THE STATUS OF ACOUSTICS IN NIGERIA: A PAPER IN HONOUR OF PROFESSOR ALEX I. MENKITI

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Abstract

In assessing the status of acoustics in Nigeria, efforts have been made to review the work of researchers of various nationalities, appraise the role of some countries of the world vis-à-vis that of the Federal Republic of Nigeria in promoting anti-noise laws, ordinances and other governmental acoustical matters that bother on noise. Expounded in this study are the published works of many Nigerians in acoustical physics as pioneered by Professor Alex I. Menkiti, the honoree. The different areas considered are architectural and room acoustics, environmental noise pollution and control, traffic noise, community and indoor noise, industrial and occupational noise, and atmospheric and jungle acoustics. Results have shown characteristics of some available local materials that could find application in vibration and structure-borne noise isolation. Most of the results in environmental acoustics have also characterized cities in Nigeria where the investigations were conducted with remarkable consistency with those of early surveys elsewhere with similar features. It is believed that acoustical research in Nigeria will be given more attention and greater impetus in future.

Keywords: *Acoustics, Nigeria, traffic noise, environmental acoustics and jungle acoustics.*

1. Introduction

As in some other countries of the world, acoustics is a developing science in Nigeria. Its importance has gained tremendous ascendancy. This is partly as a result of the fact that every moving device and most electronic/electrical gadgets generate one form of sound or the other. Different types of machines with varying speeds are expected in our world that is swept regularly by technological advances. Therefore, sound of varying characteristics are expected to be generated and propagated. The use to which an acoustic signal could be put is yet another reason for its real importance.

Although applications of acoustics such as in the selection of a flawless pot or cup among the newly fired earthen wares or metal from the newly produced ones have been with man, the earliest known research in the broad area of acoustics dates back to the late 19th century when the first attempt was made to control sounds (Cunniff, 1977). In 1895, the President of Harvard University was unhappy about the acoustics in a new building on the campus. He asked Wallace C. W. Sabine, who was an Assistant Professor of Physics, to *do something* about the situation. Sabine, who had little or no guidance from the literature on architectural acoustics, decided to make some measurements in the room using a pipe organ, stopwatch and his own good hearing with understanding results.

Buildings are design by people for other people to work and live in. Incidentally, time has changed. There are now a great diversity of building types. They include factories, offices, schools, hospitals, universities, hotels, restaurants, houses and studios. These buildings are erected in ever increasing numbers for increasing populations of people to work and live in. More people, more buildings; more transport bring more pollution and more stress. Since the work of Sabine, most of which were published as collected papers on Acoustics by Harvard University Press (Sabine, 1923) researchers of various nationalities have made significant contributions to room acoustics. Haas (1951) and Thiele (1953) stated that reflections with delay times of less than 50 ms are useful but those delayed by a time interval greater than this are detrimental. Schroeder (1975), described some research into the most important objective and subjective factor of concert hall design. When the reverberation time fell below 2.2s, or rose above 2.4s, it became one of the most important parameters. Definition as defined by eqn. (2) was also found to be of high subjective importance and an inverse correlation was found to exist between it and reverberation time.

Churches, Chapels or Cathedrals all interact in some mysterious way to create an atmosphere of quiet and peace necessary for prayer and meditation. This is because of the noble and splendid nature of such edifices designed by architects. The size, the shape, the surface textures, the space, the depth and quality of light were borne in mind when such buildings were being designed. Construction of places of worship, classrooms, lecture halls, studios and conference halls requires achievement of high-quality sound. Therefore, acoustical design of these buildings is very important.

Acoustical studies have been conducted for places of worship (Lannie, 1994; Lannie and Makrinenko, 1994; Lannie *et al.*, 1997; Lannie and Soukchov, 1999) and for other buildings meant for speech making (Tisseyre *et al.*, 1997, 1998; Tisseyre and Moulinier, 1999; Goydke, 1997; EN ISO, 1995; ISO/DIS, 1994; ISO, 1986; ISO, 1991; Tisseyre and Moulinier, 1999; Fausti *et al.*, 1999; Pompoli, 1990-1994; Ermann, and Beranek, 1996; Siebein *et al.*, 1992; Barron and Lee, 1998; Bies and Hansen, 2002; Nurzynski, 2006; Davidsson *et al.*, 2004 and Warnock, 1999).

