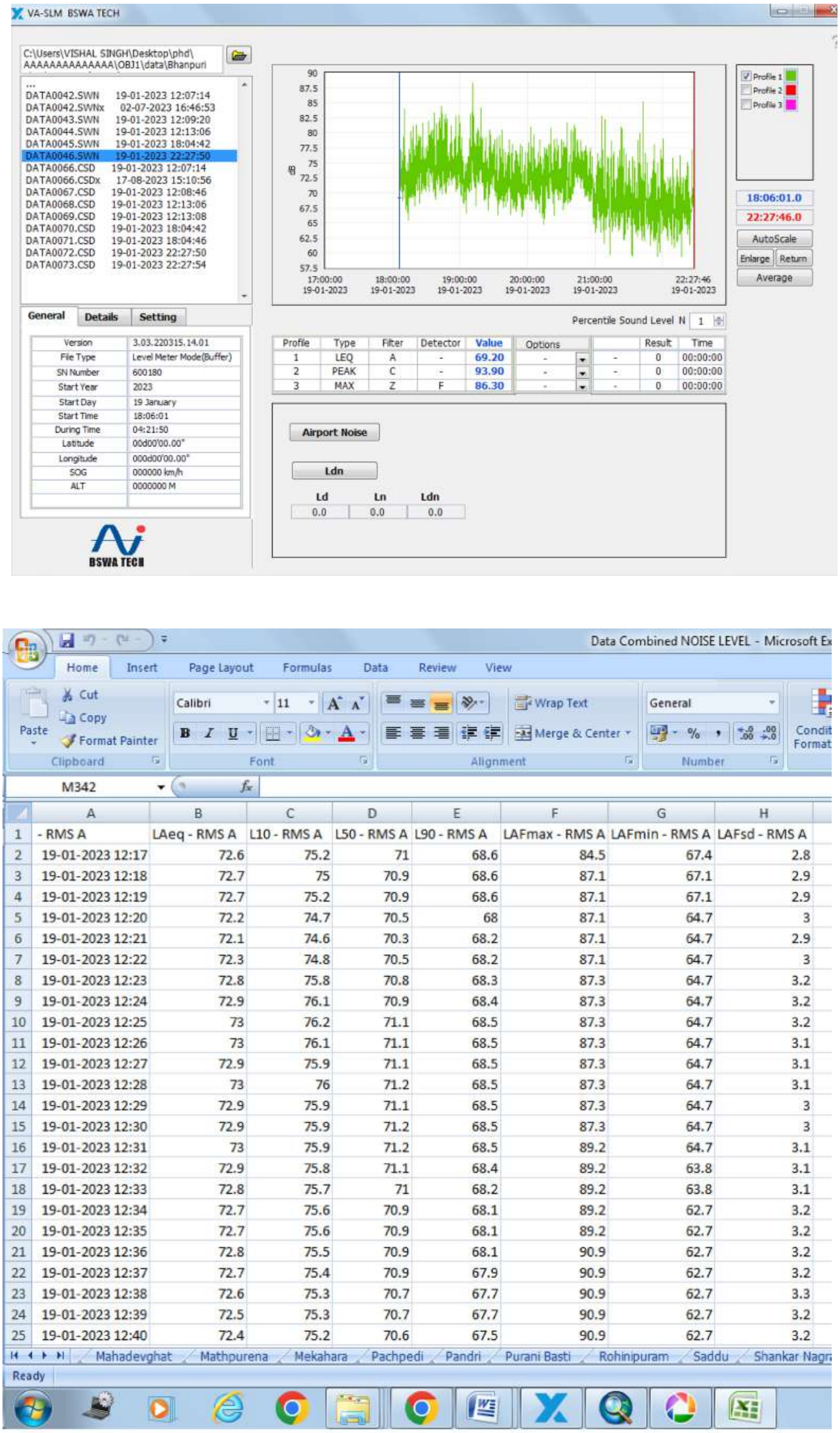


Fig. 1. Study area



	A	B	C	D	E	F	G	H
1	- RMS A	LAeq - RMS A	L10 - RMS A	L50 - RMS A	L90 - RMS A	LAFmax - RMS A	LAFmin - RMS A	LAFsd - RMS A
2	19-01-2023 12:17	72.6	75.2	71	68.6	84.5	67.4	2.8
3	19-01-2023 12:18	72.7	75	70.9	68.6	87.1	67.1	2.9
4	19-01-2023 12:19	72.7	75.2	70.9	68.6	87.1	67.1	2.9
5	19-01-2023 12:20	72.2	74.7	70.5	68	87.1	64.7	3
6	19-01-2023 12:21	72.1	74.6	70.3	68.2	87.1	64.7	2.9
7	19-01-2023 12:22	72.3	74.8	70.5	68.2	87.1	64.7	3
8	19-01-2023 12:23	72.8	75.8	70.8	68.3	87.3	64.7	3.2
9	19-01-2023 12:24	72.9	76.1	70.9	68.4	87.3	64.7	3.2
10	19-01-2023 12:25	73	76.2	71.1	68.5	87.3	64.7	3.2
11	19-01-2023 12:26	73	76.1	71.1	68.5	87.3	64.7	3.1
12	19-01-2023 12:27	72.9	75.9	71.1	68.5	87.3	64.7	3.1
13	19-01-2023 12:28	73	76	71.2	68.5	87.3	64.7	3.1
14	19-01-2023 12:29	72.9	75.9	71.1	68.5	87.3	64.7	3
15	19-01-2023 12:30	72.9	75.9	71.2	68.5	87.3	64.7	3
16	19-01-2023 12:31	73	75.9	71.2	68.5	89.2	64.7	3.1
17	19-01-2023 12:32	72.9	75.8	71.1	68.4	89.2	63.8	3.1
18	19-01-2023 12:33	72.8	75.7	71	68.2	89.2	63.8	3.1
19	19-01-2023 12:34	72.7	75.6	70.9	68.1	89.2	62.7	3.2
20	19-01-2023 12:35	72.7	75.6	70.9	68.1	89.2	62.7	3.2
21	19-01-2023 12:36	72.8	75.5	70.9	68.1	90.9	62.7	3.2
22	19-01-2023 12:37	72.7	75.4	70.9	67.9	90.9	62.7	3.2
23	19-01-2023 12:38	72.6	75.3	70.7	67.7	90.9	62.7	3.3
24	19-01-2023 12:39	72.5	75.3	70.7	67.7	90.9	62.7	3.2
25	19-01-2023 12:40	72.4	75.2	70.6	67.5	90.9	62.7	3.2

Fig. 2. Process of retrieval of data

Traffic noise modeling and model testing

