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REVIEW ARTICLE

Traffic noise monitoring and modelling — an overview

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Abstract

Noise has emerged as a leading environmental problem and is an underestimated threat. The most significant source of noise pollution is road traffic. Road traffic noise problem has reached alarming levels. This proves the severity and necessity of mitigating the traffic noise from every delicate corner possible. Noise monitoring is required to check the noise levels and effectiveness of control methods implemented. Road traffic noise control can be exercised with the help of prediction models. This paper presents the traffic noise status of developing countries and a quantitative review and comparison of traffic noise prediction models developed by researchers for various cities. Findings suggest that most of the researchers have used regression modelling and use of evolutionary computing methods like genetic algorithm, fuzzy systems, and neural networks to develop traffic noise prediction model is lacking. The effect of many important variables affecting traffic noise like pavement type, vegetation along roads, road surface roughness, and gradient still needs to be studied. Further, studies are required to measure in vehicle noise levels on same roads to compare the noise levels tolerated by residents, road users, and the commuters; this will help in formulating traffic noise regulations.

Keywords Environment · Road traffic noise · Noise pollution · Noise monitoring · Noise prediction models

Introduction

Noise pollution is an invisible danger, which cannot be seen but present everywhere. Noise pollution refers to unwanted or disturbing sound in the environment, caused by humans and that threaten the health or well-being of humans or animal inhabitants. Continuous exposure to unwanted sounds affects the human health both psychologically and physiologically; some of the affects to mention are hearing impairment, heart diseases, bowel movement, annoyance, tinnitus, hypertension, anti-social behaviour, sleep disturbance, stress, cardiovascular effects, and many more (Sørensen et al. 2011; Kumar 2019; Banerjee 2012; Sahu et al. 2021; Tsaloglidou et al. 2015).

Ambient noise is included as environmental quality parameter in section 5.2.8(IV) of National Environment Policy 2006 (http://www.indiaenvironmentportal.org.in/content/438249/status-of-ambient-noise-level-in-india-2015); therefore, proper monitoring and assessment of ambient noise levels in urban areas are required regularly. Road traffic noises have been reported as the most important source of noise pollution by many researchers (Mocuta 2012; Hamad et al. 2017; Koushki et al. 1993). Around 1.1 billion people between 12 and 35 years of age group are in danger of deafness (https://www.who.int/news-room/fact-sheets/detail/deafness-and-hearingloss). As per survey conducted by the founder of the digital hearing app "Mimi Hearing Technologies GmbH" and analyses of results of hearing test of 200,000 of their users and WHO noise pollution data, "the average city dweller has a hearing loss equivalent to 10–20 years older than their actual age" (https://www.weforum.org/agenda/2017/03/these-are-the-cities-with-the-worst-noise-pollution/) This shows the importance and requirements of traffic noise studies so that mitigation measures can be adopted suitably. Traffic noise measurement is time-consuming, complicated, and unfeasible at the planning and design stage. Ambient traffic noise levels can be determined by measurements or by software simulation. Simulation needs mathematical modelling of environment and traffic conditions. Prediction of traffic noise using mathematical models started somewhere 50 years back, and these models are developed considering variables like traffic speed, traffic variation, road dimensions, and environmental

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conditions. Urban planners use road traffic noise models to predict the noise emitted in the environment based upon traffic and road characteristics. This is more useful when a new infrastructure has to be developed, that is in a planning stage or for a road already in operation. Prediction models can be used to monitor the noise impact on the surrounding environment by giving input of few traffic and road parameters (An et al. 2013). In design of highways and for assessment of existing roads, traffic noise models are needed as an aid (Golmohammadi et al. 2007). These models are used to forecast noise levels in terms of L_{eq}, $L_{10,}L_{90}$ etc. and can be used to plan proper mitigation measure to reduce traffic noise (Ramírez and Domínguez 2013). Many developed countries like USA, UK, and Germany have developed good models (CoRTN, FHWA TNM, RLS-90 etc.) to predict noise levels for homogenous traffic conditions. Now other developing countries are also giving trials to develop suitable noise prediction models for their countries (Lekshmi et al. 2018). Traffic noise prediction modelling trend is varying from basic regression models to genetic algorithm, artificial neural network, convolutional neural network, fuzzy system, graph theory approach etc.

From the literature survey, it is determined that a number of studies have been conducted in the field of traffic noise monitoring and various models to predict traffic noise have been developed. Therefore, in this paper, an attempt has been made to present the quantitative review of the models developed by various researchers for different cities, unfolding the main features and peculiarities of each model.

Methodology

The good research papers were identified by literature search of all databases like SCOPUS, Springer, Web of Science, Academia, Elsevier, and Taylor & Francis using terms "noise monitoring, traffic noise modelling, road traffic noise, transport noise, traffic noise index, noise pollution level, traffic noise monitoring, and traffic noise mapping." An attempt was made to screen the identified research paper's titles, abstracts, figures and tables, results, and then full texts, against eligibility criteria. Identified and pertinent papers were deeply analysed to extract information, and database was prepared with different details like author's details, publication year, study location, variables considered, sampling procedure used, data analysis, specific variables found, modelling equation developed, and observed R^2. Where a publication was not open access, it was requested from authors. Reference lists of these papers were also searched for literatures. Only those papers were included for review in which location and duration of sampling were well defined, and which applied developed models for noise prediction.

In total, 37 research papers were studied and summarized in the review and around 21 traffic noise models from different cities were compared.

