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Applying mathematical modeling for predicting urban road traffic noise levels in Port Harcourt Metropolis, Nigeria

***George Daye Mandy C. and Okeke Peter Ndu**

Department of Environment Technology, School of Environmental Technology, Federal University of Technology, Owerri, Imo State, Nigeria

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ABSTRACT

An attempt was made to assess the noise levels of 10 locations in Port Harcourt metropolis, Nigeria, during four periods of the day using noise dosimeter and prediction model. On subjecting the data generated by both methods of measurement, using pearson' product moment correlation (r), the result revealed that there was strong relationship between the actual and predicted equivalent noise levels (Leqs). To further confirm the applicability, the data was subjected to single factor anova and the result showed that there was no statistically significant difference (P>0.05). Comparison of predicted equivalent noise level with that of actual measured data demonstrated that the model used for the prediction has the ability to calibrate urban traffic noise and yielded reliable results close to that by direct measurement. After comparison of results it was observed that Calixto model could be satisfactorily applied for the Nigerian conditions as they give acceptable results with good "r" value.

Keywords: Calixto model, urban road traffic, noise prediction, Port Harcourt, Metropolis.

INTRODUCTION

The development of models to predict traffic noise started more than 50 years ago and the results have been very accurate. Usually, these kind of models are developed taking into account mainly traffic flow, both of light and heavy vehicles, features of the road surface, distance between carriage and receivers. Moreover, since several models have been developed all around the world, the peculiarities of different countries, in terms of roads, kind of vehicles and weather features have to be taken into account.

Many countries decided to regulate the use of these models, establishing which one can be adopted in traffic noise simulation. This is because it can be used in the designing of new road infrastructures in order to evaluate the acoustical impact and to avoid post construction mitigation actions that often present a greater cost. It can be used on an existing road network, so that the measurement campaign can be minimized and can be used just for the tuning of the model.

One of the first models, developed in 1952, is the one reported in Handbook of Acoustic Noise control [1]. This model states that the 50 percentile of traffic noise for speed of 35-45 mph (about 55-75 km/h) and distance greater than 20 feet (about 6 meters) is given by: $L_{50} = 68 + 8.5Log\,(Q) - 20Log\,(d)$.Where Q is the traffic volume of vehicles per hour and d is the distance from observation point to the center of the traffic lane, in feet: no specification is included about vehicles and roads type.

In the following years, [2] and [3], presented a new model in which a new parameter is included to relate the model with the experimental data. Later, [4], presented a new traffic noise model taking also into account the mean speed of vehicles in mph, V. The model presents a good agreement with the experimental data for a percentage of heavy vehicles from 0% to 40%. Some years later, [5], improved this model taking into account the percentage of heavy vehicles *p*.

The models developed in the next years introduced the equivalent level L_{eq} as sound level indicator. One of the most used is the [6], applied for the first time in Sydney in Australia. Using the same notation of the previous expression, the sound levels is giving by: $L_{eq} = 55.5 + 10.2 Log\ (Q) + 0.3p – 19.3\ Log\ (d)$. Another most used calculation formula is called [7]. In particular, they propose the evaluation of equivalent noise level starting from the percentile levels. Several years later, [8], improved the previous models by introducing the motorcycles and buses flux, Qm and Q_{Bus}. Most recently, prediction models developed have been applied to ascertain their applicability in evaluating urban road traffic noise level in different countries of the world. One of such model is the [9] model which have been used to predict urban road traffic noise in India. According to them, data collected was analyzed and compared with the values predicted by calixto et al. model. After comparison of results, it was observed that calixto model could be satisfactorily applied for Indian conditions as they give acceptable results with a good R^2 value.

Traffic noise prediction models was used in the city of Hamadan with the ultimate objective of setting up a traffic noise model based on the traffic conditions of Iranian cities. Noise levels and other variables were measured in 282 samples to develop a statistical regression model based on A-weighted equivalent noise level. Comparing means of predicted and measuring equivalent sound pressure level (L_{Aeq}), showed small differences for Tehran and Hamadan cities respectively. It was concluded that the model could be effectively used as a decision support tool for predicting equivalent sound pressure level index in the cities of Iran [10].

