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Simulation Based Traffic Noise Modelling and Assessment-A Sample Study in Kandy City, Sri Lanka

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Abstract: Traffic noise plays a significant role in worldwide urban areas, impacting public health and quality of life.This study has focused on assessing traffic noise levels at selected locations in Kandy, Sri Lanka, using simulation-based modelling techniques. SoundPLAN was used as the modelling software, and the study was carried out using three distinct traffic noise models: ASJ RTN 2013, CNOSSOS-EU 2015 and FHWA TNM 2.5 to map the noise propagation. Real-time sound measurements were also taken to validate a model. According to the results, the ASJ RTN 2013 model illustrated the lowest percentage error for both daytime and nighttime simulations alongside the measured sound data. Thus, it was chosen as the best match of the three models used. Furthermore, the chosen traffic noise model was further used to map the noise propagation around a complex junction within the same city. Then, the simulated results were used to assess noise pollution levels. The main intention of this study is to demonstrate the use of established traffic noise models in predicting traffic noise in Sri Lanka. It can be taken as a sample study for future investigations into traffic noise management and mitigation strategies in Sri Lanka.

Keywords: Traffic Noise, SoundPLAN, ASJ RTN 2013, CNOSSOS-EU 2015, FHWA TNM 2.5

1. Introduction

In urban areas, road traffic is widely regarded as the primary source of noise pollution [1],[2],[3]. Engines, exhaust systems, aerodynamic friction, rolling tyres on roads, and interactions among vehicles are the major sources of noise in a vehicle [4],[5]. The growing vehicle population and increasing traffic flow directly contribute to the rise in traffic noise. Exposure to high levels of noise can result in communication disruption, cardiovascular issues, sleep disturbances, decreased performance, annoyance, and changes in social behaviour. Moreover, prolonged exposure to significant noise levels can also lead to hearing impairment [6],[7]. The World Health Organization (WHO) has issued recommended levels for road traffic noise and noise mitigation interventions to address these issues [8]. In Sri Lanka, the National Environmental (Noise Control) Regulations (No. 1 of 1996) [9] and guidelines issued by the Central Environmental Authority (CEA) [10] serve as the assessment criteria for traffic noise.

Conventional methods for environmental sound monitoring rely on short-term measurements using costly equipment, which require skilled and expensive personnel for setup and operation [11],[12]. Rather than using sound monitoring, it is more convenient to use noise modelling software to simulate sound propagation over large areas. SoundPLAN [13], IMMI [14] and CadnaA [15] are some of the most commonly used noise modelling software. Several studies have been done worldwide to model sound propagation and create noise maps using these tools [16]-[19]. However, according to the literature, only a few traffic noise studies have been conducted in Sri Lanka, and these have exclusively relied on measurement-based techniques to model sound propagation [20]-[25].

This study has been carried out as an initial step to model traffic noise pollution in Sri Lanka using a simulation-based approach and to identify a suitable traffic noise model for future studies. Furthermore, this study demonstrates how this model can be used to assess the noise pollution level in accordance with Sri Lankan noise control regulations [9].

This paper is structured as follows: Sec. 2 addresses the theoretical background and discusses three widely used road traffic noise models. Next, Sec. 3 states the measurements and modelling procedure along with the study's results. Finally, Sec. 4 and Sec. 5 provide an overall summary and future work.

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2. Noise Mapping and Theoretical Background

Noise mapping is essential for assessing, managing, and mitigating environmental noise pollution. It involves creating detailed maps that visualize noise levels across different geographical areas. The process integrates various noise prediction models and measurement techniques to represent the noise landscape accurately. The implementation of noise maps is particularly crucial in urban areas with high traffic density, where noise pollution poses significant health risks.

2.1 Traffic Noise Models

Traffic noise models aim to accurately predict the behaviour of sound waves as they travel through various mediums, considering factors such as vehicle density, average vehicle speed, atmospheric conditions, and terrain characteristics. Using mathematical algorithms and computational simulations, these models offer valuable insights into the distribution of sound energy generated by vehicles over distance and time.

