A TRAFFIC NOISE POLLUTION MODEL FOR AN URBAN ARTERIAL: CASE STUDY OF TANKE - UNIVERSITY ROAD, ILORIN (NIGERIA)

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Abstract

Traffic noise was investigated along an urban arterial for the purpose of developing a model for the management and control of traffic noise pollution on main corridors of movement in the area. Noise levels were measured at morning and afternoon peak periods at major sections, (nodes and links), with respect to the prevailing traffic on Tanke Road, the main arterial linking the Ilorin Township to the University community. Regression analysis was performed on the traffic and noise data generated at different times of the day. The traffic noise level on the Tanke – unilorin road in the units of sound equivalent, Leq are in the order of 73.5 dB at all the sections of the road, which are higher than the World Health Organization (WHO) threshold but lower than the Nigerian's Federal Environmental and Protection Agency (FEPA) standard of 90 dB (A). The results imply that the noise pollution on the studied arterial is high and can adversely affect the welfare and daily activities of the residents within the neighbourhood. The regression analysis established a strong relationship between the average equivalent noise level (Leq) and Traffic described with a polynomial of order three to six with R2 values ranging from 0.73 to 0.98; and a relatively weaker relationship, with R2 of 0.13 to 0.92 for the traffic noise index (TNI) at all sections of the arterial.

Keywords: Noise pollution, Traffic noise equivalent, sound level, traffic noise index, urban arterial.

INTRODUCTION.

Environmental pollution is a growing problem in an urban environment that is increasingly developing with the attendant generation of wastes and pollutants from the daily human and occupational activities and motorised movements. Noise pollution in particular is generally considered to be the third most hazardous type of pollution, right after air and water pollution. It is also the major environmental source of pollution in cites of developing and developed nations; WHO (2004) and Zannin et al. (2001). Noise is the sound with intensity in excess of normal human expectations and designated as sound pressure level, SL, which, is the threshold of hearing to the onset of pains to the ears of human beings expressed by equation (1).

$$SL = 20\log_{10}\frac{P}{P_0}$$

Where, P and Po - root mean square of and standard reference sound pressure respectively, in N/m^2,

The traffic noise measurements normally show a substantial level of variation which is dependent on the time of measurement; the n-percentage of the time such level of sound is exceeded (Ln) and whose effect on human beings also depends on duration of exposure. For traffic noise description, the L10 (18 hour) of 68 dB (A) and L10 (1 hour) of 70 dB (A) have been used in the U.K. and Hongkong Environmental Protection Department respectively. Noise pollution can be generated in urban areas by many activities, amongst which include uncontrolled music, hawkers of wares by city streets, electricity power generating sets and or unhealthy altercation of hagglers over sales by the road side. Traffic induced noise is produced much from tire-road contact, engines running at high speeds, blaring of horns, and shifting gears of poorly operated and maintained vehicles. The noise caused by traffic keeps on gaining an increasing importance and relevance due to a) the ever expanding growth in the number of circulating private and public cars and goods' trucks in urban areas b) the social economic and hazardous health implication because it can generate hearing impairments and pains to the wall of the hear if up to 140 deci bells (dB) or 65 dB(A) of A - weighted equivalent level (Leq), Bernajee et al. 2008 and Arnaa and Gracia 1998. Indeed, traffic generated noise pollution along major roads has been reported to have constituted the noisiest areas in major cities of the world, Noble (1980). The effect of transportation induced noise level (by transport mode), has been characterized by the annoyance level to people at different times of the day (day - night and day – evening - night)