Furthermore, [11], investigated the integration and comparison of assessment and modeling of road traffic noise in Baripada town, India, to assess the noise level in 12 different squares. Prediction model was used to predict noise level alongside noise dosimeter. Comparison of the predicted equivalent noise with that of the actually measured data demonstrated that the model used for the prediction has the ability to calibrate the multi-component traffic noise and yielded reliable results close to that by direct measurement.

Road traffic model predicting noise levels in urban areas have been developed and applied in some countries like Italy, India and Iran. But this is lacking in Nigeria, hence, the need to apply Calixto et al., model to determine its applicability for predicting noise levels, in Nigeria. The aim of this paper is to ascertain the applicability of mathematical model for predicting urban road traffic noise in Port Harcourt metropolis, South-South, Nigeria. This will be achieved through the following objectives:
(1).Determination of equivalent continuous A-weighted sound pressure levels (L_{Aeq}) using a dosimeter and Calixto et al., 2003 model.
(2).Comparison of the measured L_{eq} with the calculated L_{eq}.
(3).Validation of the model using both descriptive and inferential statistics.

MATERIALS AND METHODS

2.1 Study area.
Port Harcourt metropolis is located in the Niger Delta, south-south geopolitical zone of Nigeria. The city, lies between longitudes $6^0 55'$E and $7^0 55'$ E, and latitude $4^0 35'$N and $5^0 10'$N and has an elevation of 1.00 – 3.00m above sea level.

Like many cities in Nigeria, the population of Port Harcourt metropolis is ever growing from the day of its creation to date. Port Harcourt population was given as 440,399 by the 1991 national census but results of the 2006 population census put the population at 1,255,387 and projected at 1,337,800 in 2009 [12]). It is a highly industrialized city hosting most of the major oil and allied companies in Nigeria.

2.2 Experimental Procedure
The measurements were made using an Extech 407780A digital sound level meter. The instrument was held comfortably in hand with the microphone pointed at the suspected noise source at a distance of 1.5m away from any reflecting object. Measurements were taken under suitable meteorological conditions, i.e in the absent of wind and

rain. The time for which measurements were taken lapsed from between 8:30am to 7:10pm. This time interval was further divided into four periods: morning (8:30am -8:40am), afternoon (1:00 pm -1:10 pm), evening (4:00 pm – 4:10pm) and night (7:00 pm – 7:10 pm).

A mathematical model developed by Calixto *et al* (2003), was applied to predict noise levels (Leq) based on the total number of vehicular flow/hour for the different periods of the day, and the percentage of heavy vehicles. The [1] formula used is given as shown below:

L_{Aeq}=19.92224Log [Q (1+ 0.1 x VP)] + 12.59764

Where: Q= Total number of vehicles flowing per hour in the selected locations at different time intervals.
VP=Percentage of heavy vehicles per hour in the selected locations at different time intervals.

3.3 Statistical Analysis

The estimated L_{eq} values were then compared with observed L_{eq} values to test for the fitness of the model in noise measurement using statistical method of pearsons' product moment correlation (r) and scatter plot or graph of observed L_{Aeq} against calculated L_{eq} values. In addition, descriptive statistics of mean ± SD, coefficient of variance and standard error were employed to test for the validity of the method used in the evaluation. Finally, inferential statistics using F-distribution (one way anova) was applied on both the measured and calculated data to ascertain if there are any significant differences between the model and measured noise values. All these were applied through 2007 excel package.