Prediction of traffic noise will help policymakers as well as the planning and design of new and existing roads. Hence, in this study, we have tried to study a few noise models suitable for our study area. Generally, most of the traffic noise is generated from different vehicles playing on the roads. As a result of this, the main source or major contributor to noise pollution is vehicles. A few existing models were found suitable for our study area after a literature survey was performed and their accuracy was checked. After testing the models, we also formulated a befitting model for the prediction of traffic noise. There are many models available, but the six most suitable as per our study area have been tested on the present road and traffic conditions in Raipur City. The tested models are as follows:

Burgess model

Developed by Malcolm Burgess in the 1970s, this model is primarily designed for road traffic noise prediction. It takes into account traffic volume, vehicle speed, and road characteristics to estimate noise levels. The Burgess model is widely used due to its simplicity and ability to give reasonably accurate predictions.

Burgess model [13]

$$L_{eq} = 55.5 + 10.2 \text{ Log } Q + 0.3P - 19.3 \text{ Log } (L/2) \quad (1)$$

Fagotti-Poggi model

This model, developed by Italian researchers Fagotti and Poggi, is based on a mathematical approach to noise propagation. It accounts for factors like distance from the source, ground absorption, and atmospheric conditions to predict sound levels at various points.

Fagotti- Poggi model [17]

$$L_{eq} = 10\text{Log } (N_c + N_m + 8N_{hv} + 88 N_b) + 33.5 \quad (2)$$

Calixto model: Named after the Brazilian researcher Calixto, this model focuses on noise prediction in specific urban and suburban environments, particularly in Latin American cities. The Calixto model integrates traffic conditions and local topographical factors to estimate noise levels, but it tends to under predict noise compared to actual measurements.