Some of the most commonly used sound propagation models:the Federal Highway Administration Traffic Noise Model (FHWA TNM) version 2.5 [26],[27],ASJ RTN 2013[28], Common NOiseaSSessmentmethOdS in Europe (CNOSSOS-EU) 2015 [29], the national German standard for the prediction of road and parking lot noise (RLS 90 model)[30], French method for road traffic noise prediction (NMPB-Routes-2008 model) [31], Calculation of Road Traffic Noise (CoRTN88) from United Kingdom, and Nord 2000 from Danish Environmental Protection Agency [32]-[34] are utilized across various applications and countries. In this study, particular attention was given to FHWA TNM 2.5, ASJ RTN 2013, and CNOSSOS-EU 2015,as these models have been extensively validated and are widely used in literature, ensuring reliability and acceptance among researchers and policymakers.

2.1.1 FHWA TNM 2.5

The highway traffic noise prediction and analysis model, developed by the United State's Federal Highway Administration, computes highway traffic noise as an A-weighted sound level for different vehicle categories: automobiles, medium trucks, heavy trucks, buses, and motorcycles. This model predicts the noise level through a series of adjustments to a reference sound level, EL_i,which represents the mean noise emission level of the i^{th} vehicle class. The equivalent sound level for the i^{th} vehicle class over one hour ($L_{Aeq,1h}$) is calculated using,

$$L_{Aeq,1h} = EL_i + A_{\text{traffic}(i)} + A_d + A_s \qquad ...(1)$$

where $A_{\text{traffic}(i)}$ is the adjustment for traffic flow,which depends on vehicle speed. A_d is the adjustment for distance from the road and the road length, given by,

$$A_d = 10 \ lg \left[\left(\frac{d_0}{d}\right)\left(\frac{\alpha}{180}\right)\right], \qquad \ldots(2)$$

where d_0 is the reference distance at which the emission levels are measured (15m in FHWA model), d is the perpendicular distance from the traffic lane centerline to the observer and α is the angle subtended by the elemental roadway segment in degrees. In Eq. ...(1), A_s represents the adjustments for barriers, trees, ground effects, etc. and notably, the FHWA model does not account for atmospheric effects.

2.1.2 ASJ RTN 2013

The ASJ RTN-Model, is a road traffic noise prediction model developed by the Acoustical Society of Japan. Its 2013 version is applicable for predicting traffic noise on general roads and special road sections, without limitations on traffic volume. It can be applied for both steady and non-steady vehicle running conditions. This model assumes that the noise is emitted from a single source point within a vehicle. As the sound power level of a road vehicle is primarily influenced by vehicle speed, the model calculates the sound power level as,

$$L_{\text{WA}} = a + b \ \lg(V) + C, \qquad \ldots(3)$$

where L_{WA} is the sound power level in dB, a and b are regression coefficients and V is the vehicle speed in km/h. C is the correction term accounting for various factors such as pavement type, road slope, and noise directivity. The correction $C$is defined as,

$$C = \Delta L_{\text{surf}} + \Delta L_{\text{grad}} + \Delta L_{\text{dir}} + \Delta L_{\text{othr}}, \qquad \ldots(4)$$

where ΔL_{surf} is the correction for a drainage asphalt pavement [dB], ΔL_{grad} is the correction for road gradient [dB], ΔL_{dir} is the correction for sound radiation directivity [dB] and ΔL_{othr} is the correction for other factors [dB].

The method also addresses the fluctuation in A-Weighted sound pressure levels caused by meteorological variables like wind and incorporates sound reflection and transmission calculations. Additionally, the ASJ RTN 2013 modelincludes methodologies for assessing noise in road junctions, signalized intersections, road tunnels and depressed/semi-underground roads, viaduct structure-borne noise, and adjustments for noise reduction due to special pavement types considering vehicle speed, running mode (e.g. acceleration and deceleration), and the time elapsed since pavement installation [28],[31].

2.1.3 CNOSSOS-EU 2015

The CNOSSOS-EU road traffic noise emission model, developed by the European Commission, predicts noise levels by calculating rolling noise generated by tyre-road interaction and propulsion noise from vehicle components such as the engine, exhaust, gears, and air intake.These calculations are performed for various vehicle categories as functions of speed and frequency. The model classifies vehicles into five categories; light, medium, heavy, powered two-wheelers and other. For the first three categories (light, medium and heavy vehicles), the total sound power level is the sum of rolling and propulsion noise,

$$L_{W,i,m}(v_m) = 10lg\left(10^{\frac{L_{WR,i,m}(v_m)}{10}} + 10^{\frac{L_{WP,i,m}(v_m)}{10}}\right) \quad (5)$$

where $m \in \{1,2,3\}$ represents the vehicle category with a $v_m$average speed in the vehicle flow.$L_{WR,i,m}$ is the sound power level for rolling noise and $L_{WP,i,m}$ is the sound power level for propulsion noise.