Traffic noise monitoring

Noise is not only tough on our nerves (Faisal et al. 2008); it is bad for our physical and mental health also (Anees et al. 2017). Exposure to continuous noise levels beyond 85 dB for 8 h or more may be hazardous (WHO 2005). Growth of cities, industries, and infrastructure around the urban environment poses a health risk among urban populations (Debnath et al. 2022). "Traffic noise is the only biggest source of noise pollution and is directly proportional to the volume of vehicles" (Vijay et al. 2015). Prolonged exposure to noise develops into diseases and leads to early death, but it is not easy to identify. Research on traffic noise monitoring conducted in various cities all over the world are summarized in this section to assess traffic noise status of various countries (see Table 1).

Mavrin et al. (2018) assessed the impact of the noise level of road traffic on the state of the environment. The results of the investigation indicate that the measured noise levels are exceeding the maximum acceptable level (55DBA). Nury et al. (2012) performed a study to obtain traffic noise index (TNI), equivalent noise level, noise climate (NC), and hazard due to noise pollution at Sylhets's eight major intersections. From the analysis, it was found that average noise level was approximately 74 dBA exceeding the acceptable 45 dBA limit set by Department of Environment. Dulal (2008) assessed highway traffic noise pollution and its effect in and around Agartala, India. The noise level in various locations is much higher than the standard limit prescribed in Indian Standard codes for residential area. Noise perception study indicates that 62.5% is affected by the highway noise both physiologically and psychologically. Masum et al. (2021) conducted spatiotemporal monitoring of noise levels in Chattogram city in Bangladesh. Based on land use, 123 data monitoring points selected in 41 wards of Chattogram city corporation. It was found that population experienced high noise level surpassing the values set by DOE, Bangladesh, for different land uses pattern. Results indicate that out of the 41 wards, only 3 were within the acceptable condition. McAlexander et al. (2015) measured street level noise at 99 sites located in New York City and revealed the variation of 55.8 to 95 dBA. Mishra et al. (2019) performed traffic noise analysis at 10 locations in Delhi based on land use pattern and found that the noise level at all 10 locations were above the acceptable limits set by central pollution control board.

A noise monitoring study was conducted by Swain et al. (2012) at Bhubaneshwar city; results show that the minimum value of L_{eq} 70.4 dBA is also above the permissible limit of 70 dBA. Alam et al. (2020) analysed

Table 1 List of studies on road traffic noise monitoring

Author	City	Type of study	Max acceptable level (dBA)	Equivalent noise levels (dBA)	No of observation sites	No of exceedance sites
Dulal (2008)	Agartala, India	On site investigation	45–55	82.34 to 94.74	48	32
Chandio et al. (2010)	Larkana, Pakistan	Onsite investigation	85	91 to 101	9	9
Kupolati et al. (2010)	Ibadan, Nigeria	Onsite investigation	50–55	53.8 to 65.2	10	8
Chowdhury et al. (2010)	Dhaka, Bangladesh	Onsite investigation	Sensitive area-45 Residential-50 Mixed area-60 Commercial-70 Industrial-75	82	10	Exceeds for mixed area
Gholami et al. (2012)	Tehran, Iran	Onsite investigation	Class I (Residential, educational and health-care)-55 Class-II (residential and commercial)-60 Class III (commercial centres)-65	Class-I 65.9 to 69 Class-II 70.56 Class-III 72.9	41 (11 in educational areas, 4 in healthcare, 5 in commercial areas, 12 in commercial-residential areas, and 9 in residential places.)	66.7% of class 1, 58.3% of class 2, and 20% of class 3
Nury et al. (2012)	Sylhet, Bangladesh	On site investigation	45	68 to 78	28	28
Swain et al. (2012)	Bhubaneshwar, India	On site investigation	70	70.4 to 80.6	16	07
Goussous et al. (2014)	Amman, Jordan	Onsite investigations	55	70	18	18
Zuo et al. (2014)	Toronto, Canada	Onsite investigations	55	31.6 to 77.2	554	442
McAlexander et al. (2015)	New York, USA	On site investigation	45	55.8 to 95	329	241
Mavrin et al. (2018)	Naberezhnye, Russia	On site investigation	55	73 to 80.30	17	17
Chebil et al. (2019)	Monastir, Tunisia	Onsite investigations	55	69.4 to 75.3	16	16
Mishra et al. (2019)	Delhi, India	On site investigation	55 to 65	70.2 to 80.5	10	10
Laxmi et al. (2019)	Nagpur, India	Onsite investigation	WHO guidelines for community noise-55 Industrial area-75 Commercial area-65 Residential area-55	National highways-90 ± 7.2 State highway-89.4 ± 6.6 Ring road-91.4 ± 6.3 Major road-90 ± 6.8 Minor road-90.7 ± 7.4 Industrial-81.2 ± 4.8 Commercial-92.9 ± 7.9 Residential-84.1 ± 6.6	NH-137 SH-68 Ring Road-100 Major Road-188 Minor road-88 Industrial-54 Commercial-24 Residential-41	Exceeds for all sites
Alam et al. (2020)	Delhi, India	Onsite investigations	75 (industrial area) 65 (commercial area) 55 (residential area) 45 (silent area)	44.45 industrial area, 59.36 commercial, 76.62 residential area, 58.58 silent zone	16(07 residential, 03 commercial, 04 industrial, 02 Silent)	12
Masum et al. (2021)	Chattogram, Bangladesh	On site investigation	40–50	65–85	123	114