Calixto model [10]

$$L_{eq} = 10 \text{ Log } [\ Q \ \{1 + 10\ (P/100)\ \}] \quad (3)$$

RLS-90 Model: The RLS-90 (Richtlinien für den Lärmschutz an Straßen) is a German model specifically tailored for road noise prediction. It incorporates detailed traffic and environmental data, such as vehicle types, road surface, and weather conditions, to predict noise levels with a high degree of precision.

Richtlinien fur Larmschutz a Straben (RLS-90) model [18]

$$L_{m,E} = 37.3 + 10 \text{ Log}\{Q.(1 + 0.082p)\} \quad (4)$$

Josse model

The Josse model is a lesser-known, yet complex model designed to predict noise from multiple sources, including traffic and industrial activities. It typically overestimates noise levels compared to actual measurements, making it more conservative in estimating the potential noise impacts.

Josse model [19]

$$L_{eq} = 38.8 + 15\text{Log } Q - 10\text{Log } L \quad (5)$$

CoRTN Model: The CoRTN (Calculation of Road Traffic Noise) model is one of the most widely adopted models globally, particularly in the UK. It was developed by the Department of Transport to estimate road traffic noise based on traffic flow, vehicle speed, and distance from the roadway. It is known for its accuracy in predicting *noise levels under various conditions.*

CoRTN model [20]

$$L_{10(1h)}=42.2 + 10Log(q), \quad (6)$$

$$L_{10(18h)}=29.1 + 10Log(Q) \quad (7)$$

Were L_{eq} is equivalent noise level in dBA, P denotes heavy vehicles percentage, L is road width in m, Q is total number of vehicles, N_c number of light vehicles per hour, N_m number of motor cycle per hour, N_{hv} number of heavy vehicles per hour, N_b number of bus per hour.

From the data collected at all locations mentioned above, traffic noise models were run to predict the noise levels at each location. L_{eq} values were also calculated along with traffic data at the same time. Hence, the observed and predicted values of noise levels were compared to find the best-suited traffic noise models for our study area. On comparison, it was found that there was a significant difference among them. An observed and calculated value of noise is mentioned in Table 1, and the coefficient of correlation between the predicted and observed values is mentioned in Table 2, respectively.

Since a significant difference between measured and predicted values is found and the values of the coefficient of correlation are not found to be good for most of the models, there is a requirement for either modification or formulation of a new model for our selected area. However, the Fagotti-Poggi model can be accepted up to a certain limit as the values are better than other models, but still, we have tried to develop a new, befitting model for our selected area to get better results than this. So the next section describes the formulation of the new model.

Table 1. Observed and predicted noise level

Symbol	Location	Predicted Noise Level						Measured Noise Level	Measured L_{10}
		Burgess Model	Calixto Model	Josse Model	Fagotti-Poggi model	RLS-90	CoRTN(L_{10})		
ML1	Pachpedi Naka	81.53	42.37	87.89	77.58	81.4	82.9	77.24	80.08
ML2	Lalpur	80.11	40.92	84.82	77.61	80.2	81.1	76.52	79.36
ML3	Santoshi Nagar	77.81	38.47	84.56	72.49	76.3	77.3	74.42	77.26
ML4	Bhatagaon	81.14	36.08	83.76	72.97	74.1	75.5	73.84	76.68
ML5	Raipura	81.62	41.99	84.71	76.09	81.6	82.5	77.07	79.91
ML6	Rohinipuram	76.22	36.92	82.18	73.06	74.9	76.8	73.16	76.14
ML7	NIT Gate	78.31	38.95	85.33	74.22	76.9	78.8	72.86	75.71
ML8	AIIMS Gate	78.68	39.33	85.82	74.70	77.3	78.9	73.14	75.98
ML9	Sunder Nagar	76.69	37.37	82.92	75.36	73.7	75.1	72.12	75.88
ML10	Mahadevghat	76.39	37.10	82.38	75.13	73.4	74.7	73.23	75.47

