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ORIGINAL RESEARCH ARTICLE

Measurement and Modelling of Diurnal Road Traffic Noise within Makurdi Metropolis, Benue State, Nigeria

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ABSTRACT
The acknowledgement of road traffic noise as a major environmental pollutant has spurred the formulation of models to predict road traffic noise using fundamental variables. This study aims to modify and assess the efficacy of certain empirical models in predicting equivalent continuous noise levels in Makurdi metropolis, utilizing specific traffic flow and meteorological parameters. Measurements were conducted at two roundabouts and two junctions within Makurdi metropolis from November to December, 2022. The traffic flow and meteorological parameters were fitted to the continuous noise level data using a nonlinear multivariate regression technique, and the validation metrics were computed to determine which model performed best. The results of noise levels indicated that the mean L_{eq} values across the study locations ranged from 68.65 ± 1.67 to 70.72 ± 0.90 dBA. These noise levels surpassed the National Environmental Standards and Regulations Enforcement Agency's recommended threshold of 60 dBA by 8.65 to 10.72 dBA. Modelling results revealed that all the models performed well; however, Model-L_{eq3} exhibited an outstanding performance with the highest R^2 value of 0.9999 at Wurukum Roundabout. Model-L_{eq3} is therefore recommended for predicting road traffic noise in Makurdi metropolis and other Nigerian cities.

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INTRODUCTION

Noise refers to unpleasant, undesirable or annoying sound (Igbokwe and Adindu, 2023; Haruna *et al*., 2024). It is unavoidable and can impact us even when we are not actively aware of it. While our eyes can be deliberately closed, our ears are always open, making it impossible to intentionally shut out unwanted sounds. Our hearing system is constantly active even when we are sleeping, making us subconsciously aware of sounds around us (Goines and Hagler, 2007). Noise has become a growing health threat and if left unchecked could lead to hazardous health conditions (Balashanmugan *et al*., 2013). The World Health Organization (WHO) ranks noise pollution as the third major environmental threat after air and water pollution (Oyedepo, 2014; Karthik and Partheeban, 2015; Haruna *et al*., 2024). Noise is a widespread problem in Nigeria, yet it receives minimal attention from environmental authorities tasked with protecting the country's ecosystem. The impact of noise on human health depends on exposure duration and volume (Naser, 2021). The World Health Organization has recognized seven harmful health effects of noise on humans. These are: hearing impairment, interference with spoken communication, impaired task performance, negative social behavior and annoyance reactions, sleep disturbance, mental health disturbance, and cardiovascular disturbances (Goines and Hagler, 2007).

Road traffic noise originates from various vehicle components, including engines, tires, exhaust systems, and brakes (Haruna *et al*., 2023). Many cities in developing countries face serious health issues due to noise pollution (Ede *et al*., 2024). Recent growth in the transportation sector has increased noise levels, accounting for 70 to 80% of urban noise pollution (Yadav *et al*., 2023). Several studies have shown that road traffic noise is the primary source of noise in cities (Igbokwe and Adindu, 2023). Fast-growing cities with poor planning and weak regulations suffer from excessive levels of road traffic noise (Nwobi-Okoye *et al*., 2015; Igbokwe and Adindu, 2023).

Models that predict road traffic noise are crucial for designing roads and assessing potential changes to existing roads, enabling the anticipation and mitigation of traffic noise. Several road traffic noise models have been developed by researchers worldwide. However, these models are not universally applicable, as they depend on the factors specific to the environment in which they were

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developed. Consequently, there is a need to modify some of these models to suit our environmental setting. Furthermore, several traffic noise models have continued to evolve with the hope of getting more accurate ones. Anila and Bino (2013) developed a statistical regression model in their study to predict road traffic noise under Indian conditions, using the average speed of light vehicles, the percentage of three-wheelers, the percentage of heavy vehicles, and traffic volume as variables. The model yielded a satisfactory result, with a coefficient of determination (R^2) value of 0.804. The drawback of this model is the negligence of meteorological parameters and the consideration of the average speed of light vehicles instead of considering the average speed of all vehicle types. Kumar and Srinivas (2014) assessed the ambient noise levels produced by traffic in an urban area of Secunderabad. The average equivalent noise levels (L_{eq}) were measured at various spots in commercial and residential areas. The predicted L_{eq} was obtained using the Calixto model, and the correlation between the measured and predicted Leq showed good R^2 values of 0.733 and 0.750, respectively, for both study locations. The variables used in the model were vehicle flow and the percentage of heavy vehicles. The drawback of this model is the negligence of vehicle speed and meteorological variables. Kaushal and Rampal (2017) measured the traffic noise in Jammu city, India, across different seasons and formulated a mathematical model to predict noise levels at various intersections. The researchers used data on atmospheric temperature, surface temperature, relative humidity, vehicle count and vehicular speed to calculate noise levels through regression analysis. The model had a coefficient of determination (R^2) value of 0.56. Heavy vehicles produce noise levels 5 to 10 dB higher than those of light vehicles (Nikolić et al., 2014). Consequently, the percentage of heavy vehicles needs to be included in the model to obtain a better result.

Similarly, the authors neglected meteorological parameters, which have a significant influence on road traffic noise. In another study, Ibili and Owolabi (2019) investigated traffic noise and related factors, including traffic composition, volume, and speed, in Ondo town's Central Business District. The collected data was fed into the Calculation of Road Traffic Noise (CRTN) model. Results showed that the measured L_{eq} for the study locations were above the World Health Organization (WHO) and Federal Highway Administration (FHWA) permissible limits. The CRTN model demonstrated strong predictive power, with an R^2 value of 0.943, indicating a reliable and accurate prediction of road traffic noise. Again, this model neglected meteorological parameters and lacked the use of a large sample size. The present study aims to modify and assess the effectiveness of various road traffic noise prediction models to determine the best fit for Makurdi metropolis.

THEORETICAL BACKGROUND

2.1 Measurement of Sound Pressure Level

Sound levels are usually measured on a decibel (dB) scale. The decibel is a logarithmic measure comparing two pressures (Enda and Eoin, 2014). The sound pressure level (L_p) in decibels is calculated thus (Akinkuade and Fasae, 2015; Jhanwar, 2016):

$$L_p(dB) = 10\,log_{10}\left(\frac{p}{p_o}\right)^2 = 20\,log_{10}\left(\frac{p}{p_o}\right) \qquad (1)$$

where p is the root-mean-square sound pressure in Newton per square meter and p_o is the standard reference sound pressure with a value of $2 \times 10^{-5} Nm^{-2}$ or $20\mu Pa$which is equivalent to the threshold of human hearing. The sound level meter, which utilizes the above equation, is designed to measure the sound pressure level.

2.2 Equivalent Continuous Noise Level

The equivalent continuous noise level (L_{eq}), expressed in A-weighted decibels (dBA) is a parameter universally used in environmental noise measurement. It is the average sound energy the human ear receives over a certain time frame (Alam *et al.*, 2001) and is given by (Thattai *et al.*, 2017; Alani *et al.*, 2020):

$$L_{eq} = 10\,log_{10}\frac{1}{n}\left[\sum_{i=1}^{n} 10^{\frac{L_{pi}}{10}}\right] \qquad (2)$$

where L_{pi} is the i^{th} sound pressure level reading in dBA and n is the number of measurements in the assessed time. The A-weighted decibels (Leq) is a widely accepted measure for describing traffic noise levels (Nwaogazie and Ofem, 2014; Sukeerth *et al.*, 2017).

2.3 Traffic Density

Traffic density, K is the total number of vehicles per unit length of a roadway. It is given by (Ogunlade *et al.*, 2021; Odiakose and Iyeke, 2024):

$$K = \frac{N_t}{L} \qquad (3)$$

where N_t is the total number of vehicles and L is the length of the roadway in kilometers (km).

2.4 Traffic Flow Rate

The traffic flow rate, Q, is the total number of vehicles traversing a certain cross-section during a given period of time and is expressed as (Ugwuanyi *et al.*, 2017; Ogunlade *et al.*, 2021):

$$Q = \frac{N_t}{T} \qquad (4)$$

where T is the time interval in hours (hrs). The flow rate is analogous to the discharge or the flux of a stream. The maximum possible flow rate of any road is called its capacity.

2.5 Space Mean Speed

The space mean speed, V_s is the average speed of vehicles over a given road segment (Ugwuanyi *et al.*, 2017). This definition of space mean speed is also known as the fundamental relation of traffic flow theory (Ugwuanyi *et al.*, 2017; Odiakose and Iyeke, 2024):

$$Q = V_s K \qquad (5)$$

When vehicles travel the same road length, that is, $L = L_1 = L_2 = L_3 = \ldots = L_n$, then V_s is given by (Ugwuanyi *et al.*, 2017; Ogunlade *et al.*, 2021; Odiakose and Iyeke, 2024):

$$V_s = \frac{L}{\left(\frac{1}{N_t}\sum_{i=1}^{n}\left(\frac{L}{T_i}\right)^{-1}\right)} \tag{6}$$

where T_i is the time interval of the i^{th} vehicle in hours (hrs).

2.6 Annual Average Daily Traffic

Annual Average Daily Traffic (AADT) is the total number of vehicles traveling across a roadway in a year, divided by 365 days. It is a metric generally applied in transportation planning and engineering. In 1992, the American Association of Highway and Transport Officials (AASHTO) introduced a method of calculating AADT without biases from seasons or days of the week by using an "average of averages" approach in their Traffic Data Programs. Recent innovations from traffic data providers now offer more detailed AADT data, broken down by roadside, day of the week, and time of day (Ugwuanyi *et al.*, 2017).

MATERIALS AND METHODS

3.1 Study Area

This study was conducted in Makurdi, the capital of Benue State. Makurdi is located in the central part of Nigeria between Latitudes 7° 38′ and 7° 50′ N, and Longitudes 8° 24′ and 8° 38′ E (Abah, 2013). It is traversed by the country's second-largest river, the River Benue. The town sits on a major transportation route connecting Nasarawa State in the North and Enugu State in the South by road and rail (Shabu and Tyonum, 2013), with a landmass of approximately 800 km² and a population of about 367,588, based on the 2006 National Population Census data (Adeke *et al.*, 2018). The area has two distinct seasons; the dry and wet seasons. The dry season typically begins in November and lasts until March, while the wet season commences in April and terminates in October, with an average annual rainfall of between 1200 and 2000 mm (Akaahan *et al.*, 2016). Makurdi typically experiences high temperatures throughout the year (Abah, 2013), with average daily temperatures varying between 21 °C and 37 °C (Hula, 2010; Odoh and Jidauna, 2013). The relative humidity of the area fluctuates with the seasons, reaching its mean monthly peak of approximately 92% during the wet season (Onah et al., 2020). Two major roundabouts (i.e., Wurukum and High Level Roundabouts) and two busy junctions (i.e., SRS and Ankpa Ward Junctions) were selected for this study.