with the following order of hierarchy; air, road and railways, Miedna and Oudshoon 2001.
And in the Chinese town of Nanjing, Kuwaiti cities and Kerman in South East Iran, noise pollution in order of 66 – 79 dB(A) and even higher values of 110.2 dB(A) (for the Banepa city in Nepal) have been reported with the adverse consequences on the people around the corridor of movement; Noble (1980), Al-Mutairi et al., (2009), Mohammadi, (2009) and Krishna et. al. (2007). These studies and the few recorded noise pollution levels in Nigeria, (Abam and Unwachukwu, (2009) and Olayinka and Abdullahi, (2008)), indicated the predominance of traffic generated noise pollution at commercial, industrial and residential/dwelling areas along highways, intersections and bus terminals (motor parks). The US National Environmental Policy Act of 1969 and the Noise Control Act of 1972 cover all sources and areas of noise. Also relevant are the UK Construction and Use Regulations of 1986 and the Road Traffic Act of 1972 which mandated car owners to fit an efficient exhaust silencer so that the cars should be without excessive noise while running the engine and or when stationary. The U. K. Act includes strict regulation on blaring motor horns between rest hours with much emphasis on the intersections of arterials and alongside the noise sensitive areas (hospitals, schools, etc) as the noise pollution concentration on the arterial. However, the noise level on the links may also be significant and its consequences cannot be neglected.
This study was therefore aimed at developing a model with which to generate traffic noise in quantitative terms that will be used in pro-active management of noise pollution at the critical positions (intersections and links) of an urban arterial. The model shall further be useful as a monitoring tool for traffic noise pollution for the ever growing industrial and commercial driven traffic movement on a corridor. It will also ensure an assured acoustic safety of the residents and dwellers along the motorized urban route. Although, both traffic volume and traffic speed dependent traffic noise models have been developed, Mappala et al., while quoting Golmohammadi et al.2007, only the traffic volume model was considered in this paper for the traffic noise equivalent, (Leq) and traffic noise index, (TNI).

2. Materials and Methods

2.1 The Study Area

The study area, Tanke-University route, is situated in the Ilorin South Local Government Area of Kwara State, Nigeria. It is the major arterial that links the community to the University of Ilorin, a higher Institution of learning established and in operation for over 35 years. The arterial originates from the University Gate and terminates at the GRA/Tanke Junction. The study corridor can be considered to be one of the busiest and crowded streets in the township because of the rapid and extensive developmental and commercial activities, heavy residences and pedestrian traffics within much of its entire length. Fig.1 is the line diagram sketch of the display of the studied arterial with the sound level measuring positions at four prominent locations (two nodes and two links). These are respectively, the Tipper Garage and Tanke Junction as Nodes 1 and 2, and the University Gate - Tipper Garage and the Tipper Garage – Tanke Junction as Links 1 and 2 respectively.

2.2 The Noise Parameters Defined

The current description of highway noise that properly captures the variability of the energy of the continuous noise level is the Equivalent Noise Level, Leq adopted in USA; (FHWA, US Transportation Department). It is often expressed in dB (A) if based on a statistical A-weighted scale. This is the average rate at which energy is received by the human ear which is an indicator of the physiological disturbance to the hearing mechanism. The various mathematical expressions for the statistical analysis of highway traffic noise are presented in equations 2 to 5, Alam et al, 2006), The Traffic Noise Index, TNI is the unit adopted for the United Kingdom, U. K. Traffic noise measurement (Langdon, 1976). The Traffic noise index, (TNI) is a parameter that indicates the degree of variation in traffic flow; while Noise climate NC, is the range over which the sound levels fluctuate in an interval of time. Each of these parameters has specific significance in the analysis of traffic noise pollution.