It was long before adverse effects of noise on man, animals and structures became evident. It was later found that noise is a serious pollutant, having wide ranging and far-reaching effects and difficult to be controlled by physical means alone. Consequently, the International Congress on Acoustics chose as its theme *Environmental Acoustics* during its meeting in London in 1971.

Attention has been drawn to hazardous noise exposure (CHABA, 1966) and regulations introduced (OSHA, 1975). Much work is being done in other countries including developing economy with the aim of limiting levels (Bathacharya *et al.*, 1990; Shaikh, 1966 and 1999; Shaikh and Zhang, 1999; and Tandon and Nakra, 1999).

Maximum permissible occupational limits have been recommended by the International Standards Organization (ISO) and the International Institute of Noise Control Engineering (I-INCE), USA. The European Economic Community and other countries follow the recommended limits. For example, ISO (1971) has recommended a limit of 85-90 dB (A) $L_{Aeq,}$ with exchange rate of 3 dB (A) per doubling or halving of exposure time; and I-INCE (1997) has recommended a limit of 85 dB (A) $L_{Aeq,}$ with exchange rate of 3 dB (A). Countries such as Argentina (ISO,1971), the United Kingdom (DoE, 1971), and China (Shaikh and Zhang, 1999) allow dB (A) $L_{Aeq,}$ with exchange rate of 3dB (A). Australia (NSON, 1993 and NCP, 1993), Germany and Sweden (I-INCE, 1997) allow 85 dB (A) $L_{Aeq,}$ with exchange rate of 3 dB (A). Canada allows 85-90 dB (A) $L_{Aeq,}$ with exchange rate of 3 dB (A) (I-INCE, 1997 and ORIEM, 1990) while Korea (TOEL, 1998) and Vietnam (NALW, 1985) allow 95 dB (A) $L_{Aeq,}$ with exchange rates of 3-5 dB (A). USA (OSHA, 1974) and Chile (NALW, 1985) allow 85 dB (A) $L_{Aeq,}$ with exchange rate of 5 dB (A). These limits, highlighted above, have been allowed for working schedules of 8h/day and 5 days a week, i.e. 40h/week. India has set up a limit of 90 dB (A) $L_{Aeq,}$ (I-INCE, 1997) without specifying exchange rate and permissible exposure time.

Apart from extensive work that has been done by the pioneer researcher, Eyring (1946), and subsequently others (Attenborough, 1983, 1985; Taylor, 1972; Piercy *et al.*, 1979; Martens, 1981; and Fégeant, 1999a and 1999b), there are now well over 521 social surveys of residents' reactions to environmental noise (Field, 2001).

Underwater acoustics, acoustics in oil and gas exploration are all areas where acoustics have found applications. Efforts are also being directed in the study of thunder acoustics, galactic and extra-galactic noise.

The objectives of this paper are to extensively review the work done by some researchers of various nationalities in the broad field of acoustics, assess the status of acoustics in Nigeria by expounding some results obtained in investigations by some Nigerians in the same field. This paper is in honour of Professor Alex I. Menkiti as he clocks 70 on 13th June, 2007.

2. Brief on Professor Alex I. Menkiti

Professor Alex I. Menkiti is a University of London trained Chartered Physicist, and Engineer and a one-time, two-term, President of Nigerian Institute of Physics (1996-2000). Since his return to Nigeria in 1976, Professor Menkiti has been in the University of Calabar, Calabar, Cross River State, where he has been teaching and involved in research in acoustical physics and related areas at both undergraduate and post-graduate levels in the Department of Physics. He has sustained research in acoustical physics and is known as the father of acoustics in our country, Nigeria. He has produced very many students at both levels. This explains why the University of Calabar has championed research in the broad area of acoustics to date. It is interesting to note that some Nigerian Universities have now introduced an aspect of acoustics into their curricula and/or as a programme either in the Department of Physics or in the Faculty of Engineering. Other Nigerian Universities are gradually embracing this trend.

Professor Menkiti is a member of the Institute of Acoustics, U.K. and a Fellow of the Nigerian Institute of Physics. He has earned other several awards such as C. Phy, C. Eng., FIEE, FNSE, etc.