For powered two-wheelers, propulsion noise is the dominant factor. Therefore, the total sound power is,

$$L_{W,i,m=4}(v_{m=4}) = L_{WP,i,m=4}(v_{m=4}). \quad \ldots(6)$$

The general equation for rolling noise is,

$$L_{WR,i,m} = A_{R,i,m} + B_{R,i,m}\lg\left(\frac{v_m}{v_{ref}}\right) + \Delta L_{WR,i,m}, \quad .(7)$$

where $A_{R,i,m}$ and $B_{R,i,m}$ are coefficients provided in octave bands for each vehicle category and for a reference speed of $v_{ref} = 70\text{km/h}$. $\Delta L_{WR,i,m}$ represents the corrections for factors such as road surface type, tyre properties, speed variations and temperature changes.

The propulsion noise is given by,

$$L_{WP,i,m} = A_{P,i,m} + B_{P,i,m}\frac{(v_m - v_{ref})}{v_{ref}} + \Delta L_{WP,i,m}, \quad (8)$$

where $A_{P,i,m}$ and $B_{P,i,m}$ are coefficients provided in octave bands for each vehicle category and for a reference speed of $v_{ref} = 70\text{km/h}$, and $\Delta L_{WP,i,m}$accounts for corrections due to driving conditions, road gradients and other influencing factors.

3. Traffic Noise Measurement and Modelling

Kandy, located in the Central Province of Sri Lanka, is the country's second-largest city after Colombo. Recognised as a UNESCO World Heritage Site, Kandy is a major tourist attraction situated in a valley surrounded by mountain rings. The city has a resident population of approximately 0.12 million, with an additional 0.1 million people visiting daily. Moreover, over 100,000 vehicles move daily within the area.

Like any developing city, Kandy undergoes continuous development, including the construction of new houses, industries, commercial complexes, and roads. However, these activities have led to significant challenges, such as traffic congestion, pollution, and a shortage of residential land.Given Kandy's unique geographical location, concerns about air pollution and its associated health impacts have become increasingly prominent. Therefore, it is essential to study and assess the noise levels in Kandy and implement appropriate measures to address the city's growing demand.

3.1 Test Site

The objective of the first phase of this study was to identify the most suitable traffic noise model. To achieve this, a relatively simple road segment within the Kandy city limits was selected for analysis. As recommended in [5], the chosen area comprises a two-lane straight stretch where a continuous, uninterrupted flow of vehicles occurs, free from obstructions such as speed bumps, junctions, or traffic signals. The second segment is more complex, in which the selected lane combines at a four-way roundabout. The test site is shown in Figure 1(a).

3.2 Methodology

After selecting the test site, real-time noise measurements were taken following the guidelines outlined in the National Environmental (Noise Control) Regulations (No. 1 of 1996) [9]. A factory-calibrated integrating averaging noise level meter, the Rion NL-42 Type II, along with a Cirrus (CR: 515) acoustic calibrator (IEC 60942: 2003 Class I), was used for measurements.As shown in Figure 2, the sound level meter was positioned on a tripod at a height of 1.25m above ground level.As recommended in [9], the equivalent continuous A-weighted sound level(L_{Aeq}) was measured over 15 minutes every hour for 24 hour period.

