

Modelling and Prediction of Road Transportation Noise Pollution in Some Capital Cities in Eastern Nigeria by Use of Artificial Neural Network

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Abstract
The study attempts to model and predict road transportation noise pollution in five capital cities in Eastern Nigeria. The capital cities are Calabar, Uyo, Umuahia, Owerri and Port Harcourt. Feed-forward neural network (FNN) with negative back-propagation algorithm was used to do this. The software used was NeuroXL. The ability of this software to handle multiple non-linear relationships makes it ideall y suited for this work. The input data used were total road traffic volume, road traffic mix, road traffic noise pollution response data, and distances from road centre-line to measurement points. The output data used was A-weighted energy mean sound level (L_Aeq). Models based on this negative back- propagation neural network were trained, validated and tested using data collected. The performance of the model was tested by an error measure, root mean square error (RMSE). RMSE is low as expected, ranges from 1.007 - 1.814, showing that the model is good for the prediction of road traffic noise data. The correlation between observed and predicted noise levels *(LAeq)* was also obtained, and ranges between +0.757 to +0.974, showing that there is no significant difference between observed and predicted noise levels, thereby, proving the model accurate and reliable.
Keywords: Artificial neural network, back-propagation, road traffic noise modeling, road traffic noise prediction, NeuroXL software
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1.0 Introduction

Nigerian urban dwellers are excessively exposed to severe environmental/city noise pollution. The most disturbing city noise source, as generally established in the developing and developed urban communities being road transportation, as noise from it causes a lot of socio-psychological and physiological problems such as annoyance, sleeplessness, hearing loss, communication disturbances, speech intelligibility, cardiovascular disorders and other health problems [1 - 9]. The heterogeneous nature of urban environments, coupled with the characteristics of road transportation noise, their spatial, temporal and spectral variability, makes the matter of modeling and prediction of road transportation pollution a very complex and non-linear problem, to which the application of artificial neural networks becomes imperative. Artificial neural networks (ANNs) are widely used in road transportation noise modeling and prediction as a preference to more conventional statistical techniques, because ANNs are non-linear, relatively insensitive to noise data, perform reasonably well when limited data are available, and provide flexibility, accuracy and fault tolerance in changing environments [9-17].

2.0 Materials and methods

2.1 Measurement sites

One hundred (100) measurement sites were randomly selected from the five (5) Nigerian capital cities surveyed. Fifty (50) sites were chosen from road transportation high noise pollution zones, where heavy road transportation volume and dense traffic mix (composition) are experienced, on daily basis to serve as study group, while 50 sites were from low noise zones to serve as control group.

Fig. 1 shows map of Nigeria indicating the surveyed capital cities, while tables 1 - 5 show the description of the measurement sites.

2.2 Materials for data collection

2.2.1 Materials for acoustic data collection

A precision sound level meter, Bruel and Kjaer (B & K), type 732 was used to assess road transportation noise levels at each measurement sites. Other materials used included measuring tape (to measure distance from the road centre line to the measurement points); stop watch/clock (to take sampling/measurement times); tally sheets (to record motor vehicle volume and motor vehicle mix during measurement/sampling times); and tripod stand (to support the sound level meter).

2.2.2 Materials for psycho-social data collection

Subjective (psycho-social) responses of respondents exposed to intense road transportation noise were obtained by use of questionnaire items. The questionnaire was designed after Fields [18] with some variations to suit the objectives of this study. The questionnaire contains a number of noise response questions to help elicit the needed social noise data from respondents on road transportation noise-induced health problems such as sleeplessness, annoyance, hearing loss, auditory communication disturbance, and others. Information on effects of road transportation noise pollution on various health challenges has six (6) rating options: Extremely severe disturbance (ESD) with response rating of 6; Very severe disturbance (VSD) with rating of 5; Severe disturbance (SD) with rating of 4; Moderate disturbance (MD) with rating of 3; Little disturbance (LD) with rating of 2; and No disturbance (ND) with response rating of 1. The questionnaire also contains information on some demographic/socio- economic variables such as: sex (male and female), age (15 years and above), marital status (single, married, divorced), educational level (primary, secondary, tertiary schools), occupation (student, civil/public servants, business/trader, artisan, jobless), occupational status (junior, senior, executive), income level (low, medium, high), among others.

2.3 Methods of data collection

2.3.1 Methods for acoustical data collection

A precision sound level meter was used to collect the road transportation noise levels in line with ISO 1996 - 1 and ISO 1996 - 2 standards [19, 20]. All measurements were done when motor vehicles (motorcycles/tricycles, cars/jeep, buses and trucks/trailers, etc) were moving past the measurement points. Readings of noise levels, background noise levels (BNLs) and A-weighted energy mean noise levels (L_{Aeq}) at each measurement point were taken every fifteen (15) minutes (sampling time or time rate) for a period of about 15 hours (7am - 10pm) daytime period, and 9 hours (10pm - 7am) nighttime period. Sound level meter (SLM) was held on a tripod stand with a microphone directly pointing toward noise source about 1.5 - 2.0m high from the ground, and 3.5m from reflecting surfaces. The distance between measurement point and road Centre line was 10 -15m. Measurement sites were randomly selected to reflect roads with high and low transportation noise pollution levels, also away from airports, factories, construction sites and any other sources of heavy and intense noise other than motor vehicles. This was to prevent or reduce undue influence of these sources to road transportation noise levels. Total road traffic volume and road traffic mix (composition) were also recorded at each measurement sites. Tables 6-10 show observed and predicted LAeq data and mean road transportation volume per hour during recording time at daytime and nighttime periods in the surveyed capital cities.

2.3.2 Methods for Psycho-social data collection

Subjective (Psycho-social) responses of respondents exposed to intense road transportation noise pollution were obtained by use of road transportation noise pollution survey questionnaire (RTNPSQ) and analysed and evaluated. Persons who have literacy skills (reading and writing skills in English), who reside at the place for atleast three (3) years as at the time the survey took place, and who were upto 15 years and above by age, were given copies of the questionnaire to complete objectively and return to the researcher. These precautions were taken to help reduce information bias on the part of the respondents. Two thousand and five hundred (2,500) persons were given copies of the questionnaire at road transportation high noise pollution sites, to serve as experimental group, while another 2,500 persons were given some copies of questionnaire at low noise pollution sites, to serve as control group. In all, the response rates at high and low noise pollution sites were 93.5% and 94.8% respectively.

2.3.3 Artificial neural network training process

Every neural network has input, hidden and output layers (nodes). Feed-forward neural network (FNN) and many other networks learn using back-propagation algorithm. The input data used in this study include total road traffic volume, road traffic composition (mix), distance from measurement point to road centre-line; and respondents' road traffic noise pollution-induced response data. The input data were divided into two sets – training (learning) data set and checking (testing) data set. Data points for road traffic high noise pollution sites were 486, 472, 454, 464 and 461 in Calabar, Uyo, Umuahia, Owerri and Port Harcourt cities respectively, while for road transportation low noise sites were 465, 480, 478, 476 and 471 in Calabar, Uyo, Umuahia, Owerri and Port Harcourt cities respectively. Table 11 shows summary of ANN training and checking data used for the study. Data points used for training ANN at high noise sites in Calabar, Uyo, Umuahia, Owerri and Port Harcourt cities were 301, 295, 297, 295 and 284 respectively, while at low noise sites were 296, 304, 295, 299 and 288 respectively. Also data points used for checking the validation of ANN at high noise sites in Calabar, Uyo, Umuahia, Owerri and Port Harcourt cities were 185, 177, 157, 169 and 177 respectively, while at low noise sites were 169, 176, 183, 177 and 183 respectively. With back-propagation, the input data were fed into the input layer to the hidden layer. Within the hidden layer they got summed, then processed by a non-linear function (usually either zero-based log sigmoid function or the hyperbolic tangent). The data were then finally multiplied by interconnection weights, then processed within the output layer to produce the neural network output. The output of the neural network was compared to the desired output, and the model error was computed. This error was then fed back (back-propagated) to the neural network and used to adjust the weights such that the model error decreased with each iteration, and the neural model got closer and closer in accuracy until the desired output was obtained, when the network no longer seemed to be learning, or an acceptable model error was reached. Fig. 2 shows a diagram demonstrating ANN training process [21], while table 12 shows summary of initial ANN training parameters. Table 13 shows the validation parameters of the ANN model.