and evaluated traffic noise levels 07 residential areas, 03 commercial areas, 04 Industrial areas, and 02 silent zones of Delhi and revealed that Delhi is exposed to high noise levels of 60–80 dBA. Spatial and temporal variabilities of noise levels of Toronto were explored by Zuo et al. (2014), and it was concluded that 80% of sites were having noise levels higher that the permissible limit of 55 dBA. Chebil et al. (2019) carried out case study of traffic noise levels at four main roads of Monastir-Tunisia and concluded that the noise levels observed are greater than the limits of Tunisian environmental standards and the WHO standards. Goussous et al. (2014) monitored noise levels in 18 selected sites of Amman, Jordon, and revealed that the average noise level was 70 dBA which is far more than the environmental standard limit of 55 dBA. Chandio et al. (2010) revealed that traffic noise levels in Larkana city exceeds the limit of 85 dBA given in National Environmental Quality standards of Pakistan. Kupolati et al. (2010) carried out traffic noise measurement at 10 locations in Ibadan and fount traffic noise levels between 53.8 to 65.2 dBA which is more than the permissible WHO standards of 50–55 dBA. Gholami et al. (2012) analysed spatial traffic noise characteristics at 41 stations in Tehran City, Iran, in residential, medical, educational, commercial-residential, and commercial use areas. Authors concluded that average noise levels were higher than the Department of Environment standards for different land uses. The amount of violation was 14.14 dB in residential and 11.11 dB in educational areas. Chowdhury et al. (2010) conducted noise monitoring in Dhaka City, and results indicate L_{eq} noise level of 82 dBA.

Laxmi et al. (2019) used cycle mounted sound level meter (an innovative method) to monitor noise levels in Nagpur city, India. In total, 700 monitoring stations were used and found that the L_{min} values at all stations are exceeding the WHO guidelines for community noise.

Review of literature indicates that road traffic noise levels were found beyond the acceptable limits in almost all the studies; therefore, road traffic noise is a matter of concern and requires an urgent action to control the alarming levels of road traffic noise.

Traffic noise prediction modelling in developing countries

Development of new roads, investment in major highway projects, and construction of tunnels are essential for developing countries and communities. But this development leads to increase in flow of traffic and causes traffic noise that have negative impact on buildings and peoples. The impacts of road traffic on local environment must be taken into consideration by urban planning and road design. For controlling traffic noise pollution in urban areas, traffic noise prediction is required. In literature survey, it was found that many works are carried for development of a predictive traffic noise model. Review of recently developed models for various cities has been presented in this section.

Delany et al. (1976) developed CoRTN model for the department of environmental engineering, UK. This model predicts noise levels in terms of L_{10}(A) which can be converted to L_{eq}(A). Barry and Reagon (1978) introduced Federal Highway Administration (FHWA) method to predict traffic noise. This model is based on L_{eq}, and an adjustment for conversion to L_{10} is provided in the model. Tandel and Macwan (2013) carried out the study to generate a traffic noise model for main Arterial roads of Surat, India, and to analyse various parameters affecting road traffic noise. Total 03 arterials roads were selected for study based on mix traffic flow and different land use pattern. In total, 96 data points/sampling sites were selected, 32 on each corridor (16 on each side). Measurements were carried out during peak hours (5:00 to 8:00 p.m.). Multiple linear regression analysis was performed on the combined effect of PCU, open spaces, and building height and model indicated good relation of the three parameters on noise. Kamineni et al. (2019) developed a comprehensive noise prediction model for eight important highways of Andhra Pradesh and Telangana, India. Measurements were done on each highway from 10:00 a.m. to 5:00 p.m. at an interval of 15 min using far field methodology. Scattered plots for L_{eq}, L10 v/s traffic volume, spot speed, and carriageway width were plotted for 08 highways. The 15-min time frame models resulted in a negative correlation compared to the hourly time frame model. Konbattulwar et al. (2016) designed in vehicle noise prediction models for Mumbai Metropolitan Region, India. Data was collected by covering total road length of 403.80 km by total 22 trips conducted on 06 different routes using different types of vehicles (AC car, non-AC car, Auto, Bus). Separate model for each type of vehicle and for each type of road was developed. Awwal et al. (2021) assessed the road side noise levels on asphalt pavements and concrete pavements. For this, Skudai-Pontian Highway having road stretches with different pavement types was selected. Noise levels were measured for three weekdays in the peak hours (5:00 to 6:00 p.m.) and off-peak hours (10:00 to 11:00 a.m.) using statistical pass by method. Separate models were developed for concrete and asphalt pavement for peak hours and off-peak hours. Suthanaya (2015) modelled traffic noise for collector roads of Denpasar City, Indonesia. Tumku Umar Road was selected for measurement from 6:00 a.m. to 6:00 p.m. (12 h); in total, 48 data sets were collected at 15-min interval. Traffic volume was classified into MC, LV, and HV. It was observed; if all other factors are kept constant, then an increase of 100 motor cycle increases traffic noise

LA_{eq} by about 0.3 dB, and increases in the values of LA_{10}, LA_{50}, and LA_{90} are 0.4, 0.4, and 06, respectively. Gharibi et al. (2016) evaluated and modelled noise from traffic on the Asian Highway in Golestan National Park, Iran. For measurement of noise and independent variables, 76 sampling stations were selected at various distances (0 to 250 m) from the road using systematic random method. Sampling for 1 week from 8:00 a.m. to 8:00 p.m. at 15-min time interval is done at each sampling station. L_{eq}-based modelling as dependent variants and 19 independent variables were performed using SPSS software.