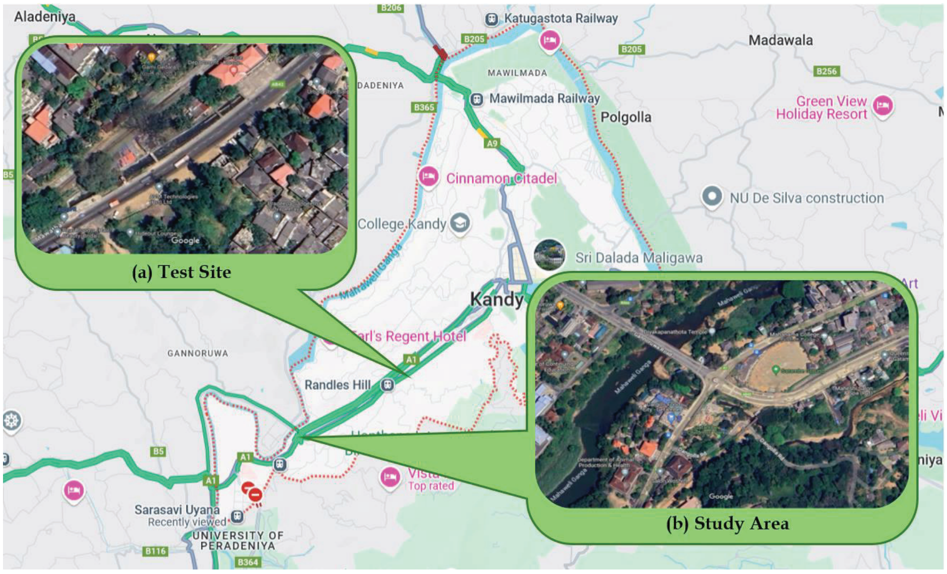


Figure 1 - Satellite Views of The Selected (a) Test Site and (b) Study Area (Courtesy-Google Maps)

Figure 2 - Sound Level Meter Positioning

Noise level for the daytime (6.00 a.m. to 9.00 p.m.), $L_{Aeq(15\text{ hours})}$, was calculated as the logarithmic average of all individual $L_{Aeq(15\text{min})}$ values,

$$L_{Aeq(15\text{hours})} = 10\lg\left[\frac{\sum_i^n 10^{\frac{L_{Aeq(15min),i}}{10}}}{n}\right], \quad \ldots(9)$$

where n is the number of $L_{Aeq(15\text{min})}$ values in each assessment period over the measurement duration. In this study, measurements were taken in the first 15-minute period of each hour, meaning$n = 15$ for the daytime period.

Similarly, the noise level for the nighttime period (9.00 p.m. to 6.00 a.m. next day) was calculated as,

$$L_{Aeq(9\text{hours})} = 10\lg\left[\frac{\sum_i^n 10^{\frac{L_{Aeq(15min),i}}{10}}}{n}\right], \quad \ldots(10)$$

where $n = 9$.

SoundPLAN noise modelling software was used to map traffic noise in selected parts of Kandy city. Accurate traffic noise modelling requires detailed traffic flow data for the specific road sector, so traffic data were collected simultaneously with the noise measurements. Table 1shows the classified traffic flow data obtained.

Table 1- Average Traffic Volume Per Hour

Vehicle Type	Time	
	Day 1	Day 2
	6.00am-9.00pm	9.00pm-6.00am
Passenger Cars	523	93
Light Trucks	298	56
Medium Trucks	146	40
Heavy Trucks	168	51
Motorcycles	1295	156
Traffic Flow Type	Unsteady	Unsteady
Road Width	7.0 m	7.0 m

Table 2 shows the sound modelling parameters used in the SoundPLANsoftware. An AutoCAD drawing of the test site, including building heights, was used to map noise propagation using the three different noise propagation models.

Table 2 - Sound Modelling Parameters

Description	Properties/Values
SoundPLAN software version	8.2 (64 bit)
Used Noise Models	ASJ RTN 2013, CNOSSOS-EU2015, FHWA TNM 2.5
Assessment	Day Night Level LDN
Emission Time Slices	Day:6.00am- 9.00pm Night: 9.00pm-6.00am
Traffic flow and road section type	Unsteady Flow
Road Condition	Motorway
Lane Width	3.5 m
Distance emission band	1.75 m
Central reservation width	0 m

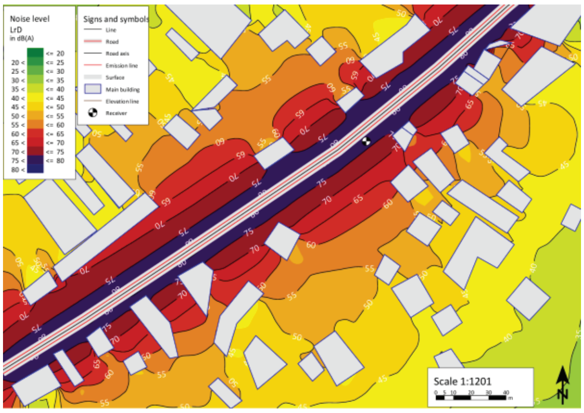
After generating all noise maps from the three models for both daytime and nighttime periods, $L_{Aeq(15hours)}$ and $L_{Aeq(9hours)}$ values were compared with the simulated values to determine the most suitable traffic noise model.To findthe most suitable traffic noise model, the Percentage Bias (PBIAS) of simulated $L_{Aeq(15hrs)}$ and $L_{Aeq(9hrs)}$ values were calculated using Eq.(11),