3. Some Theoretical Foundations

3.1 Architectural and room acoustics

The equation which W. C. Sabine developed over 100 years ago is, to this day, very useful in acoustic room design. The equation is

$$T = 0.161\tfrac{V}{a} \qquad (1)$$

where T is reverberation time, in seconds, to reduce the sound intensity from a level of 60 dB above the threshold of audibility to the threshold of audibility, V is room volume in m^3 and a is absorption in sabins. If the sound absorption coefficient is known for each surface in a room the sound absorption, a, in sabins is given by

$$a = \alpha_1 S_1 + \alpha_2 S_2 + \alpha_3 S_3 + \ldots$$

or

$$a = \sum_i \alpha_i S_i$$

where α_i=Sabine sound absorption coefficient of surface area i and S_i=area of surface i in square metres.

Thiele (1953) speaks of the *definition* of a sound signal D in a room quantified by integrating the energy contained in the useful reflections and dividing it by the total energy in the direct and total reflected sound, thus

$$D = \frac{\int_0^{5ms} \{g(t)\}^2 dt}{\int_0^{\infty} \{g(t)\}^2 dt} \qquad (2)$$

where t = 0 donates the arrival of the direct sound. A continuous transition from useful to detrimental reflections is usually assumed. This may be formulated by defining a weighted function $a(t)$ such that the useful reflections have an impulse response function given by

$$N = \int_0^{\infty} a(t)\{g(t)\}^2 dt \qquad (3)$$

and for a linear transition

$$a(t) = 1 \qquad for\ 0 \leq t < t_2 \qquad (4a)$$

$$a(t) = \tfrac{t_2 - t}{t_2 - t_1} \qquad for\ t_1 \leq t \leq t_2 \qquad (4b)$$

$$a(t) = 0 \qquad for\ t > t_2 \qquad (4c)$$

Niese (1956) suggests t_1 = *17*ms and t_2 = *33*ms for use in evaluating $a(t)$. He defines detrimental sound S as that which is delayed by more than 33ms; S can be calculated by integrating the reverberant sound energy under the sound decay curve with a lower limit of t = *30*ms. The decay curve can be expressed in terms of the reverberation time T by

$$h(t) = 0 \qquad for < t < 30\ ms \quad (5a)$$

and

$$(h) = (\tfrac{2N}{30})^{1/2} \exp\frac{-6.9(t-30)}{T} \quad for\ t > 30\ \text{ms}. \quad (5b)$$

Kuttruff (1973) states the echo degree as

$$E = \frac{S}{S+N} \qquad (6)$$

According to Kuttruff (1973), there is a good correlation between the echo degree and, syllable intelligibility. The logarithmic ratio

$$\Delta L = 10\log(\tfrac{N}{S}) \qquad (7)$$

has been found by Beranek to be related to the acceptability of concert halls, whereas Lochner and Burger (1960) have found good agreement between ΔL and speech intelligibility.

3.2 Noise rating and exposure

Noise exposure rating, *NER*, which gives a measure of the severity of occupational noise exposure, is calculated using the procedure published by the committee on Hearing, Bioacoustics and Biomechanics, CHABA (1966) and is given by

$$NER = \sum_i \frac{C_i}{T_i} \qquad (8)$$

where C_i, is the total exposure time at a given steady noise level and T_i, is the total exposure time predicted at the corresponding noise level. If $NER<1$, the noise exposure is considered acceptable.

Permissible occupational noise exposure time per day, allowed under the limits of 85, 88 and 90 dB (A) L_{Aeq}, with exchange rate of 3 dB (A), has been given (Shaikh, 1999). Percentage of overexposure per day, with reference to the maximum permissible limits of 90 and 88 dB (A) L_{Aeq}, for 8h/day, also is evaluated using the expression (Shaikh, 1999):

$$\%over\exp osure = (\tfrac{W.S}{P.E.T}x100) - 100 \qquad (9)$$

where *W. S.* is working schedule in h/day. Equation (9) can be computed using a working schedule, which is 8h/day.

