Two-dimensional road traffic noise mapping: A case study of Matara city in Sri Lanka

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Abstract *- Road traffic noise pollution is increasing year by year due to urbanization. Road traffic contributes to 80% of a city's noise pollution. Noise mapping is a comprehensive method for measuring and analyzing environmental noise, including the number of persons who are bothered by it and how often they experience its disruptive effects. This study focusses to visualize road traffic noise levels in Matara city, Sri Lanka. Traffic noise varies in different factors, a proper noise equation is essential to calculate road traffic noise. The noise observation points' separation and the precision of the noise equation are key factors in determining how well noise is represented visually. The Henk de Klujijver's noise model is used for calculating noise levels in this study. Suitable spatial interpolations are vital to interpolate traffic noise levels. Moreover, this study enhances the accuracy comparison between inverse distance weighted (IDW), kriging, and spline spatial interpolations on road traffic noise mapping. Designing noise observation points (Nops) is vital to the accuracy. Therefore, 10 metre distance interval was used for Nops. According to the Root Mean Square Error (RMSE), kriging interpolation had the minimum RMSE value. The final noise visualization was done by kriging spatial interpolation. However, 65.44% area was in less than 63dB in the morning, and 64.82% area was in less than 63dB in the evening. The results of this study can be used by urban planners for city development projects in the future.*

Keywords: Noise models, Noise visualization, Spatial interpolation, RMSE

I. INTRODUCTION

Human health is always harmed by environmental pollution such as that caused by noise pollution, hazardous waste, air pollution and water pollution (Biomagnetic Monitoring of Particulate Matter, 2016). Managing, environmental pollution is a difficult task. One of the most harmful types of pollution is noise (Environmental Pollution and Control, 2022). Noise pollution implies to increase physical and mental health issues of people. Most Sri Lankan cities have road traffic noise levels that exceed the recommended limits (Tiwari et al., 2017). Among all the noise-polluting factors, such as industrial noise, activity noise, traffic-related sources, and road traffic noise, there is a growing level of environmental concern and discomfort in urban cities with higher traffic concentrations. Road traffic is a major contributor to the ambient noise levels in most large cities and road traffic contributes about 80% of a city's noise pollution. (Grubesa and Suhanek, 2020). Figure 1 shows the distribution of noise levels according to the type of noise sources in the urban city area.

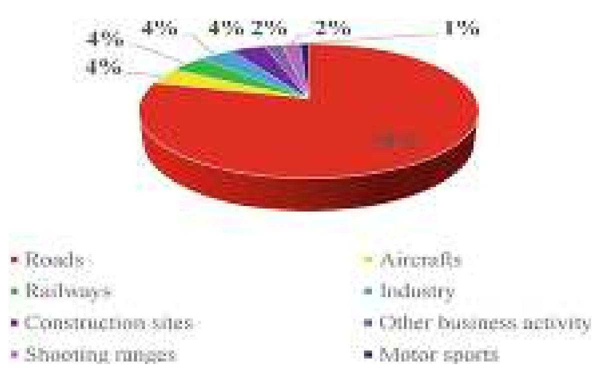

Figure 1: Noise pollution distribution by type of noise sources

Source: (Grubesa and Suhanek, 2020)

In Sri Lanka, there are certain rules and regulations regarding noise emissions. It is described under "The National Environmental Act, NO. 47 OF 1980". Table 1 is shown the standard noise emission levels in Sri Lanka. According to the act, 63 dB is the average noise level that can be emitted in the daytime. But the recommendations from the World Health Organization (WHO) mention that the A-weighted sound pressure level outside a building be no more than 55 dB during the day, and 45 dB during the night (Zagubien et al., 2015).

