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Research Article

Road traffic noise pollution modeling in Port Harcourt, Nigeria

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Abstract

Road traffic noise as one of the main sources of environmental pollution has led to the development of various mathematical models for its prediction. The relationship between volume of traffic and noise levels as reported in literature has been modeled based on regression approach. In this study, high traffic noise generating elements such as cars, buses, trucks and motorcycles were identified. A total of seven sites were isolated as critical points, and a reference location (non-critical point) for measurements of traffic flow and noise levels. The modeling involved the application of linear, quadratic and cubic curve fitting or regression on logarithm of total traffic flow per hour against logarithm of average noise level with goodness of fit of 98.4% for the quadratic option as the best fit. Similarly, the model for noise pollution level, NPL was obtained by regressing the logarithm of % time noise level is exceeded against noise level as a 2nd order polynomial with goodness of fit of 99.34%. Apparently, noise level can be predicted along the Aba-Port Harcourt expressway given either the volume of traffic per hour or % time of exceedence. The noise pollution level was evaluated as 113.46 dB (A); and this is the level of noise the pedestrians and neighborhood would contend with at peak periods. Noise pollution legislation and monitoring is recommended as part of control measures.

Keywords: Traffic noise, Regression modeling, Noise pollution level, hearing impairment, Aba-Port Harcourt Expressway, Pollution legislation

INTRODUTION

Noise as an unwanted sound emanates from different sources but traffic noise is perhaps the most pervasive and difficult source to avoid in society today. Highway traffic noise is a major contributor to overall transportation noise. Establishments like schools often locate their sites along highways for easy access to transport, often suffer from traffic noise. In such situations the buildings require noise insulation design, zoning or noise screening facility. Trucks, buses and motorcycles are the major causes of traffic noise. At low speed most noise comes from the vehicle engine while at high speed tyre/road contact noise, braking, horns and alarms dominate. Heavy vehicles can cause vibration and infrasound (low frequency noise).

The recognition of traffic noise as one of the main sources of environmental pollution has led to the development of various mathematical models and computer programs that could enable the prediction of traffic noise level from fundamental variables (USDOT, 2006; Ofem, 2006; USDOEC, 2004; Liying, 2006). Jong-San and others (2003) described the flow of vehicles using a statistical method of Poisson distribution. The models were said to have a correlation coefficient of 0.97, if the traffic flow is lower than 500 vehicles per hour (vph) and vehicle speed higher than 30 km/hr. This demonstrates that sound level (L_w) was in reality a function of the speed and type of vehicle. Models were also derived for two lane roads, taking into account the cumulative times of measurement. An ideal mathematical model of traffic noise should satisfy the following criteria:

i) Allow accurate determination of a unit that has shown good correlation with subjective response to the noise;
ii) Requires only data that are readily available; and
iii) Be as simple to allow use by all who are involved with the planning and development of areas near the roads.

Most traffic noise models in literature are to determine equivalent noise level (L_{eq}). The equivalent noise level corresponds to the sound pressure of a stationary noise source emitting the same acoustic energy as the actual non-stationary source (Cvetkovic et al., 1997). The equivalent continuous noise level in A–weighted decibels (dB (A)) is widely recognized as a stable descriptor of motor vehicle noise levels. It is recommended by many National and International regulatory agencies as a suitable index for use in motor vehicle noise assessments (Balachandran, 1992).

Mathematical models for predicting traffic noise are usually extracted from the functional relationship between the parameter of noise emission, L_{eq}, and measurable parameters of traffic and road. Such models available in literature as Cvetkovic et al. (1997) are based on measured data through semi – empirical models, as those of Burgess (1977), Josse (1972), Fagoti and Poggi (1995). These functional relationship(s) are essentially based on statistical analysis (that is, regression techniques).