3.3 Noise-level reduction and noise rating

The noise ratings are usually translated to day-night average A-weighted sound level L_{dn}, being a measure of noise exposure, using the equation (USEPA, 1973)

$$L_{dn} = 10\log\tfrac{1}{24}(15x10^{L_d/10} + 9x10(^{(L_n+10)/10}) \quad (10)$$

where L_d and L_n are the energy-average noise levels during the day-time (0700-2200) and night time (2200-0700) periods, respectively. The equivalent (mean) energy level index (L_{eq}) which is widely used, has been recommended by a subcommittee of the Noise Advisory Council (Rackl, 1975) as an index worthy of careful consideration. Hourly values of L_{eq} are usually calculated from the cumulative noise data obtained using the formula

$$L_{eq} = 10\log(\tfrac{1}{100}\sum_{i=1}^{n} f_i 10^{L_d/10}) \qquad (11)$$

In eqn. (11), f_i is the dB (A) sound level corresponding to the mid-point of class. The 24-h average value of L_{eq} is also obtained by averaging the relevant time periods. Mean values of L_{10} dB (A) over a period of 1h are calculated for each class interval for road traffic noise using the relation (Fields, 1995)

$$L_{10}(1h) = 10\log(q) + 33\log(V + 40 + 500/V) + 10\log(1 + \tfrac{5p}{V}) - 27.6dB(A) \qquad (12)$$

where *q* is the number of vehicles per hour during the recording time, *p* is the ratio of the number of heavy vehicles to the total number of vehicles and *V* is the speed in km/h.

3.4 Acoustic power spectra of road traffic noise

The model for a motor vehicle is that of a monopole acoustic radiator exhibiting omni-directional characteristics (Makarewicz, 1981). The A-weighted mean square pressure of the source, when the distance between the observer and the vehicle is a few metres is given as

$$p_A^2 = \frac{W\rho c}{2\pi r^2} \qquad (13)$$

where p_A is the pressure, ρ is the density of air, *c* is the speed of sound, ρc the specific acoustic impedance of air (= 415 Rayls), *W* the power spectrum of the source and *r* is the distance between the source and receiver. Equation (13) can be written as

$$p_A^2 = \int_0^\infty B(f)S(f)df \qquad (14)$$

where *B(f)* is the frequency-weighting function, *S(f)* is the spectral density and *f* the frequency.

Hence, the spectral density can be

expressed as

$$S(f) = \frac{W(f)\rho c}{2\pi r^2} \qquad (15)$$

The frequency band contribution *S* (f_n) and the spectral density *S* (*f*) are related according to the expression:

$$S(f_n) = S(f)\,\Delta f \qquad (16)$$

where f_n is the band centre frequency and Δf_n is the bandwidth. Using the equation (Diagle, 1984):

$$L(f_n) = 10\log(S(f_n)/p_0^2) \qquad (17)$$

we can calculate the band pressure levels $L(f_n)$ where p_0 is the standard reference pressure = 2 x 10^{-5} Pa.
Hence,

$$S(f_n) = p_0^2(10^{0.L(f_n)})$$

and

$$S(f) = \frac{S(f_n)}{\Delta f_n}, \qquad (19)$$

The resulting power spectrum from eqn. (15), (18) and (19) is thus:

$$W(f) = \frac{p_0^2(10^{0.1L(f_n)})(2\pi r^2)}{\rho c(\Delta f_n)} \qquad (20)$$

Makarewicz (1981) showed that power spectrum for the frequency range 50Hz to 10Hz is largely a decreasing exponential function, which can be described by the equation:

$$W(f) = W_0\exp(-\mu f) \qquad (21)$$

where μ is a parameter that characterizes the power spectrum. Thus, the A-weighted frequency (dependent) power, N_A, of the source (in a non-dissipative medium can be determined, viz:

$$N_A = \int_0^{\infty} W(f)B(f)df = \frac{2W_0B_0}{(k+\mu)^2} \qquad (22)$$

where *W*(*f*) is given eqn.(20) and

$$B = B_0 f^2\exp(-kf), \quad 50 \le f \le 10{,}000 \text{ Hz} \quad (23)$$

and B_0 and *k* are constants.

3.5 Some road traffic noise control theories

The model assumed for a freely flowing traffic is that of randomly distributed sources which fluctuate in number and spatial distribution on a line (Kurze, 1971) and which, as stated earlier, is an omni directional noise source. Suppose such a single omni directional source of noise, *S*, and the observation point, O, are close to the plane (x, y), such that their height above the plane, Z_s and Z_o, are substantially less than the distance between them, Makarewicz (1979) showed that the equation