Ranpise et al. (2021a, b) carried out research work to develop traffic noise model for main urban roads of residential and commercial areas of Surat, India. After proper execution of pilot survey, 03 roads were chosen out of which 02 were of rigid pavement and 01 of flexible pavement. Measurements of sound level were done for 16 h from 6:00 a.m. to 10:00 p.m. on each road. Three different models for all three roads were built, and subsequently, the last model was developed using data of all three roads. Ranpise et al. (2021a, b) measured ambient noise levels at major arterial roads of Surat, India, and compared them with prescribed standards, and developed a traffic noise model for arterial roads of Surat using an artificial neural network. Three arterial roads selected for the detailed survey were Athwa-Dumas Road, Adajan-Rander Road, and Udhna-Sachin Road. Continuous monitoring for 24 h from 9:00 a.m. morning to 9:00 a.m. next morning was done on all three roads.

Monazzam et al. (2014) designed a traffic noise forecasting model for highways of Ahvaz city, Iran. A total of 1344 observations were recorded at 112 stations selected on 07 roads of the city. Observations were made for 4 weekdays, three times a day. Out of 15 independent variables considered, only 9 variables were used in development of model. Golmohammadi et al. (2007) developed road traffic model for Iranian Cities; in total, 282 data sets were considered, and measurements were carried out between 7 a.m to 10 p.m. and 10 p.m. to 7 a.m. Four explanatory factors involving twelve variables were used for regression analysis, which indicated high $R^2 = 0913$. Shalini and Kumar (2018) measured road traffic noise at 7 different locations in Varanasi, and total 14 sets of data were collected. Linear regression analysis using SPSS was performed, and model equation was developed considering traffic volume, noise climate, noise range, weightage of traffic volume, and % of heavy vehicles as independent variables. Garg et al. (2014) conducted traffic noise survey at different sites in Delhi, and four different models were developed for L_{eq}, L_{10}, TNI (traffic noise index), and NPL (noise pollution levels) using equivalent vehicle speed and equivalent traffic flow as independent variables. Ramakrishna et al. (2021) developed MLR and ANN models for predicting traffic noise levels in residential, commercial, industrial, and silent zones of Vijayawada, Andhra Pradesh. Four sampling locations one in each zone were selected, and data was collected for 3 days at each site, four times a day. Sooriyaarachchi and Sonnadara (2006) developed traffic noise prediction model for 08 different classes of vehicles (motorcycles, three-wheeler, car, van, double cab, Jeep, bus, and Lorry) in Srilanka considering distance from centre line (2.5 m, 5.0 m, 7.5 m, 10.0 m, 12.5 m, 15.0 m). A total 650 data sets were collected for 8 different classes of vehicles.

Kumar (2015) used genetic algorithm and regression approach to predict noise levels for Patiala city, India, using vehicle volume and percentage of heavy vehicle as variables. Mean square error of GA models is in the range of 0.5558–0.6123, while regression model shows error from 0.7575 to 0.7623. The author concluded that GA model performs much better than regression model. Cirianni and Leonardi (2012) measured noise levels at 14 sites (total 154 records) in city of villa s Giovann, Italy, and recalibrated the three regression models (Burgess (1977), CoRTN model (2011), and García and Bernal (1985)) with genetic algorithm. It was observed that GRNN (general regression neural network) is well suited for simulation of phenomenon and can be used for more complex areas and greater traffic variability. Gilani and Mir (2021) used graph theory approach for predicting traffic noise using five parameters (traffic volume, volume of heavy vehicles, traffic speed, honking, and pavement width). Data for selected variables was collected for 3 months, and noise parameters L_{eq}, L_{10}, and L_{90} were included in the study. Variables considered were assigned weightage from 1 to 5 and were incorporated into a matrix, weightage for variable interaction also decided based on human knowledge, and permanent function matrix was formed to calculate permanent noise index. Model was developed using PNI and noise parameters. Patthanaissaranukool et al. (2019) predicted noise levels for Phuket province, Thailand, using NMTHAI1.2 model, and study revealed that model is overestimating the traffic noise contribution. Lekshmi et al. (2018) developed an artificial neural network model and regression model to predict traffic noise on NH66, Kochi, India. Six sites with 500-m interval were selected, and measurements on each site for 6 h/day for 6 days were carried out. Traffic flow, speed, and percentage heavy vehicles were used as input variables in both the models. Comparison of both models indicates ANN model is more reliable for traffic noise prediction.

A comparison of different features of models developed for various cities is shown in Table 2.

Figure 1 displays a timeline plot that indicates specific years when each disruptive model was introduced based on available data of R^2 and MSE observed.