METHODOLOGY

Area of Study

The choice of Aba – Port Harcourt expressway as the study area (see Figure 1) was due to the fact that this road could serve as a typical traffic noise pollution source in Port Harcourt. The City of Port Harcourt is an operating base of major oil industries and densely populated. Noise level is unavoidably high and yet it is given little or no consideration on environmental policies, implementation and enforcement. The Aba- Port Harcourt Expressway is the main industrial and transit access road into the City, which qualifies it as a good sampling area to gather data to generate a representative model for traffic noise pollution. The study area is carefully chosen to quantify the level of traffic noise pollution in Port Harcourt metropolis.

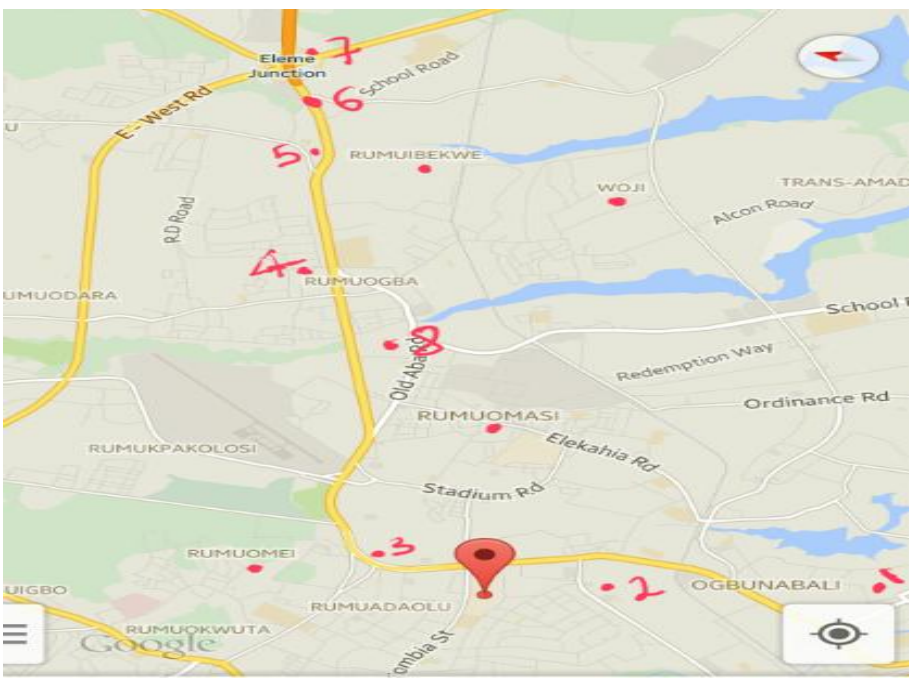

Figure 1. Map of the study area: Aba- Port Harcourt Expressway

Noise Level and Traffic Flow Survey

The field assessment was conducted between Garrison junction and Eleme junction along Aba – Port Harcourt expressway (see Figure 1). Eight points were considered along the expressway with five most busy and traffic interrupted junctions along the stretch (Garrison, Rumuola, Artillery, Oil mill and Eleme Junction), two free runs (between

Garrison and Waterlines and CFC) and one control point at Polo Club (see Table 1). Special attention was paid to these critical locations because they are high noise generation areas and the density of pedestrians is considerably high. Noise Positioning Satellite measurements were conducted with noise meter (Digital sound level meter, Extech model 407750) at different time intervals such as 10, 20, and 120seconds, respectively. Garrison junction was spotted as the most congested location; therefore further noise data were collected, as well as characteristic features generating superimposing noise values. The traffic flow data were collected at certain time intervals on same locations. The vehicles were classified in four categories: Category 1: Cars and four wheels open vans referred to as cars; Category 2 :Buses of all classes; Category 3: Heavy truck vehicles; and Category 4: Motorcycles. Data were recorded on selected junctions and free flow locations, same as the noise level surveying points.

Data Analysis and Modeling

Noise pollution modeling is dependent on the data from a noise frequency and noise level measurements. The data utilized in this study were systematically collected to capture the areas with high noise levels along the expressway with a reference point on a nearby quiet residential area(s). Modeling was actualized in two different ways, that is:

(a) Applying regression analysis to develop a Noise Level - Frequency model and from the model or its plot determine the values of 10, 50 and 90% Noise Levels (NL_{10}, NL_{50} and NL_{90}) required to calculate the Noise Pollution Level (NPL) from the standard formula (Nwaogazie and Owate, 1995; 1999); and

(b) A traffic flow model to be generated to show the relationship between traffic flow to noise level along the stretch of the Expressway.