3.2 Data Collection

The road traffic sound pressure level was measured using a microprocessor digital sound level meter, model SL-5858. The meter was mounted on a stand 1.5 m above ground and 0.5 m from the operator to minimize the echoing of sound waves from the body. In order to avoid the effect of sound reverberation, measurements were taken at a distance of at least 3.5 m from any reflecting surface. The meter was positioned at a distance of 1.5 m from the edge of road shoulder. Readings from the meter were recorded every 10 minutes from 7:00 am to 6:00 pm each day at each study location, and the hourly equivalent continuous noise levels were computed for each location. Ambient temperature and relative humidity were measured at the study sites using a digital thermo-hygrometer, whereas the wind speed was measured with the aid of a digital thermo-anemometer. The instruments were mounted on a stand 1.5 m above the ground, and readings from the instruments were recorded every 10 minutes from 7:00 am to 6:00 pm each day at each study location.

A traffic count was conducted using Closed-Circuit Televisions (CCTVs), commonly known as CCTV cameras. The CCTVs were mounted on separate stands and positioned alongside the road at the study locations to capture moving vehicles from 7:00 am to 6:00 pm each day. The devices were positioned in areas with a free flow of traffic. The CCTVs were linked to mobile phones through Wi-Fi for monitoring. A 20000 mAh power bank powered each CCTV. A 4 m length of road section was marked on each roadway, and the number of vehicles crossing the marked sections was recorded. The CCTVs were positioned at each leg of the roundabouts and junctions to record only the incoming vehicles. The hourly number of vehicles for each day was later extracted by replaying the videos from the CCTVs on laptops, and the hourly average number of vehicles for each study location was computed in accordance with the American Association of State Highway and Transportation Officials (AASHTO) guidelines for calculating Annual Average Daily Traffic (AADT). The vehicles were counted and grouped into three (3) categories as motorcycles/tricycles (MT), cars/buses/vans (CBV) and heavy vehicles (HV). The road traffic sound pressure measurements, meteorological parameter measurements, and traffic counts were carried out at two major roundabouts and two busy junctions (cross intersections) within Makurdi metropolis for five days (i.e., Mondays, Wednesdays, Fridays, Saturdays, and Sundays) at each study location. All measurements at a particular location were carried out concurrently.

MODELLING APPROACH

4.1 The Modified Road Traffic Noise Models

The modified multivariate models are presented in Table 1. The empirical model equations are labelled: Model-L_{eq1}, Model-L_{eq2}, Model-L_{eq3}, Model-L_{eq4}, and Model-L_{eq5}. The table also highlights the modifications made to the original model equations.

where RH is the relative humidity in %, T_a is the ambient temperature in ^oC, V_w is the wind speed in km/hr, MT is the number of motorcycles and tricycles, CBV is the number of cars, buses and vans, HV is the number of heavy vehicles, N_t is the total number of vehicles, PHV is the percentage of heavy vehicles, K is the traffic density in veh/m, Q is the traffic flow rate in veh/hr, V_s is the space mean speed in km/hr, T_s is the average surface temperature in ^oC, T is the percentage of three wheelers, S is the average speed of light vehicles in km/hr, T_{in} is the time index and a_1, a_2, a_3, …, a_{12} are regression constants. The time index T_{in} is a continuous count over the 24 hr period of the day beginning from 00:00 to 1:00 hr assigned index 1, 1:00 to 2:00 hrs assigned index 2, …, 7:00 to 8:00 hrs assigned index 8, 8:00 to 9:00 hrs assigned index 9, 9:00 to 10:00 hrs assigned index 10, … and 17:00 to 18:00 hrs assigned index 18.

Table 1: The Modified Multivariate Models

Model	Model Name	Model Parameters	Modified Model Equation	Modification
Model-L_{eq1}	Mod. CRTN	PHV, Q, V_s, T_{in}	$L_{eq} = a_1 \log Q + a_2 \log\left[a_3 + V_s + \frac{500}{V_s}\right] + a_4 \log\left[1 + a_5 \frac{PHV}{V_s}\right] + a_6 T_{in} + a_7$	T_{in} added to the original model equation.
Model-L_{eq2}	Mod. Kaushal and Rampal	T_a, RH, N_t, V_s	$L_{eq} = a_1 + a_2 T_a + a_3 RH + a_4 N_t + a_5 V_s + a_6 T_{in}$	T_{in} added, while T_s is expunged from the original model equation.
Model-L_{eq3}	Mod. Anila and Bino	$RH, T_a, V_w, MT, CBV, HV, N_t, PHV, K, Q, T_{in}$	$L_{eq} = a_1 + a_2 RH + a_3 T_a + a_4 V_w + a_5 MT + a_6 CBV + a_7 HV + a_8 N_t + a_9 PHV + a_{10} K + a_{11} Q + a_{12} T_{in}$	RH, T_a, V_w, MT, CBV, HV, K, Q and T_{in} added, while S and T are expunged from the original model equation.
Model-L_{eq4}	Mod. Calixto	PHV, Q, T_{in}	$L_{eq} = a_1 + a_2 \log\left[Q \times \left(1 + a_3 \frac{PHV}{100}\right)\right] + a_4 T_{in}$	T_{in} added to the original model equation.
Model-L_{eq5}	Mod. Anila and Bino quad.	$RH, T_a, V_w, MT, CBV, HV, N_t, PHV, K, Q, T_{in}$	$L_{eq} = a_1 + a_2 RH^2 + a_3 T_a^2 + a_4 V_w^2 + a_5 MT^2 + a_6 CBV^2 + a_7 HV^2 + a_8 N_t^2 + a_9 PHV^2 + a_{10} K^2 + a_{11} Q^2 + a_{12} T_{in}$	S and T are expunged from the original model equation and the remaining variables are squared, while T_{in} and square of RH, T_a, V_w, MT, CBV, HV, K and Q are added to the equation.

Table 2: Regression Constants and Validation Parameters of Model-L_{eq1-5} for Wurukum Roundabout

Model	Regression Constants												Validation Parameters			
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	RMSE	MAE	MAPE	R^2
Model-L_{eq1}	5131.66	2308.5102	-40.168	9.5836	-6.9777	-0.3489	17492.321						0.2114	0.1777	0.2545	0.9866
Model-L_{eq2}	67.5977	0.2899	-0.1205	0.4853	-92.6303	-0.4841							0.2217	0.1781	0.2538	0.9853
Model-L_{eq3}	33.249	0.8016	3.2934	-0.0227	-0.185	-0.1784	1.5083	-0.1438	136.1216	1.8197	-0.1438	0.9459	0.0056	0.0044	0.0063	0.9999
Model-L_{eq4}	24.7778	23.1597	2.998	0.2794									0.385	0.2913	0.417	0.969
Model-L_{eq5}	14.3847	0.0046	0.0419	-0.1112	-0.000002	-0.00001	0.0019	0.00001	-13.4287	0.0004	-0.00001	0.5956	0.0186	0.0129	0.0186	0.9999

Table 3: Regression Constants and Validation Parameters of Model-L_{eq1-5} for High Level Roundabout

Model	Regression Constants												Validation Parameters			
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	RMSE	MAE	MAPE	R^2
Model-L_{eq1}	13.9222	13.5919	62.9845	2.094	3.1452	-0.0142	-9.539						0.273	0.2217	0.3221	0.8658
Model-L_{eq2}	12.1582	0.9651	0.3472	-1.8428	352.098	0.814							0.1151	0.0955	0.1384	0.9783
Model-L_{eq3}	70.6538	0.0861	0.1932	0.0282	13.6886	13.6853	15.9601	-7.1502	108.6603	0.9916	-6.7893	0.5115	0.0827	0.0654	0.0951	0.9876
Model-L_{eq4}	67.2612	0.1717	303.0303	0.1008									0.1804	0.1412	0.2051	0.9759
Model-L_{eq5}	18.5096	0.0042	0.0449	-0.1095	-0.0001	-0.0002	-0.046	0.00002	10.6129	0.0001	0.00002	0.1216	0.0745	0.0616	0.0893	0.9892

Table 4: Regression Constants and Validation Parameters of Model-L_{eq1-5} for SRS Junction

Model	Regression Constants											Validation Parameters			
		a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	RMSE	MAE	MAPE	R^2
Model-L_{eq1}	15.7107	3.374	-40.5063	37843.203	0.0011	0.4399	4.0439						0.4559	0.3726	0.5386	0.9306
Model-L_{eq2}	44.8353	0.3626	0.1201	-0.9976	190.6507	0.4136							0.3397	0.2879	0.418	0.9696
Model-L_{eq3}	17.5302	0.2525	0.8596	-4.5057	0.6244	0.6337	0.5998	-0.142	-2.4544	-1.3464	-0.142	0.3775	0.2989	0.2347	0.3413	0.973
Model-L_{eq4}	44.0653	7.8259	-43.0953	-0.0252									0.3653	0.3044	0.4446	0.9688
Model-L_{eq5}	44.645	-0.0027	0.0023	27.1442	0.0001	0.0003	-0.0288	-0.0001	33.2993	0.0002	-0.00005	1.6217	0.1101	0.0782	0.115	0.9958

Table 5: Regression Constants and Validation Parameters of Model-L_{eq1-5} for Ankpa Ward Junction6

Model	Regression Constants											Validation Parameters			
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}	a_{11}	a_{12}	RMSE	MAE	MAPE	R^2
Model-L_{eq1}	16.0972	2.3652	-41.8816	240.0453	-0.0079	-0.11	11.4963						0.3212	0.2627	0.3746	0.8677
Model-L_{eq2}	102.9222	-0.4659	-0.2477	0.5273	-100.7159	-0.4535							0.1881	0.1455	0.2068	0.9692
Model-L_{eq3}	73.2995	-0.0828	-0.2543	1.2473	0.1169	0.1121	-2.7002	2.6289	127.3174	-2.5645	0.2629	0.3486	0.0551	0.0445	0.0634	0.996
Model-L_{eq4}	62.1695	1.9019	-175.383	0.0973									0.2251	0.1781	0.2531	0.9732
Model-L_{eq5}	21.8594	0.0044	0.0252	0.0587	0.00001	0.00004	0.0071	0.00002	5.969	-0.0009	0.00003	0.5502	0.1622	0.1397	0.1982	0.9645

4.2 Model Validation

The modified model equations are presented in Table 1. Figures 5 to 8 (5, 6, 7, & 8) presents a display of the model performance for the prediction of equivalent continuous noise level (L_{eq}) using some traffic and meteorological parameters as exogenous variables for the different study locations, while the correlation between predicted and measured L_{eq} across the study locations is illustrated in Figure 9 to 12 (9, 10, 11 & 12). It can be observed from the graphs that all the models performed well, as there is only a slight variation between the measured and predicted L_{eq}. The models were validated using performance functions such as Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), and Coefficient of determination (R^2) (Tikyaa *et al.*, 2018; Patel *et al.*, 2024):

$$\boldsymbol{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(L_{eqm}-L_{eqp})^2}{n}} \quad (7)$$

$$\boldsymbol{MAE} = \frac{1}{n}\sum_{i=1}^{n}|L_{eqm} - L_{eqp}| \quad (8)$$

$$\boldsymbol{MAPE} = \frac{1}{n}\sum_{i=1}^{n}\frac{|L_{eqm}-L_{eqp}|}{L_{eqm}} \times 100 \quad (9)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(L_{eqm}-L_{eqp})^2}{\sum_{i=1}^{n}(L_{eqm}-\overline{L}_{eqm})^2} \quad (10)$$

where L_{eqm} is the measured equivalent continuous noise level, L_{eqp} is the predicted equivalent continuous noise level, $\overline{L}_{eqm}$ is the mean of the measured L_{eq} and n is the number of measurements.