Table 2. Coefficient of correlation (R) between predicted and observed values

Location	Coefficient of correlation (R) between predicted and observed values					
	Burgess Model	Calixto Model	Josse Model	Fagotti-Poggi model	RLS-90	CoRTN(L_{10})
ML1	0.54	0.31	0.63	0.74	0.81	0.67
ML2	0.51	0.23	0.58	0.68	0.77	0.65
ML3	0.40	0.33	0.61	0.75	0.77	0.66
ML4	0.64	0.31	0.63	0.68	0.89	0.61
ML5	0.31	0.29	0.60	0.66	0.80	0.64
ML6	0.37	0.33	0.53	0.72	0.81	0.60
ML7	0.39	0.30	0.56	0.68	0.71	0.62
ML8	0.52	0.35	0.51	0.86	0.75	0.71
ML9	0.32	0.42	0.62	0.74	0.71	0.60
ML10	0.34	0.42	0.58	0.66	0.72	0.62

Formulation of befitting model

A detailed study of traffic data was done before the development of the befitting model. Background noise for each location was found by measuring the noise levels when vehicles were about 100 m away from the SLM. Most of the locations had noise levels above 50 dBA; hence, we can categorise all the locations as high-noise areas. The traffic data used in the above model testing and measured L_{eq} using SLM was used to develop a new model by using the multiple linear regression method. Different classes of vehicles (2-wheelers, autorickshaws, cars, light commercial vehicles, bus trucks) and road widths were taken into consideration for the development of the model. Road width plays an important role because as the road width decreases, traffic congestion occurs, resulting in an increase in noise levels. We have also neglected the gradient because the study area is in the plane region and almost all roads are in the plane. The coefficient of the five intercepts was found, and an equation was developed to predict the noise level in the different locations of the study area. After the analysis, the following equation has been developed to predict the average L_{eq} for 1 h on the basis of traffic data and road width.

$$Y=72.91+0.00114\,X1-0.00108\,X2+0.00653\,X3+0.00462\,X4-0.21071\,X5 \quad (8)$$

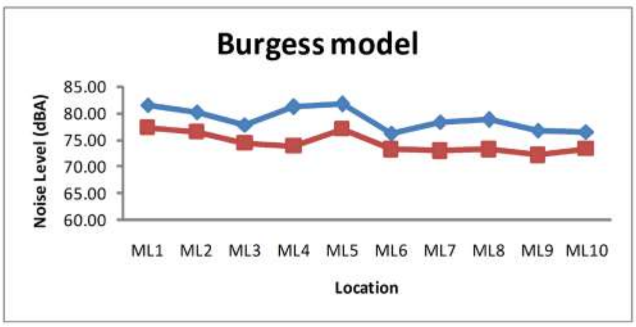
Where Y denote L_{eq}, X1 denote 2 wheeler, X2 denote Light motor vehicles(Auto, car,and commercial vehicles) , X3 denote Heavy

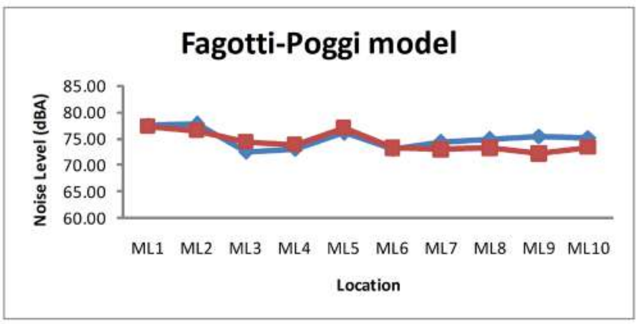
Vehicles, X4 denote Bus, and X5 denote Road Width respectively. Hence equation can rewrite as:

$$L_{eq} = 72.91 + 0.00114\ TW - 0.00108\ LMV + 0.00653\ HV + 0.00462\ NB - RW \quad (9)$$