The collected data were classified by grouping using the standard scale. With the volume of noise levels measured, grouping was made to isolate those that fall in the range of very loud, deafening and threshold of pain (90-120 dB (A)) for modeling purposes. The data were so chosen because sound at the level of inconvenience or harmful limit is of special interest in this study. Some of the data were rated above the health limit for the pedestrians, thus, constitute the bulk of data employed for the road traffic noise pollution modeling (see Table 2). From the raw noise data collected at the various measuring points the arithmetic mean value of the first three high values was obtained that would be used for Noise – traffic flow rate evaluation. Arithmetic mean seems to be a better average with least deviation and good representation of the data collected from each location. This is measured in average count per hour.

Traffic volume is an easier parameter and less expensive to measure. In other to demonstrate the relationship between traffic volume and noise level, a number of plots were made on logarithmic scales. A quadratic regression model was found superior to both linear and cubic curve fitting (see Equation.(1)):

$$\text{Log NL} = 1.603 + 0.297\text{LogQ} - 0.0516\text{LogQ}^2 \qquad (1)$$

Where Q is the sum of the volume of types of motor vehicles (cars, V_c; buses, V_b; trucks/trailers, V_t; and motor cycles, V_{mb}) passing through the road in an hour; that is, $Q = V_c + V_b + V_t + V_{mb.}$

The coefficient of variation, r^2 for Eq. (1) is obtained as 0.984 (98.4%).

Similar to Equation (1), a quadratic regression model was developed for predicting Noise Level, NL, given the percent of time NL is exceeded (see Equation 2). By method of ranking a total of 87 spot readings (or field measurements) of noise levels and corresponding probability computation via Weibul's method (Nwaogazie, 2006), the plot of Figure 3 was obtained as well as Equation (2). The computed coefficient of variation, r^2= 0.9934 (99.34%) and standard error, $S_{yx=}$ 0.0834 (8.34%):

$$y = 2.0615 - 0.0116x - 0.0154x^2 \qquad (2)$$

Where y and x are logarithm of Noise Level (NL) and logarithm of % Time Exceeded (%TE), respectively; and by substituting into Equation (2) we obtain the following:

$$\text{Log NL} = 2.0165 - 0.0116 (\text{Log \% TE}) - 0.0154 (\text{Log \% TE})^2 \qquad (3)$$

In other to evaluate the noise pollution level of the road under study, certain functions will be read off the graph (Figure 3). The noise pollution level (NPL) was calculated using Equation (4) (Nwaogazie and Owate, 1999);

$$\text{NPL ,dB(A)} = NL_{50} + (NL_{10} - NL_{90}) + \frac{(NL_{10} - NL_{90})^2}{60} \qquad (4)$$

Taking the values of $LogNL_{10}$ = 2.032 (NL_{10}= 107.6465 dB(A)), $LogNL_{50}$ = 1.995 (NL_{50}= 98.8553 dB(A)), $LogNL_{90}$ = 1.98 (NL_{90}= 95.4993 dB(A)) as read from Figure 3 (or from Equation 3); then Equation (4) gives:

$$\text{NPL, dB(A)} = 98.8553 + (107.6465 - 95.4993) + \frac{(107.6465 - 95.4993)^2}{60}$$

$$= 113.46 \text{ dB(A)}$$

Table 1. Noise data collected at all the 8 sampling points along Aba – Port Harcourt Expressway