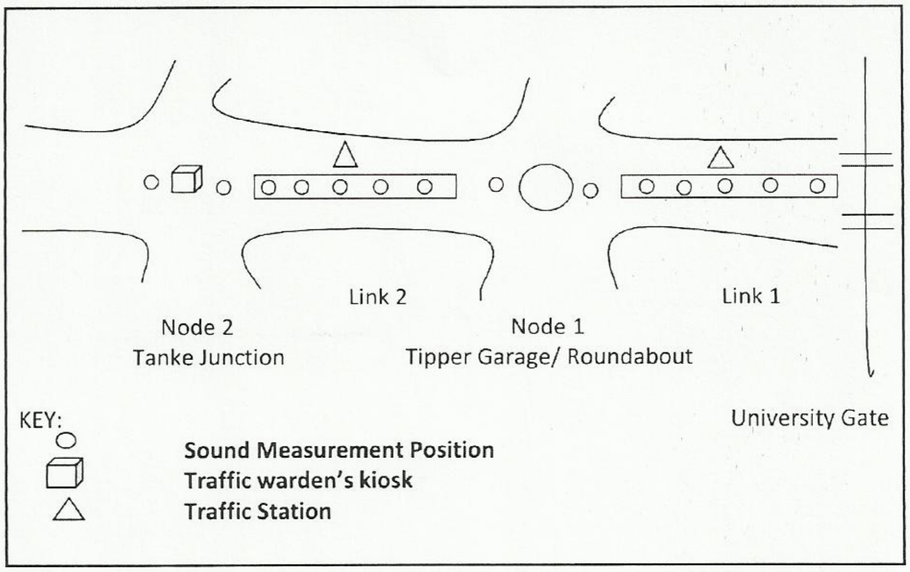

Fig. 1 Sketch of the study arterial with data collection points

$$L_{eq} = 10\log_{10}\left[\frac{1}{N}\sum_i 10^{(L_i/10)}\right] \quad 2$$

$$L_{np} = L_{50} + \frac{(L_{10} - L_{90})^2}{60} + (L_{10} - L_{90}) \quad 3$$

$$TNI = 4(L_{10} - L_{90}) + (L_{90} - 30) \quad 4$$

$$NC = (L_{10} - L_{90})\, dB(A) \quad 5$$

Where, L_i, is the average noise level at interval i; L_{np} is the noise pollution level, which is the measure of varying level of noise that takes into account the variations in sound signal;

L_{10}, L_{50}, L_{90} are the respective levels exceeded for 10%, 50% and 90% of the time of exposure to the sound level.

2.3 Methods for Data Collection

The intensity of generated noise at selected positions of the links and nodes of the study arterial was measured at morning (07:00 - 10:00 am) and afternoon/ evening (2:00 - 5:00 pm) traffic rush hours, Nigerian time. The prevailing traffic levels at the time of measurement were also determined by visual and observatory approaches. Noise levels were measured in the middle of the road median (the link) and the centre of the intersections (the node). Fifty readings were taken for each data point, 10 at 5 locations on the link and 50 at the nodes, immediately before and immediately after each side of the node for three consecutive week days in 2010.

The A-weighted sound level meter (GA 202 Sound Level Meter Type 2, Model IEC 651 Bs5969 ANSI, S1-4 Manufactured by Castle Associates Limited, England) was used to obtain the noise levels in accordance with FHWA's standard procedure of sound Level meter for highway and transportation study. The sound level meter consists of a microphone, amplifiers and a voltage meter. The microphone converts the pattern of sound pressure fluctuations into the voltage meter which is calibrated and converted to decibel, equation 1. The mean values of the traffic trend on urban arterial between the University Gate and Tanke Junction, Ilorin Nigeria and the corresponding characteristic sound level parameters for the two nodes and two links were determined and summarized in Tables 1a-d.

Table 1. Traffic (pcu) and Noise Parameters (dB(A)) at morning and evening rush hours

. Node 1 (Tipper Garage

Time of day	Traffic / L_{10}	L_{max} / L_{50}	L_{min} / L_{90}	L_{eq} / TNI
07.00 –	3812	85.7	68.3	76.6
08.00	76.8	73.8	70.3	74.1
08.00 –	3135	84.7	69.7	77.6
09.00	80.7	74.7	71.0	79.8
09.00 –	2560	78.0	66.7	72.2
10.00	74.7	71.7	68.6	62.9
14.00 –	2166	76.7	63.3	69.6
15.00	72.7	68.8	65.6	64.0
15.00 –	2346	81.0	64.0	72.7
16.00	75.0	70.5	67.0	70.6
16.00 –	2963	86.3	66.0	77.4
17.00	80.4	75.0	71.0	78.6

. Node 2 (Tanke Junction

Time of day	Traffic / L_{10}	L_{max} / L_{50}	L_{min} / L_{90}	L_{eq} / TNI
07.00 –	3584	84.3	60.3	74.8
08.00	78.1	70.8	65.0	87.4
08.00 –	2625	82.0	65.7	73.7
09.00	76.7	71.3	68.3	71.9
09.00 –	1851	79.0	62.0	71.1
10.00	74.4	68.3	64.3	74.7
14.00 –	1969	80.3	63.0	71.2
15.00	75.0	69.2	64.7	76.1
15.00 –	2007	80.3	64.3	72.0
16.00	74.7	69.7	66.3	70.0
16.00 –	2853	84.0	62.0	74.6
17.00	77.4	71.0	66.6	79.7

. Link 1 (University Gate - Tipper Garage

Time of day	Traffic / L_{10}	L_{max} / L_{50}	L_{min} / L_{90}	L_{eq} / TNI
07.00	1764	85.0	61.7	76.6
08.00	80.0	72.8	65.3	94.2
08.00 –	1466	85.0	56.3	74.2
09.00	77.4	70.3	61.6	94.8
09.00 –	1149	79.0	59.0	71.2
10.00	74.7	68.3	61.6	84.2
14.00 –	1190	79.0	50.7	69.5
15.00	73.4	63.0	54.3	100.7
15.00 –	1369	79.7	58.3	71.6
16.00	75.4	68.7	63.0	82.6
16.00 –	1408	83.3	57.0	74.1
17.00	77.4	71.5	66.1	81.1