Results and discussion

Fig. 3 shows the results of six different models for predicting noise levels at ten different locations, denoted by ML1 to ML10. The horizontal axis of each graph represents the location, and the vertical axis represents the noise level in decibels (dBA). The solid line represents the predicted noise level, and the dashed line represents the measured noise level. The Burgess model predicted noise levels are closest to the measured noise levels across at some locations. For example, at location ML3, the Burgess model predicts a noise level of 77 dBA, while the measured noise level is 78 dBA. In contrast, the other models tend to deviate more from the measured noise levels. For example, at location ML3, the Fagotti-Poggi model predicts a noise level of 82 dBA, while the Calixto model predicts a noise level of 68 dBA. The Fagotti-Poggi appears to be the most accurate overall, as its predicted noise levels are consistently closest to the measured noise levels across all ten locations. However, the Fagotti-Poggi model tends to overestimate noise levels, particularly at locations ML5, ML7, and ML9. The Calixto model tends to underestimate noise levels, particularly at locations ML3, ML4, and ML8. The RLS-90 model is difficult to assess due to the lack of data points for some locations. However, the available data suggests that it may be more accurate for lower noise levels. The CoRTN model is also difficult to assess due to the lack of data points for some locations. However, the available data suggests that it may be more accurate for higher noise levels. The Josse model is difficult to assess due to the lack of data points for some locations. However, the available data suggests that it may be more accurate for locations with fluctuating noise levels. From Figs. 4 and 5, there appears to be a positive correlation between the observed level and the predicted level for all ten models. This means that as the observed level increases, the predicted level also tends to increase. The strength of this correlation is measured by the R-squared value (R^2) which is shown on each graph. An R^2 value closer to 1 indicates a stronger positive correlation.