NOISE MEASUREMENT ALONG ABA-PORT HARCOURT EXPRESSWAY													
S/N	**STATION**	**GPS**	**DAY/TIME(Hrs)**	**Noise Levels, dB(A)**									
				1	2	3	4	5	6	7	8	9	10
		Elev. = 19m	Mon. 1200	76.9	74.5	76	75.8	82.5	89.2	74.1	76.4	88	77.1
1	Garrison	N 04^0 48.356'	Wed. 1500	71.1	74.1	75	104.6	76.1	78.4	81.7	90.4	74.7	79.8
		E 007^0 00.534'	Thur. 0700	73.3	78	78.7	74.8	77.7	69.9	95.2	84.9	79.5	80.5
2	Control	Elev. = 19m	Mon. 1203	45.9	48.1	43.7	41.4	62.4	45.7	54.3	55.2	61.7	68.1
	Polo Field	N 04^0 50.012'	Wed. 1504	44.9	53	40.1	45	52.1	48.1	51.4	70	61.1	57.7
		E 007^0 01.801'	Thur. 0703	42.9	44.1	45.8	51.6	46	67.1	53.6	64.3	47.2	49.1
	Free Run b/w	Elev. = 20m	Mon. 1204	78.7	104.6	78.1	80	79.1	79.9	105.5	110.7	81.6	76.3
3	Garrison and	N 04^0 48.808'	Wed. 1506	70.2	71.4	73	68.5	81.7	68.7	76.9	74.4	76.1	72.1
	Waterlines	E 007^0 00.594'	Thur. 0705	72.3	74.4	81	101.1	98	78	85	75.2	82.2	75.5
		Elev. = 20m	Mon. 1206	107.5	75.3	78.3	82.8	80	113.1	76.1	88.2	91	76.6
4	Rumuola	N 04^0 49.858'	Wed. 1509	79	94.5	81.7	83.3	95.2	86.7	80.4	96.5	81	79.8
		E 007^0 00.223'	Thur. 0708	76.3	94.6	80.6	91.8	77.6	88.8	79.6	81.9	75.8	77.2
		Elev. = 4m	Mon. 1210	91	93.1	83.8	98.5	107.1	77.6	90.8	87.9	112.2	90.9
5	Artillery	N 04^0 50.587'	Wed. 1512	71.5	81.6	81.2	104.5	86.5	104.5	97.1	84.5	96.9	88.5
		E 007^0 02.274'	Thur. 0713	70.9	80.6	82.9	83.2	96.5	91.7	79.6	84.1	92.7	87.6
	Free Run	Elev. = 14m	Mon. 1217	79	114.8	85.5	70.4	66.8	81	69.4	79.7	113.9	78.8
6	CFC	N 04^0 50.854'	Wed. 1517	82.7	85	80.4	81.5	90.1	88.5	91.6	106	82.5	87.1
		E 007^0 02.863'	Thur. 0717	81.4	72.8	78.2	94.6	75.8	71.7	86	88.5	96.7	70.8
		Elev. = 19m	Mon. 1220	74.6	74.6	79.7	99.1	76.8	64.5	72.3	70.8	74.7	80.1
7	Oil Mill	N 04^0 51.244'	Wed. 1521	73.5	74.1	94.7	79.5	106.7	114.1	76.7	82.6	88.9	94.4
		E 007^0 03.842'	Thur. 0721	77.9	71.1	69.6	81.5	65.8	76.4	90.1	66.6	95.4	81.6
	Eleme	Elev. = 22m	Mon. 1224	74.6	78.7	76.4	73.4	74.1	67.6	70.6	70.5	77.6	81.7
8	Junction	N 04^0 51.360'	Wed. 1528	82.2	82.7	76.8	74.6	81.7	88.5	99.1	86.6	87.4	96
		E 007^0 04.026'	Thur. 0726	70.6	69.8	68.1	73.9	74.6	76.1	106	74.1	80.1	69.8

Noise meter specification: Extech Instrument, Digital Sound Level Meter, Model: 407750, GPS – Global