$$\text{PBIAS} = \frac{10lg\left(\frac{\sum_{i=1}^{n} 10^{S_i}}{n}\right) - 10lg\left(\frac{\sum_{i=1}^{n} 10^{O_i}}{n}\right)}{10lg\left(\frac{\sum_{i=1}^{n} 10^{O_i}}{n}\right)} \times 100 \quad \ldots(11)$$

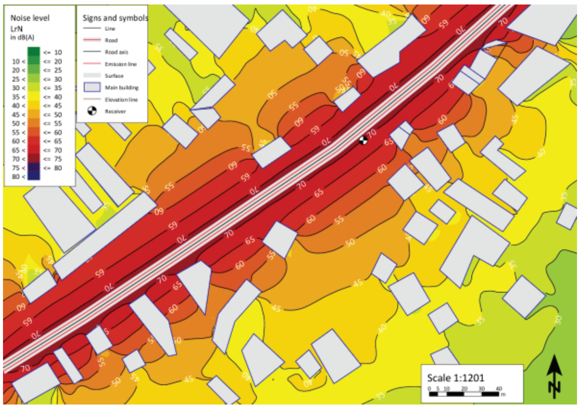
where $S_i = \frac{L_{Aeq(15min),i}^{Sim}}{10}$ is the simulated noise value and $O_i = \frac{L_{Aeq(15min),i}^{Obs}}{10}$ is the measured noise value in the i[th] hour and n is the total number of observations.

3.3 Noise Model Selection

Figure 3 shows the simulated noise propagation maps using ASJ RTN 2013, CNOSSOS- EU2015 and FHWA TNM 2.5 noise models for both daytime and nighttime.



(a)



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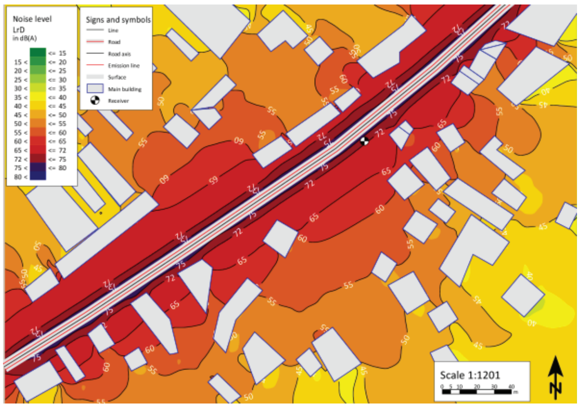

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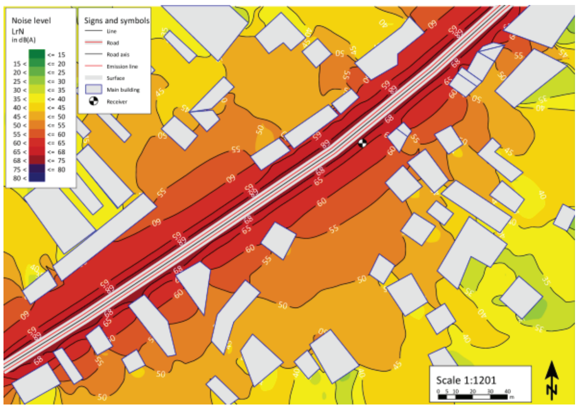

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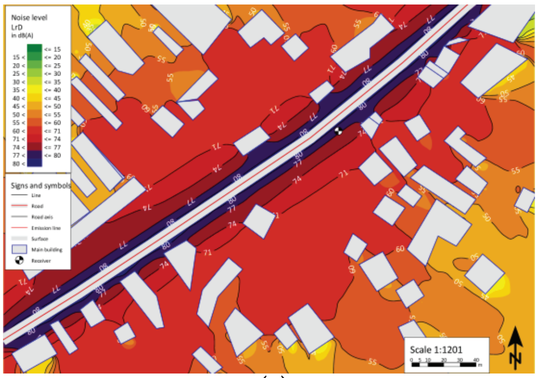