RESULTS AND DISCUSSION

5.1 Measured Equivalent Continuous Noise Level and Traffic Parameters at Various Study Locations

The measured values of road traffic sound pressure level (L_p) from the field survey were used to compute the equivalent continuous noise level (L_{eq}) at each study location using equation 2. Similarly, the total number of vehicles (N_t) was used to calculate the traffic density (K), traffic flow rate (Q), and space mean speed (Vs) using Equations 3, 4, and 6, respectively. Results of diurnal variation of equivalent continuous noise level (L_{eq}), total number of vehicles (N_t), traffic density (K), traffic flow rate (Q), and space mean speed (V_s) across the study locations are presented in Figures 1(a-e) to 4(a-e).

The hourly variation of L_{eq}, N_t, K, Q and V_s across the study locations is represented in Figure 1(a-e) to 4(a-e). Figure 1a indicates that a minimum L_{eq} of 65.59 dBA occurred between 7 and 8 am, whereas a maximum L_{eq} of 72.56 dBA occurred between 1 and 2 pm at Wurukum Roundabout. The Wurukum market and most of the motor parks in Makurdi's metropolis are located close to the Wurukum Roundabout. The low noise level recorded in the morning at this location may be attributed to the low traffic and commercial activities, while the high noise level recorded in the afternoon could be due to the high traffic and commercial activities. This could also be attributed to temperature variation at the location. Sound level increases as the temperature increases (Loonkar, 2023).

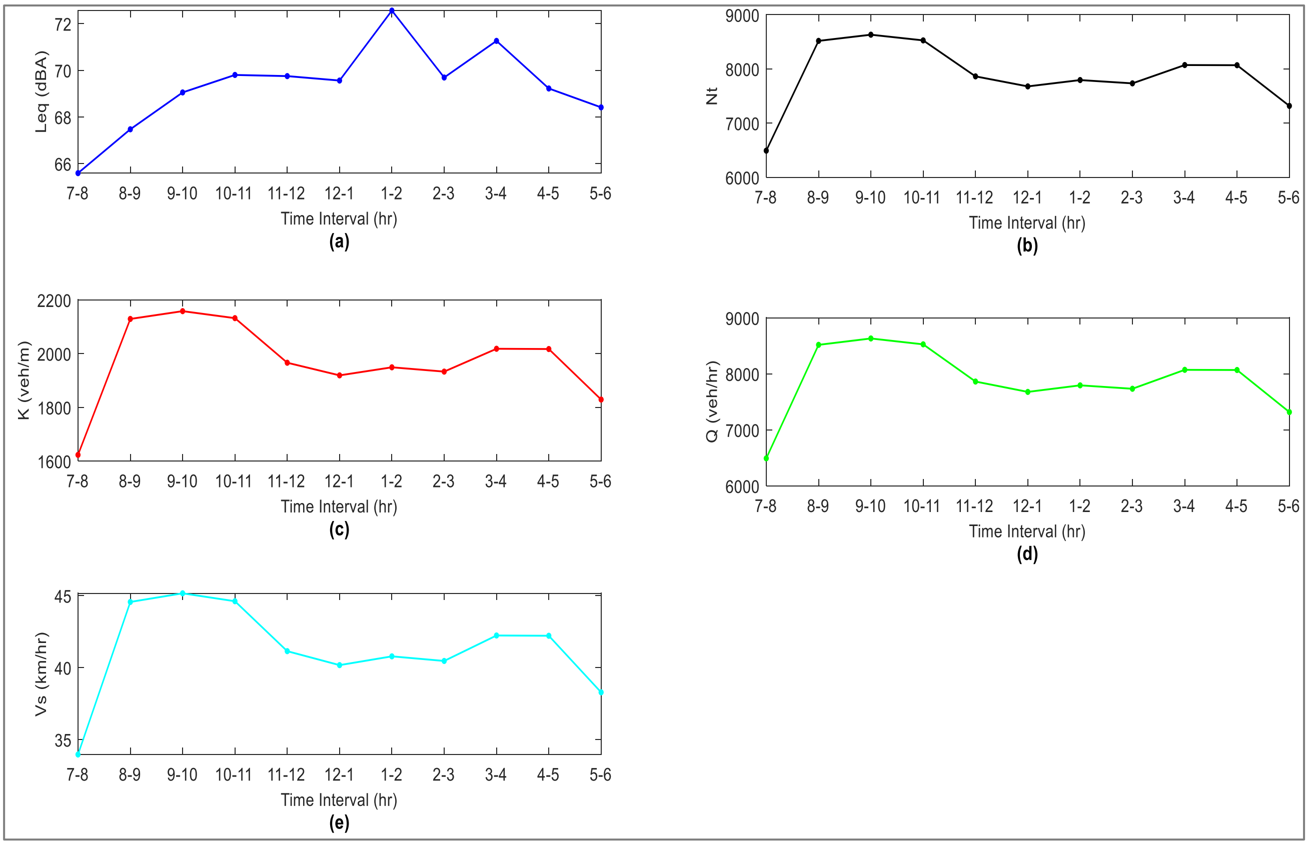

Figure 1: Diurnal Variation of: (a) L_{eq}, (b) N_t, (c) K, (d) Q and (e) V_s at Wurukum Roundabout

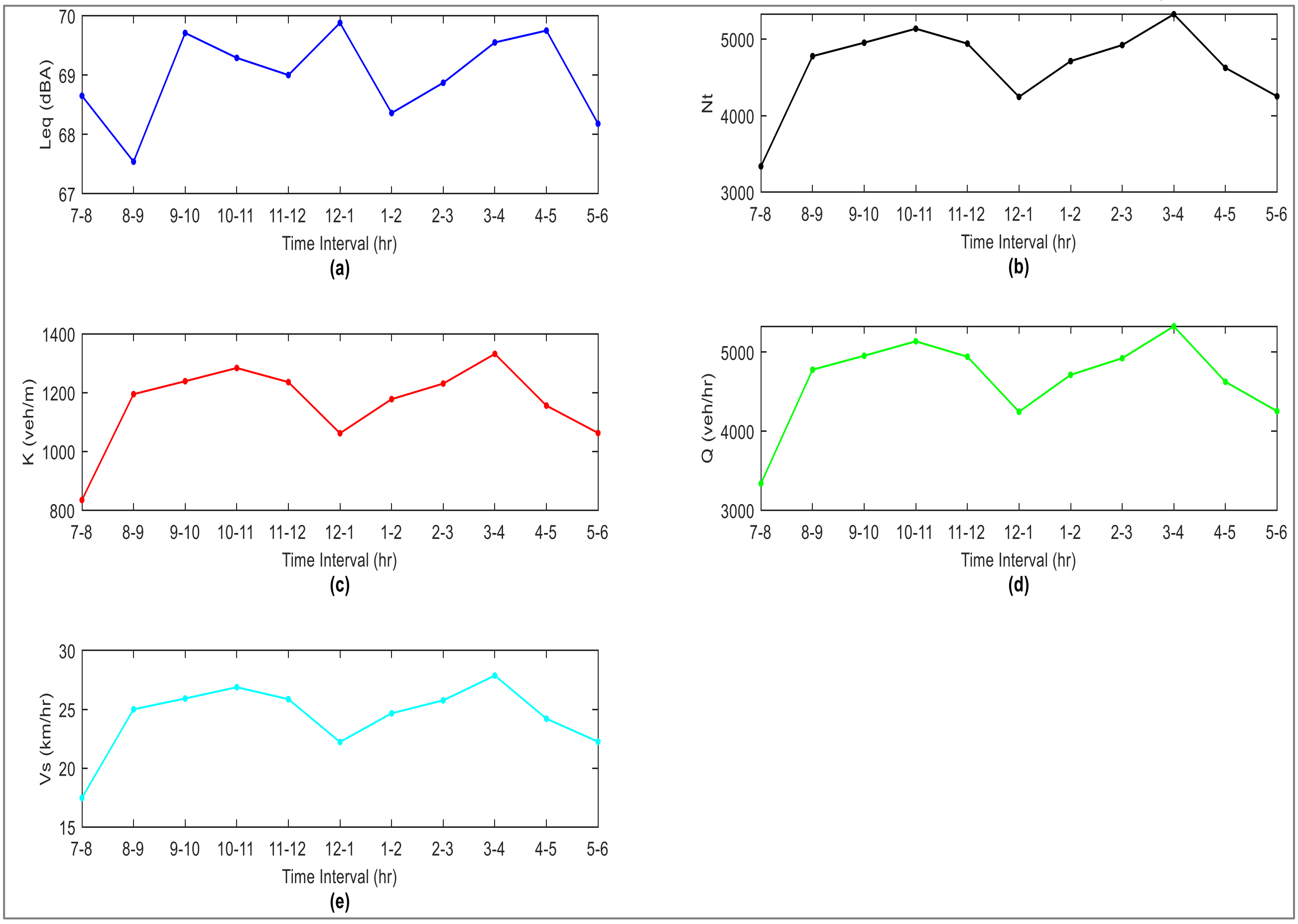

Figure 2: Diurnal Variation of: (a) L_{eq}, (b) N_t, (c) K, (d) Q and (e) V_s at High Level Roundabout