Table 1: National environmental act of Sri Lanka

Area	Laeq T	
	Day Time	Night Time
Low Noise	55	45
Medium Noise	63*	50
High Noise	70	60
Silent Zone	50	45

Source: (The National Environmental Act No. 47 of 1980)

Two-dimensional (2D) road traffic noise visualisation is useful to urban planners to identify silent zones. The horizontal can be used to abstract the high-risk, medium-risk, and low-risk noise areas. When looking at the noise map, it's clear that roads and junctions have a lot of noise, thus they can only be used for commercial purposes (Kurakula et al., 2014). This has benefited urban planners in reducing road traffic noise pollution in cities and villages. The representation of sound emission in noise maps is commonly indicates with color notifications. Color can help people comprehend how road traffic noise is distributed in city areas and to improve map use (Weninger, 2015). The recommended color scheme is illustrating in Figure 2.

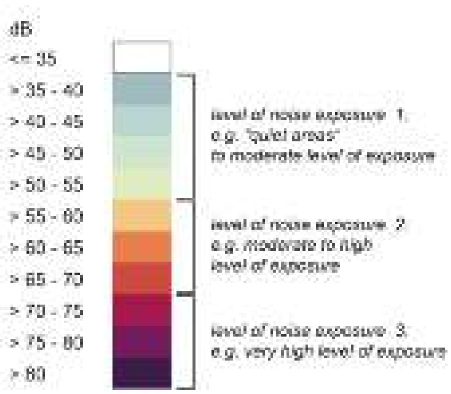

Figure 2: The color scheme for noise levels

Source: (Weninger, 2015)

II. METHODOLOGY AND EXPERIMENTAL DESIGN

A. Study Area

The selected study area is 0.6 km^2. The study area is shows in Figure 3. The main objective of this study is to determine the road traffic noise levels of the selected area. The study area is located about 450m away from Galle-Matara main road and located 2km away from Matara town area. There is density populated in Matara. The study area is surrounded by five schools. As a pilot survey, it was found, there is a higher road traffic with noise. Furthermore, there is a higher traffic flow due to the Godagama and Palatuwa southern express highway entrance and exits are situated along Akuressa road which is passing through this study area. Matara-Akuressa main road also expand and developed due to the Southern express highway. Therefore, the urban population is growing fast because of these reasons. When designing silent places such hospitals, courts, and libraries, the noise levels in these regions must be considered.

The aim of this study is to identify noise risky areas by embedding two-dimensional road traffic noise visualization according to the national environmental policies in Sri Lanka.

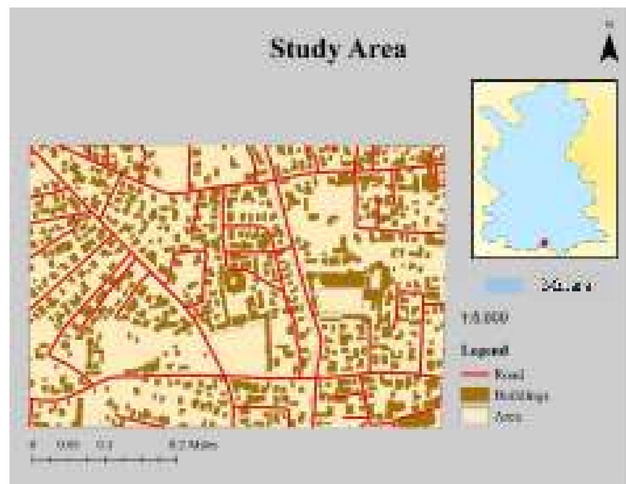

Figure 3: Study area

Source: (Survey Department of Sri Lanka)

B. Flow Chart of Methodology

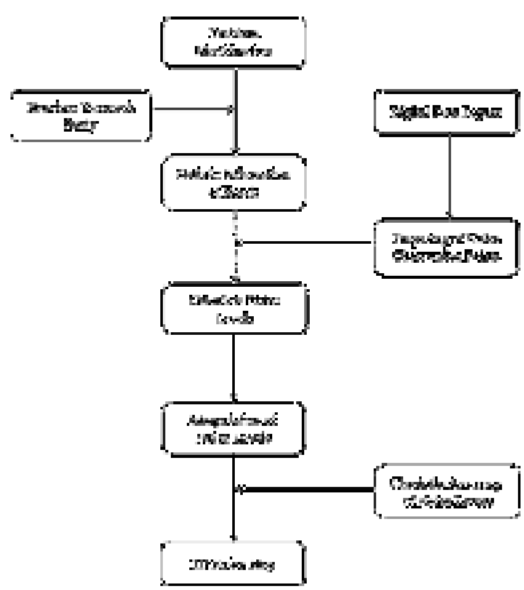

Figure 4: Research workflow of the study

The Figure 4 shows the research workflow of this study.