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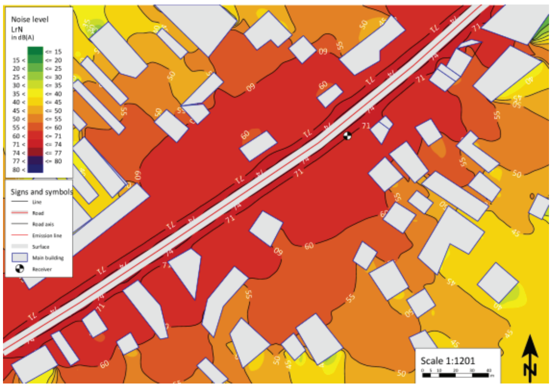


(f)

Figure 3 - (a) ASJ RTN 2013 Daytime (b) ASJ RTN 2013 Nighttime (c) CNOSSOS-EU2015 Daytime (d) CNOSSOS-EU2015 Nighttime (e) TNM 2.5 Daytime (f) FHWA TNM 2.5 Nighttime

Table 3 presents the PBIAS values calculated for each model using Eq. (11).

Table 3 - PBIAS of Each Noise Model

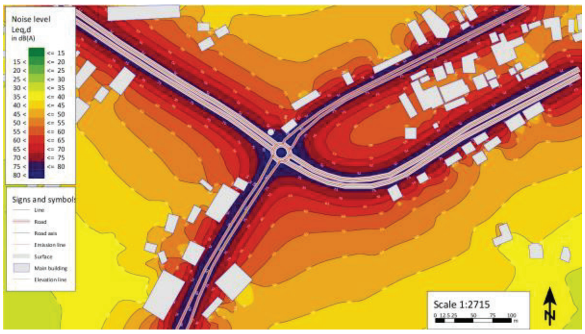
Model	$L_{Aeq(15hrs)}$ **(dB)**	**PBIAS of** $L_{Aeq(15hrs)}$	$L_{Aeq(9hrs)}$ **(dB)**	**PBIAS of** $L_{Aeq(9hrs)}$
Logarithmic Average of Measured SPL	75.76	-	69.98	-
ASJ RTN 2013	74.7	-1.40%	68.1	-2.69%
CNOSSOS-EU2015	73.3	-3.25%	66.9	-4.40%
FHWA TNM 2.5	78.3	3.35%	71.9	2.74%

As shown in Table 3,ASJ RTN 2013 model demonstrates the lowest PBIAS values for both daytime and nighttime compared to the other two models. Additionally, the ASJ RTN2013 model consistently underpredicts noise levels relative to the measured values. Hence, when compared with the other two selected models, the ASJ RTN 2013 model is the most suitable for modelling traffic noise propagation in Kandy city.

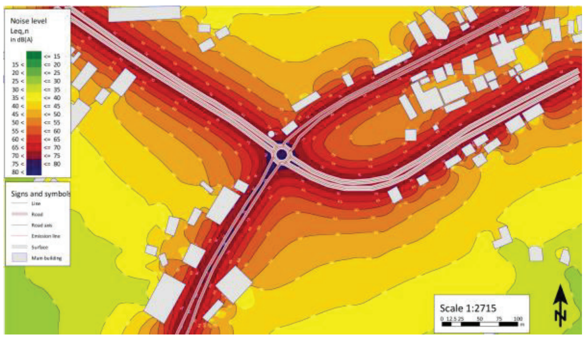
3.4 Noise Assessment

Noise regulations establish the maximum permissible noise levels and outline the methods for measuring and calculating environmental noise levels, in line with the standards set by the International Organization for Standardization. In Sri Lanka, noise assessments are conducted in accordance with the National Environmental (Noise Control) Regulations No.1 1996 [9], and the Guideline for Traffic Noise Assessment Criteria for Expressway issued by Central Environmental Authority [10]. Noise maps serve as valuable tools for monitoring noise distribution and identifying areas most affected by traffic noise.