Link 2 (Tipper Garage – Tanke Junction)

Time of day	Traffic / L_{10}	L_{max} / L_{50}	L_{min} / L_{90}	L_{eq} / TNI
07.00 –	2363	82.7	65.0	76.2
08.00	76.8	74.2	68.0	86.1
08.00 –	1839	81.0	65.3	75.1
09.00	80.7	73.8	67.7	80.3
09.00 –	1285	79.3	61.3	73.6
10.00	74.7	71.5	65.3	83.6
14.00 –	1451	77.3	58.0	70.2
15.00	72.7	68.5	62.3	75.3
15.00 –	1782	79.3	59.0	71.3
16.00	75.0	68.8	62.3	80.7
16.00 –	2122	81.7	63.0	76.0
17.00	80.4	75.0	68.3	83.9

2.4. Traffic - Noise Model Development.

The general trend of the noise level with respect to the hourly traffic for each of the selected nodes and links on the fixed facility of the transportation system was first displayed in scatter diagram. Mathematical correlation models were developed separately for the links and the nodes because of deviations indicated on the graphs. The computer spreadsheet software with the intercept consigned to zero, in order to reflect the realistic belief that there cannot be any traffic noise if there were no traffic on the road was used. Many forms of the relationship Leq – Volume of Traffic and TNI – Volume of Traffic were tried with the extracts from the data of Table 1 (Traffic, Leq and TNI).

3.0 Results and Discussions

3.1. The traffic level

The traffic at the morning and afternoon/evening rush hours on the studied urban road comprised four classes of vehicles respectively; motor cycles; cars and taxis; mini and midi buses and goods trucks. The peak hour traffic, occurring between 07:00 and 08:00 hours is in the range of 1764 – 3812 pcu with the lower values recorded at the links, while the corresponding values for the evening range between 1408 and 2963 pcu and occurring at 1600 – 17:00 hours.

A lot of commercial establishments exist at the frontage with many residences predominating at the immediate vicinity and back of the arterial and along the entire length of the studied roadway. The intensity of the noise is more prominent within the two nodes and the second links. Vehicles traversing the portion of the arterial with less intensity of development (residences and business) would generally travel faster because of the lack of the frictions usually associated with highly urbanized and motorized areas. Most of the portion of the arterial between the university gate and the tipper garage junction, (link 1) was free of features that would make vehicles and pedestrians sprawl with the attendant traffic congestions. that will likely cause significant high traffic noise. In other words, Link 1 is relatively free of such problem, and would experience faster movement of vehicles, less time of contact between the tires and pavement; and hence less generation of noise. The two traffic factors of volume and speed might account for the noise level varying from 69.6 – 77.6 dB(A) (Leq) and 62.9 – 100.7 dB(A) (TNI) as observed from Tables 1a-d above.

3.2. The Noise Level

The traffic noise measured at the two nodes and links of the arterial was more than 60 dB(A), implying that the entire road studied is noisy with respect to global and other developed countries' environmental standard of 55dB(A). As can be observed from Tables 1a -1d, the traffic noise parameters Leq for Tipper Garage and Tanke junctions (the two nodes) varied between 69.6 and 77.4 dB(A) and the TNI values of 62.9 and 87.4 dB(A). The corresponding noise levels for links 1 and 2 are 69.5 dB (A) and 77.1; and 75.3 and 100.7 dB (A) respectively. Fig.2 shows the variation of traffic noise along the distance of the arterial, gradually increasing from the relatively sparsely urbanized region to the more developed sections of the road.