$$I = \frac{P}{2\pi r^m} \qquad (28)$$

can give a good approximation of the noise intensity, *I*, assumed to be a decreasing function due to a single vehicle. *P* in eqn. (28) may depend on the speed of the source and together with *m* (a positive integer) characterize all possible phenomena which accompany noise propagation (reflection from the ground, air attenuation, scattering by turbulence, etc.). Under the assumption that during the interval, *T*, the point of observation, O, is passed by N_{ij} sources of the ith class, moving along the jth path at constant speed, the average intensity of the sound over time is (Fisk,1975 and Makarewicz, 1976),

$$< I > = (\tfrac{1}{R})\sum_{ij}\int_{-\infty}^{\infty} I_{ij}(t)dt + < I_0 > \qquad (29)$$

where I_{ij} is the passby intensity time history and $<I_o>$ is the time average intensity of the background noise emitted by unidentified sources. The rest of the formulation are found in Makarewicz (1978 and 1982).

3.6 Objective and subjective responses, complaints and noise measures

Studies of responses to aircraft noise have led to equations that relate the percent of people who are highly annoyed by noise to the percent of people who actually complain of the noise in some official manner (Patterson and Connor, 1973). A typical example is (Galloway, 1974):

$$\%\ Highly\ annoyed = 2\ x\ (\%\ complaining) + 20 \qquad (24)$$

Schultz (1978) on synthesis of social surveys on noise annoyance has developed empirical relationships between percent of respondents who are highly annoyed and percent of people who are complaining.

Robinson (1970a and 1970b) carried out a number of subjective reaction tests and showed that there is good correlation between subjective ratings of vehicle noise and a variety of noise units; and that where good correlation has been obtained the unit used has a simple empirical relationship of the other units, such as

$$PNdB = dB(D) = dB(A) + 13 \qquad (25)$$

where *PNdB* is the *PN* in dB.

Several studies (Griffiths and Langdon, 1968; Hall and Taylor, 1977; Rylander and Dunt, 1991; and Tahara and Miyajima, 1998) have only considered subjective aspects of noise in relation to its levels as against the relationship between the latter and objectionable qualities, which have received relatively less attention.

The total loudness L_T in sones for indoor noise is determined from the formula

$$L_T = L_{\max.}(1 - F) + F\sum_{j=1}^{N} L_j \text{ sones,} \qquad (26)$$

where $L_{max.}$ is the numerically largest loudness index in the data, and $\sum_{j=1}^{N} L_j$ is the sum of all the loudness indices over the band (including $j = m$) and F is a bandwidth correction factor usually given as 0.15 for $\frac{1}{3}$-octave bands of noise. Corresponding values of the loudness level (*LL* in phones) are also read from contours of equal loudness index. Also the total noisiness N_T (in noys) for the indoor noise can be calculated using the expression:

$$N_T = N_{\max.}(1 - F) + F\sum_{j=1}^{N} N_j \text{ noys,} \qquad (27)$$

where $N_{max.}$ is the numerically largest noisiness index in the data and $\sum_{j=1}^{N} N_j$ is the sum of all the noisiness indices over the band (including $j = m$). F has the same meaning as in eqn. (26). Corresponding values of the perceived noisiness level (in *PN* dB) were determined from contours of perceived noise (in noys).

4 Acoustical Ensembles for Nigeria

It is now worthwhile to consider acoustics as a whole in Nigeria. Acoustical ensembles for Nigeria will be considered under the following headings; viz: past, present and future.

4.1 Past

As stated in the introduction, the earliest application of acoustics was its use in the selection of good pots with cracks from a group of newly fired pots. A tap at a newly fired pot that has no crack gives a characteristic tone that distinguishes it from the one that contains cracks or flaws. There existed gongs in the villages used to attract the attention of villagers when announcements are being made. Gongs are still being used for such purposes. Local musical instruments such as flutes, guitar, xylophones which depend on sound for their operation were also and are still in use.