Table 2. Average Noise level and Traffic flow per Hour

Critical Points	Ave. NL±	CAR per Hr	BUS per Hr	TRUCK per Hr	BIKE per Hr	TOTAL per Hr	Log TF± per Hr	Log NL dB(A)
Reference	68.4					0	0	1.6031
Garrison	96.73	1958	490	44	288	2780	3.4440	1.9855
G/WL±	106.93	1901	395	45	193	2534	3.4038	2.0291
Rumuomasi	105.7	2111	403	50	300	2764	3.4415	2.0241
Artillery.	107.93	1377	397	128	167	2069	3.3158	2.0331
CFC	111.57	945	389	103	93	1530	3.1847	2.0475
OIL MILL	106.63	646	342	90	160	1238	3.0927	2.0279
ELEME	100.36	704	336	120	248	1408	3.1486	2.0015

±Note: NL = Noise level; G/WL = Garrison-Water Line Junction; TF = Traffic flow; bike = Moto cycles

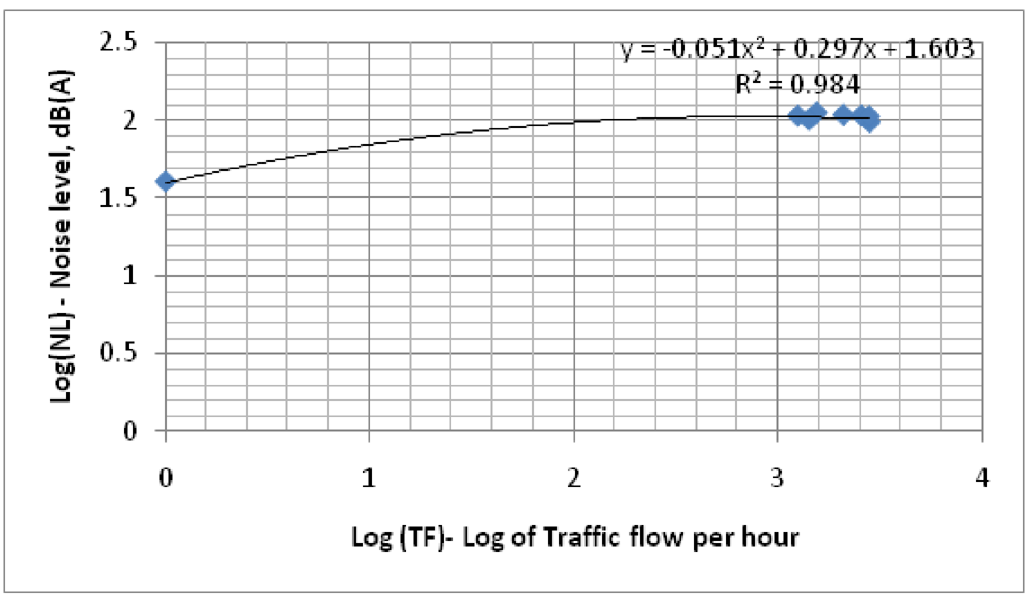

Figure 2. Traffic Flow against Noise level as a 2nd order Polynomial

RESULTS AND DISCUSSION

Large set of data were gathered with several conditions and at different days and time but in all, high values were always observed on every critical location. Shown in Figure 4 is a pie chart representation of all the data collected in the entire period. Figure 4 clearly illustrates the intensity of sound emitted into the study area of the city which in turn proportionally defines the severity of noise the road users and nearby residents are exposed to on a daily basis. Each shaded band represents a category of noise. The noise pollution level at some point is as high as 113.46 dB(A). Through these two models (Equations (3) and (4)) an approximate value of the noise pollution level (NPL) was determined.