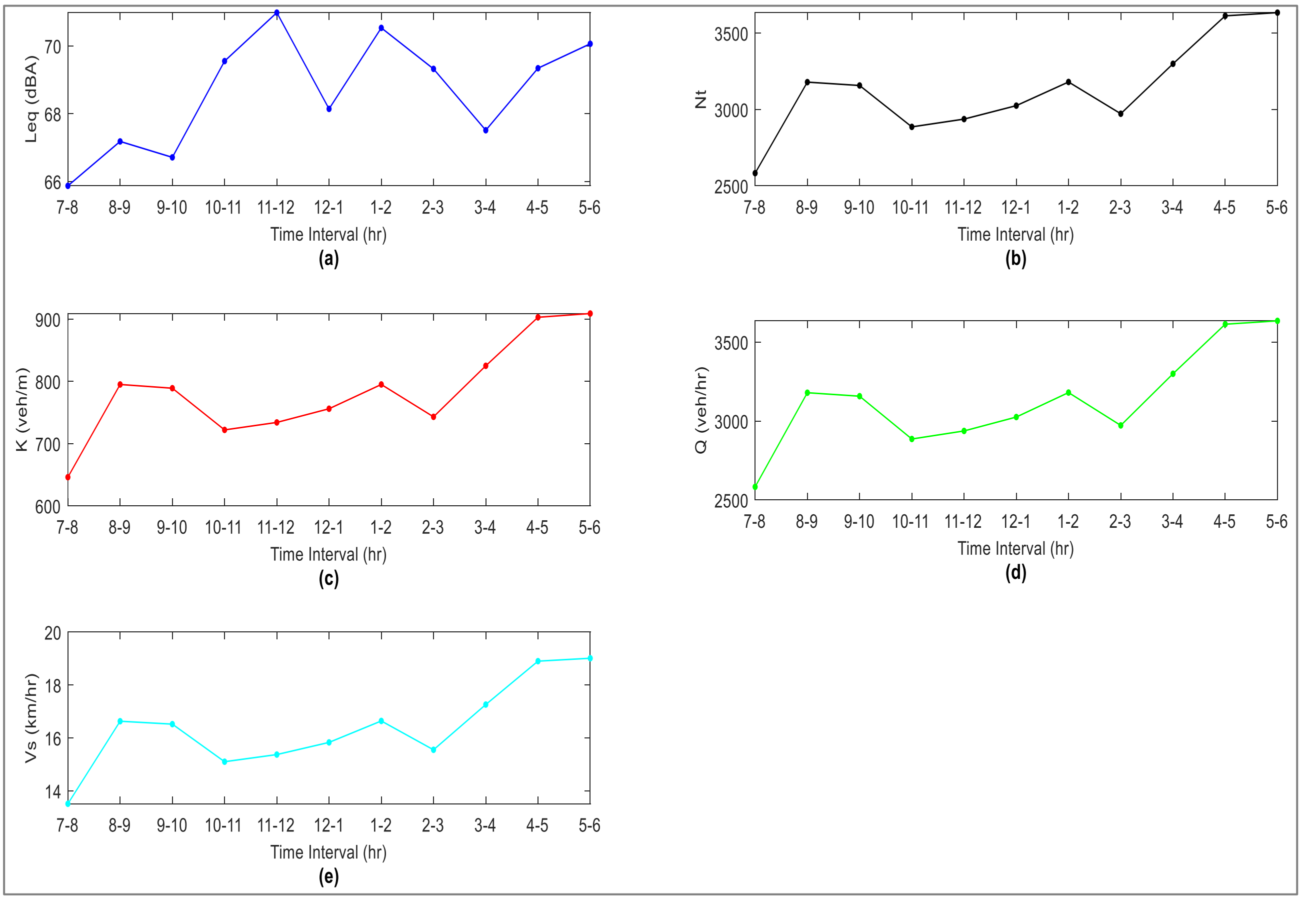

Figure 3: Diurnal Variation of: (a) L_{eq}, (b) N_t, (c) K, (d) Q and (e) V_s at SRS Junction

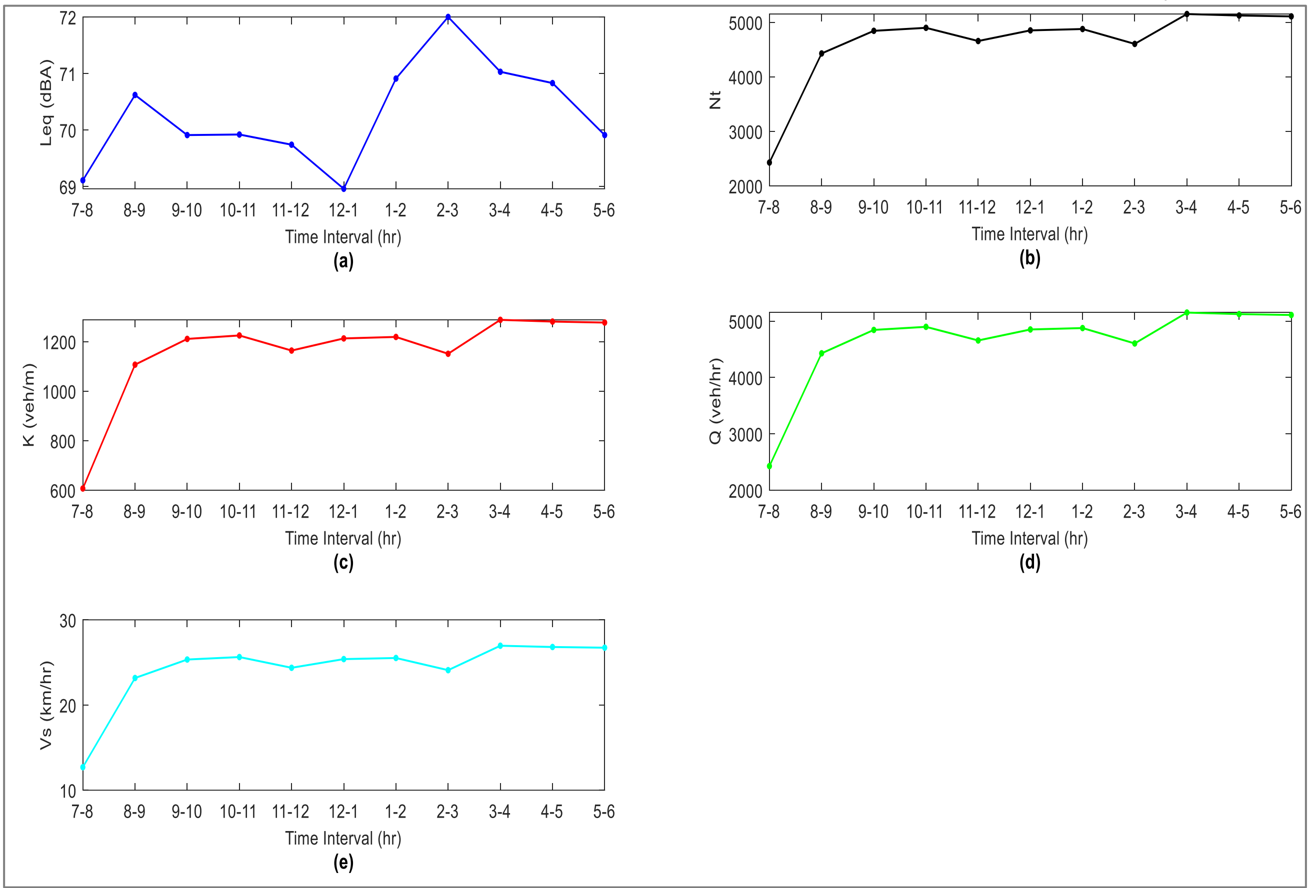

Figure 4: Diurnal Variation of: (a) L_{eq}, (b) N_t, (c) K, (d) Q and (e) V_s at Ankpa Ward Junction

Temperatures in Makurdi metropolis are usually low in the morning and high in the afternoon. In Figure 2a, a minimum L_{eq} value of 67.54 dBA was recorded between 8 and 9 am, whereas a maximum L_{eq} of 69.88 dBA was recorded between 12 noon and 1 pm at High Level Roundabout. The High Level Roundabout is situated close to the motor park and High Level market. Again, the low noise level experienced in the morning could be due to the low traffic and commercial activities, whereas the high noise level observed at this location in the afternoon could be attributed to the high traffic and commercial activities. It could also be due to temperature variation at the location. At SRS Junction (Figure 3(a)), the L_{eq} reached a minimum value of 65.87 dBA from 7 to 8 am and a maximum value of 70.98 dBA from 11 am to 12 noon. The road to Akawe Torkula Polytechnic, Special Science Senior Secondary School and Joseph Sarwuan Tarka University, Markurdi is linked to SRS Junction. The road leading to the Northern part of the country is also linked to this junction. The morning's varying noise levels may be due to lighter traffic early on and heavier traffic later, as travelers head to the northern part of the country and workers commute to their workplaces. Figure 4(a) shows that a minimum L_{eq} of 68.96 dBA and a maximum L_{eq} of 72.00 dBA were obtained from 12 noon to 1 pm and from 2 to 3 pm, respectively, at Ankpa Ward Junction. The road to Makurdi modern market is linked to this junction. There is also an Event Centre located close to this junction. The low noise levels recorded between 12 noon to 1 pm could be attributed to low traffic and low commercial activities at the Event Center and other places around this junction, while the high noise level experience between 2 and 3 pm could be due to high traffic and high commercial activities as customers rush to Modern market and music is played to entertain customers at the Event Centre. The diurnal mean L_{eq} of 69.31, 68.98, 68.65, and 70.72 dBA were found at Wurukum Roundabout, High Level Roundabout, SRS Junction, and Ankpa Ward Junction respectively. SRS Junction and Ankpa Ward Junction recorded the minimum and maximum mean L_{eq} of 68.65 and 70.72 dBA, respectively. These noise levels are above the safety threshold of 60 dBA prescribed by the National Environmental Standards and Regulations Enforcement Agency (NESREA). This implies that those who reside or spend most of their time around these areas are consistently exposed to harmful noise levels. The L_{eq} at the study sites is comparable to that reported for other towns, such as Abeokuta metropolis, Port Harcourt, and the Federal Capital Territory (FCT) Abuja, by Oguntoke et al. (2019), Amah and Udeh (2023), and Ekom et al. (2024), respectively.