4.2 Present

4.2.1 Anti noise laws, ordinances and other governmental acoustical matters.

When it became very clear that noise is a serious environmental pollutant of this age, Nigeria tried to join some other countries of the world in enacting noise laws and ordinances. Lagos state in 1976 passed the control of *drumming adoptive by-law* (1973). *The law stated that no person should beat a drum without a permit which may be obtained by paying a prescribed fee.* In 1976, for the first time in Nigeria and in treatise that could aptly be described as lamentation for his people, Menkiti (1976) drew the attention of the public to the need to combat the menace of noise. Since then, a lot have been said, written and published about environmental noise in Nigeria (Menkiti, 1979a, 1979b, 1979c, 1980, 1985a, 1985b; Onuu and Menkiti, 1990; Onuu, 2000a, 2000b, 2000c, and 2001)

The emergence of a few series of *latent* legislation against noise in some states of the Federation was witnessed between 1970 and 1980. The old Bendel State Government came up with a law prohibiting high sound level of amplified music in certain areas. This law did not, however, specify any limit. In 1979, a certain numbers of laws were passed in the former Cross River State to control noise pollution. These laws captioned *peace, good order and welfare adoptive by-laws* were aimed at protecting the public places of worship, hospitals, offices and community residents from noisy musical instrument and systems such as loudspeaker, gramophone, amplifier, drums, hawkers and touts. In 1985, the old Rivers State enacted a noise control edict. According to the edict: *it is an offense for any record seller to play his music to the hearing of the general public; every musical record seller shall provide ear muff for the use of prospective record buyers when playing his record; it is an offence for any driver to toot the horn of his vehicle and for anyone to willfully and wantonly shout or blow any horn or sound and play any musical instrument or sing or make any other loud noise to the annoyance and disturbance of the general public; it is an offence to mount a loudspeaker or any other public address system on a motor vehicle without the written permission from the authority. Playing of drum, gong, tom-tom or other similar instrument between 8 o'clock in the evening and 6 o'clock in the morning without approval is prohibited.*

Menkiti (1985b), in a critical appraisal of the measures taken in Nigeria against the menace of noise pollution had a number of reservations against these laws and by-laws as good as they are. For example, they were not publicized. The consequence was that people could not obey them and did not even report or complain that their rights were being infringed upon since they were ignorant of the existence of such laws. Some of the laws were simply a means of raising money for the governments concerned and had nothing to do with environmental noise control. The anti noise laws and ordinances were enacted wrongly and in a hurry and so ended up being impracticable. None of the laws specified the sound pressure level that constituted violation. The word *noisiness* without a figure quantifying it is of no real significance and makes no sense. The questions that should be answered are *who determined the annoyance factor and how was it determined*? Loose definitions and primitive concepts were used for subjective terms like *loudness, noisiness, annoyance, disturbance and nuisance* and these really made the law vague.

On Monday, April 26, 1982, the House of Representatives Committee on Housing, Community Development and Environment, Federal Republic of Nigeria, in an advertisement signed by one Emmanuel Igho Ukrakpor for the Clerk of the House, called for memoranda from the public on *Noise Pollution-Urban Noise Control* on the Federation Environmental Bill, 1981. This, no doubt, was a bold step by the House of Representatives. In response to the advertisement, Menkiti sent a memorandum on May 12, 1982. The memorandum read in part *...There is no doubt that noise needs to be controlled, needs to be abated. While this abatement is in part a technical problem science alone cannot provide the answers. Solutions to this problem carries price tags, the balance is struck in the political arena. Law making is the answer....* Yes, it is only at the price of money that one can sleep in the city.

While we commend the Senate of the Federal Republic of Nigeria for its moves towards the control and abatement of environmental noise pollution, a menace that cannot be controlled by physical means alone and a nuisance whose damage risk is imminent even before it is noticed, and in seeking to maintain a healthy, decent and clean environment, it is pertinent to state the approach that is usually followed and which has been followed all over the world. The right approach to legislation against environmental noise is that the Federal Government has to set up *Noise Advisory Council*. The Council will then set up Noise Abatement Zones in which offending sources of environmental noise can be readily identified. Environmental noise survey and measurements are then simultaneously carried out throughout the zones (all over the country) to identify offending sources, and measure noise levels and their characteristics before imposing meaningful levels that should not be exceeded. So before any meaningful legislation against noise is embarked upon, we have to accumulate empirical/scientific data of noise and analyze same. It is only when such physical measures and attitudinal surveys are conducted shall we be somewhere near effective noise control. Really, environmental noise control is a combined work of scientists, lawmakers and, indeed, all stakeholders in the environment. Anti-noise laws, ordinances and other governmental acoustical matters that bother on noise decreed from the desk will end in a fiasco (Onuu, 2001). The anti-noise bill that was to be signed into law by the immediate past President of Nigeria, Chief Olusegun Obasanjo, passed through first and, perhaps, second readings in the Senate that wound up with him. It is hoped that the present Senate will complete the process so that the President and Commander-in-Chief of the Armed Forces of the Federal Republic of Nigeria, Alhaji Umaru Musa Yar'adua, will sign the bill into law.