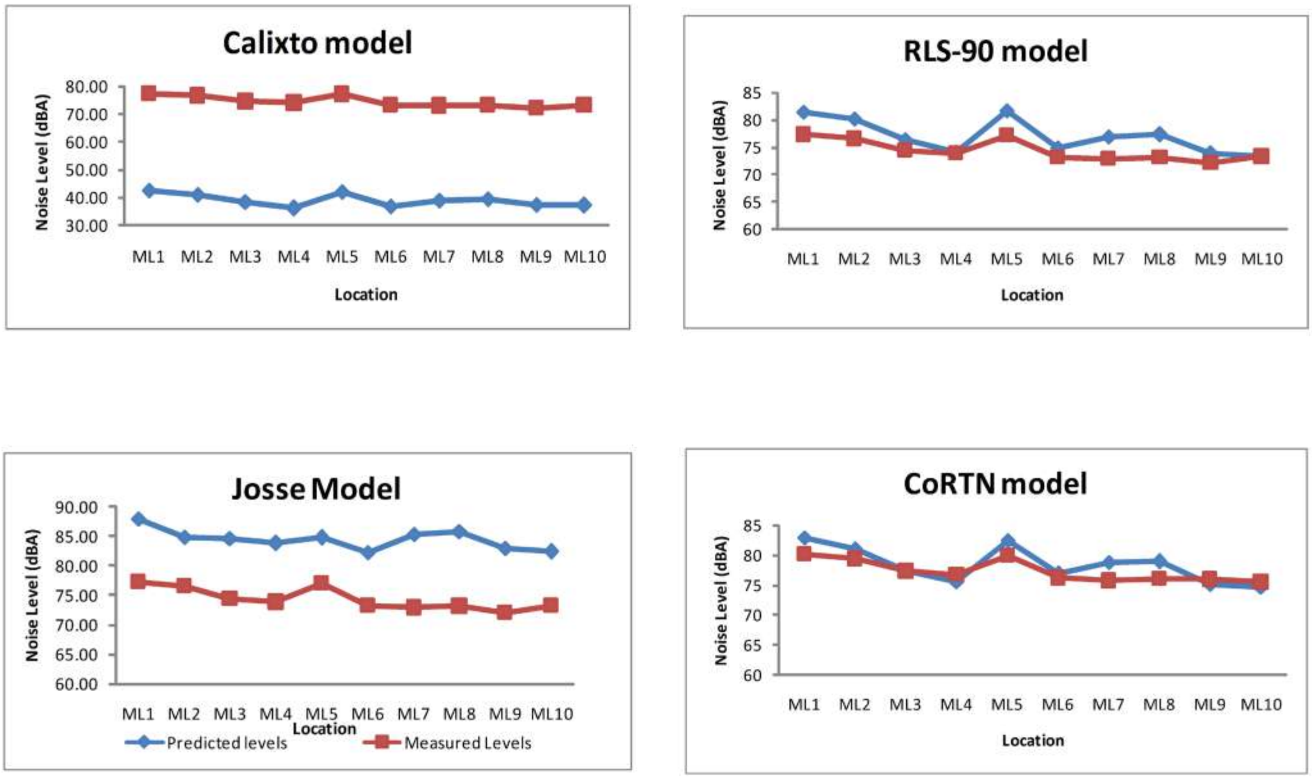
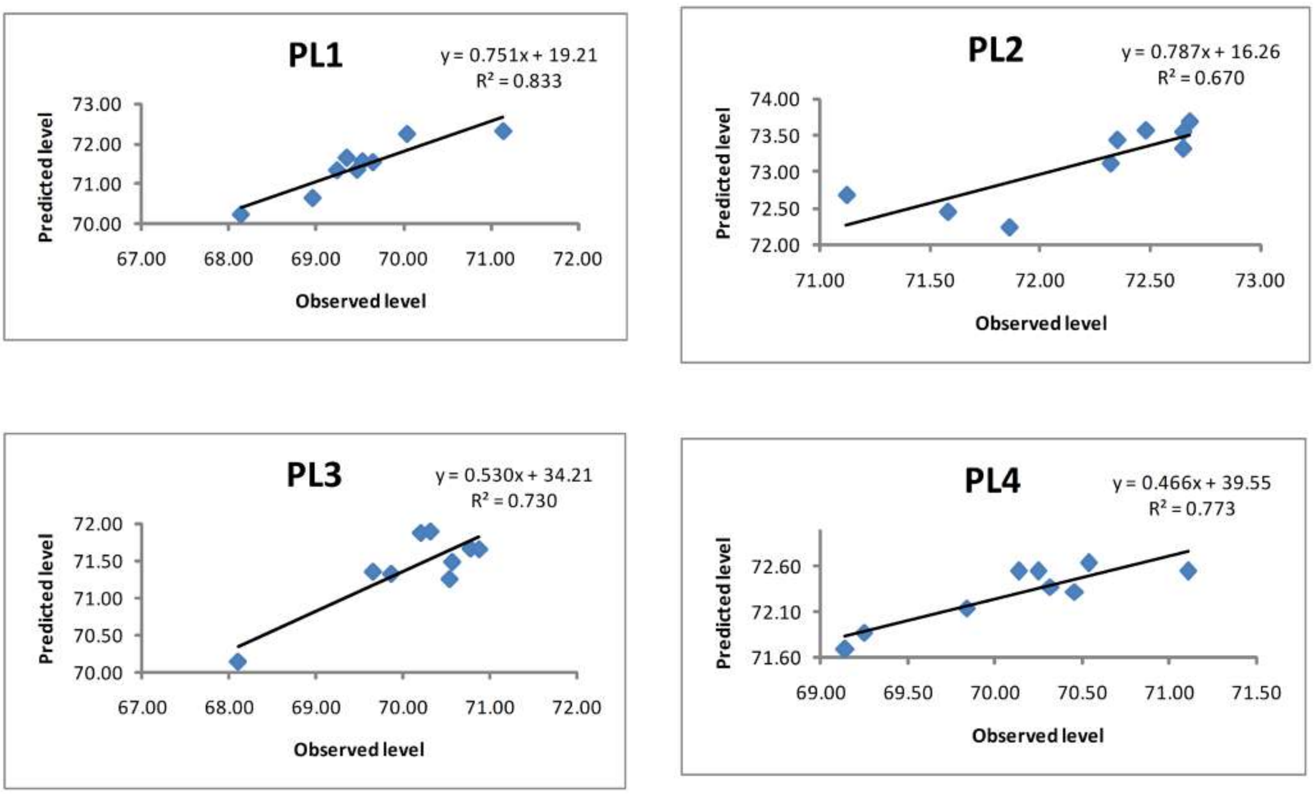