2.4 Data analysis/reductions

The following noise measure or descriptor was used:

Energy mean A-weighted sound pressure level (L_{Aeq}): This is mathematically expressed in Eqn. 1.

$$L_{Aeq,}1hr = 10log_{10}\left[\sum_{N=1}^{N} fi \times 10^{\left(L_i/_{10}\right)}\right] dB(A) \quad (1)$$

Where L_i = sound pressure level (in *dB(A)*)

f_i = fraction of observation time that L_i is present (in seconds)

Σ=summation symbol

The energy mean A-weighted sound pressure level, L_{Aeq} is the energy average sound level occurring at a particular location over a given time interval. It is the most widely used measure to assess and regulate road and other transportation noise pollution because it correlates well with psycho-social responses of noise as well as its simplicity of use [22, 23] Root mean square error (RMSE): This is expressed in Eqn. 2

$$RMSE = \sqrt{\frac{\Sigma(Y_i - X_i)^2}{N}} \quad (2)$$

Correlation coefficient (r): This is expressed as in Eqn. 3

$$r = \frac{\frac{\sum XY - \bar{X} \cdot \bar{Y}}{N}}{\sigma_X \cdot \sigma_Y}$$

$$\text{where } \sigma_X = \sqrt{\frac{\sum X^2}{N_X} - \bar{X}^2} \; ; \quad \sigma_Y = \sqrt{\frac{\sum Y^2}{N_Y} - \bar{Y}^2}$$

Y_i = predicted values
X_i = observed values
N = Number of data points
$\bar{X}$ = mean of observed data
$\bar{Y}$ = mean of predicted data
σ_x = standard deviation for observed data
σ_y = standard deviation for predicted data

3.0 Results

The findings of this study are summarized in tables 6 – 10, 13 and Figs. 3 – 7. Tables 6 – 10 show observed (measured) and predicted (calculated) noise levels (L_{Aeq}) and mean road traffic volume and traffic mix at daytime and nighttime periods in the surveyed Nigerian cities. Table 13 shows the calculated validation parameters of the ANN model. Figs. 3a – 7a show correlation curves and R^2-values between observed and predicted L_{Aeq}, while Figs. 3b – 7b show ANN performance curves for checking (testing) data for road traffic high and low noise pollution sites, indicating respondents' noise reactions against observed and predicted L_{Aeq} at surveyed Nigerian cities.

4.0 Discussion of Results

From Tables 6 – 10 the observed and predicted L_{Aeq} appear to be correlating well. They are found to be high, beyond the recommended World Health Organization's standard [24]. The L_{Aeq} ranged from 87.1 – 98.5 dB(A) (observed)in Calabar city high noise sites. Similar trends were observed in other surveyed cities. Such levels of noise are high enough to cause human annoyance, discomfort, sleeplessness, hearing loss, communication disturbances, among other physiological and psycho-social health disorders [9]. The mean road traffic volume per hour (VPH) is much as observed in tables 6 – 10 at high noise sites. It was shown that noise level is a function of traffic volume. Percentage of heavy duty vehicles ranged from 9.1 – 20.3%. This magnitude of motor vehicles is alarming [9, 24]. Table 13 shows the calculated parameters for ANN model validation. The root mean square is the ANN error measure used in validating the network. From table 13 RMSE is quite low, within the theoretical values acceptable for ANN model to be acceptable and accurate [25]. RMSE is a measure of the spread of observed values about the predicted values. A large RMSE means a poor model because of a large variance [25] while a small RMSE means a good ANN model. In this study the RMSE values range from 1.007 – 1.814, a reasonably low error values, proving that the ANN model is accurate. The correlation values between observed and predicted L_{Aeq}, from table 13, range from +0.592 to +0.950 showing that there is no significant difference between observed and predicted L_{Aeq}, further proving that the ANN model is accurate [9].

In order to certify the good results obtained with the developed ANN based prediction model, correlation values between observed and predicted L_{Aeq} are shown in Figs. 3a – 7a while Figs. 3b – 7b display the ANN model performance curves of observed and predicted values of the output variables (L_{Aeq}) for all data used for the checking (testing) phase based on noise impact responses from respondents. From the results obtained, the proposed ANN based model has achieved prediction with a reasonably low RMSE, and has shown a great capacity for generalization. The neural network is capable of predicting, with considerable precision and accuracy, the sound pressure level (L_{Aeq}) and even temporal and spectral composition of the different types of situations presented to the network [26].

5.0 Conclusion

Due to their well-known characteristics, the use of artificial neural networks to approach a complex problem of modelling and prediction of urban noise seemed highly recommended [9, 17]. Based on the results discussed in this paper this hypothesis is certified. The developed ANN based prediction model is capable of predicting, with great accuracy, road traffic noise levels as well as their temporal and spectral compositions in cities. In this study, the model developed is not only able to learn and predict those data presented during the training phase, but also is able, with great success, to predict noise data used for the testing phase, which inform about its great capacity of generalization. This goes to show that the model will not only be very useful for cities surveyed under this study, but also for other cities which have similar noise situations and characteristics [9, 26].

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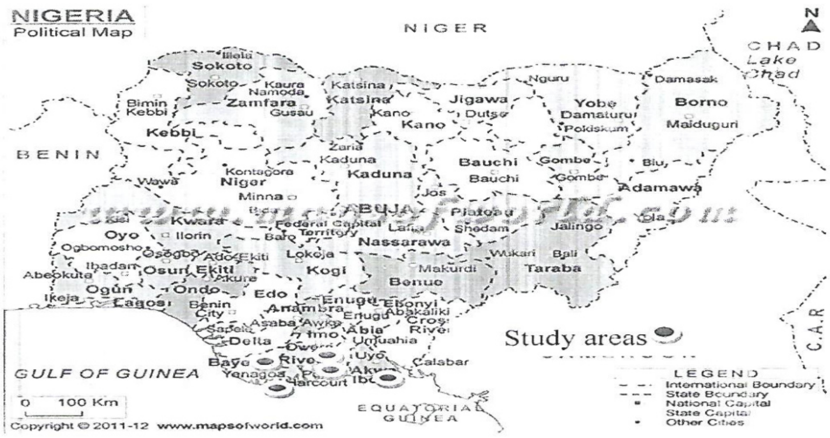

Fig. 1: Map of Nigeria showing study areas.

Table 1: Codes, measurement sites and GPS readings for Calabar study area.

Road transportation high noise pollution sites (HNPSs)			Road transportation low noise pollution sites		
Codes	Measurement sites	GPS	Codes	Measurement sites	GPS
HCA 1	Mbukpa Road	$5^{0}10^{1}N,7^{0}05^{1}E$	LCA 1	New Airport Road	$5^{0}43^{1}N,7^{0}35^{1}E$
HCA 2	Mayne Avenue	$5^{0}15^{1}N,7^{0}45^{1}E$	LCA 2	Anantigha Road	$5^{0}40^{1}N,7^{0}48^{1}E$
HCA 3	Calabar Road	$6^{0}0^{1}N,7^{0}25^{1}E$	LCA 3	Edibe-Edibe Road	$5^{0}20^{1}N,7^{0}33^{1}E$
HCA 4	Mount Zion Road	$6^{0}17^{1}N,7^{0}30^{1}E$	LCA 4	Jebs Road	$6^{0}15^{1}N,7^{0}40^{1}E$
HCA 5	Ekpo Abasi Street	$6^{0}20^{1}N,7^{0}45^{1}E$	LCA 5	Iman Street	$6^{0}17^{1}N,8^{0}10^{1}E$
HCA 6	Etta Agbo Road	$5^{0}50^{1}N,7^{0}50^{1}E$	LCA 6	MCC Road	$5^{0}15^{1}N,7^{0}20^{1}E$
HCA 7	IBB Way	$5^{0}35^{1}N,7^{0}40^{1}E$	LCA 7	Otop Abasi Street	$5^{0}19^{1}N,7^{0}35^{1}E$
HCA 8	Atimbo Road	$6^{0}40^{1}N,7^{0}20^{1}E$	LCA 8	Atekong drive	$6^{0}20^{1}N,8^{0}15^{1}E$
HCA 9	Ndidem Usang IsoRoad	$6^{0}55^{1}N,7^{0}55^{1}E$	LCA 9	Diamond Hill	$6^{0}50^{1}N,8^{0}25^{1}E$
HCA 10	Murtala Mohammed Highway	$5^{0}18^{1}N,7^{0}50^{1}E$	LCA 10	Old Odukpani Road	$5^{0}55^{1}N,7^{0}19^{1}E$

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Table 2: Codes, measurement sites and GPS readings for Uyo study area.

Road transportation high noise pollution sites. (HNPSs)			Road transportation low noise pollution sites.		
Codes	Measurement sites	GPS	Codes	Measurement sites	GPS
HUY 1	Ikpa Road	$4^{0}30^{1}N,7^{0}35^{1}E$	LUY 1	IBB Road	$4^{0}41^{1}N,7^{0}40^{1}E$
HUY 2	Ibom Plaza	$4^{0}45^{1}N,7^{0}20^{1}E$	LUY 2	Uruan Road	$4^{0}50^{1}N,7^{0}36^{1}E$
HUY 3	Oron Road	$4^{0}40^{1}N,7^{0}40^{1}E$	LUY 3	Nasarawa Road	$4^{0}51^{1}N,7^{0}43^{1}E$
HUY 4	Urua Ekpa Road	$5^{0}15^{1}N,7^{0}20^{1}E$	LUY 4	Nkemba Street	$4^{0}45^{1}N,7^{0}25^{1}E$
HUY 5	Aka Road	$4^{0}50^{1}N,7^{0}42^{1}E$	LUY 5	Barracks Road	$4^{0}30^{1}N,8^{0}05^{1}E$
HUY 6	Ikot Ekpene Road	$4^{0}55^{1}N,7^{0}36^{1}E$	LUY 6	Iboko Street	$5^{0}15^{1}N,8^{0}17^{1}E$
HUY 7	Abak Way	$5^{0}06^{1}N,8^{0}02^{1}E$	LUY 7	Esuene Street	$4^{0}50^{1}N,7^{0}40^{1}E$
HUY 8	Nwana Iba Road	$5^{0}15^{1}N,8^{0}20^{1}E$	LUY 8	Brook Street	$5^{0}09^{1}N,7^{0}48^{1}E$
HUY 9	Aka Etinan Road	$4^{0}45^{1}N,7^{0}38^{1}E$	LUY 9	Umoren Street	$4^{0}45^{1}N,7^{0}51^{1}E$
HUY 10	Ukana Offot Road	$4^{0}29^{1}N,7^{0}47^{1}E$	LUY 10	Udo Udoma Street	$4^{0}55^{1}N,7^{0}36^{1}E$

Table 3: Codes, measurement sites and GPS readings for Umuahia study area.