Similarly, the results of traffic parameters revealed that at Wurukum Roundabout, the minimum values of N_t, K, Q and V_s were obtained from 7 to 8 am, while the maximum values were recorded from 9 to 10 am as illustrated in Figure 1(b-e). The high values of traffic parameters recorded between 9 and 10 am could be due to heavy traffic flow as travelers leave the motor parks, traders and workers rush to Wurukum market and work respectively, while the low values of traffic parameters recorded between 7 and 8 am could be attributed to low traffic flow due to low number of vehicles taking off from the parks and low number of vehicles conveying traders to Wurukum market. The High Level Roundabout had minimum values of Nt, K, Q, and Vs from 7 to 8 am and maximum values from 3 to 4 pm, as illustrated in Figure 2(b-e). The low traffic parameters at this location in the morning could be a result of low traffic flow due to a low number of vehicles leaving High Level Park or conveying traders to High Level market, while the high evening traffic parameters values likely resulted from increased traffic flow as travelers, traders and workers headed home after the day's activities. In the same light, minimum values of N_t, K, Q, and V_s were recorded from 7 to 8 am, while the maximum values occurred from 5 to 6 pm at SRS Junction, as shown in Figure 3(b-e). The low traffic parameters recorded in the morning at this location could be a result of low traffic flow due to a low number of vehicles leaving Makurdi to Northern Nigeria, while the significant levels of traffic parameters obtained in the evening could be attributed to high traffic flow as travelers, students and workers return from the day's activities. In Figure 4(b-e), minimum values of N_t, K, Q and V_s were found between 7 and 8 am, whereas the maximum values were obtained between 3 and 4 pm at Ankpa Ward Junction. Again, the low traffic parameters recorded at this location in the morning could be as a result of low traffic flow due to low number of vehicles conveying traders and customers to the Modern market, while the elevated levels of traffic parameters obtained in the evening could be linked to high traffic flow as traders and customers return from the market. In general, the results indicated substantial variation in noise levels and traffic flow across various locations and times of the day, confirming the trend of inconsistent variation in noise levels and traffic flow. These results align with those of Oguntoke *et al.* (2019) and Alani *et al.* (2020).

5.2 Results of Empirical Multivariate Models for Prediction of Equivalent Continuous Noise Level

The results displayed in Tables 2 to 5 (2, 3, 4, & 5) show the regression coefficients and model validation statistics, whereas Figures 5 to 8 present a display of the model performance for the prediction of the equivalent continuous noise level, L_{eq}. Similarly, Figures 9 to 12 show the regression plots of measured and predicted Leq for the four study locations, demonstrating the goodness-of-fit of the five empirical models.

The regression coefficients and model validation statistics of the four (4) study locations are presented in Tables 2 to 5 (2, 3, 4, & 5). Table 2 (Wurukum Roundabout) revealed that Model-L_{eq1} had RMSE, MAE, MAPE and R^2 values of 0.2114, 0.1777, 0.2545 and 0.9866 respectively, whereas Model-L_{eq2} recorded RMSE, MAE, MAPE and R^2 values of 0.2217, 0.1781, 0.2538 and 0.9853 respectively. The RMSE, MAE, MAPE, and R^2 values of 0.0056, 0.0044, 0.0063, and 0.9999 were recorded for Model-Leq3, while Model-Leq4 had RMSE, MAE, MAPE, and R^2 values of 0.3850, 0.2913, 0.4170, and 0.9690, respectively. Model-L_{eq5} recorded 0.0186, 0.0129, 0.0186, and 0.9999 values for RMSE, MAE, MAPE, and R^2, respectively. The results indicate that Model-L_{eq4} has the least performance, as it has the highest values of RMSE, MAE, and MAPE, and the lowest R^2 value. In contrast, Model-Leq3 performed best, with the lowest values of RMSE, MAE, and MAPE and the highest R^2 value. At High Level Roundabout (Table 3), RMSE, MAE, MAPE and R^2 values of 0.2730, 0.2217, 0.3221 and 0.8658 were respectively recorded for Model-L_{eq1}, while Model-L_{eq2} had RMSE, MAE, MAPE and R^2 values of 0.1151, 0.0955, 0.1384, and 0.9783 respectively.

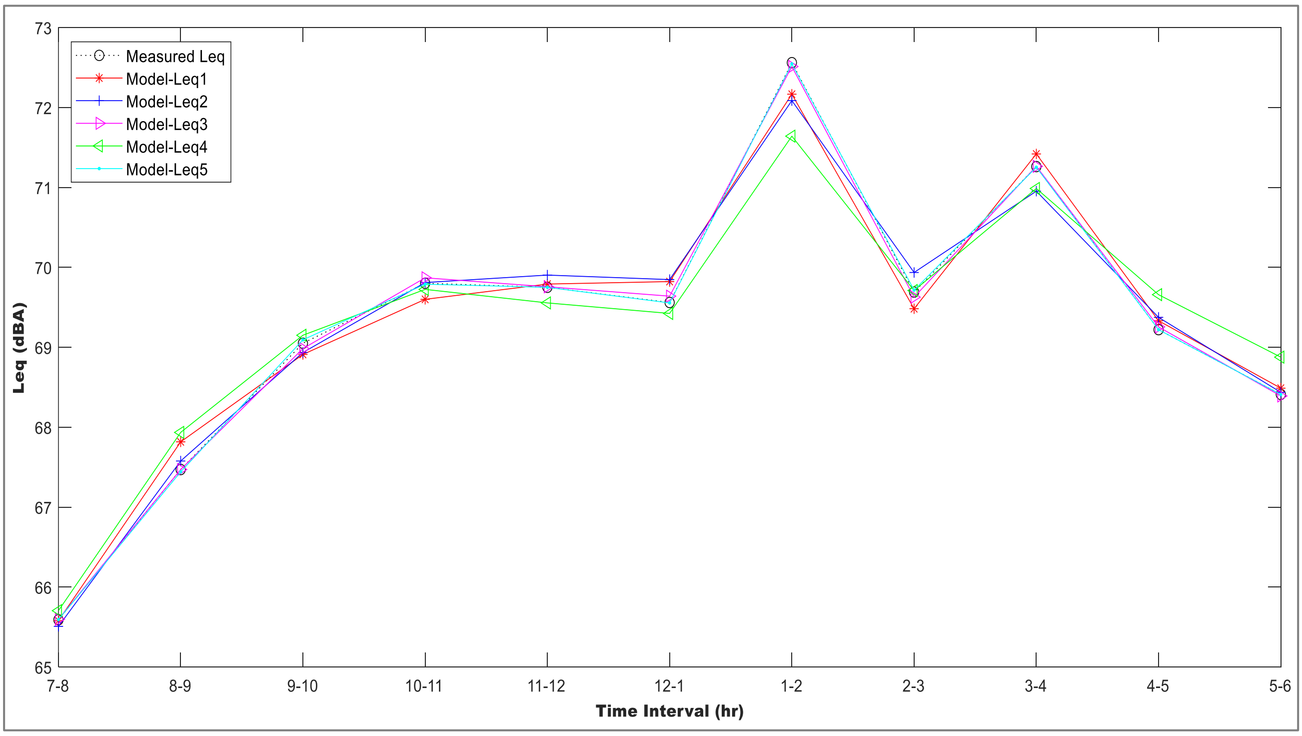

Figure 5: Prediction Results of L_{eq} using the five Models with Exogenous Variables for Wurukum Roundabout

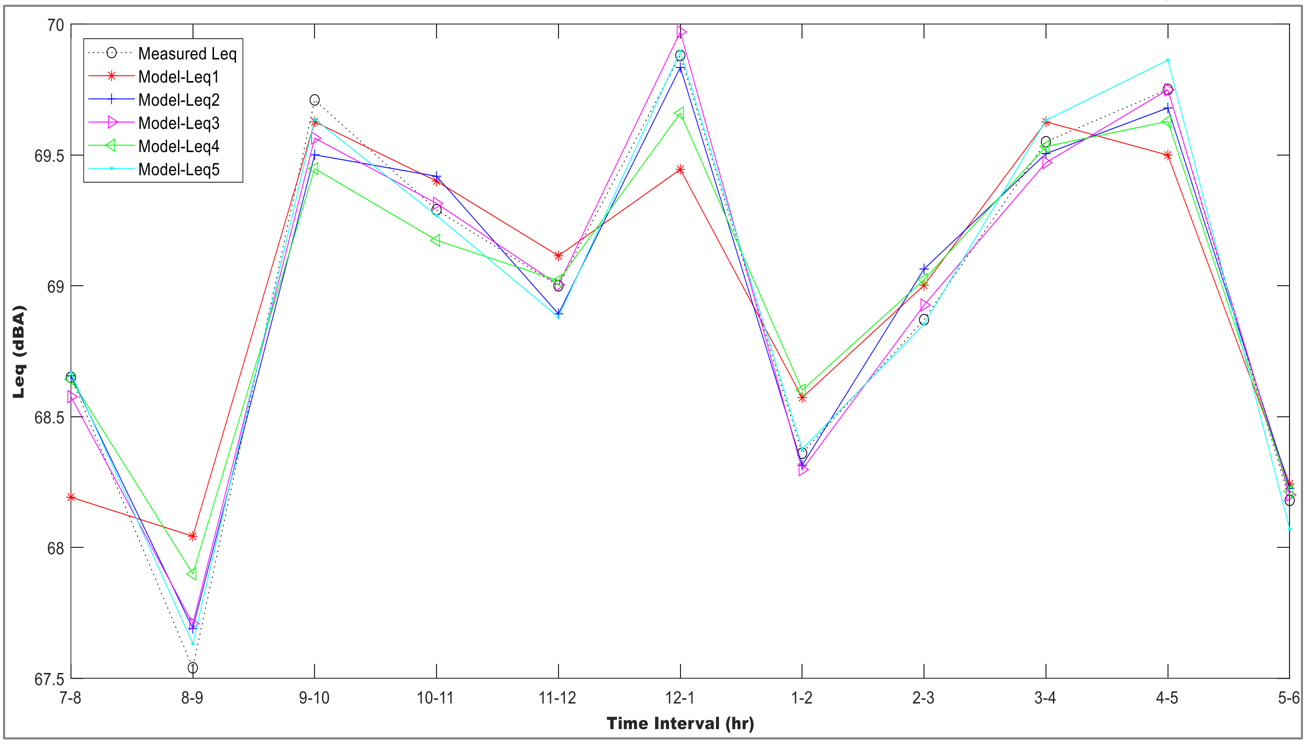

Figure 6: Predicted Results of Leq using the five Models with Exogenous Variables for High Level Roundabout