1) Digital data layers

Using digital data layers in GIS vector format at a scale of 1: 10,000, the 2D digital data layers were selected; buildings, roads and land use layer were used to creating the two-dimensional study area. Figure 4 shows the data layers. The area is considered to be flat. As a result, the GIS analysis does not include with contour layer.

2) Statistic data

The number of vehicles, speed of vehicles, and vehicle's type are the three types of statistic data for taking to find road traffic noise levels. Vehicle amount is one of important factor to increase the traffic noise levels (Ibili et al., 2022). Vehicles were categorized under the light vehicles, medium vehicles, and heavy vehicles. Categorization was based on the engine capacity of the vehicle. Such as less than 1500cc, between 1500cc – 3000cc and more than 3000cc. Vehicle speed is another important component to increase road traffic noise levels (Disomimba et al., 2022). The average vehicle speed for light, medium, and heavy vehicles was taken after observing ten vehicles for each group. A speed gun was used to measure the speed of vehicles. However, number of vehicles were manually collected for around three weeks, from 7:00 a.m. to 9:00 a.m. and 4:00 p.m. to 6:00 p.m. The average vehicle amount was taken to calculate road traffic noise levels. The reference speed was set at $40kmh^{-1}$ for light, medium and heavy vehicles. Data collection was done in three weeks of period continuously.

3) Preparing noise model using proposed noise models

The dB vision's noise specialist Mr. Henk de Klujijver has suggested a model for resolving issues, taking into consideration natural, physical, and traffic factors. This proposed model is extremely flexible, enabling it to run with a variety of parameters and in a variety of environments. Therefore, this traffic noise model was used for calculating noise levels in this study. (Kurakula and Kuffer, 2008).

$$L_{Aeq} = E+C_{optrek}+C_{reflectie}-D_{afstand}-D_{lucht}-D_{bodem}-D_{meteo}-D_{barrier} \quad (1)$$

(Ranjbar et al., 2012)

Equation (1) shows the Henk de Klujijver Road traffic noise equation. The L_{Aeq} is noise level of a receiver points. Equation (2) shows the emission of road traffic noise for the day.

$$E = 10\log\{(10^{\wedge E_{lv}/10}) + (10^{\wedge E_{mv}/10}) + (10^{\wedge E_{zv}/10})\} \quad (2)$$

Equations (3), (4), and (5) show the noise emission by the engine. Where, E_{lv} is the noise emission of the light vehicles, E_m is the noise emission of medium vehicles, and E_{zv} is the noise emission of the heavy vehicles

$$E_{lv} = 69.4+27.6\log\{V_{lv}/V_o\}+10\log\{Q_{lv}/V_{lv}\}+C_{wegdek,lv} \quad (3)$$
$$E_{mv}=73.2+19.0\log\{V_{mv}/V_o\}+10\log\{Q_{mv}/V_{mv}\}+C_{wegdek,mv} \quad (4)$$
$$E_{zv} =76.0+17.9\log\{V_{zv}/V_o\}+10\log\{Q_{zv}/V_{zv}\}+C_{wegdek,zv} \quad (5)$$