The statistically developed parameters of Lmax, Lmin, Lmean and L10, L50, L90 for the Tipper Garage and Tanke junctions, (nodes 1 and 2) respectively are in the ranges of 70 dB (A). However, the average Leq ranges from 70.20 to 77.58 dB(A) at the intersections and 69.48 to 76.59 dB(A) at the trunks (links). This implies that the noise generated at the links is as important as that at the nodes. The higher speeds that are more likely at the links may be one of the factors accounting for the higher sound levels recorded at the trunks, because vehicles generate higher sound pitch at higher speeds, notwithstanding that the probability of driver – vehicle - pavement perceptions and accompanying activities is higher at the nodes (intersections) where road side businesses, more frequent braking instances and changing of gears and pedestrian traffic occur. The number of driver's perceptions as a result of the driver-vehicle –road interactions deduced from statistical analysis of vehicles' instantaneous speeds has been reported to increase as the level of urbanization increases from sub urban to urban sections of an arterial (Jimoh (2010)). Also a computation of the coefficient of variation (defined as standard deviation /mean values) for the developed traffic noise data, indicate the consistency of the measurements for the prevailing sound levels as well as the likely uniformity of the sound level generated by traffic. The sound levels are also relatively higher than those reported for Calabar (58.5 – 72.3 dB (A), a State Capital in South - South geopolitical region in Nigeria but lower than that for Lagos (70 – 75 dB(A)), the former Nigerian Capital city as well as the country's commercial nerve centre, Abam and Unachukwu (2009). The observed results seem consistent with the general belief that Lagos with the higher traffic than Ilorin should generate more traffic noise pollution while that of Calabar, would be lower than that of Ilorin. It is obvious from the result that Ilorin urban city is becoming a noisy environment and planning and provision of adequate mitigation schemes be considered for the noise pollution along the urban arterial in order to check its consequence on human being, the habitat and the environment.

The equivalent noise level Leq exceeded the acceptable WHO standards of 55 – 65 dB (A) for residential areas but however lower than the Nigerian's FEPA limits of 90dB. This observation implies that a review of the Nigerian noise pollution standard is highly and urgently desirable in order to comply with the global best practices and check the impending traffic noise induced health hazard. Some immediate land use abatement strategy need to be put in place, which may include development of green belt and noise barriers along the route in order to bring down the noise levels.

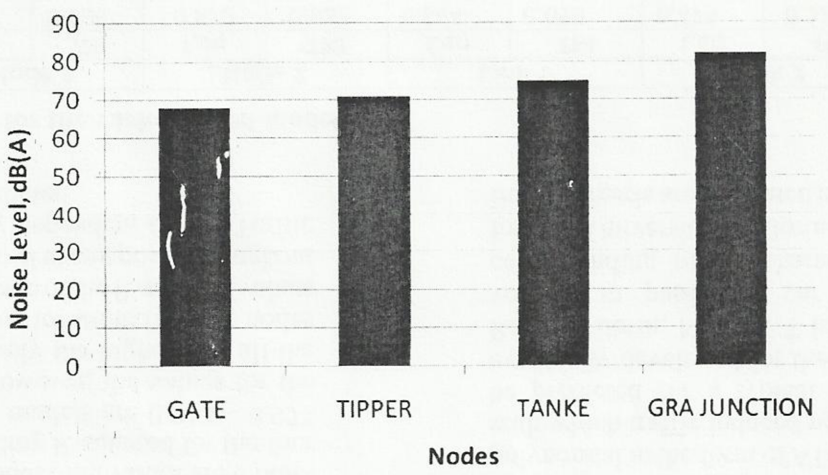

Figure 2. Typical variation of noise level along the study arterial

3.3. Traffic Noise Models

The analysis established a strong relationship between Noise Level Equivalent Leq and the traffic volume at the studied node and links. Table 2 gives the summary of the correlation coefficient for all the tried models from which the most favourable model was selected on the basis of highest of R2 values respectively for each of the nodes and the links. The correlation coefficient (R2) for the Leq ranges from 0.442 - 0.864 for the links (the Tanke Junction – Tipper Garage and Tipper garage - University Gate) while respectively for the nodes , the values are 0.660 - 0.989. The corresponding R-squared for the four locations for the TNI models are 0.013 – 0.977 and 0.408 – 0.923. However, the values for the polynomial are relatively the highest for all the tried models and the four locations (the two nodes and links). The high range of the R-squared values means that the noise level at any point throughout the arterial is strongly dependent on the Traffic volume and can be predicted with the polynomial models on the arterial to high level of reliability. Although the values of R2 obtained at the intersections are relatively higher than those obtained at the trunk (sections) of the arterial.

An inspection of the table shows that the most prominent traffic induced noise model is the polynomial who's R –squared values are in the range 0.774 – 0.989. Incidentally, the R-squared values of the polynomial as from order four and higher did not indicate any significant difference in magnitude. Hence the fourth degree polynomial in the form of AT4 +BT3 +CT2 +DT, with which traffic induced noise pollution could be predicted for a typical urban arterial was eventually developed for the Tanke - University Road in Ilorin, Nigeria, T is the hourly traffic volume in passenger car units (pcu). The corresponding model characteristics estimated for the University of Ilorin – Tanke Junction, Ilorin, Nigeria are presented in Table 3.