RESULTS AND DISCUSSION

4.1 Results

Table 1. Measured and Prediction noise levels at different locations and time of the day

		Morning		Afternoon		Evening		Night	
S/N	**Monitored locations**	**Predicted noise Level**	**Actual L_{eq} measured**	**Predicted noise Level**	**Actual L_{eq} measured**	**Predicted noise Level**	**Actual L_{eq} measured**	**Predicted noise Level**	**Actual L_{eq} measured**
1	Rumuola (Commercial)	89	93	98	100	79	82	76	81
2	1st Artillery(Commercial)	80	85.3	99	102	97.4	101	79	79.2
3	Air force(bus stop)	91	93	98	99.2	88	89	90	91
4	2nd Artillery(bus stop)	88.1	88.3	96	96.5	85	85.2	97	97.3
5	2nd Artillery(junction)	94	94.2	97	98	92	92.1	100	101.2
6	Air force(junction)	84.8	85	96	98	94.2	99	95	100.1
7	Tere Ama(residential)	57.5	58	57.8	58.5	58.4	63.4	60.7	64.8
8	Differi road, femie (residential)	56.5	59	58.4	59.7	60.4	62.7	61.2	64.4
9	Iyaminima St GRA (residential)	52	52.1	56.2	56.6	58.4	56	55.4	55.6
10	Orogbum crescent GRA (residential)	56	57.2	58	58.1	60.4	60.5	60.7	61

Source: Author's field survey, January, 2015.

Table 2. No of Cars that Passed in a Day at Different Times in all the locations Monitored

	Morning			Afternoon			Evening			Night			
Monitored sites	Total no. of vehicles/hour (Q)	No.of heavy vehicles (HV)	% of heavy vehicles (VP)	Total no. of vehicles/hour (Q)	No. of heavy vehicles (HV)	% of heavy vehicles (VP)	Total no. of vehicles/hour (Q)	No. of heavy vehicles (HV)	% of heavy vehicles (VP)	Total no. of vehicles/hour (Q)	No.of heavy vehicle (HV)	% of heavy vehicle (VP)	Total no. of vehicles
1stArtilery (Commercial)	3187	102	3.2005	5900	950	16.1017	6000	1200	20.00	1290	74	5.7364	16,377
Rumuola(Commercial)	3900	275	7.0912	4500	435	9.6667	1281	74	5.7767	1217	24	1.9721	10,898
Air force (passenger loading bus stop/parks)	4260	189	4.4366	6080	874	14.3911	3850	58	1.5065	6500	970	14.9231	20,690
Artillery(passenger loading bus stop/parks)	5800	142	4.2414	6055	775	12.7993	4487	149	3.3207	5545	235	4.2380	21,887
2nd Artillry(busy road junction/intersection)	5900	650	11.0170	6700	990	14.7761	5550	375	6.7568	6500	1800	27.6923	24,650
Air force (busy road junction/intersections)	3200	103	3.21896	7900	346	4.3797	8520	400	4.6948	8900	460	5.1685	28,520
Iyaminima Street(low residential area)	85	1	1.1765	155	0	0	200	0	0	140	0	0	580
Orogbum crescent (low density residential area)	150	0	0	160	3	1.875	250	0	0	259	0	0	819
Tere-ama (high density residential area)	167	1		160	2	1.2048	170	3	1.7647	190	7	3.6842	687
Differi street in femie(high density residential area)	160	0	0	170	3	1.7647	250	0	0	275	0	0	855
GROUND TOTAL OF VEHICLE FLOW													**125,963**

Table 3: Statistical Evaluation of Measured Leq and Predicted Leq at Different Periods of the Day (n=10)

S/N	**Periods of the Day**	**Predicted Leq MEAN ± SD**	**Actual Leq MEAN ± SD**
1	Morning	74.89 ± 17.1400	76.51 ± 17.5216
2	Afternoon	81.44 ± 20.5456	82.66 ± 21.0915
3	Evening	77.32 ± 16.2208	79.09 ± 16.9420
4	Night	77.50 ± 17.2307	79.56 ± 17.3340

S/N	**Periods of the day**	**Predicted Leq Coefficient of variance (CV)**	**Actual Leq Coefficient of variance(CV)**
1	Morning	0.218	0.2290
2	Afternoon	0.242	0.2552
3	Evening	0.201	0.2142
4	Night	0.214	0.2179

S/N	Periods of the day	Predicted Leq Standard Error (SE)	Actual Leq Standard Error (SE)
1	Morning	5.42016	5.5408
2	Afternoon	6.4971	6.6697
3	Evening	5.1295	5.3575
4	Night	5.4488	5.4815