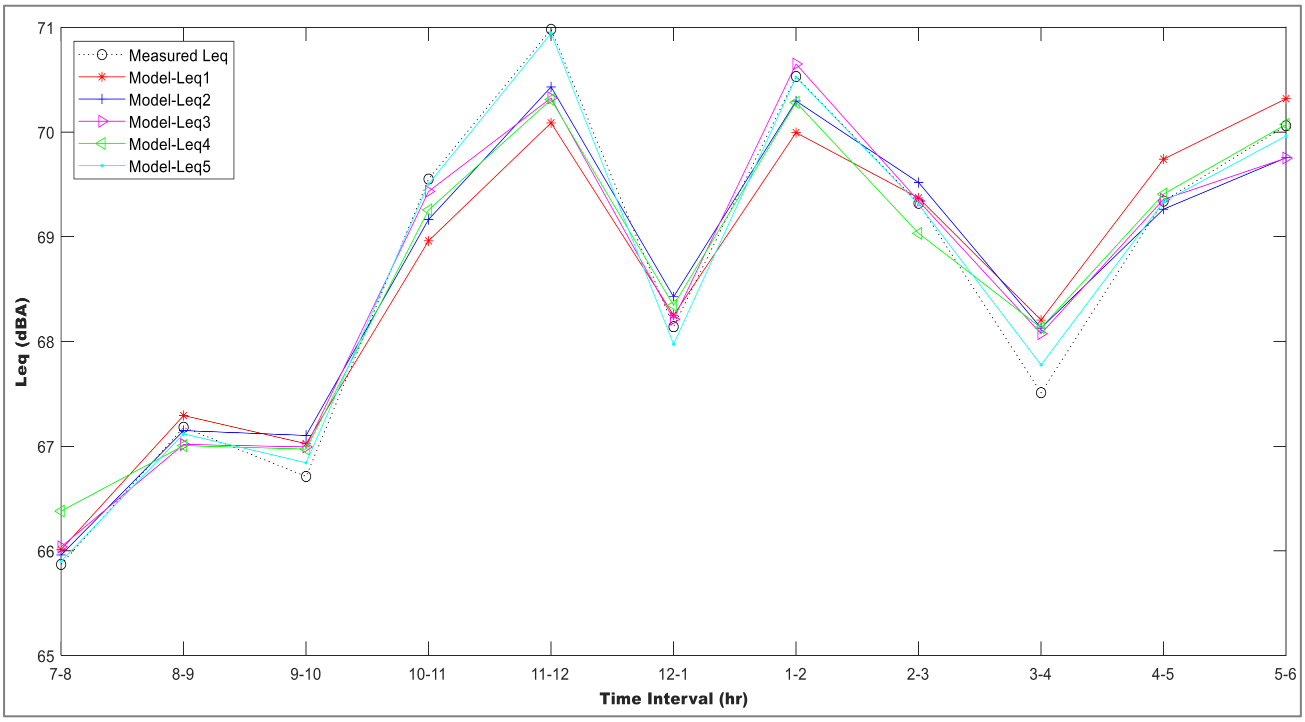

Figure 7: Prediction Results of L_{eq} using the five Models with Exogenous Variables for SRS Junction

Model-L_{eq3} recorded 0.0827, 0.0654, 0.0951 and 0.9876 for RMSE, MAE, MAPE and R^2 respectively, while Model-L_{eq4} had 0.1804, 0.1412, 0.2051 and 0.9759 values for RMSE, MAE, MAPE and R^2 respectively. Model-L_{eq5} had RMSE, MAE, MAPE and R^2 values of 0.0745, 0.0616, 0.0893 and 0.9892 respectively. The model with the least performance in this location is Model-L_{eq1}, whereas the one with the best performance is model Model-L_{eq5}. RMSE, MAE, MAPE and R^2 values of 0.4559, 0.3726, 0.5386 and 0.9306 were respectively obtained for Model-L_{eq1} at SRS Junction (Table 4), whereas Model-L_{eq2} had 0.3397, 0.2879, 0.4180 and 0.9696 for RMSE, MAE, MAPE and R^2 respectively. Model-L_{eq3} recorded RMSE, MAE, MAPE and R^2 values of 0.2989, 0.2347, 0.3413 and 0.9730 respectively, while RMSE, MAE, MAPE and R^2 values of 0.3653, 0.3044, 0.4446 and 0.9688 were respectively obtained for Model-L_{eq4}. RMSE, MAE, MAPE and R^2 values of 0.1101, 0.0782, 0.1150 and 0.9958 were respectively recorded for Model-L_{eq5}. Again, Model-L_{eq1} is the model with the least performance, whereas Model-L_{eq5} performed best. In the same light, at Ankpa Ward Junction (Table 5), Model-L_{eq1} recorded RMSE, MAE, MAPE and R^2 values of 0.3212, 0.2627, 0.3746 and 0.8677 respectively, however, 0.1881, 0.1455, 0.2068 and 0.9692 values of RMSE, MAE, MAPE and R^2 were respectively obtained for Model-L_{eq2}. Model-L_{eq3} had RMSE, MAE, MAPE and R^2 values of 0.0551, 0.0445, 0.0634 and 0.9960 respectively, whereas Model-L_{eq4} recorded 0.2251, 0.1781, 0.2531 and 0.9732 for RMSE, MAE, MAPE and R^2 respectively. RMSE, MAE, MAPE and R^2 values of 0.1622, 0.1397, 0.1982 and 0.9645 were respectively obtained from Model-L_{eq5}. Model-L_{eq1} and Model-L_{eq3} have shown the least and best performance respectively.

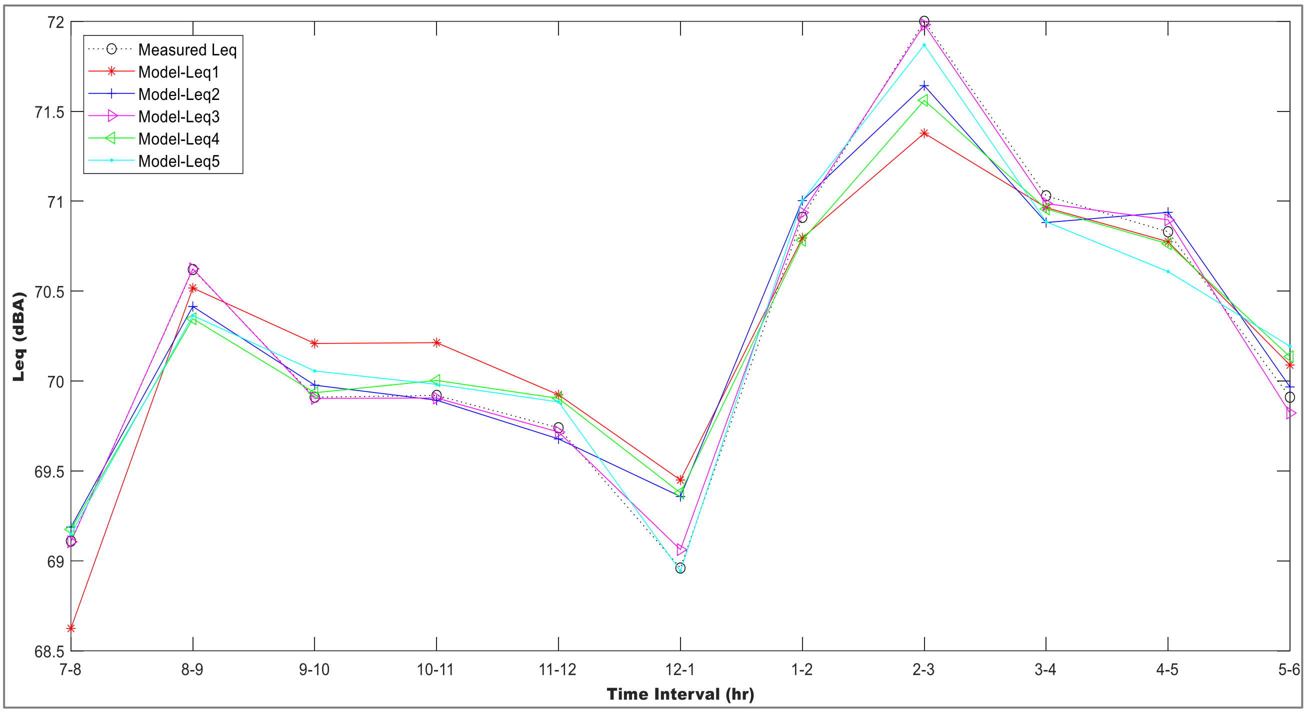

Figure 8: Prediction Results of L_{eq} using the five Models with Exogenous Variables for Ankpa Ward Junction

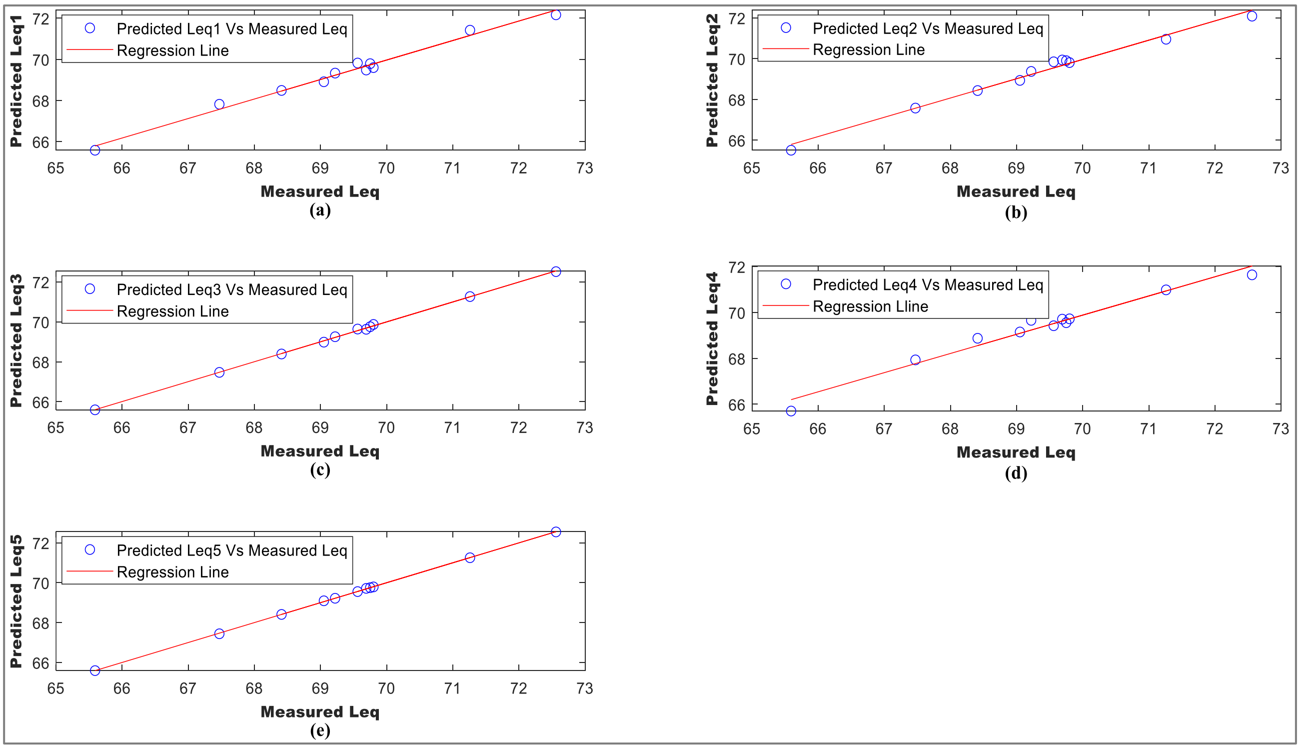

Figure 9: Predicted L_{eq} Versus Measured L_{eq} for Wurukum Roundabout

The above analysis revealed that the coefficient of determination (R^2) of Model-L_{eq1}, Model-L_{eq2}, Model-L_{eq3}, Model-L_{eq4} and Model-L_{eq5} ranged from 0.8658 to 0.9866, 0.9692 to 0.9853, 0.9730 to 0.9999, 0.9685 to 0.9759 and 0.9685 to 0.9999 respectively across the study locations, with Model-L_{eq3} having the highest R^2 range of 0.9730 to 0.9999. These R^2 values are higher than those obtained by Akpen *et al.* (2018), Ibili and Owolabi (2019) and Amah and Udeh (2023) in Makurdi metropolis, Ondo town and Port Harcourt metropolis respectively.