Table 2 Comparison of developed models

Author	City, country	Variables considered	Noise data requirement	Model equation/details	R^2/MSE observed	Prediction	Limitations
Delany et al. (1976)	UK	Traffic composition (light and heavy), traffic speed	L_{10}	L_{eq}(A), hourly = 0.57 × L10(A), 1 h + 24.46 dB		Prediction for single traffic noise (using CoRTN model)	Prediction based on L_{10}, that is obsolete
Barry and Reagon (1978)	USA	Traffic speed, traffic flow, environmental conditions, local characteristics	L_{eq}, L_{10}	$L_{eq(hourly)} = Eli + A_{traffic\ (i)} + A_d + A_s$ *$A_{traffic\ (i)}$ is adjustment for traffic flow, A_d represents the adjustment for distance between the roadway and receiver, and A_s represents correction for shielding and ground effects*		For predicting traffic noise on constant speed highway traffic. (FHWA TNM)	In this model, only three classes of vehicles are used (light commercial vehicles, medium trucks and heavy trucks). Acceleration or deacceleration lane concept not considered
Sooriyaarachchi and Sonnadara (2006)	Srilanka	Distance from centre line and speed of vehicles	L_{eq}	$Y_{bus} = 53.07 + 0.7772\ s - 16.58Ln(d)$ $Y_{car} = 44.56 + 0.5047\ s - 12.84Ln(d)$ $Y_{Double\text{-}Cab} = 60.05 + 0.4009\ s—17.32Ln(d)$ $Y_{Jeep} = 67.23 + 0.2206\ s - 13.24Ln(d)$ $Y_{Lorry} = 79.89 + 0.1812s - 20.06Ln(d)$ $Y_{Motorcycle} = 56.42 + 0.4476\ s - 15.48Ln(d)$ $Y_{Three\text{-}wheeler} = 60.64 + 0.4692\ s - 17.04Ln(d)$ $Y_{Van} = 73.98 + 0.0447\ s - 14.80Ln(d)$		Predicting the combined traffic noise using varying traffic volume, distance and speed (using MLR model)	As uncontrolled approach used for model development, a more realistic model can be development by using controlled approach
Golmohammadi et al. (2007)	Hamadan, Iran	Noise emission level, road dimensions, traffic flow factor, traffic speed factor	L_{eq}, L_{10}, L_{max}, $L_{eq(30)}$, $L_{eq(45)}$, $L_{eq(60)}$	$L_{eq} = 54.013 + \Delta N + \Delta V + \Delta D$ $\Delta N = (3.542logN_{car}) + (0.308logN_{mini}) + (2.361logN_{truck}) + (0.173logN_{cycle})$ $\Delta V = (0.668logV_{car}) + (0.907logV_{mini}) + (0.176logV_{truck}) + (0.302logV_{cycle})$ $\Delta D = 0.001\ L - 0.104\ W + 0.24H + 0.068S$	$R^2 = 0.913$	Prediction of L_{eq} (30 min) in Iran's cities (using MLR model)	Suitable only for speed below 90 kmph and traffic volume below 5000 v/h
Cirianni and Leonardi (2012)	Villa S. Giovanni, Italy	Traffic flow Q (veh/h), percentage of heavy vehicles *p* (%), average speed *V* (km/h), slope of the road G (%)	L_{eq}, L_{10}, L_{50}, L_{90}	Burgess model *M1: Leq = 10,838.log (Q) + 0.127p + 40.69* Garcia and Bernal model *M2: Leq = 9565.log (Q) + 0.166.p − 0.055 V + 45.081* CoRTN model *M3: Leq = 10.213 log (Q) + 6.69. log (V + 40 + 500/V) − 1.544. log (15/d) 0.103. p + 44.62* *For equation M1 and M2, coefficient relative to the distance d is negligible in regards to the others*	MSE (GRNN) = 0.941	For prediction in more complex areas, with greater variability in traffic conditions (general regression neural network)	Consideration of factors such as ground type, road surface, classification of vehicles, reflective surface, can provide a comprehensive model
Tandel and Macwan (2013)	Surat, India	Traffic flow(vehicles/hr), open spaces, building heights	L_{avg}	$y = 73.99 + 0.05\ X1 + 1.14\ X_2 - 0.088X_3$ $X_1 = PCU/minute$, $X_2 = Building\ height(m)$ $X_3 = open\ space(m)$	$R^2 = 0.76$	Noise prediction for urban corridors (using MLR model)	Traffic speed not included in the model. Temporal correlation not evaluated

Table 2 (continued)