V_{lv} = Average speed of light vehicles, V_{mv} = Average speed of medium vehicles, V_{zv} = Average speed of heavy vehicles, Q_{lv} = Amount of the light vehicles, Q_{mv} = Amount of the medium vehicles, Q_{zv} = Amount of the heavy vehicles

$$C_{wegdek} = \Delta lm + bm\log (v_m/v_{om}) \quad (6)$$

The Equation (6) shows, the C_{wegdek} is that represent the noise emission relevant with the road surface. Δlm and bm have different values according to the road surface. C_{oprek} represents the extra noise emission from vehicle breaking and accelerating. Reflective noise is the extra noise that buildings and the sides of roadways emit. (Ranjbar et al., 2012)

$$C_{reflectie} = 1.5*fob_j \quad (7)$$

Equation (7) shows the reflectance noise by buildings and barriers. The Fob_j is reflection noise (value between 0 and 1). It is part on the opposite side of the road. Only when an object is placed at a respectable distance will it be considered as reflecting noise. The Equations (8), and (9) show reduction of the noise with the distance and absorption by the air. The $D_{afstand}$ is reduction of noise with the distance, D_{lucht} is reduction of the noise absorption from the air and r is shortest distance between road and calculation point.

$$D_{lucht} = 0.01*r^{0.9} \quad (8)$$
$$D_{afstand} = 10\log(r) \quad (9)$$

However, the main limitations of this study are, road traffic noise absorption by ground, impact by weather conditions (wind), and noise mitigation by barriers are not considered in this analysis.

4) Noise observation Points (Nops)

Noise sources are two types such point source and line source. If the source is a point source, the noise reduces 6 dB doubling with the distance. If the source is a line source, this scenario is not happened. The noise source is considered as a line source in Henk de Klujijver road traffic noise model. (Kurakula and Kuffer, 2008). Furthermore, the buildings are vital for designing the horizontal spacing of noise observation points. The shape of the buildings is required for designing the spacing of observation points in the horizontal direction. Building height is not considered because the purpose of this study was to prepare a 2D noise map. Nops were placed parallel to the road, with short intervals between them to provide a high density of points. Therefore, used 10m distance between the designed observation points. But points were not designed inside the buildings. Because buildings made with cement block out sounds entire. The following Figure 4 shows the designing of noise observation points in this study.

Figure 4: Noise observation points in the study area

5) Interpolation of noise observation points

The spline, kriging and IDW spatial interpolations were used for interpolation (Harman, Koseoglu, and Yigit, 2016). The interpolation function's power was set at 2 degrees. Higher order polynomial functions provide a highly smooth surface, but they can also cause unpredictable oscillations. Higher order polynomial function was not utilized to relieve those issues (Escobara, 2021). The output cell size was set at 1m. The number of points used was 12, and the search radius was set as "variable". The Gaussian was used for the semivariogram method in kriging, while the ordinary was utilized for the kriging method (Kurakula and Kuffer, 2008).

6) Validation of noise levels

All noise levels were calculated by using MATLAB software for the proposed noise model. However, the real noise levels (sample points) in the field must be taken for the validation. For observing sample noise in the field, the DEKKO SL-130, sound level meters are used. The accuracy of this noise meter is ± 0.1 dB. Sample observations are taken during two hours in morning and evening. To identify, location coordinates of sample observations, Handheld Global Positioning System (GPS) instrument was used. For the validation of interpolated noise levels, well distributed noise sample points were taken. According to the previous studies, the noise meter has been kept 1.5m above the ground levels when obtaining sample noise levels. (Rossi et al., 2022). Figure 5 shows the graphical locations of sample noise observation points.

Figure 5: Sample points in the study area

The value comparison of interpolated surfaces of IDW, kriging and spline by RMSE and mean error with sample points are shown in below table 2 and table 3. Kriging was selected as the suitable spatial interpolation technique for the final noise visualization. Then according to the NATIONAL ENVIRONMENT ACT, NO. 47 OF 1980 noise limit in an urban area must be less than 63dB during daytime. Therefore, kriging interpolation noise visualization was reclassified into 2 classes such less than 63dB and more than 63 dB. Figures 6 and 7 illustrates the final 2D road traffic noise visualisation.