Table 2: Values of R^2 for the various tried models

Model	Node 1		Node 2		Link 1		Link 2	
	Leq	TNI	Leq	TNI	Leq	TNI	Leq	TNI
Exponential	0.657	0.408	* 0.872	*0.632	0.544	0.019	0.478	0.329
Logarithmic	0.734	0.450	*0.922	0.585	0.557	0.010	0.442	0.277
Polynomial	*0.989	*0.790	* 0.984	* 0.923	*0.774	*0.996	*0.864	*0.977
Power	0.730	0.453	*0.920	0.569	0.557	0.013	0.436	0.273

*Selected R^2 values for most appropriate models

Table 3: Characteristics of the parameters for the fourth degree polynomial of traffic noise model for Tanke Road Ilorin.

Parameters	A	B	C	D
Node 1 Node 2 Link 1 Link 2	- 5.10^{-11} 2.10^{-12} 1.10^{-8} 4.10^{-10}	2.10^{-7} 4.10^{-9} 3.10^{-5} 1.10^{-6}	0 4.10^{-5} - 0.028 - 0.001	0.32 0.096 10.23 0.799

This form of the model developed for Ilorin is different from the linear model as developed by Alam et al (2006), for neither the city of Sylhet, Bangladesh nor that of the log by Golmohammadi et al., 2007. Some of the reasons likely to account for the differences include i) the assumption of the linear model to have an intercept implying that there would be a traffic noise without any traffic which was not the case of this study, ii) the former studies were specifically for the critical noise spots of schools, hospitals where proper noise control enforcement practices operate as the data center, iii) noise barriers are already in existence by the sides of the streets of Sylhet streets.

The results of the regression analysis indicated one other important issue, that with the rapidly growing rate of car ownership due to higher income level and infrastructural development, it is almost certain that the challenge of traffic noise pollution will continue to be problematic. The problem could even degenerate to consequential health hazard and have adverse effects on the quality of urban life. It is therefore getting more discernable that much attention is necessary to pro actively assure acoustic discipline and safety desirable for a continuously growing and motorized trip from the urbanization and industrialization.

4. Conclusions and Recommendations

4.1 Conclusions

The study considered the noise level generated by road traffic with corresponding flow rate, at the two important sections of a transportation fixed facility, the node and the link, on the University / Tanke Road, Ilorin, for the development of statistical correlation of the intensity of sound and traffic. The following conclusions can be drawn from the results of the study:

The average equivalent noise level (Leq) on the University of Ilorin main arterial is 73.5 dB (A), which is generally above World Health Organization (WHO) acceptable level of 55 dB(A), but lower than the limit specified by the Nigeria Federal Environmental Protection Agency (FEPA).

Traffic is a major source of noise pollution along the University of Ilorin and Tanke Junction Road, Ilorin Nigeria, an urban arterial; because the intensity exceeds the acceptable thresholds for areas designated for residential and commercial purposes.

A polynomial of order four and more was developed at correlation coefficient R2 values of 0.73 – 0.98 for Leq and Traffic and TNI and Traffic at all sections of the urban arterial (intersections and trunks) with which the traffic noise pollution could be predicted and pro actively managed as car ownership increases in an urban, educational, commercial, industrial and other activity district.

The characteristics of the fourth order polynomial are, A between (2 - 100)10-12, B (4 – 3000)10-9, C (4 – 28)10-5 and D 0.096 – 10.2 for the typical urban arterial in Ilorin Nigeria.

4.2 Recommendations

Due to the indication of the high traffic noise pollution on the University – Tanke Road, prevention of the effect of the noise level on human health should be undertaken by Government to reduce the auditory and non-auditory health impacts on the population.

Control measures on the strict regulation of source of noise generation and installation of barriers between noise source and receiver to attenuate noise levels should be undertaken.

The design and construction of buildings should include the use of noise absorbing materials.

The awareness on the health impact of exposure to high traffic noise among the populace must be seriously awoken.

The noise level model generated for the traffic volume in this study is recommended for development of noise impact assessment data base, control strategy and noise pollution management tool in a typical urban arterial in a developing country, such as Nigeria where control is still lagging.

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