Author	City, country	Variables considered	Noise data requirement	Model equation/details	R^2/MSE observed	Prediction	Limitations
Monazzam et al. (2014)	Ahvaz, Iran	N1—no of passing vehicle max wt 4500 kg, N3—no of vehicles having wt above 12,000 kg, N4—no of motorcycles and tricycles, V1—avg speed of N1 vehicles, V3—avg speed of N3 vehicles, H—ht of surrounding buildings, T—dry weather temperature, RH—relative humidity	L_{eq}	L_{eq} *dBA* = *64.67* + *3.93 logN1* + *2.69logN3* − *1.048 log N4* − *3.84log V1* + *1.71logV3* − *0.034RH* − *0.042 T* − *0.011 W* − *0.04H*	R^2 = 0.92	Prediction for highways (using MLR model)	Models valid only for Ahvaz city's conditions and not suitable for field study
Garg et al. (2014)	Delhi, India	Traffic flow and Traffic speed	LA_{eq} L_{10}	LA_{eq} = *67.969* + *4.165log* Q_{eqv} − *3.857log* V_{eq} + *0.077(*V_{eq}*-50)* L_{10} = *71.639* + *3.627log* Q_{eqv} − *4.176log* V_{eq} + *0.024 (*V_{eq}*-50)* *NPL* = *73.454* + *5.532log* Q_{eqv} − *6.881log* V_{eq} + *0.069(*V_{eq}*-50)* *TNI* = *55.382* + *6.785log* Q_{eqv} − *8.971log* V_{eq} + *0.047(*V_{eq}*-50)* *Where* Q_{eqv} = *equivalent traffic flow,* V_{eq} = *equivalent vehicle speed*	R^2 = 0.5424	Predict the TN levels with accuracy of ± 2 dB(A) (using MLR model)	Does not consider geometrical propagation and receivers location resulting in uncertainty in prediction
Suthanaya (2015)	Denpasar, Indonesia	Traffic volume, traffic speed, road geometrics	L_{eq}, L_{10}, L_{50}, L_{90}	L_{eq} = *76.019* + *0.003X1* − *0.07X2* + *0.54 X3* L_{10} = *78.049* + *0.004 X1* − *0.09 X2 -0.09 X3* L_{50} = *73.952* + *0.004X1* − *0.014 X2* − *0.017X3* L_{90} = *67.783* + *0.006X1* − *0.13X2* − *0.013X3* *X1 is traffic volume of motor cycle, X2 is light vehicle and X3- heavy vehicle*	L_{Aeq} R^2 = 0.408, L_{A10} R^2 = 0.571, L_{A50} R^2 = 0.779, L_{A90} R^2 = 0.703	Prediction for collector roads (using MLR model)	Speed not included in the model, limited to predict for collector road with an average speed between 23.8 to 49.09 kmph
Kumar (2015)	Patiala, India	Vehicle volume, % of heavy vehicles	L_{eq}	*For regression model* *Leq [dB (A)]* = *57.56* + *5.357* × *Log Q* + *0.0325* P* *Where Q is vehicles /h and P is % of heavy vehicles* *For GA model* *Population size* = *30* *Crossover function* = *2 points* *Maximum range of 3 constants* = *60 10 0.08* *Minimum range of 3 constants* = *50 5 0.2* *Crossover operator use* = *uniform, roulette wheel, tournament*	*MSE* = *0.0558* *MSE* = *0.7575*	Predict equivalent continuous sound level (using MLR and GA model)	Data from single station/point used for developing the model. Hence, it is possible that developed model does not take into account all the variations. Speed not considered as variable
Konbattulwar et al. (2016)	Mumbai, India	Vehicle speed, traffic intensities, pavement type, no of lanes	L_{avg} peak hour L_{avg} off peak hour	$N^C_{CAC} = 61.993 + 0.067N + 7.311I + 0.001732V + 1.9924S$ N^B_{CAC} = *61.611* + *0.211 N* + *7.14I* + *0.0007621 V* + *0.1404S* $N^C_{NAC} = 69.624 + 0.0876N + 2.675I + 0.0019V$ N^B_{CNAC} = *69.611* + *0.0875 N* + *2.678I* + *0.0022 V* *N* = *no of lanes, V* = *traffic volume, S* = *speed, I* = *intersection area*	R^2 = 0.78 (AC car, concrete road), R^2 = 0.72 (AC car, bituminous road), R^2 = 0.78 (non-AC car, concrete road), R^2 = 0.75 (non-Ac car, bituminous road)	In vehicle noise prediction (using MLR model)	Noise emitted by the test vehicle (i.e., noise generated by the engine, body interior noise, etc.) is not considered in development of model.

Table 2 (continued)

Author	City, country	Variables considered	Noise data requirement	Model equation/details	R^2/MSE observed	Prediction	Limitations
Gharibi et al. (2016)	Golestan National Park, Iran	Speed of medium weight vehicles, no of light weight vehicles, ground roughness coefficient, road distance (distance from traffic line), moisture, altitude	L_{eq}	$L_{eq(1\,h)}=75.61–14.2\log(Road_{dis})+0.654\log(rugged)+0.018(V_m)+0.106(moist)+0.006(z)+0.005(NI)$ $Road_{dis}$ — distance from traffic line to receiving point V_m — speed of medium weight vehicles *Moist* — % moisture *Z* — altitude *N1* — no. of light weight vehicles	$R^2=0.726$	Prediction on Asian highways (using MLR model)	May not be easily transferable to other datasets
Shalini and Kumar(2018)	Varanasi, Delhi	Traffic Volume, Noise Climate, noise range, Weight of traffic volume, % of heavy vehicles	L_{eq}	$L_{eq}=(8.873NR)+(1.302P)-(0.892Qw)-(0.394NC)-5.623$ dBA *where NR = noise range, p = percentage of heavy vehicles, Qw = the weighted traffic volume, and NC = noise climate*	$R^2=0.809$	Prediction of L_{eq} in India traffic flow (using MLR model)	Small sample size reduces the power of study
Lekshmi et al. (2018)	Kochi, India	Traffic volume, traffic speed and percentage of heavy vehicles	L_{eq}	*Regression model* $L_{eq}=50.844+0.6662\times S+0.001\times TV+0.013\times P$ *ANN model: feed forward propagation neural network* *Architecture = 3–15-1*	R^2 (regression) = 0.84 R^2 (ANN) = 0.94 MSE (regression) = 10.295×10^{-3} MSE(ANN) = 2.26×10^{-3}	For predicting *Leq* (continuous sound level) in dB (A) (using MLR model and ANN model)	Parameters such as road width, buildings heights, honks and others could be studied in order to maximize the accuracy of the modelled results
Kamineni et al. (2019)	Andhra Pradesh and Telangana, India	Traffic volume, avg traffic speed, traffic composition, carriageway width	L_{10}, L_{eq}	$L_{eq}(1\,h)=56.32+0.0301TV+0.171\,ATS+0.0691\%$ *of heavy vehicles* $+0.328\%$ *of cars* $L_{10}(1\,h)=51.071+0.0372TV+0.147ATS+0.370\%$ *of heavy vehicles* $+0.0592\%$ *of 2 W* *TV — traffic volume, ATS — average traffic speed*	$R^2=0.892$ for L_{eq} (1 h), $R^2=0.934$ for L_{10} (1 h)	Prediction of highway traffic noise for heterogenous traffic (using MLR model)	Model lacking the use of large sample size
Patthanaissaranukool et al. (2019)	Thailand	Speed of vehicle, traffic volume, the ratio of trucks and heavy trucks to the total number of vehicles, number of lanes, and distance from the traffic lane to the receiving point	L_{eq}	$L_{eq}=PWL-10\log 2ld+Ld+Lg$ *where* $PWL=67.8+20.4\log V+10\log((1-a)+5.37a)$ *a = ratio of large vehicles to the total number of vehicles* *l = distance from the traffic lane to the receiving point (m)* *d = average distance between cars (m)* *Ld = the correction value for diffraction* *Lg = the correction value for ground surface attenuation*	$R^2=0.655$	Could be used to predict traffic noise of other cities of Thailand (NMTHAI 1.2)	NMTHAI 1.2 model seems appropriate only for predicting the road traffic noise level in urban areas
Awwal et al. (2021)	Johor, Malaysia	Traffic volume (% of HV), speed and head way, pavement type	L_{Aeq}	*Asphalt pavement (PH)* $L_{Aeq}=78.525+0.185S-0.872H-0.210H_v$ *Asphalt pavement (OPH)* $L_{Aeq}=79.208+0.198S-1.026H-0.337H_v$ *Concrete pavement (PH)* $L_{Aeq}=74.444+0.291S-1.150H-0.193H_v$ *Concrete pavement (OPH)* $L_{Aeq}=77.761+0.183S-0.914H-0.045H_v$ *where s = speed, H = headway, and Hv = % of heavy vehicles*	Asphalt pavement(PH) $R^2=0.89$, asphalt pavement(OPH) $R^2=0.87$, concrete pavement (PH) $R^2=0.98$, concrete pavement (OPH) $R^2=0.80$	Prediction on selected pavement type (using MLR modelling)	Traffic noise pattern for different types of pavements is not same under different traffic conditions, so a new traffic noise model for specific condition is required for better prediction of traffic noise
Ranpise et al. (2021a, b)	Surat, India	Traffic volume count, building height, road width	L_{eq}	$Y=30.212–2.132X_1+2.156X_2+1.6X_3+25.671X_4$ X_1-2 W, X_2-3 W, X_3-4 W count, X_4-Avg Height of buildings	$R^2=0.511$	Prediction at major urban roads (using MLR model)	Model developed is week and not reliable