Road transportation high noise pollution sites.			Road transportation low noise pollution sites.		
Codes	Measurement	GPS	Codes	Measurement	GPS
HUM 1	Umuwaya Road	$5^{0}20^{1}N, 7^{0}15^{1}E$	LUM 1	Niger Road	$5^{0}30^{1}N, 7^{0}20^{1}E$
HUM 2	Owerri Road	$5^{0}24^{1}N. 7^{0}20^{1}E$	LUM 2	Ibeku Road	$5^{0}20^{1}N. 7^{0}25^{1}E$
HUM 3	Aba Road	$5^{0}30^{1}N, 7^{0}25^{1}E$	LUM 3	Calabar Road	$5^{0}22^{1}N, 7^{0}22^{1}E$
HUM 4	Bende Road	$5^{0}28^{1}N, 7^{0}21^{1}E$	LUM 4	Warri Street	$5^{0}26^{1}N, 7^{0}23^{1}E$
HUM 5	Okwuro Road	$5^{0}26^{1}N. 7^{0}20^{1}E$	LUM 5	Kaduna Street	$5^{0}21^{1}N. 7^{0}27^{1}E$
HUM 6	Umuahia Road	$5^{0}31^{1}N, 7^{0}30^{1}E$	LUM 6	Akanu Ibiam Road	$5^{0}23^{1}N, 7^{0}24^{1}E$
HUM 7	School Road	$5^{0}20^{1}N, 7^{0}23^{1}E$	LUM 7	Azikiwe Road	$5^{0}25^{1}N$, 70281E
HUM 8	Bank Road	$5^{0}22^{1}N, 7^{0}25^{1}E$	LUM 8	Afara Road	$5^{0}24^{1}N. 7^{0}30^{1}E$
HUM 9	Amakama Road	$5^{0}26^{1}N, 7^{0}27^{1}E$	LUM 9	Okigwe Road	$5^{0}31^{1}N, 7^{0}21^{1}E$
HUM 10	Uzuakoli Road	$5^{0}23^{1}N, 7^{0}21^{1}E$	LUM 10	Finbarrs Road	$5^{0}28^{1}N, 7^{0}26^{1}E$

Table 4: Codes, measurement sites and GPS readings for Owerri study area.

Road transportation high noise pollution sites.			Road transportation low noise pollution sites.		
Codes	Measurement	GPS	Codes	Measurement	GPS
HOW 1	Amaieke Road	$5^{0}35^{1}N. 6^{0}55^{1}E$	LOW 1	School Road	$6^{0}21^{1}N. 7^{0}50^{1}E$
HOW 2	MCC Road	$6^{0}20^{1}N, 7^{0}15^{1}E$	LOW 2	World Bank Road	$6^{0}25^{1}N, 6^{0}45^{1}E$
HOW 3	Douglas Road	$6^{0}15^{1}N, 7^{0}20^{1}E$	LOW 3	Tetlow Road	$6^{0}51^{1}N, 6^{0}55^{1}E$
HOW 4	Orlu Road	$5^{0}50^{1}N.6^{0}45^{1}E$	LOW 4	Royce Road	$7^{0}40^{1}N. 6^{0}10^{1}E$
HOW 5	Imsu Road	$5^{0}40^{1}N, 6^{0}30^{1}E$	LOW 5	West End Road	$7^{0}36^{1}N, 6^{0}15^{1}E$
HOW 6	Fire Service Road	$5^{0}25^{1}N, 6^{0}47^{1}E$	LOW 6	Ikenegbu Road	$6^{0}40^{1}N, 6^{0}25^{1}E$
HOW 7	Mbaise Road	$6^{0}50^{1}N, 7^{0}15^{1}E$	LOW 7	Prisons Road	$6^{0}50^{1}N, 6^{0}36^{1}E$
HOW 8	Nekede Road	$7^{0}10^{1}N, 7^{0}20^{1}E$	LOW 8	Asumpta Road	$6^{0}55^{1}N, 6^{0}20^{1}E$
HOW 9	Wedtharl Road	$5^{0}25^{1}N, 6^{0}50^{1}E$	LOW 9	Mbari Road	$7^{0}25^{1}N, 7^{0}30^{1}E$
HOW 10	Okigwe Road	$6^{0}26^{1}N, 7^{0}20^{1}E$	LOW 10	Lagos Street	$6^{0}45^{1}N, 7^{0}05^{1}E$

Table 5: Codes, measurement sites, and GPS readings for Port Harcourt study area.

Road transportation high noise pollution sites.			Road transportation low noise pollution sites.		
Codes	Measurement	GPS	Codes	Measurement sites	GPS
HPH 1	Rumola Road	$4^{0}30^{1}N. 6^{0}25^{1}E$	LPH 1	Agip Road	$4^{0}25^{1}N. 6^{0}50^{1}E$
HPH 2	Choba Road	$4^{0}20^{1}N. 6^{0}15^{1}E$	LPH 2	Shell Gate Road	$4^{0}30^{1}N. 6^{0}45^{1}E$
HPH 3	NTA Road	$4^{0}25^{1}N. 6^{0}20^{1}E$	LPH 3	Mile 1 Market Road	$4^{0}32^{1}N. 6^{0}40^{1}E$
HPH 4	Atillery Road	$4^{0}15^{1}N. 6^{0}21^{1}E$	LPH 4	Refinery Way	$4^{0}40^{1}N. 6^{0}55^{1}E$
HPH 5	Rumokoro Road	$4^{0}35^{1}N. 6^{0}40^{1}E$	LPH 5	Borokiri	$4^{0}45^{1}N. 6^{0}36^{1}E$
HPH 6	Bori camp Road	$4^{0}40^{1}N. 6^{0}50^{1}E$	LPH 6	Airport Road	$4^{0}35^{1}N. 6^{0}30^{1}E$
HPH 7	Slaughter Road	$4^{0}25^{1}N. 6^{0}30^{1}E$	LPH 7	Garrison Road	$4^{0}33^{1}N. 6^{0}52^{1}E$
HPH 8	Eleme Road	$4^{0}20^{1}N. 6^{0}26^{1}E$	LPH 8	Oroworoko Street	$4^{0}46^{1}N. 6^{0}45^{1}E$
HPH 9	Water Line	$4^{0}50^{1}N. 6^{0}45^{1}E$	LPH 9	Port Harcourt Road	$4^{0}55^{1}N. 6^{0}25^{1}E$
HPH 10	Ada George Road	$4^{0}36^{1}N, 6^{0}35^{1}E$	LPH 10	Bulletin Street	$4^{0}50^{1}N, 6^{0}48^{1}E$

Table 6: Statistics of measured (observed) and calculated (predicted) road transportation noise levels/indices obtained at both road transportation high and low noise pollution sites and corresponding road traffic volume per hour (VPH) during recording time at daytime and nighttime periods, under free flow conditions, in Calabar city.

Sites	Measured (observed) noise levels (±5.0dB(A)		Calculated (predicted) noise levels/indices (dB(A))	Mean road traffic volume per hour (VPH)									
				Daytime					Nighttime				
	BNL	LAeq (SPL) Day	LAeq	Trucks	Bus	Cars	Motorcycle	Total vol.	Trucks	Bus	Cars	Motorcycle	Total vol.
Road transportation noise levels/indices and traffic volume per hour at road transportation high noise pollution sites													
HCA 1	48.2	90.0	90.4	327	289	447	538	1601	286	193	317	415	1211
HCA 2	46.6	96.0	97.2	481	507	815	549	2352	150	275	283	361	1069
HCA 3	41.3	87.0	87.1	416	503	613	432	1964	109	182	314	307	912
HCA 4	45.2	94.0	95.8	294	476	588	469	1827	87	219	496	211	1013
HCA 5	50.4	99.0	97.0	313	394	601	456	1764	205	337	504	315	1361
HCA 6	51.2	100.0	98.5	489	610	829	441	2369	189	223	461	209	1082
HCA 7	43.1	89.0	88.2	391	533	565	602	2091	273	486	514	356	1629
HCA 8	40.4	92.0	90.0	503	642	471	459	3075	197	318	472	291	1278
HCA 9	41.7	97.0	98.0	367	470	386	373	1596	265	401	519	306	1491
HCA 10	43.3	100.0	98.4	412	593	617	408	2139	214	396	502	179	1291
Total				3993	5017	5932	4727	19669	1975	3030	4382	2950	12337
%				20.3	25.5	30.2	24.0	100.0	16.0	24 6	35.5	23.9	100.0
Road transportation noise levels/indices and traffic volume per hour at road transportation low noise pollution sites													
LCA 1	35.5	70.0	70.4	81	176	223	230	710	34	51	113	15	213
LCA 2	40.7	72.0	73.2	179	217	319	236	951	100	67	161	24	352
LCA 3	44.4	79.0	78.5	153	291	306	221	971	89	82	185	17	373
LCA 4	43.3	76.0	74.6	102	283	291	347	923	91	69	87	30	277
LCA 5	42.4	74.0	72.2	89	106	204	233	632	65	53	92	11	221
LCA 6	45.6	80.0	80.0	164	214	301	325	1004	68	97	193	8	366
LCA 7	54.7	81.0	80.2	106	215	199	362	882	72	103	78	23	276
LCA 8	48.7	79.0	80.1	211	277	218	268	974	79	92	107	18	296
LCA 9	46.1	78.0	77.5	67	186	173	316	743	34	104	86	16	240
LCA 10	57.2	74.0	72.0	133	239	247	290	909	46	89	114	39	288
Total				1285	2204	2481	2728	8698	678	807	1216	201	2902
%				14.8	25.3	28.5	31.4	100.0	23.4	27.8	41.9	6.9	100.0

Table 7: Statistics of measured (observed) and calculated (predicted) road transportation noise levels/indices obtained at both road transportation high and low noise pollution sites and corresponding road traffic volume per hour (VPH) during recording time at daytime and nighttime periods, under free flow conditions, in Uyo city.