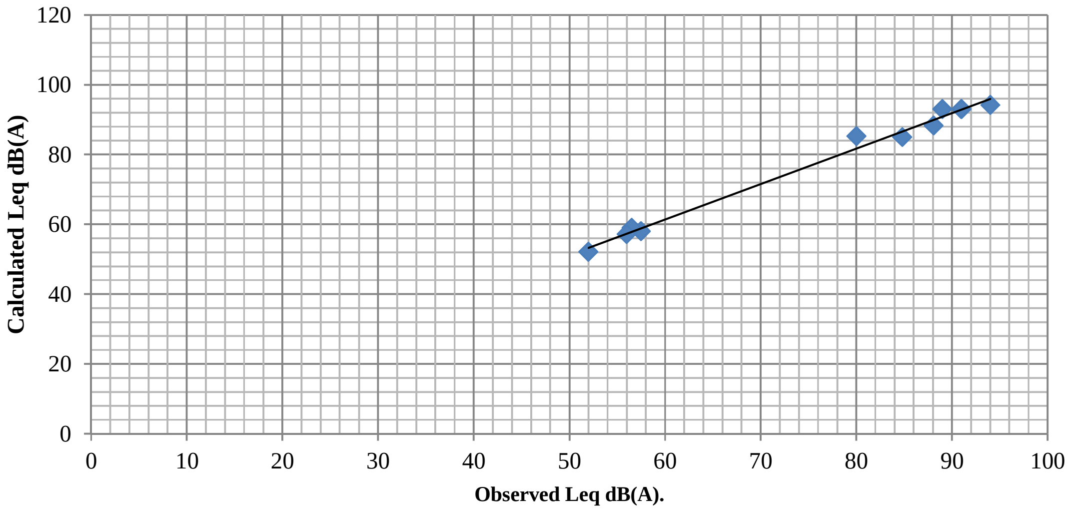

Figure1: observed Leq dB(A) against calculated Leq(dBA) for the morning period.

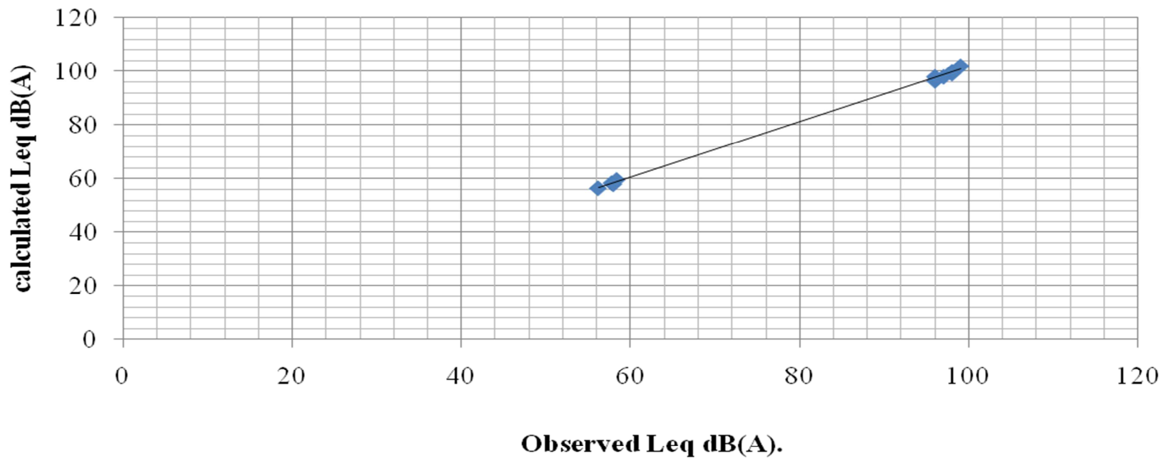

Figure3:observed Leq dB(A) against calculated Leq dB(A) for the afternoon period.