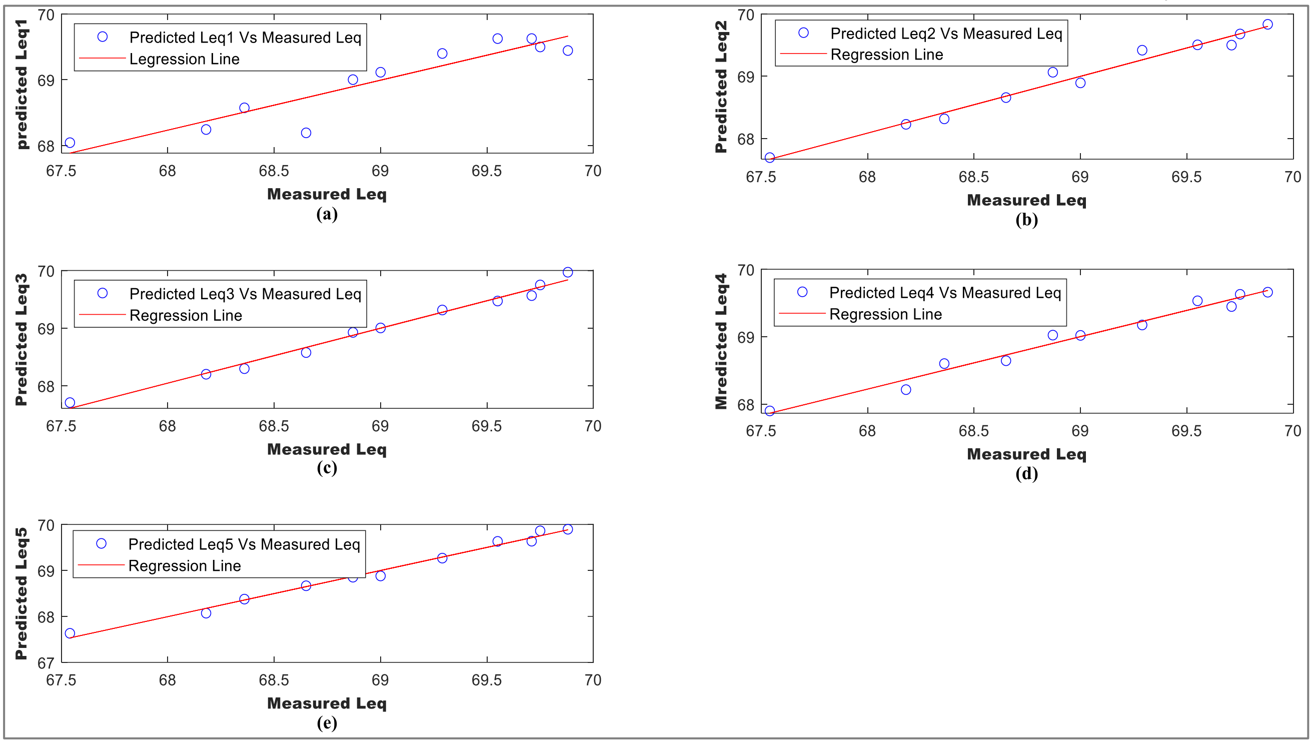

Figure 10: Predicted L_{eq} Versus Measured L_{eq} for High Level Roundabout

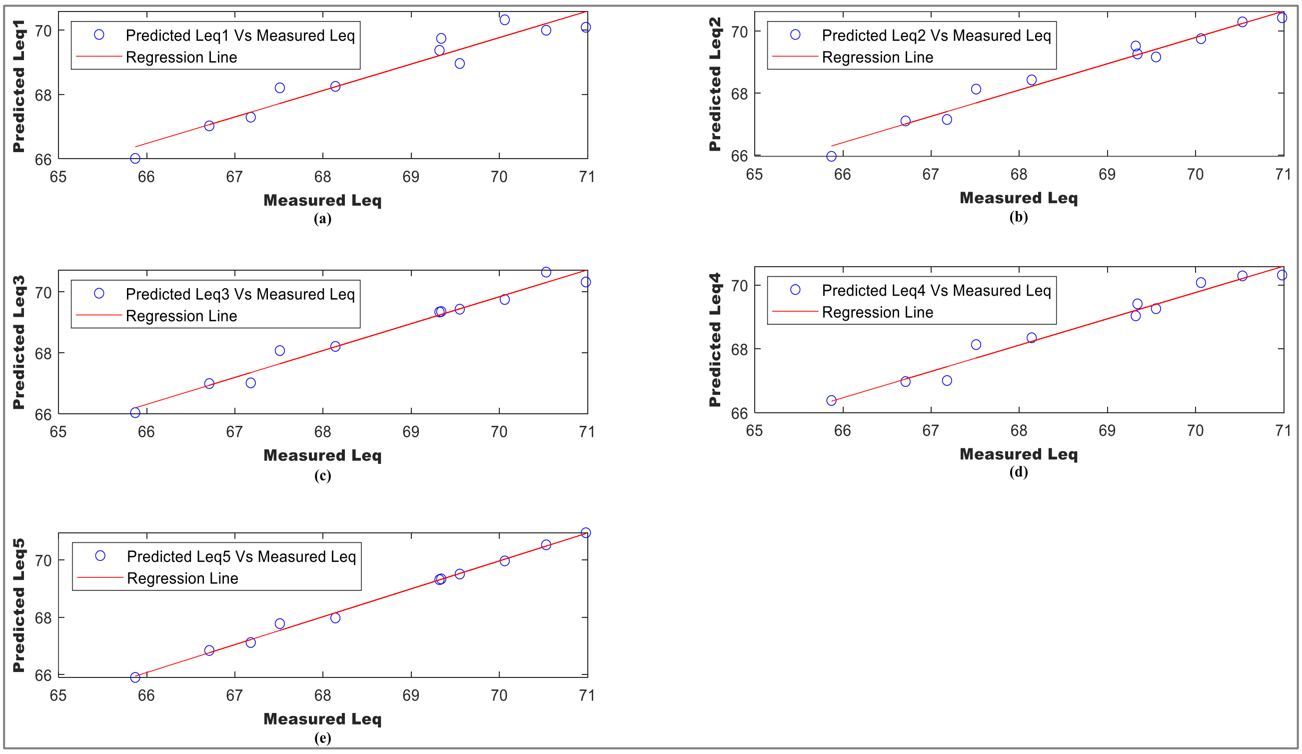

Figure 11: Predicted L_{eq} Versus Measured L_{eq} for SRS Junction

CONCLUSION

In this study, measurement and modelling of diurnal road traffic noise was carried out within Makurdi metropolis. Measurements were conducted at 2 roundabouts and 2 junctions (cross intersections) for 20 days within the metropolis. These locations were selected on the basis that they are critical to traffic flow. The results of noise levels showed that the mean L_{eq} values across the study locations ranged from 68.65 to 70.72 dBA. These noise levels were 8.65 to 10.72 dBA above NESREA's 60 dBA set limit. This implies that residents and workers in these areas are likely to experience health issues associated with noise pollution. Modelling results revealed that all the models performed well, with Model-Leq1 having the least performance, as it had the highest values of RMSE, MAE, and MAPE, and the lowest R^2 value of 0.8658 at the High Level Roundabout. Model-L_{eq3} exhibited an outstanding performance, as it had the lowest values of RMSE, MAE, and MAPE, and the highest R^2 value of 0.9999 at Wurukum Roundabout. Model-L_{eq3} is therefore recommended for predicting road traffic noise in Makurdi metropolis and other Nigerian cities.

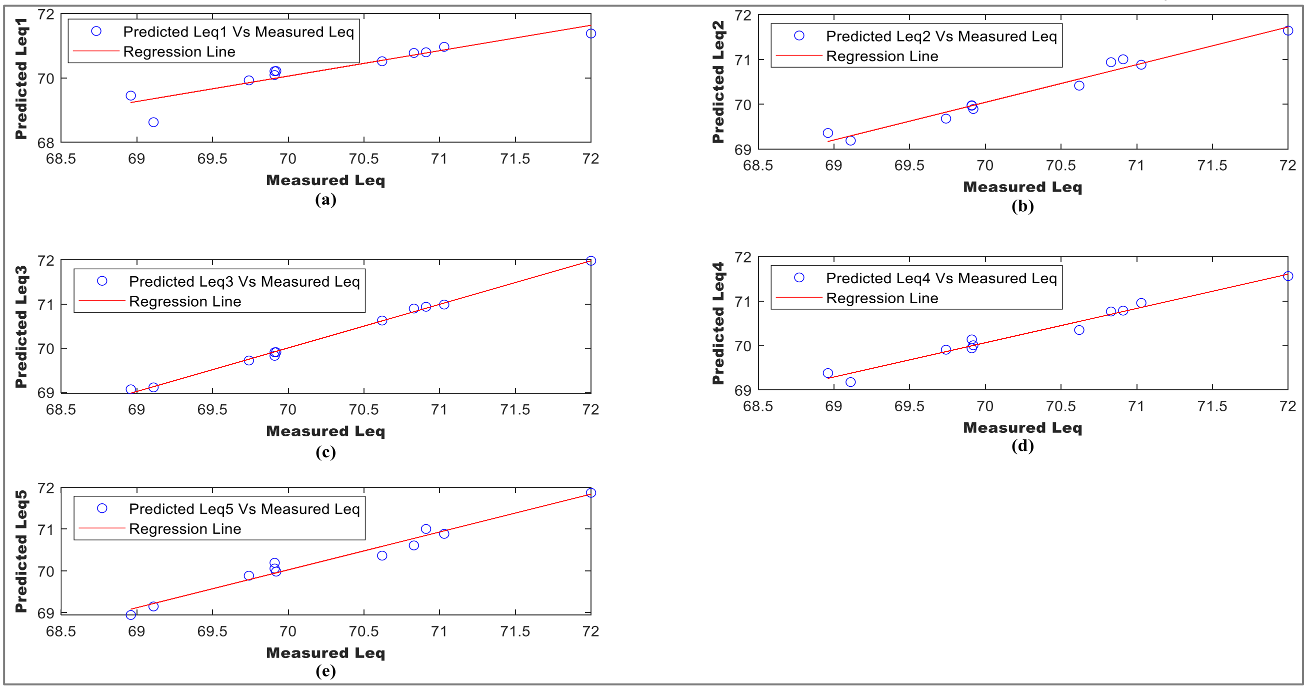

Figure 12: Predicted L_{eq} Versus Measured L_{eq} for Ankpa Ward Junction

REFERENCES

Abah, R. C. (2013). An application of geographic information system in mapping flood risk zones in a North Central city in Nigeria. *African Journal of Environmental Science and Technology, 7*(6), 365–371. [Crossref]