Sites	Measured (observed) noise levels (±5.0dB(A)		Calculated (predicted) noise levels/indices (dB(A))	Mean road traffic volume per hour (VPH)									
				Daytime					Nighttime				
	BNL	LAeq (SPL) Day	LAeq	Trucks	Bus	Cars	Motorcycle	Total vol.	Trucks	Bus	Cars	Motorcycle	Total vol.
Road transportation noise levels/indices and traffic volume per hour at road transportation high noise pollution sites													
HUY 1	40.2	93.0	93.7	313	602	1054	619	2588	219	316	614	207	1356
HUY 2	41.1	96.0	95.0	217	670	1321	626	2834	210	414	591	280	1495
HUY 3	53.3	101.0	100.2	209	813	979	543	2544	157	209	516	191	1073
HUY 4	42.4	98.0	98.0	318	789	1894	827	3828	161	211	473	86	931
HUY 5	42.5	98.0	97.4	396	801	1903	639	3739	213	218	617	103	1151
HUY 6	53.0	102.0	100.8	264	858	2015	851	3988	207	189	790	115	1301
HUY 7	51.0	100.0	101.0	319	692	1900	749	3660	159	231	881	97	1368
HUY 8	50.6	100.0	102.0	375	959	2561	653	4548	266	267	863	90	1486
HUY 9	50.2	101.0	98.5	381	986	1811	759	3937	104	186	554	84	928
HUY 10	54.4	100.0	98.0	493	898	2009	965	4369	98	269	518	113	998
Total				3285	8048	17447	7231	36011	2694	2710	6417	1366	13187
%				9.1	22.3	48.5	20.1	100.0	20.4	20.5	48.7	10.4	100.0
Road transportation noise levels/indices and traffic volume per hour at road transportation low noise pollution sites													
LUY1	36.0	71.0	76.0	117	276	515	224	1132	53	106	221	94	474
LUY2	36.0	80.0	81.0	181	214	433	318	1146	76	110	165	89	440
LUY3	40.0	82.0	81.0	140	283	391	313.0	1124	72	93	160	81	406
LUY4	38.0	75.0	76.0	149	301	488	413.0	1351	88	114	187	63	452
LUY5	35.0	70.0	70.2	132	295	562	316.0	1305	65	151	216	69	501
LUY6	36.0	80.0	79.0	236	300	607	220.0	1363	57	89	189	60	395
LUY7	38.0	82.0	81.1	253	197	542	209.0	1210	61	70	108	60	299
LUY8	41.0	81.0	82.0	160	289	785	344.0	1578	154	78	231	104	467
LUY9	40.0	82.0	80.0	95	362	389	436.0	1284	92	117	253	56	518
LUY10	42.0	80.0	78.8	89	190	416	441.0	1136	37	103	180	72	392
Total				3252	2707	5128	3234	14321	655	1021	1910	548	4134
%				28.7	23.9	45.3	2.1	100.0	15.8	24.7	46.2	13.3	100.0

Table 8: Statistics of measured (observed) and calculated (predicted) road transportation noise levels/indices obtained at both road transportation high and low noise pollution sites and corresponding road traffic volume per hour (VPH) during recording time at daytime and nighttime periods, under free flow conditions, in Umuahia city.

Sites	Measured (observed) noise levels (±5.0dB(A)		Calculated (predicted) noise levels/indices (dB(A))	Mean road traffic volume per hour (VPH)									
				Daytime					Nighttime				
	BNL	LAeq (SPL) Day	LAeq	Trucks	Bus	Cars	Motorcycle	Total vol.	Trucks	Bus	Cars	Motorcycle	Total vol.
Road transportation noise levels/indices and traffic volume per hour at road transportation high noise pollution sites													
HUM 1	42.2	102.0	100.0	519	716	1138	353	2726	374	467	315	429	1585
HUM 2	37.3	98.0	99.0	536	810	2511	267	4124	311	405	227	336	1279
HUM 3	40.3	98.0	97.8	501	728	1807	271	3307	242	491	569	372	1674
HUM 4	38.5	97.0	98.0	643	903	2009	402	3957	253	366	471	416	1506
HUM 5	36.6	92.0	90.2	415	907	2138	513	3973	316	289	392	290	1287
HUM 6	42.5	100.0	100.1	397	1079	2215	576	4267	208	313	513	415	1449
HUM 7	41.5	100.0	98.6	384	811	1900	691	3786	129	217	308	261	915
HUM 8	36.1	94.0	93.7	528	1814	819	1037	4198	186	198	262	376	1022
HUM 9	38.2	99.0	100.0	642	1703	921	965	4231	204	152	488	493	1337
HUM 10	40.3	100.0	101.0	588	960	1073	533	3154	261	317	369	272	1219
Total				5153	10431	16531	5408	37523	2484	3215	3914	3600	13213
%				13.7	27.8	44.1	14.4	100.0	18.8	24.3	29.6	27.3	100.0
Road transportation noise levels/indices and traffic volume per hour at road transportation low noise pollution sites													
LUM 1	34.3	79.0	80.0	83	225	316	254	878	121	157	206	279	763
LUM 2	30.4	76.0	75.2	127	231	274	196	828	163	131	184	283	761
LUM 3	33.2	78.0	80.0	133	198	281	175	787	117	246	261	177	801
LUM 4	32.1	74.0	72.0	241	266	368	193	1068	89	175	237	206	707
LUM 5	36.1	85.0	82.0	319	183	357	201	1060	103	138	266	154	661
LUM 6	30.6	76.0	76.0	106	217	493	164	980	76	131	302	146	655
LUM 7	35.7	78.0	80.0	92	304	217	190	803	81	216	103	127	527
LUM 8	36.5	82.0	80.0	173	213	109	367	862	65	103	98	138	404
LUM 9	38.4	72.0	70.0	126	257	213	281	877	73	115	279	200	667
LUM 10	30.3	70.0	68.5	191	299	216	393	1099	102	176	118	233	629
Total				1591	2393	2844	2414	9242	990	1583	2954	1843	7316
%				17.2	25.9	30.8	26.1	100.0	13.4	21.5	40.1	25.0	100.0

Table 9: Statistics of measured (observed) and calculated (predicted) road transportation noise levels/indices obtained at both road transportation high and low noise pollution sites and corresponding road traffic volume per hour (VPH) during recording time at daytime and nighttime periods, under free flow conditions, in Owerri city.

Sites	Measured (observed) noise levels (±5.0dB(A) BNL	LAeq (SPL) Day	Calculated (predicted) noise levels/indices (dB(A)) LAeq	Mean road traffic volume per hour (VPH) Daytime Trucks	Daytime Bus	Daytime Cars	Daytime Motorcycle	Daytime Total vol.	Nighttime Trucks	Nighttime Bus	Nighttime Cars	Nighttime Motorcycle	Nighttime Total vol.
Road transportation noise levels/indices and traffic volume per hour at road transportation high noise pollution sites													
HOW 1	46.1	100.0	98.8	623	815	1311	257	3006	409	426	618	372	1825
HOW 2	46.3	99.0	100.0	487	736	645	375	2243	281	253	425	189	1148
HOW 3	40.2	96.0	95.0	461	725	718	407	2311	372	460	417	156	1405
HOW 4	51.5	102.0	100.0	554	913	1607	252	3326	490	511	630	233	1864
HOW 5	48.5	100.0	98.0	630	817	1312	1314	4073	461	527	589	467	2044
HOW 6	49.7	100.0	100.0	393	569	2613	1819	5394	312	296	637	519	1764
HOW 7	39.6	98.0	97.0	458	912	964	417	2751	419	455	484	266	1624
HOW 8	40.2	100.0	101.5	565	961	889	464	2879	416	419	316	375	1526
HOW 9	41.3	95.0	94.0	532	877	2183	390	3982	698	367	993	153	2211
HOW 10	48.4	100.0	98.0	491	906	2627	557	4581	356	476	979	221	2032
Total				5194	8231	14849	6252	34546	4214	4190	6088	2951	17443
%				15.0	24.0	43.0	18 0	100 0	24 0	24.0	35.0	17.0	100.0
Road transportation noise levels/indices and traffic volume per hour at road transportation low noise pollution sites													
LOW 1	38.0	88.0	80.0	137	264	403	367	1171	59	135	367	107	668
LOW 2	36.0	86.0	86.2	226	251	367	285	1129	107	146	315	76	644
LOW 3	36.0	84.0	83.0	84	343	256	299	982	41	69	247	315	672
LOW 4	34.0	80.0	81.4	67	172	243	316	798	82	132	189	214	617
LOW 5	40.0	83.0	80.0	186	297	376	182	1041	73	167	158	263	661
LOW 6	35.0	85.0	83.0	251	226	381	155	1013	76	89	213	180	558
LOW 7	38.0	74.0	74.8	143	279	409	170	1001	54	103	217	229	603
LOW 8	42.0	91.0	90.0	92	183	194	252	721	61	86	376	147	670
LOW 9	33.0	84.0	82.0	155	206	277	256	894	103	98	149	83	433
LOW 10	37.0	70.0	71.0	108	233	412	318	1071	92	173	152	136	553
Total				1449	2464	3318	2600	9831	748	1198	2383	1750	6079
%				14.7	25.1	33.8	26.4	100.0	12.3	19.7	39.2	28.8	100.0

Table 10: Statistics of measured (observed) and calculated (predicted) road transportation noise levels/indices obtained at both road transportation high and low noise pollution sites and corresponding road traffic volume per hour (VPH) during recording time at daytime and nighttime periods, under free flow conditions, in Port Harcourt city.