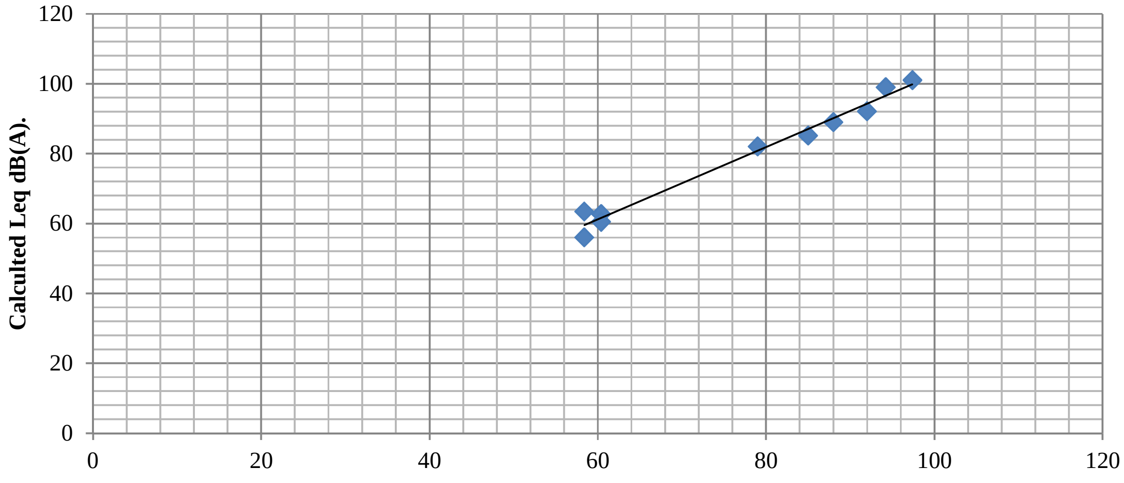

Figure 3:Observed Leq dB(A) against calculated dB(A) for the evening period.

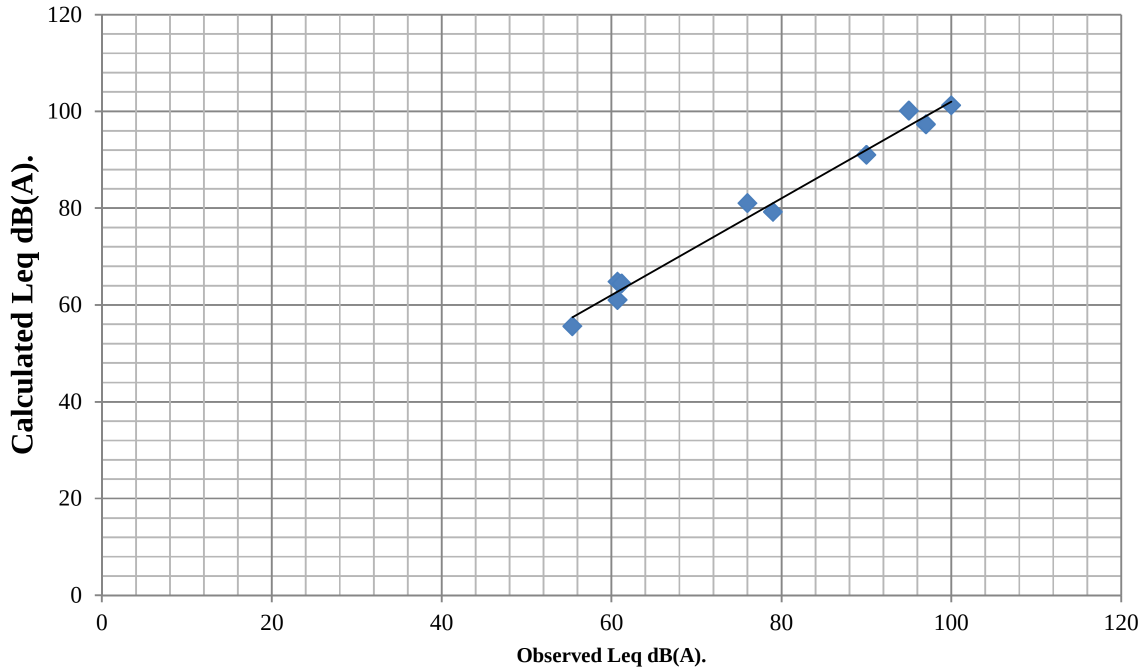

Figure 4:Observed Leq dB(A) against calculated Leq dB(A) for the night period.