Table 2 (continued)

Author	City, country	Variables considered	Noise data requirement	Model equation/details	R^2/MSE observed	Prediction	Limitations
Ranpise et al. (2021a, b)	Surat, India	Traffic volume, average spot speed, building height	L_{eq}	*Network type — feed-forward back propagation* *Training function — TRAINLM* Learning function — LEARNGDM Performance function — MSE Number of neurons — 11 Transfer function — TANSIG	$R^2 = 0.979$ *MSE = 0.022 for artificial neural networks*	Prediction for major arterial roads (using ANN model)	Does not give idea about significant variables and not provide correlation between variables
Ramakrishna et al. (2021)	Vijaywada, Andra Pradesh, India	Traffic flow, traffic composition	L_{eq}, L_{10}, L_{50}, L_{90}	*Refression model* $Y_{Residential} = 70.71 + 0.005554(Q) - 0.16129(P)$ $Y_{Commercial} = 65.155662 + 0.007255(Q) + 0.196743(P)$ $Y_{Industrial} = 67.05215 + 0.005511(Q) + 0.199601(P)$ $Y_{Silent} = 69.72 + 0.003595(Q) + 0.030977(P)$ *Q is vehicles flow per hour* *P is percentage of heavy vehicles*	$R^2 = 0.529$ $R^2 = 0.687$ $R^2 = 0{,}351$ $R^2 = 0.534$	Predict TN levels in residential, commercial, industrial, and silent zones (using MLR model and ANN model)	Less number of data points are used in present study for development of model. Hence, the developed model does not take into account all the variations in the data base leading to traffic noise in the results
Gilani and Mir (2021)	Jammu and Kashmir, India	Traffic volume, traffic speed, volume of heavy vehicles, pavement width, and honking	L_{eq}, L_{10}, L_{90}	*Leq,1 h(Morning) = 9.91 log PNI + 69.324* *Leq, 1 h(Afternoon) = 3.19 log PNI + 66.840* *Leq, 1 h(Evening) = 4.62 log PNI + 69.197*	0.969 0.846 0.889	For prediction of traffic noise in developing countries like India having heterogeneous traffic condition (Graph theory approach)	Only five parameters from traffic subsystem used for modelling and inclusion of other subsystems (like road, environment and driver behaviour) is an essential component that influences RTN