Sites	Measured (observed) noise levels (±5.0dB(A)		Calculated (predicted) noise levels/indices (dB(A))	Mean road traffic volume per hour (VPH)									
	BNL	LAeq (SPL) Day	LAeq	Daytime: Trucks	Bus	Cars	Motorcycle	Total vol.	Nighttime: Trucks	Bus	Cars	Motorcycle	Total vol.
Road transportation noise levels/indices and traffic volume per hour at road transportation high noise pollution sites													
HPH 1	49.7	100.0	99.0	576	615	2413	557	4161	283	.376	615	268	1542
HPH 2	38.6	98.0	96.0	513	728	3116	583	4940	326	384	1017	203	1930
HPH 3	39.2	98.0	97.0	581	784	1969	674	4008	334	469	618	217	1638
HPH 4	39.2	99.0	100.0	494	616	2337	465	3912	276	291	813	278	1658
HPH 5	48.6	100.0	100.3	387	539	918	452	2296	309	415	406	216	1346
HPH 6	49.5	101.0	99.8	392	557	876	663	2488	107	372	235	448	1157
HPH 7	48.5	100.0	98.6	618	473	1779	488	3358	269	253	365	338	1225
HPH 8	45.3	96.0	95.0	621	869	2275	426	4191	281	365	338	175	1159
HPH 9	49.1	100.0	98.0	593	719	1866	591	3769	296	274	249	490	1309
HPH 10	48.2	100.0	98.5	477	804	2913	604	4798	361	387	886	344	1978
Total				5252	6704	20462	5503	37921	2842	3586	5540	2942	14910
%				13.8	17.7	54.0	14.5	100.0	19.1	24.1	37.1	19.7	100.0
Road transportation noise levels/indices and traffic volume per hour at road transportation low noise pollution sites													
LPH 1	36.5	76.0	76.6	388	276	1533	366	2563	183	89	615	178	1045
LPH 2	34.4	80.0	79.0	269	453	927	257	1906	107	226	538	203	1074
LPH 3	36.3	83.0	82.6	371	464	508	341	1684	223	278	264	185	950
LPH 4	43.2	86.0	86.4	383	360	871	363	1977	217	180	356	152	905
LPH 5	38.1	77.0	76.0	262	451	562	377	1652	182	277	289	216	964
LPH 6	39.5	79.0	78.0	280	337	557	382	1556	124	130	227	170	651
LPH 7	40.3	85.0	84.5	263	367	380	247	1257	215	169	172	143	699
LPH 8	32.4	75.0	73.0	224	299	492	286	1301	98	156	303	127	684
LPH 9	39.2	84.0	82.0	317	386	1075	192	1970	276	204	429	86	995
LPH 10	35.3	80.0	78.0	286	473	1169	374	2392	172	225	618	168	1183
Total				3043	3866	8074	3185	18168	1777	1924	3811	1638	9140
%				16.7	21.4	44.4	17.5	100.0	19.4	21.0	41.7	17.9	100.0

Table 11: Summary of ANN training and checking data used for the study

Data	Calabar		Uyo		Umuahia		Owerri		Port	
	HCA	LCA	HUY	LUY	HUM	LUM	HOW	LOW	HPH	LPH
Data points	486	465	472	480	454	478	464	476	461	471
Training data	301	296	295	304	297	295	295	299	284	288
Checking data	185	169	177	176	183	157	169	177	183	177

Table 13: Statistics for validation of the ANN model

Statistics	Calculated values									
	Calabar		Uyo		Umuahia		Owerri		Port Harcourt	
	HNPS	LNPS	HNPS	LNPS	HNPS	LNPS	HNPS	LNPS	HNPS	LNPS
Root mean square error (RMSE)	1.310	1.007	1.385	1.109	1.155	1.814	1.358	1.538	1.332	1.295
Mean observed data ($\overline{OB}$)	94.400	76.300	98.900	78.900	98.000	77.00	99.000	82.500	99.200	80.500
Mean predicted data ($\overline{PR}$)	93.980	75.970	98.460	78.510	97.830	76.37	98.200	82.000	98.220	79.550
Standard deviation for Observed data (σ_{OB})	4.499	3.490	2.587	3.673	2.864	4.243	2.000	6.004	1.400	3.667
Standard deviation for predicted data (σ_{PR})	4.310	3.720	5.021	3.398	3.185	4.555	1.061	6.137	1.654	3.908
t-test (t)	0.213	0.2[illegible]4	0.138	0.552	0.126	0.320	1.446	0.184	1.430	0.561
Correlation between observed and predicted data (r)	+0.962	+0.75[illegible]	+0.843	+0.846	+0.937	+0.927	+0.847	+0.97[illegible]	+0.847	+0.974

(critical t = 2.101 for ∝1: 0.025, ∝2: 0.05; and critical t = 2.86[illegible] for ∝1: 0.005, ∝2: 0.01; degree of freedom (df) = 18)

Table 12: Summary of initial ANN training parameters.

S/N	Parameters	Values
1	Initial weight	0.3
2	Learning rate	0.3
3	Momentum	0.6
4	Activation function	Zero-based log sigmoid function
5	Maximum number of epochs	3000
6	Minimum weight	Range of 0.001 and 0.0001
7	Number of neurons in the hidden layer	0 or 1

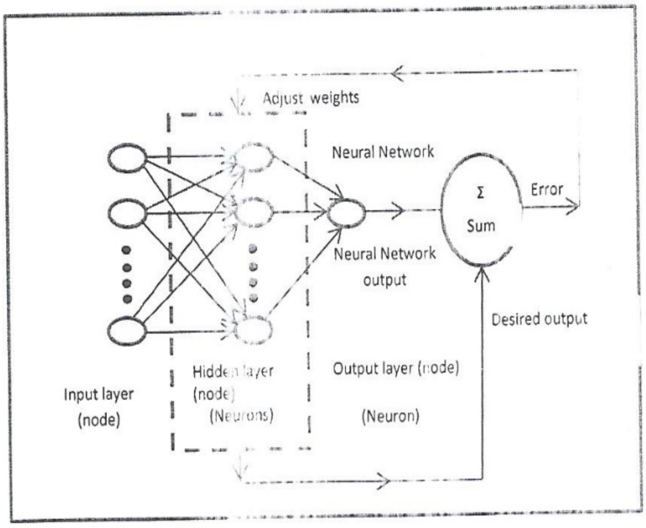

Fig. 2: Multilayer Perceptron (MLP) – type of supervised neural network demonstrating neural network training (learning) process.

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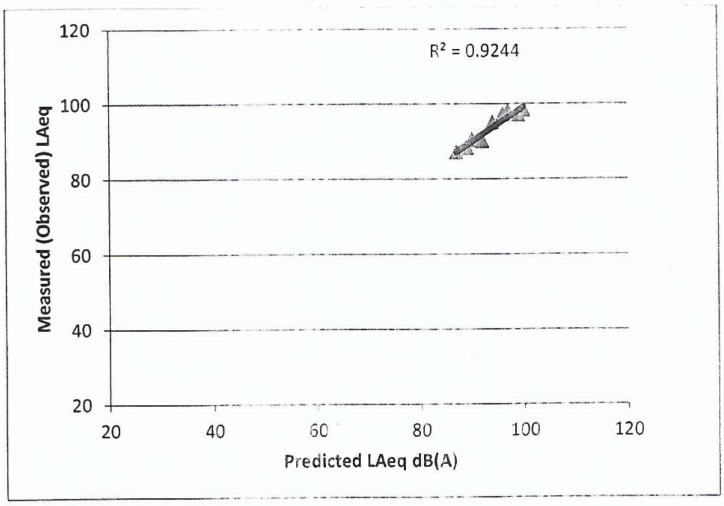
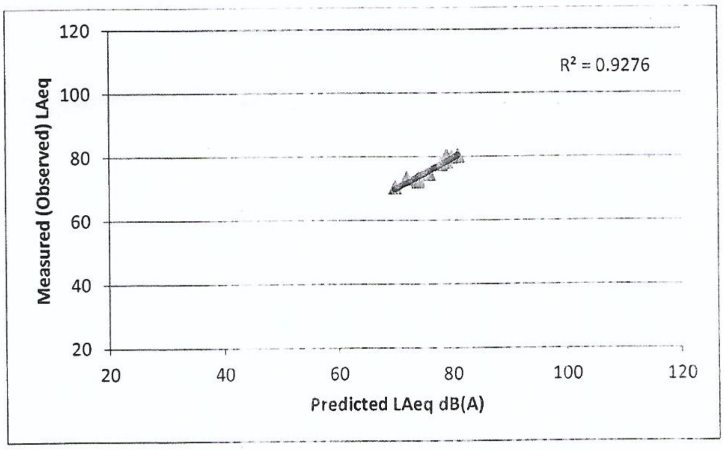
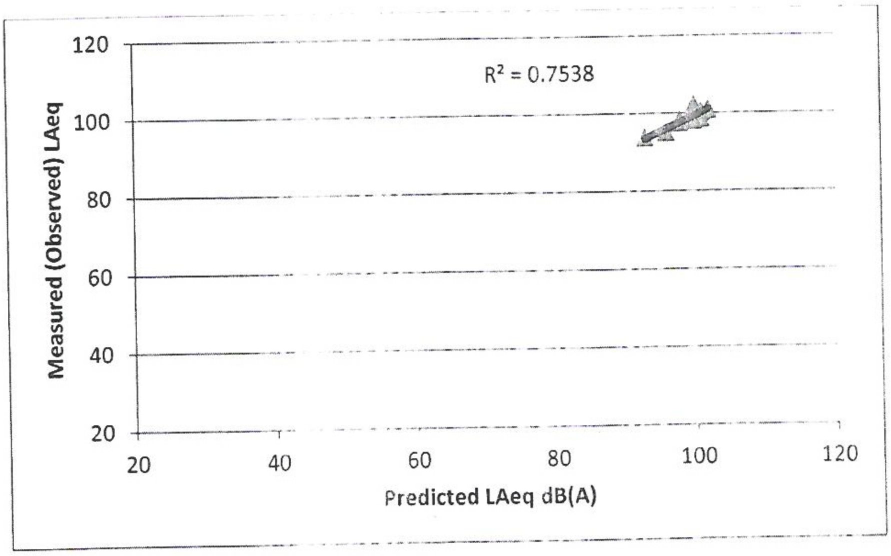