4.2 Discussion

Table 1 depicted the actual measured noise levels and the predicted noise levels at each location by using the Calixto model. It is observed that the value of predicted noise level is close to the respective actual equivalent noise level measured. Such comparison depicted that the model used for the prediction has the applicability to evaluate urban road traffic, since it yielded reliable results close to that by direct measurement. It was clearly observed that the equivalent continuous sound pressure levels (L_{Aeq}) for the city were higher than the WHO permissible limit of 65dB (A). The mean value were (90.44dB (A)), for commercial areas, (92.44 dB (A)), for passenger loading bus stop and (95.93 dB (A)) for busy road junction/major intersections respectively. The high noise value is a function of the increase in the number of vehicle. Thus, the main contributor of noise in Port Harcourt metropolis is vehicular traffic as depicted in table 2.The table revealed that as the number of vehicle increased, so also the noise level increased for example, the number of vehicles in the commercial areas are 16,377 and 10,898 with a mean value of 90dB(A); while for the passenger loading bus stop it is 20,690 and 21,887with a mean noise value of 92dB(A) and 95.93dB(A) for the passenger loading bus stop with a total number of 20,690 and 21,887 vehicles .

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4.2.1 Method and Model Validation

For the validation of the new developed urban road traffic noise prediction model given by the Calixto equation, calculated Leq by the equation is then compared with observed values , using pearson' product moment correlation (r). This is done to test how close the measured Leq is to the calculated Leq for the different periods of the day. The values obtained from morning through night were recorded as 0.9971 (morning), 0.9994 (afternoon), 0.9969 (evening) and 0.9929 (night) respectively. The result revealed that there is a strong relationship between the predicted and measured L_{Aeq} values, exhibiting a near perfect relationship. This is in agreement with the works of [13] and [14].

Scatter plot for the validation was also plotted and shown in figures 1- 4 to further confirm the linearity of the calculated and measured values. The graph showed that a plot of the calculated against the observed Leq, always produce a straight line graph.

Descriptive statistics of mean ± standard deviation, coefficient of variance and standard error was also applied as depicted in table 3 .The result revealed that there was only a very small difference in these values about the mean. This confirmed how close the predicted values are to the measured values and correctness of the method used (George *et al*., 2014).

In order to ascertain if there are any significant differences in the measured and predicted Leq values, the data was subjected to statistical analysis of variance for a single factor experiment, using F-distribution, on the predicted and actual Leq values. For actual measured sound levels, the sum of squares between is 220.3747 while the sum of squares within is 11483.23. This gives us mean square values of 73.4583 and 318.9786, respectively. For predicted sound levels, the sum of squares between is 190.893 while the sum of squares within is 12054.19. This gives us mean square values of 63.631 and 334.8385, respectively. At 95% confidence level, the mean square ratio (MSR) calculated for the actual measured Leq is 0.230292, while the tabulated value is 2.8662666. Similarly, at the same confidence level, the mean square ratio (MSR) calculated for the predicted Leq is 0.190035 and the tabulated value remains as 2.866266. Since, in the two cases, the calculated MRS is smaller than the tabulated value, there is no significant difference ($P>0.05$) in the measured Leq and predicted Leq in the different periods of the day at the monitored locations, based on the data analyzed at 95% confidence level.

CONCLUSION

The model developed in the present paper can be used effectively for noise prediction for an existing busy road or a proposed new one. Hence, the calibrated model can be used for the Nigerian road conditions. The present study reveals that using road transportation noise prediction model developed so far, traffic noise level can be reduced, and so health problems of people living in close proximity to busy roads. The method is also simple, reproducible and less expensive.

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