Adeke, P. T., Atoo, A. A., & Zava, E. A. (2018). Modelling traffic noise level on roadside traders at Wurukum market area in Makurdi Town, Benue State-Nigeria. *Nigerian Journal of Technology (NIJOTECH), 37*(1), 28–34. [Crossref]

Akaahan, T. J. A., Leke, L., & Eneji, I. S. (2016). Seasonal variation in hydrochemistry of River Benue at Makurdi, Benue State, Nigeria. *International Journal of Environment and Pollution Research, 4*(3), 73–84. eajournals.org

Akinkuade, S. T., & Fasae, K. P. (2015). A survey of noise pollution in Ado-Ekiti metropolis using mobile phone. *Natural Science, 7*(10), 475–482. [Crossref]

Akpen, G. D., Utsev, J. T., & Ekom, R. (2018). Road traffic noise prediction model for Makurdi metropolis, Nigeria. *Journal of Emerging Trends in Engineering and Applied Sciences (JETAS), 9*(1), 22–26. hdl.handle.net

Alam, J. B., Rauf, A. F., & Ahmed, M. F. (2001). Traffic induced noise pollution in Dhaka City. *Journal of Civil Engineering, The Institute of Engineers, Bangladesh, CE 29*(1), 55–63. jce-jeb.org

Alani, R. A., Ogunmoyela, O. M., Okolie, C. J., & Daramola, O. E. (2020). Geospatial analysis of environmental noise levels in a residential area in Lagos, Nigeria. *Noise Mapping, 2020*(7), 223–238. [Crossref]

Amah, V. E., & Udeh, N. U. (2023). Daytime vehicular traffic noise analysis and modeling at selected roads in Port Harcourt. *Advances in Research, 24*(5), 8–7. [Crossref]

Anila, C., & Bino, I. K. (2013). Modelling of road traffic noise. *International Journal of Innovative Research in Science, Engineering and Technology, 2*(1), 125–130. researchgate.net

Balashanmugan, P., Ramanathan, A. R., Nehrukumar, V., & Balasubramaniyan, K. (2013). Assessment of noise pollution in Chidambaram Town. *International Journal of Research in Engineering and Technology, 2*(10), 85–95. ijret.org

Ede, A. O., Nwazunku, A. A., Ihekwoaba, E. N., Orji, S. M., Rotimi, E. A., Ingwu, J. A., Nwankwor, J. C., Onyeje, B. T., Odok, E. A., & Ibecheozor, C. E. (2024). Assessment of noise pollution in the motor parks at Izuchukwu Junction and its axis in Nnewi, Anambra State, Nigeria. *International Journal of Scientific Research in Multidisciplinary Studies, 10*(5), 11–18. [Crossref]

Ekom, M., Oko, T., Aguoru, C. U., Olasan, J. O., & Odunu, L. G. (2024). Assessment of noise level from selected highways and motor parks in the Federal Capital Territory (FCT) Abuja. *Applied Sciences Research Periodicals, 2*(1), 8–16. hspublishing.org

Enda, M., & Eoin, A. K. (2014). *Environmental noise pollution: Noise mapping, public health and policy* (1st ed.). Elsevier Inc., USA. amazon.com

Goines, L., & Hagler, L. (2007). Noise pollution: A modern plague. *Southern Medical Journal, 100*(3), 287–294. [Crossref]

Haruna, L. Z., Belel, A. S., & Andrew, B. J. (2024). Structural framework for managing road traffic noise in Jos Metropolis, Nigeria. *British Journal of Earth Sciences Research, 12*(2), 1–22. [Crossref]

Haruna, L. Z., Fasakin, J. O., & Emmanuel, A. A. (2023). Analysis of traffic noise levels on land use in Jos Metropolis, Nigeria. *International Journal of Advanced Research, 6*(1), 88–101. [Crossref]

Hula, M. A. (2010). Population dynamics and vegetation change in Benue State, Nigeria. *Journal of Environmental Issues and Agriculture in Developing Countries, 2*(1), 53–69. icidr.org.ng

Ibili, F., & Owolabi, A. O. (2019). Replication of calculation of road traffic noise model for traffic noise prediction at the Central Business District of Ondo Town, Nigeria. *Journal of Geotechnical and Transportation Engineering, 5*(1), 1–7. researchgate.net

Igbokwe, E. E., & Adindu, R. U. (2023). Assessment of noise pollution in Aba North Local Government Area, Abia State, Nigeria. *International Journal of Pure and Applied Science Research, 11*(10), 104–113. [Crossref]

Jhanwar, D. (2016). Noise pollution: A review. *Journal of Environment Pollution and Human Health, 4*(3), 72–77. [Crossref]

Karthik, K., & Partheeban, P. (2015). Studies on noise pollution model for Chennai. *International Journal of Earth Sciences and Engineering, 8*(5), 2074–2078. researchgate.net

Kaushal, A., & Rampal, R. (2017). Regression modelling of traffic noise pollution at various crossings in Jammu City (J & K). *ESSENCE-International Journal for Environmental Rehabilitation and Conservation, VIII*(2), 15–21. semanticscholar.org

Kumar, K. V. D., & Srinivas, N. (2014). Study of noise levels at traffic density areas in an urban environment. *International Journal of Engineering Research and Technology (IJERT), 3*(11), 783–786. ijert.org

Loonkar, R. (2023). Analyzing the relation between the temperature of a medium and the speed sound. *International Journal of Advances in Engineering and Management (IJAEM), 5*(8), 540–544. [Crossref]

Naser, I. H. (2021). A review of speed-flow relationships in traffic studies. *Global Journal of Engineering and Advances, 6*(1), 26–35. [Crossref]

Nikolić, A., Nikolić, D., Nikolić, E., & Vujačić, V. (2014). Urban noise modelling in Boka Kotorska Bay. *Promet-Traffic and Transportation, 26*(2), 151–157. [Crossref]

Nwaogazie, I. L., & Ofem, E. E. (2014). Road traffic noise pollution modelling in Port Harcourt, Nigeria. *Standard Scientific Research and Essays, 2*(11), 570–576. standresjournal.org

Nwobi-Okoye, C. C., Uyaelumuo, A. E., Okoronkwo, G. O., & Duru, C. A. (2015). Analysis and modelling of road traffic noise in Onitsha Metropolis, Nigeria. *International Journal of Advanced Multidisciplinary Research Reports, 1*(1), 1–20. rex.commpan.com

Odiakose, U. C., & Iyeke, S. D. (2024). Traffic congestion analysis of Asaba Road using volume to capacity ratio and speed performance index. *Journal of Applied Sciences and Environmental Management, 28*(4), 1315–1326. [Crossref]

Odoh, R., & Jidauna, G. G. (2013). The spatial effect of rusty roof on water quality in Otukpo Local Government Area of Benue State, Nigeria. *International Journal of Marine, Atmosphere & Earth Sciences, 1*(1), 27–37. researchgate.net

Ogunlade, T. O., Ogunyebi, S. N., Akindutire, O. R., Ajewole, O. R., & Okoro, J. O. (2021). Sustainability assessment of traffic flow in Ekiti, Southwestern Nigeria. *IOP Conference Series: Materials Science and Engineering, 1107*(2021), 1–14. [Crossref]

Oguntoke, O., Tijani, Y. A., Adetunji, O. R., & Obayagbona, O. N. (2019). Spatial analysis of environmental noise and auditory health of Abeokuta residents, Ogun State, Nigeria. *Journal of Applied Sciences and Environmental Management, 23*(9), 1699–1707. [Crossref]

Onah, M. A., Akuratse, S. A., & Anjember, P. S. (2020). Trend analysis of temperature and wind speed characteristics over Fiidi Area of Makurdi, Benue State, Nigeria. *Climate Change, 6*(22), 168–176. discoveryjournals.org

Oyedepo, O. J. (2014). Evaluating performances of traffic noise models. *Nigerian Journal of Technology (NIJOTECH), 33*(4), 442–446. [Crossref]

Patel, R., Singh, P. K., & Saw, S. (2024). Traffic noise modeling under mixed traffic condition in mid-sized Indian city: A linear regression and neural network-based approach. *International Journal of Mathematical, Engineering and Management Sciences, 9*(3), 411–434. [Crossref]

Shabu, T., & Tyonum, T. E. (2013). Residents coping measures in flood prone areas of Makurdi Town, Benue State. *Applied Ecology and Environmental Sciences, 1*(6), 120–125. [Crossref]

Sukeerth, G., Munilakshmi, N., & Anilkumarreddy, C. (2017). Mathematical modeling for the prediction of road traffic noise levels in Tirupati Town. *International Journal of Engineering Development and Research, 5*(2), 2091–2098. rjwave.org

Thattai, D., Sudarsan, J. S., Sathyanathan, R., & Ramasamy, V. (2017). Analysis of noise pollution level in a university campus in South India. *IOP Conference Series: Earth and Environmental Science, 80*(2017), 1–7. [Crossref]

Tikyaa, E. V., Echi, M. I., Isikwue, B. C., & Amah, A. N. (2018). A hybrid SARIMA-NARX nonlinear dynamics model for predicting solar radiation in Makurdi. *International Journal of Mathematics and Computation Science, 4*(2), 35. aiscience.org

Ugwuanyi, H. K., Okafor, F. O., & Ezeokonkwo, J. C. (2017). Assessment of traffic flow on Enugu highways using density regression coefficient. *Nigerian Journal of Technology (NIJOTECH), 36*(3), 749–757. [Crossref]

Yadav, A., Parida, M., & Kumar, B. (2023). Statistical modeling of traffic noise at intersections in a mid-sized city, India. *Noise Mapping, 2023*(10), 1–16. [Crossref]