(a) HCA High traffic

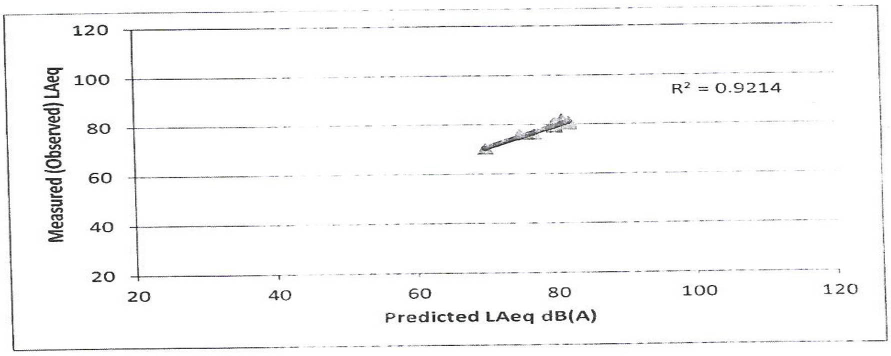


(b) LCA Low traffic

Fig. 3a: Correlation curves of observed LAeq versus predicted LAeq for study Calabar high and low study areas

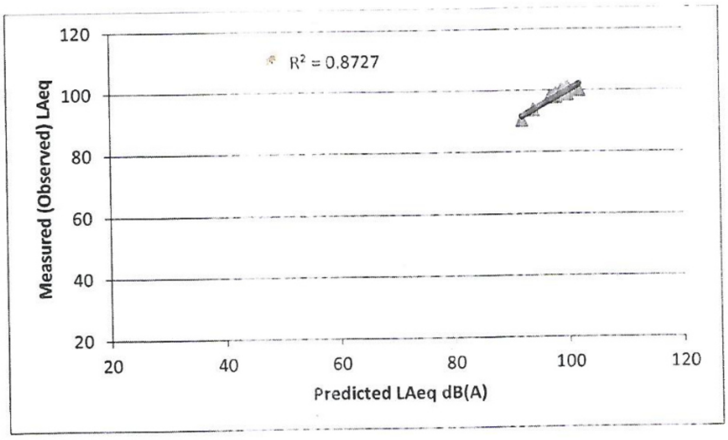


(a) HUY High traffic

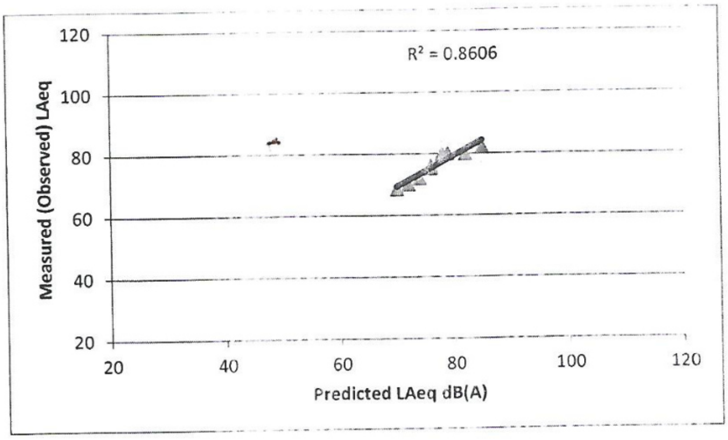


(b) LUY Low traffic

Fig. 4a: Correlation curves of observed LAeq versus predicted LAeq for study Uyo high and low study areas.

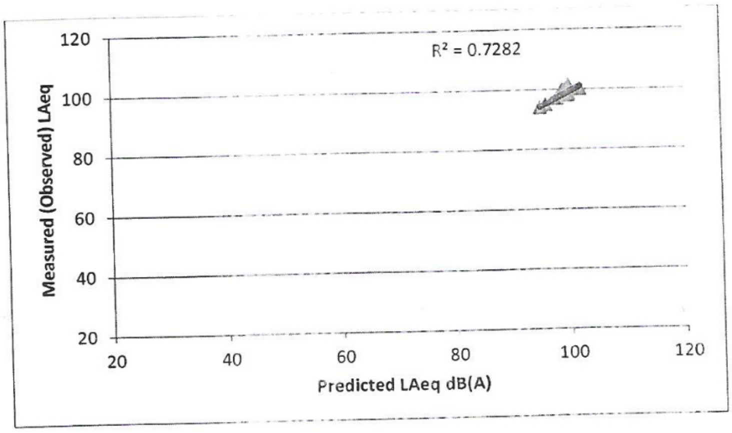


(a) HUM High traffic

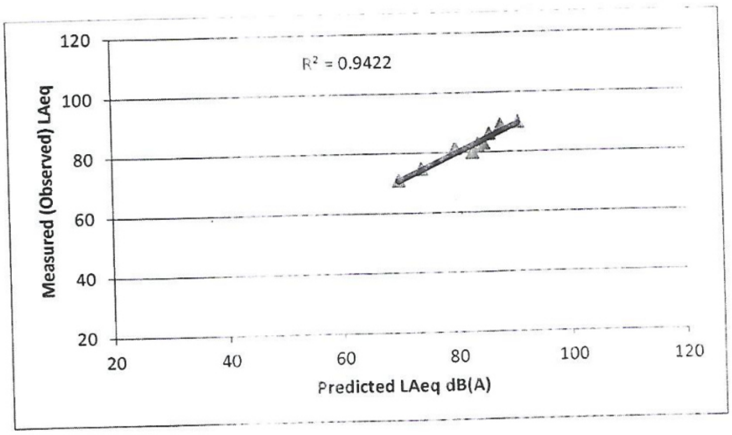


(b)LUM Low traffic

Fig. 5a: Correlation curves of observed LAeq versus predicted LAeq for study Umuahia high and low study areas.

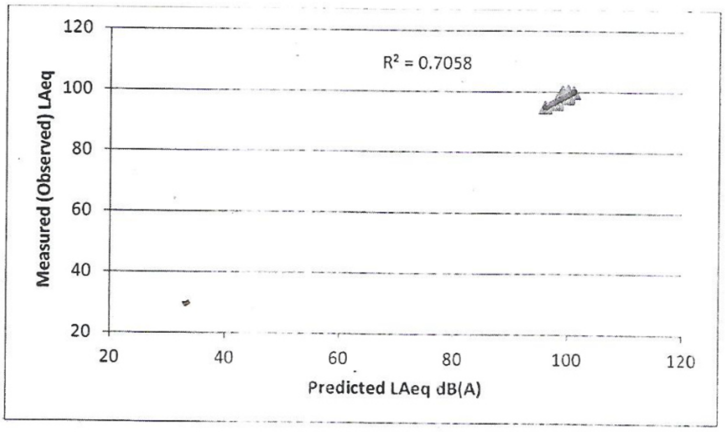


(a) HOW High traffic

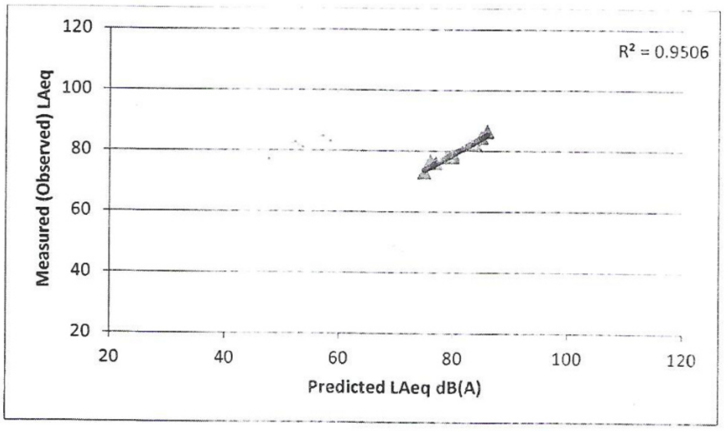


(b) LOW- Low traffic

Fig. 6a: Correlation curves of observed LAeq versus predicted LAeq for study Owerri high and low study areas.