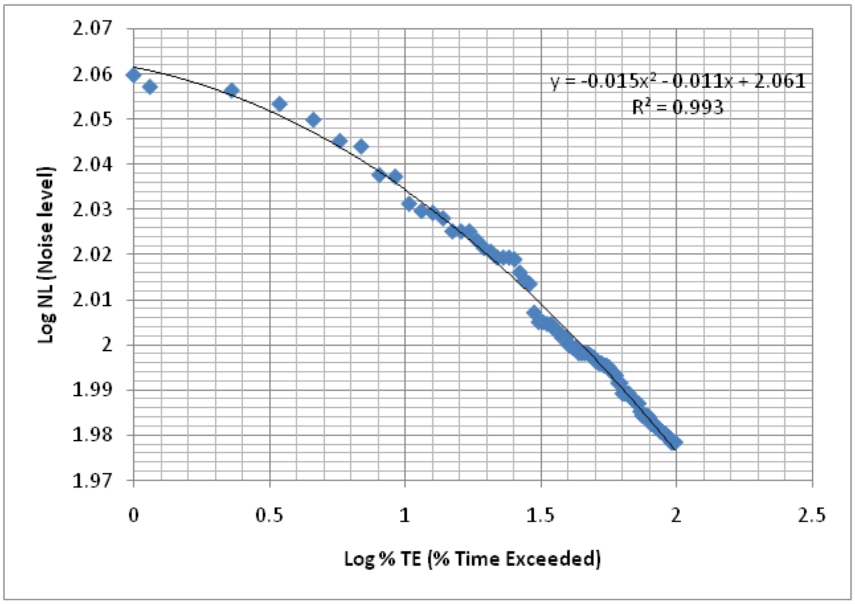

Figure 3. A plot of Log NL against Log % Time exceeded

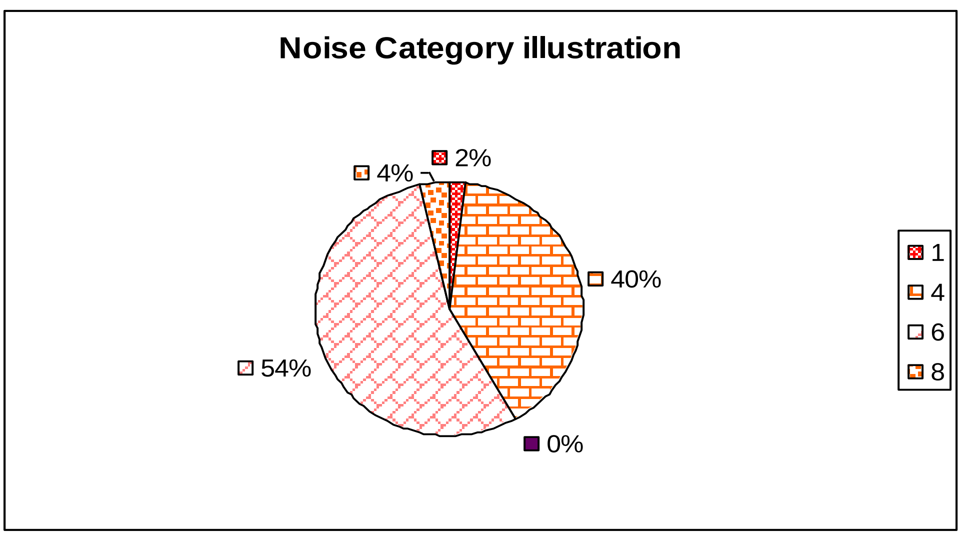

Figure 4. Different categories of Noise levels

Represents threshold of pain noise band (above 110 dB(A))
Represents Deafening noise band (above 90 dB(A))
Represents noise level at Very Loud noise band (above 70 dB(A))
Represents Loud noise band (64 – 69.9dB (A))

The traffic volume was presented as hourly traffic observed and the noise was measured at intervals (transient noise, L_{eq}). This was necessary because the determination of noise pollution level across the road requires more than one value; also, few traffic volumes are recommended to be collected along the length of the road for a more accurate pollution value to be determined.

The US Environmental Protection Agency regulation (effective from January 1, 1988) standardized the noise level allowable for newly manufactured loaded tucks of weight over 4,545 kilograms between 80 to 87 decibels at the distance of 15 m interval from the road centerline. The noise level on Aba – Port Harcourt Expressway is above recommended limits as shown on the measured data on Table 1. Therefore, abatement procedures are necessary, carefully planned and effectively implemented to protect the health and well being of pedestrians and neighborhood residents to the expressway.