Fig. 3. Comparison of different model



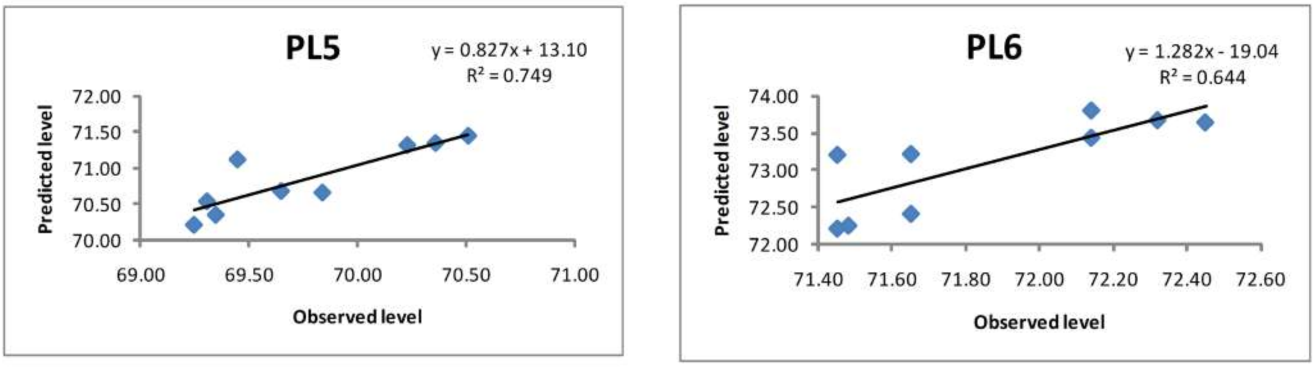


Fig. 4. R^2 value for PL1 to PL6

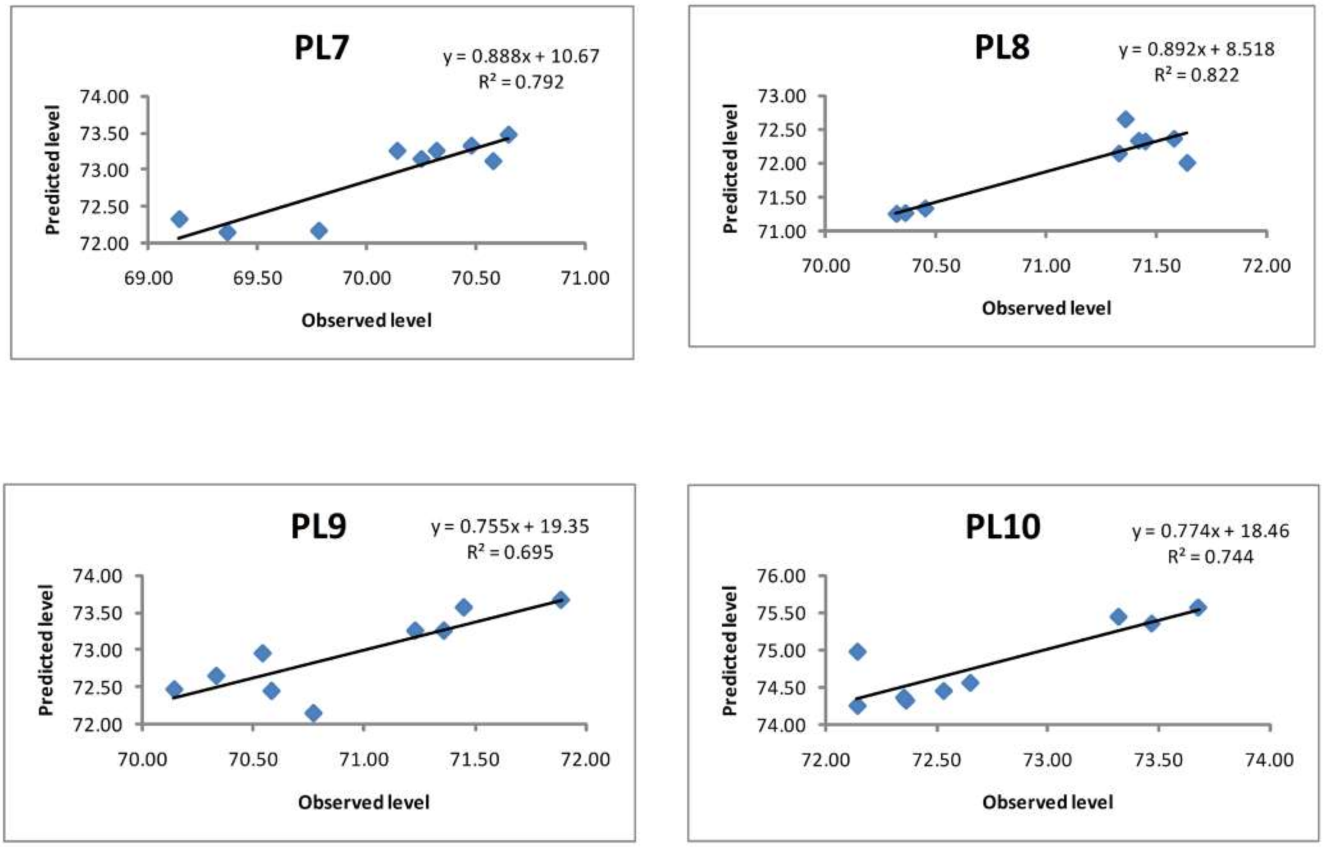


Fig. 5. R^2 value for PL6 to PL10

Table 3. Statistical analysis of befitting model

Predicted location	Symbol	Coefficient of determination(R^2)	Mean Absolute Deviation (MAD)	Root Mean Squared Error (RMSE)
Rohinipuram	PL1	0.83	1.929	1.955
Amapara	PL2	0.67	0.924	0.973
Agrasen Chowk	PL3	0.73	1.297	1.374
Samta	PL4	0.77	2.175	2.203
Choubey	PL5	0.74	1.081	1.106
Danganiya	PL6	0.69	1.239	1.295
Kabir Nagar	PL7	0.79	2.829	2.839
Kota	PL8	0.82	0.859	0.884
Katora Talab	PL9	0.69	2.012	2.035
Hirapur	PL10	0.79	2.074	2.093

Validation of developed model

Validation of a model is required to check its accuracy; hence, we conducted validation of our model by collecting traffic data and noise levels at five different locations in our study area. These locations were different from the locations used in the development of models. Traffic data, road width, and L_{eq} were measured for different times and days. At each location, noise levels were predicted using our developed model and the coefficient of determination (R^2), Mean Absolute Deviation (MAD), and Root Mean Squared Error (RMSE) for all 10 locations were found to validate our new model. Statistical analysis of befitting model is shown in Table 3.

The dataset provides an analysis of noise pollution mitigation effectiveness across ten different locations, represented by their predicted location symbols (PL1 to PL10). The effectiveness is measured through three key statistical metrics: Coefficient of Determination (R^2), Mean Absolute Deviation (MAD), and Root Mean Squared Error (RMSE). These metrics help in understanding the reliability, accuracy, and variability of the noise pollution predictions for each location.

Coefficient of determination (R^2)

An R^2 value closer to 1 indicates a better fit. PL1 and PL8 have the highest R^2 values of 0.83 and 0.82 respectively, suggesting that the model predictions are highly reliable for these locations. PL2 has the lowest R^2 value of 0.67, indicating the model is less reliable here compared to other locations. Most other locations have R^2 values ranging from 0.69 to 0.79, indicating moderate to good model reliability.

Mean absolute deviation (MAD)