III. RESULTS AND ANALYSIS

Table 2: Accuracy validation for the morning period

	Spline interpolation	Kriging interpolation	IDW interpolation
Minimum dB	41.087727	45.980556	45.345634
Maximum dB	83.644768	74.150482	78.013908
Mean dB	63.89146461	62.06133208	64.26284883
Std. Deviation	10.91280735	7.499705791	10.10405533
RMSE(with sample points)	6.441545777	4.656562523	5.84605542

Table 3: Accuracy validation for the evening period

	Spline interpolation	Kriging interpolation	IDW interpolation
Minimum dB	42.506461	47.497345	46.895523
Maximum dB	84.401283	75.861496	78.601955
Mean dB	64.74503957	63.04094078	65.0854237
Std. Deviation	10.61522913	7.431378557	9.747948253
RMSE(with sample points)	6.506582746	4.605905668	5.561692636

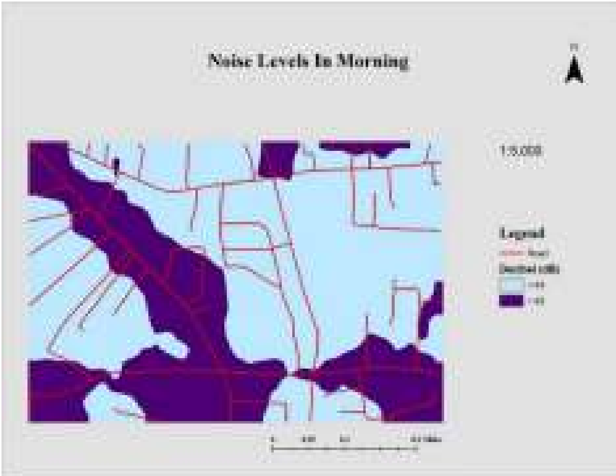

Figure 6: 2D noise map for the morning

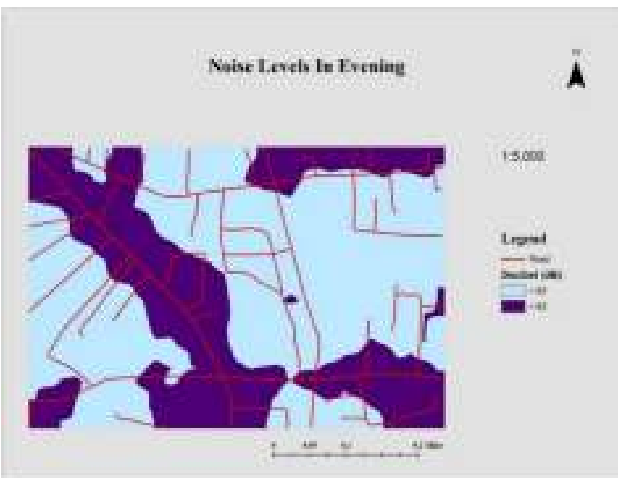

Figure 7: 2D noise map for the evening

III. DISCUSSION AND CONCLUSION

A) Discussion

The Henk de Klujijver traffic noise model is vital for calculating road traffic noise levels in urban areas. Because this noise model considers the categorization of vehicles and considers environmental and physical factors also. Moreover, the Henk de Klujijver noise model was combined with several equations. And this noise model is more flexible than the other noise model. Therefore, it was easy to modify, the equations to match with the study area. The spline, kriging and IDW are the better spatial interpolation techniques for road traffic noise interpolation because these methods generate continuous surfaces. The spline interpolation in the morning period gives the noise levels from 0 dB to the highest dB level. But in kriging and IDW interpolation techniques were shown noise levels from 45 dB to 80 dB only. It has been same for the evening period. Therefore, among them, kriging and IDW techniques are the most suitable techniques because there were continuous surfaces. Both interpolation methods provide a surface that fits with the sample noise observations more precisely. But the most suitable technique must be found. When checking Root mean square errors (RMSE) and mean error for the interpolation values with the sample values, the RMSE value and mean error of kriging is smaller than the RMSE and mean error of IDW value and RMSE and mean error of spline value in both morning and evening periods. Kriging shows the 4.666 RMSE for the morning period and 4.690 RMSE for the evening period. Kriging interpolation were used to create final road traffic noise maps for the morning and evening periods, with reclassifying into two classes, such as less than 63dB and more than 63 dB. Because here mainly focusing to see if there is any violation of the National Environmental Act in the selected study area. Considering the final noise maps, the total area is 5.75 km^2. From that area, 3.76 km^2 is an area less than 63dB in the morning period. It is 65.44% of the study area. And the 3.72 km^2 is an area of less than 63dB in the evening period. It is 64.82% of the study area.