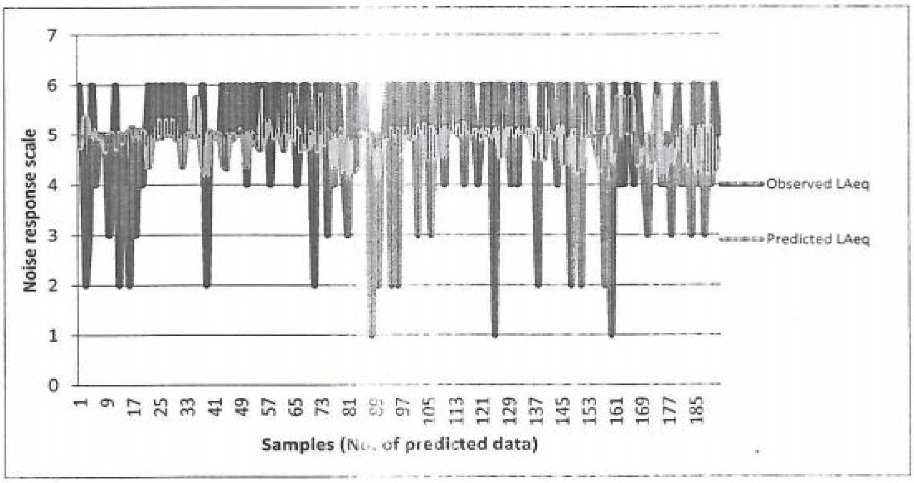


(a) HPH High traffic

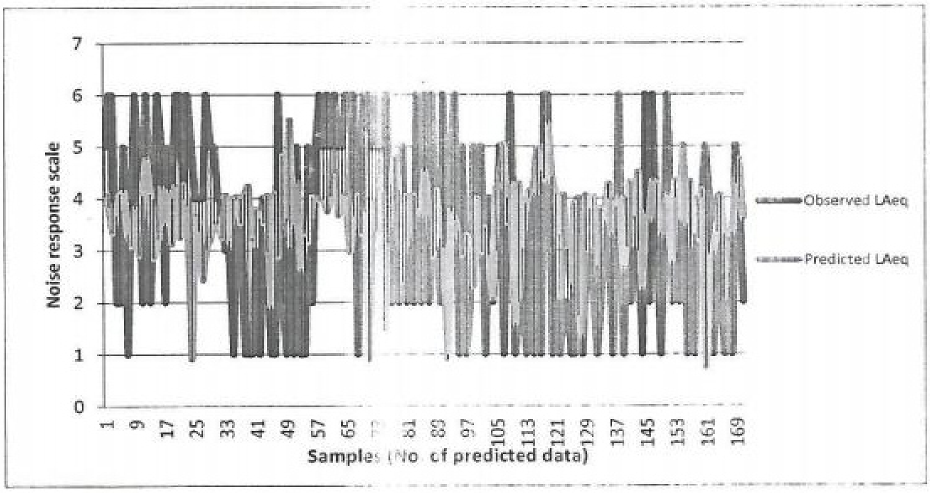


(b) LPH Low traffic

Fig. 7a: Correlation curves of observed LAeq versus predicted LAeq for study Port Harcourt high and low study areas.

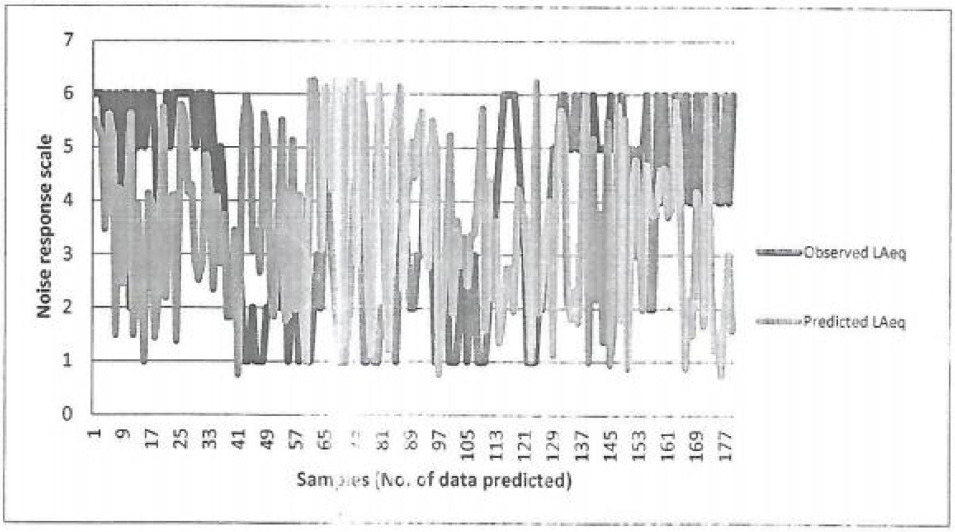


(a) HCA High traffic

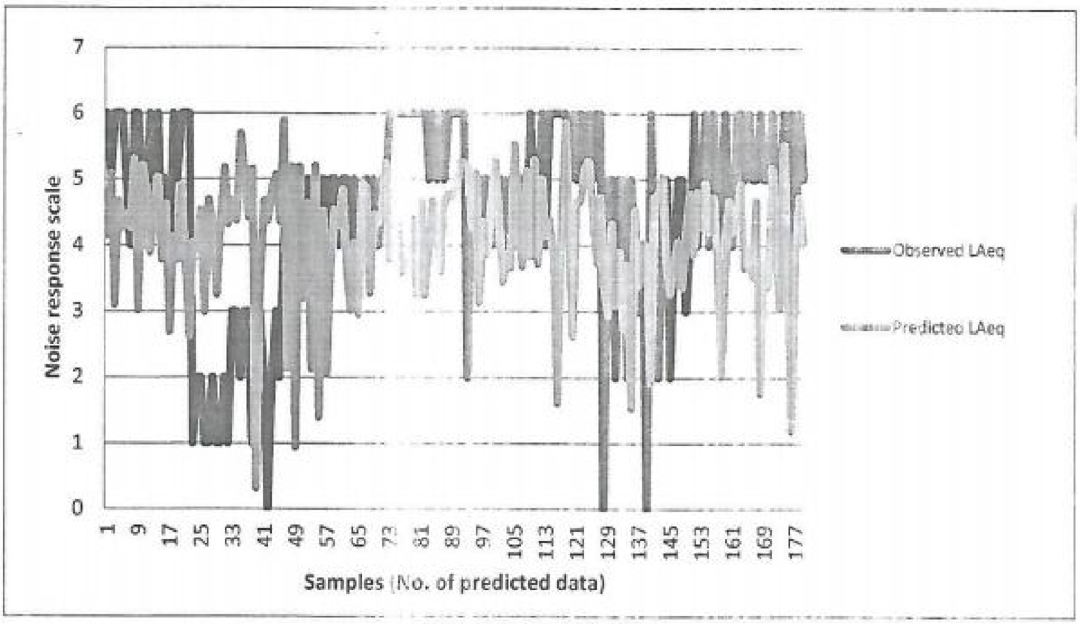


(b) LCA Low traffic

Fig. 3b: Artificial neural network (ANN) model performance curve for checking data for Calabar high and low road traffic noise pollution sites showing respondents' noise reactions against observed and predicted noise levels.