Hearing loss is the most reported and concerned effect of noise pollution (NANC,1981; Nunez,1998). Constant exposure to high noise level could result to two types of hearing loss, conductive and sensori-neural loss:

(i) Conductive hearing loss is usually associated with the outer or middle ear. This kind of loss is usually caused by a perforation or infection in the middle ear or an inflammation of the middle ear bones. It blocks transmission of sound to the cochlea or inner ear. Very high amplitude impulse or blast from horns or other high noise sources could rupture the ear drum and disturb the middle ear bones, called traumatic hearing loss. The maximum conductive loss is usually around 50 to 60 dB(A). Conductive losses are correctable by surgery.

(ii) Sensori hearing loss results from damage to the cochlea or neural structures of the ear. Birth defects, noise, drugs, fever, or trauma may cause this type of loss. Noise-induced sensori-neural hearing loss has been traced to the continued exposure to hazardous noise. The computed noise pollution level of 113.4 dB(A) along Aba-Port Harcourt expressway is high enough for hearing loss if exposure is reasonable.

Most of the high noise levels emitted in the study area are through horning and certain makes of motorcycle (Kymco bike). Table 3 shows the noise data collected as per noise generating sources. The noise classified on the two shaded areas on Figure 4 is characteristic of irrelevant horning and firing by motorists.

Table 3. Horn generated Noise and their respective Sources

S/N	Noise Level, dB(A)	Source
1	114.8	Loaded trailer
2	113.1	Truck
3	104.6	Datsun 1.8 model, 3m away
4	97.2	Honda bike*
5	99	Stallion bike
6	92.7	Kymco bike firing
7	101.2	Bike horn
8	109	Waste truck with load
9	99.2	Nainyang bike horn
10	104.9	Mercedes Benz 3340 model, 6m away
11	100.7	Horn
12	97.6	Toyota corolla 1.8 model, 6m away
13	103.2	Power bike horn, 6m away
14	99.9	Toyota Prado Jeep, 5m away
15	109.1	Trailer, 7m away

*bike = Motorcycle

CONCLUSION

Road traffic noise has been recorded as a nuisance to residents and pedestrians near the major highways. The road traffic noise measured at Aba – Port Harcourt expressway is at a level of health concern particularly to regular road users from Port Harcourt. Based on the results of this study the following conclusion can be drawn:

1. There is a high correlation between traffic volume and noise level as per the statistical modeling of the noise data in the range of threshold of pain to very loud noise.
2. The second model was on traffic noise versus percentage time a particular noise level is exceeded. The model gave a high coefficient of variation of 0.9934 and a standard error of 8.34%.
3. The traffic Noise Pollution Level, NPL on the expressway is calculated as 113.4 dB(A). This value is high enough to cause extra-auditory effect or hearing impairment.
4. The major noise source in the study area is motor horning which ranges from 92.7 to 114.8 dB(A) and is very frequent and disturbing.

RECOMMENDATIONS

The following recommendations could serve as noise abatement measures for the study area given that no existing fundamental abatement measures are in place.

(i) Control of blasting of horns through legislation and conscientious effort of drivers: - The use of horns by motorcycles, cars, buses, trucks and trailers have eaten deep into the culture of drivers on this road and other Nigerian roads.

(ii) . As a matter of safety and orderliness, it is highly recommended that all drivers should be retrained and licensed.

(iii) Highway Code Implementation: - Marking of roads such as speed limits, directions, keep clear, no u-turn, etc and provision of warning or hazard signs could greatly reduce the traffic noise level

(iv) High Penalties and Fines: - The penalties that should be imposed on convicted offenders include fines, withdrawal of driver's license and re-examination and testing. Such penalties could restore sanity on this road.

(v) Noise Pollution Policy: - The volume of motorists and road users are rapidly increasing because Port Harcourt is an oil city. It is therefore essential to develop adequate noise control policies.

(vi) Education: - In order to accelerate the awareness on traffic noise pollution on this road and any other roads, it is recommended that a public awareness on the effect of traffic noise should be created through the media such as television, radio, and symposia.

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