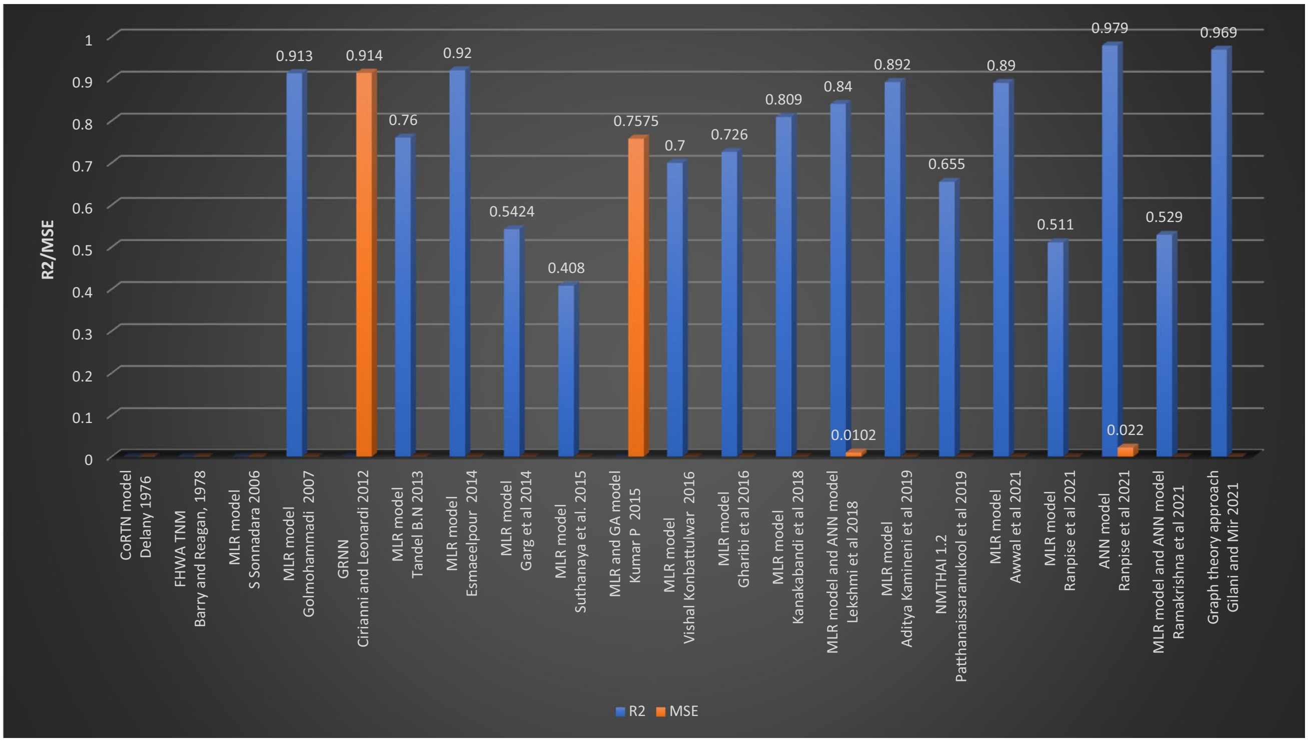

Fig. 1 Timeline plot indicating specific years when each disruptive model was introduced and R^2/MSE observed

Conclusion

In this work, literature related to traffic noise monitoring and predictive modelling of traffic noise was studied. Based on the review of the literature, it is concluded that around 82% of noise monitoring studies are focused on traffic noise near roadways, and only 18% were related to traffic noise in different zones (residential, industrial, commercial, and silent zones). Noise monitoring studies are reported to have been carried out on different days and times, but effect of different seasons has not been considered. Mostly, the acoustic energy descriptor used is equivalent sound level L_{eq}; only in some cases, the percentile levels L_{10} or L_{50} are used.

Most of the models have been developed considering average speed, percentage of vehicle, traffic volume, and road dimensions. Undoubtedly traffic noise also depends on pavement type, vegetation along roads, barriers, road surface (roughness), gradient effect, wind speed, honking of horns, reflective surface etc.; therefore, considering these factors can give a more comprehensive model. Most of the noise prediction models worldwide have been built using regression modelling; therefore, an attempt to develop traffic noise prediction model using evolutionary computing methods like genetic algorithm, fuzzy systems, and neural networks and comparison of their results with traditional regression models can bring forth certain interesting results. Further models can be developed based on studies conducted in all four seasons, all days of week, for different conditions (like dry and wet surface) of road, and these studies can be further extended to measuring in vehicle noise levels on same roads to compare the noise levels tolerated by residents, road users, and the commuters; this will help in formulating traffic noise regulations.

From the study, it can be concluded that for algorithm-based modelling, large datasets are required to get the benefit of generalization and nonlinear mapping, whereas linear regression models need least data points, more than the number of variables, which can be small set. Algorithm-based models predict better but do not quantify the effects of various factors contributing to noise, whereas basic regression models have lesser prediction accuracy but are able to quantify the effects of a factor. Therefore, algorithm-based models are more suitable for application like estimation of cost related to noise pollution and regression models can be used in planning stage where effects need to be studied.

Noise mitigation measures suggested by researchers in different studies can be broadly categories into traffic control and management, technological solutions, and road design measures. Use of intelligent transport system (ITS) in transportation planning can help to control mobility, traffic volume, vehicle speed, composition etc. Technological solution includes innovative studies like utilization of sonic crystals in construction of noise barriers, poroelastic road surfaces (PERS), and application of active noise control (ANC).

Introduction of roundabouts, chicanes, dense vegetation, green area etc. are the road design measures.

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Availability of data and materials Not applicable.

Declarations

Ethical approval The manuscript entitled "Traffic noise monitoring and modelling — an overview." It has not been published elsewhere and that it has not been submitted simultaneously for publication elsewhere. Further I have not submitted my manuscript to a preprint server before submitting it to *Environmental Science and Pollution Research*.

Consent to participate Not applicable.

Consent for publication I Suman Mann transfers to the Environmental Science and Pollution Research journal the non-exclusive publication rights and warrants that my contribution is original and that I have full power to make this grant. I accept responsibility for releasing this material on behalf of all co-authors. This transfer of publication rights covers the non-exclusive right to reproduce and distribute the article, including reprints, translations, photographic reproductions, microform, electronic form (offline, online), or any other reproductions of similar nature.

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