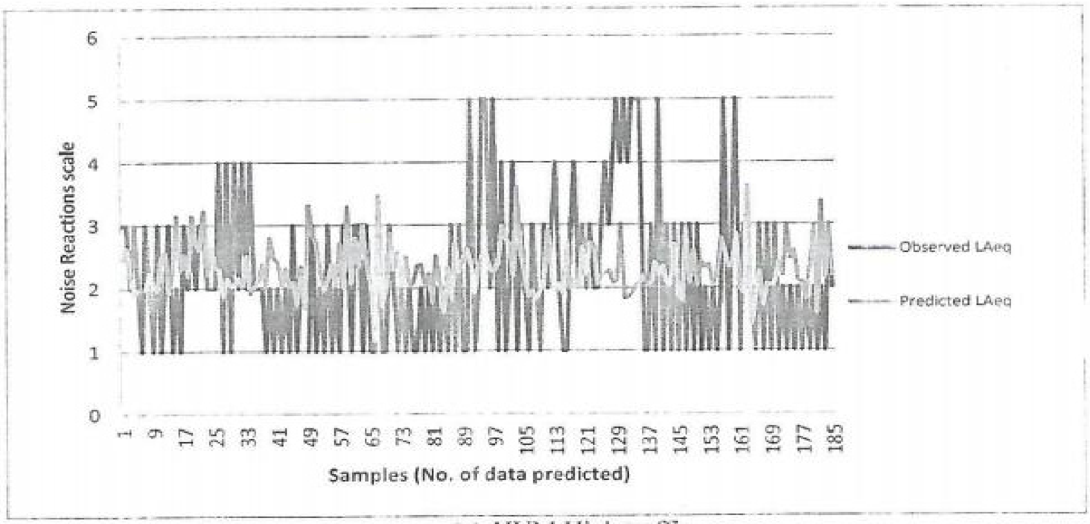


(a) HUY High traffic

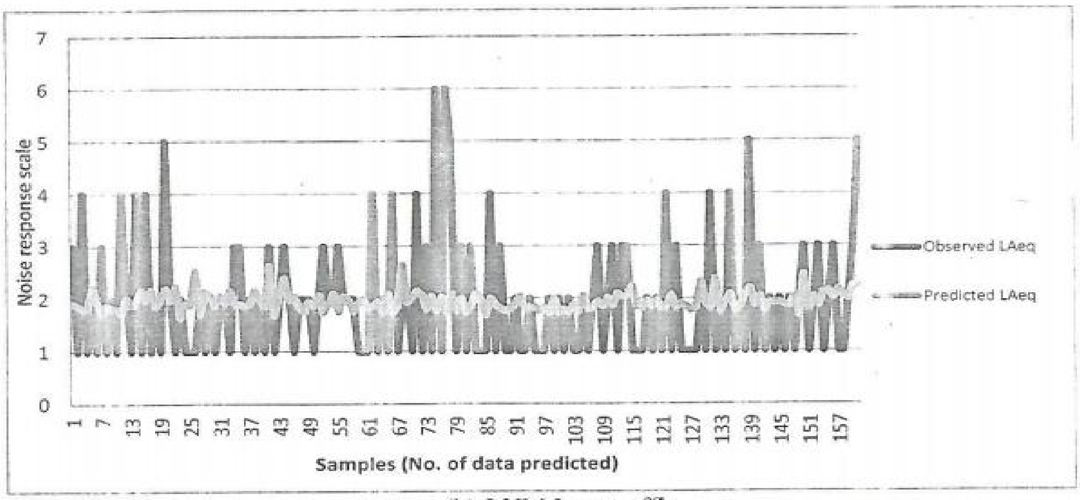


(b) LUY Low traffic

Fig. 4b: Artificial neural network (ANN) model performance curve for checking data for Uyo high and low road traffic noise pollution sites showing respondents' noise reactions against observed and predicted noise levels.

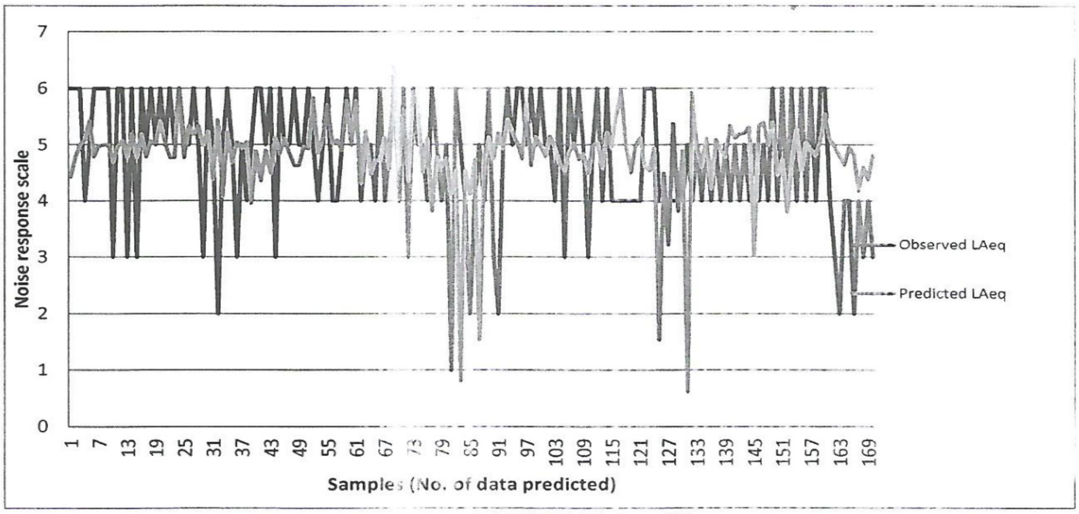


(a) HUM High traffic

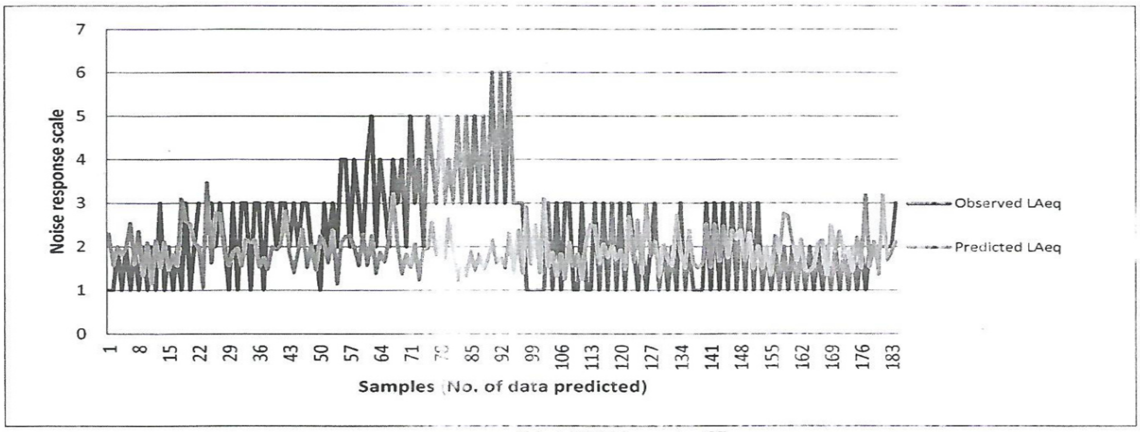


(b) LUM Low traffic

Fig. 5b: Artificial neural network (ANN) model performance curve for checking data for Umuahia high and low road traffic noise pollution sites showing respondents' noise reactions against observed and predicted noise levels.

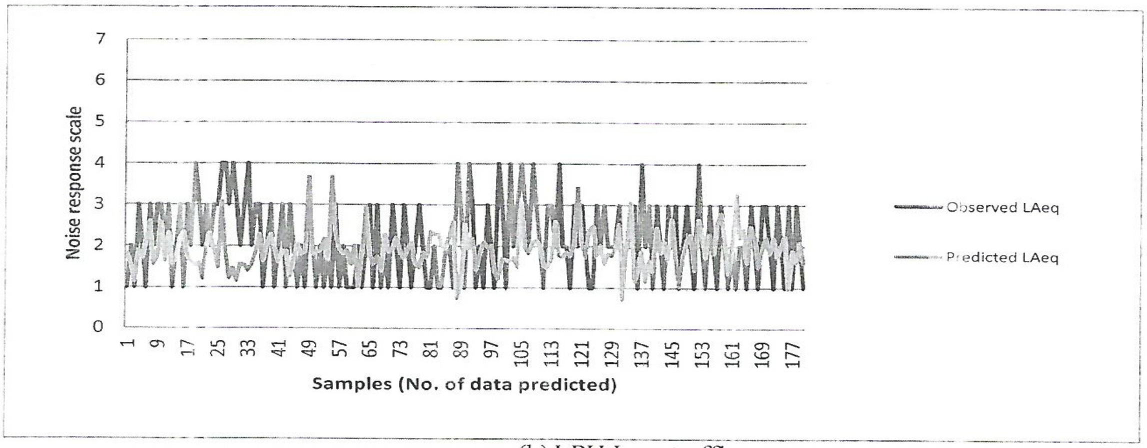


(a) HOW High traffic



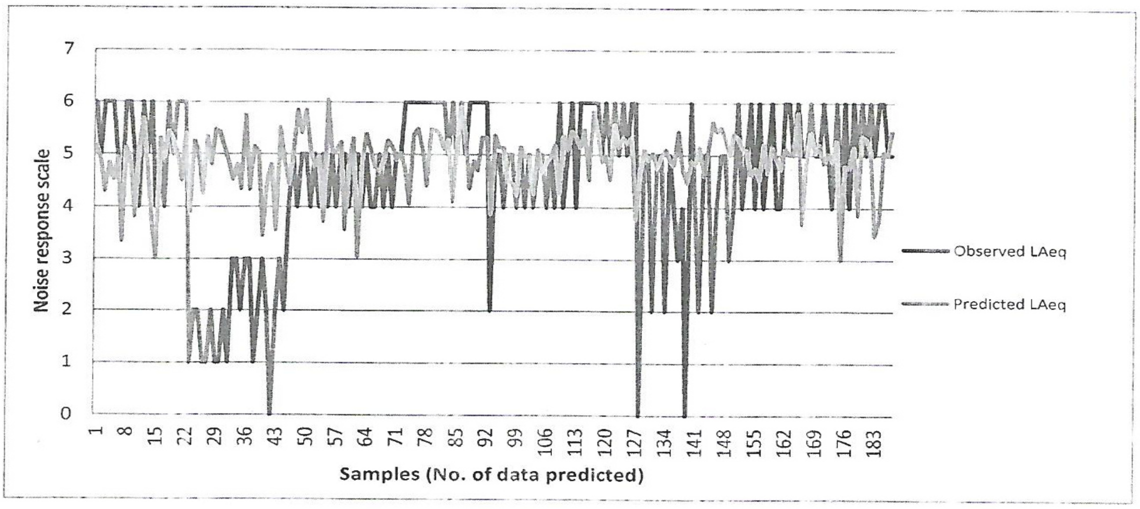
(b) LOW Low traffic

Fig. 6b: Artificial neural network (ANN) model performance curve for checking data for Owerri high and low road traffic noise pollution sites showing respondents' noise reactions against observed and predicted noise levels.



(b) LPH Low traffic

Fig. 7b: Artificial neural network (ANN) model performance curve for checking data for Port Harcourt high and low road traffic noise pollution sites showing respondents' noise reactions against observed and predicted noise levels.



(a) HPH High traffic