The following Figures show the locations of the schools in the study area and buffers around the schools on a morning period noise map. Buffers were created in 50m, 100m, 150m and 200m. Figure 8.1 shows the 50m buffer around the schools. It is a 0.0078km^2 from the study area. According to 50m buffer two schools (Rahula collage & Rahula primary school) are situated in the high noise level zone and the other two (Sujatha vidyalaya & Sujatha primary school) are in the low noise level zone. But in 100m, 150m and 200m buffer zones caught the high noise levels in all the schools.

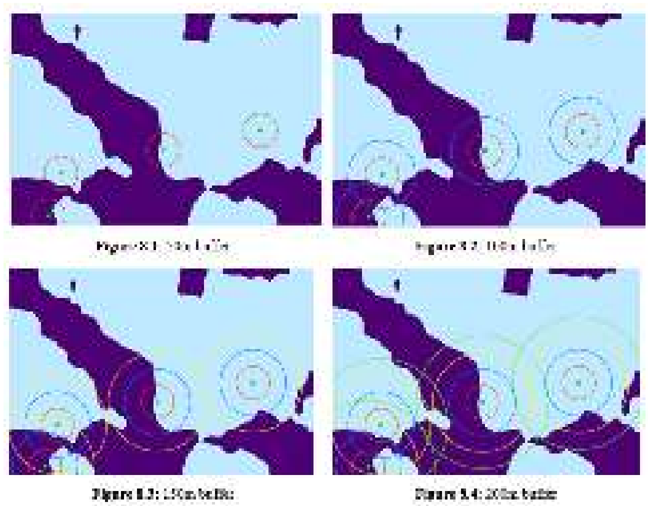

Figure 8: Buffer zones for morning

B) Conclusion

Due to its very adaptable approach to noise interpolation, the 2D city model is frequently used for noise mapping. A 2D city model may be created more quickly and inexpensively. The three-dimensional (3D) city model typically provides better cartographic visualization than the 2D city model. It is easy to set up a three-dimensional noise observation point, but calculating the noise levels requires knowledge of several factors, such as the height of the buildings, the height of the noise reflectors, and the height of the noise observation points above the reference road surface. Using a 2D city model, the researchers were able to obtain extremely precise results. The Henk de Klujijver Road traffic noise model was used combined with several equations. Some of them were not used here because of different reasons. The reflected noise from buildings and noise barriers was not used. Because the reflected noise value is between 0 and +1.5 dB. It is a smaller value when considering other noise values. The weather, particularly the wind, prevented the use of the final equation, which reduced noise levels. When the wind speed was measured, it was quite low and the surroundings were relatively peaceful. Therefore, the reduction of noise due to wind direction was not calculated.

2D noise map is abstracted along its horizontal surfaces. In this study, distance interval of two consecutive noise observation points was 10 m. This interval was maintained to reduce the complexity and processing time of the study. Distinctive noise levels are depicted by color in the final less than 63dB and more than 63dB for the morning and evening. (Figures 6 and 7). The light blue color shows less than 63dB and dark purple show more than 63dB noise levels. The areas with light blue show the depopulated areas and inside of school areas. There is less chance of making a loud noise. Roads' intersections have significant noise levels according to the map, hence only commercial activity is permitted there. These areas are shown in dark purple color. Dark purple areas were shown on the roads, road junctions, near the schools, bus stops, etc. in the morning period. But it was different for the evening period. The dark purple areas in the evening period were more than in the morning period. Because the evening period has a busier and noisier environment than the morning period. In the evening noise is not only make around schools but also all over the roads. Additionally, this has assisted urban planners for reducing road traffic pollution in cities and small towns. This study suggests that the main factors affecting noise pollution are vehicle density and speed.

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