MAD measures the average magnitude of errors between predicted and observed values, without considering their direction. A lower MAD value indicates more accurate predictions. PL8shows the lowest MAD value of 0.859, reflecting high prediction accuracy. PL2 also has a low MAD value of 0.924, indicating accurate predictions. PL7 exhibits the highest MAD value of 2.829, suggesting the predictions for this location are less accurate. The other locations have MAD values ranging from 1.081 to 2.175, showing varying degrees of prediction accuracy.

Root mean squared error (RMSE)

RMSE is a quadratic scoring rule that measures the average magnitude of the error. It squares the difference between predicted and observed values before averaging them, making it more sensitive to larger errors compared to MAD. PL8 again shows the lowest RMSE value of 0.884, reinforcing the high prediction accuracy for this location. PL2 follows closely with an RMSE of 0.973, indicating reliable predictions. PL7 has the highest RMSE of 2.839, further highlighting the larger prediction errors for this location. Other locations have RMSE values ranging from 1.106 to 2.203, indicating varying degrees of prediction reliability.

Conclusion

From the study, it is concluded that predicting the noise model in an Indian scenario is difficult when using international models. On comparing the six selected models, we found none of the models giving results nearer to the observed location; however, the Fagotti-Poggi model is best suited among the six selected models. Our developed model was found to be best suited to our scenario and is giving a more accurate result with a difference of ±1.5 to ±2 dBA. The model has been validated and shows a good statistical correlation. Hence, we can use our developed model for predicting noise levels, and it will help policymakers and government organisations in developing the city and also in mitigating noise pollution.

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Competing interests

The authors declare that they have no competing, personal and financial interests in this manuscript.

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Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy, etc) have been completely ob-served by the authors."

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