Accordingly, ASJRTN 2013 model can be utilised to create noise maps for other parts of Kandy city after obtaining traffic flow data. For example, the noise around the Gatambe junctional area, a major gateway to Kandy city, is modelled to predict the noise effect on the surrounding selected locations.Due to frequent traffic congestion, this area experiences increased air pollution, leading to various health and economic complications as well [35]. Further, it includes non-residential lands that are sensitive to noise.Figure 1(b) shows the Getambe junctional area, and Figure 4 shows the noise maps simulated using SoundPLAN software, based on the traffic flow data for the area, as per the ASJ RTN 2013 model.



(a)



(b)

Figure 4 - (a) Daytime Noise Propagation Around Getambe Junctional Area (b) Nighttime Noise Propagation Around Getambe Junctional Area

Table 4 presents the noise assessment results for three selected locations within the studied areas, done according to National Environmental (Noise Control) Regulations No.1 1996 [9]. Accordingly, in all three representative locations, the daytime and nighttime noise levels are higher than the stipulated values.

4. Limitations and Future Work

While the ASJ RTN 2013 model demonstrated promising results, it is important to acknowledge the limitations of this study. The research focused on a specific urban area and traffic conditions, which may not fully represent other parts of Kandy or other cities in Sri Lanka. Additionally, the study relied on real-time measurements for model validation. Although these measurements are accurate, they can be influenced by short-term anomalies in traffic flow or environmental conditions, potentially impacting the generalizability of the findings.

Future research should consider a broader range of urban settings and include long-term data collection to account for temporal variations in traffic noise. Additionally, integrating other noise sources, such as construction activities and industrial operations, into the models could offer a more comprehensive assessment of urban noise pollution. Advancements in noise modelling software and computational techniques could further enhance the precision and applicability of these models across diverse urban environments.

5. Conclusions

This study addresses the significant urban challenge of traffic noise pollution by employing simulation-based noise modelling techniques in Kandy City, Sri Lanka using three different traffic noise models—ASJ RTN 2013, CNOSSOS-EU 2015, and TNM 2.5 using SoundPLAN. The research aimed to identify the most accurate model for predicting traffic noise in this specific urban environment. The results demonstrated that the ASJ RTN 2013 model achieved the lowest PBIAS when compared to real-time noise measurements, thereby establishing its suitability for this context.Conversely, the CNOSSOS-EU 2015 and TNM 2.5 models exhibited comparatively higher PBIAS values. This discrepancy can be attributed to differences in model algorithms, the specific parameters they account for, and the degree to which these parameters align with Kandy's unique traffic and road conditions. For example, CNOSSOS-EU 2015, developed for European conditions, may not fully capture the nuances of traffic behaviour and road characteristics in Sri Lanka. Similarly, TNM 2.5 might lack certain adjustments necessary for accurate noise prediction in this environment. In contrast, the ASJ RTN 2013 model's accurate performance in both daytime and nighttime simulations is noteworthy. Its ability to incorporate factors such as vehicle speed, pavement type, and road gradient likely played a significant role in achieving precise predictions.

The findings of this study have significant implications for urban planning and public health in Kandy. Accurate noise prediction models serve as essential tools for city planners and policymakers, enabling informed decision-making to address traffic noise pollution.By reliably mapping noise propagation, these models can identify noise hotspots and facilitate the implementation of targeted noise mitigation strategies. For example, the noise maps generated using the ASJ RTN 2013 model around the Gatambe junction highlight areas where noise levels exceed permissible limits. These insights can guide interventions such as noise barriers or modifying traffic flow to reduce noise exposure in affected areas.

Table 4 - Noise Assessment Results

Location	Type of the Area	Critical Limit	Actual Noise Band Region	Comments
Land in front of the KMC Fire Brigade	Urban /Rural/Mixed Residential	$65L_{Aeq(15\text{hours})}$	75dB(A) - 80dB(A)	Exceed the limit
		$56L_{Aeq(9\text{hours})}$	65dB(A) - 70dB(A)	Exceed the limit
Diyakapanathota Temple	Silent Zone	$50L_{Aeq(15\text{hours})}$	75dB(A) - 80dB(A)	Exceed the limit
		$45L_{Aeq(9\text{hours})}$	55dB(A) - 60dB(A)	Exceed the limit
Mahanama College	Silent Zone	$50L_{Aeq(15\text{hours})}$	65dB(A) - 75dB(A)	Exceed the limit
		$45L_{Aeq(9\text{hours})}$	50dB(A) - 55dB(A)	Exceed the limit

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