4.2.2 Architectural acoustics

Menkiti and Etienam-Umoh (1994) investigated the sound absorption properties of two common acoustics materials (Fig. 1). Menkiti and Onuu (1994) also conducted vibration and noise pollution studies at a microwave station and *designed-out noise* in the University of Calabar Conference Centre (Menkiti and Onuu,1994). Work on isolation of vibration and structure-borne noise has also been done (Onuu *et al.,* 2000). Some of the results of this investigation are shown in Table 1. Some of the works in architectural acoustics in Nigeria have resulted in the characteristics of some available local materials that could find application in vibration and structure-borne noise isolation.

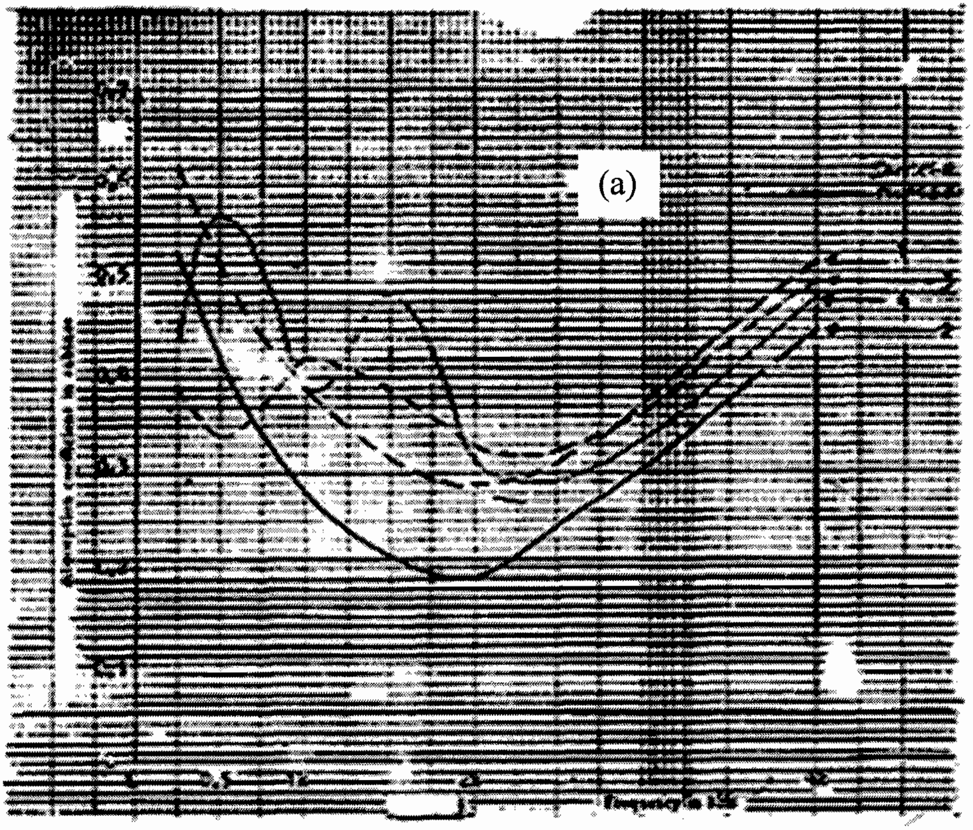
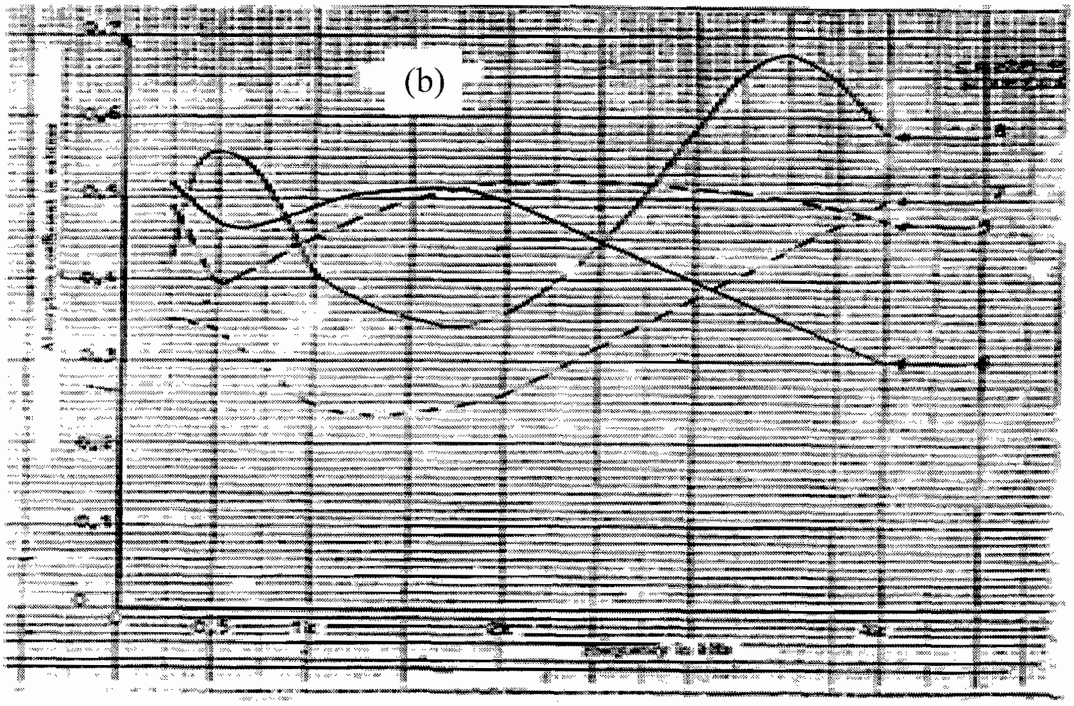
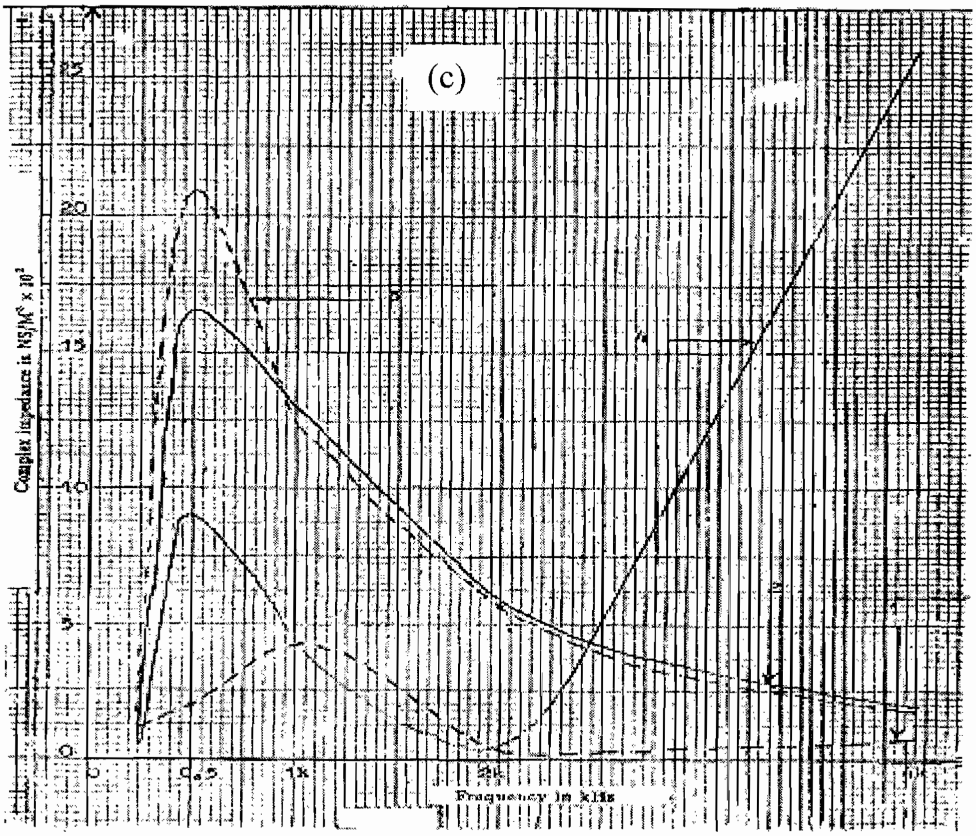


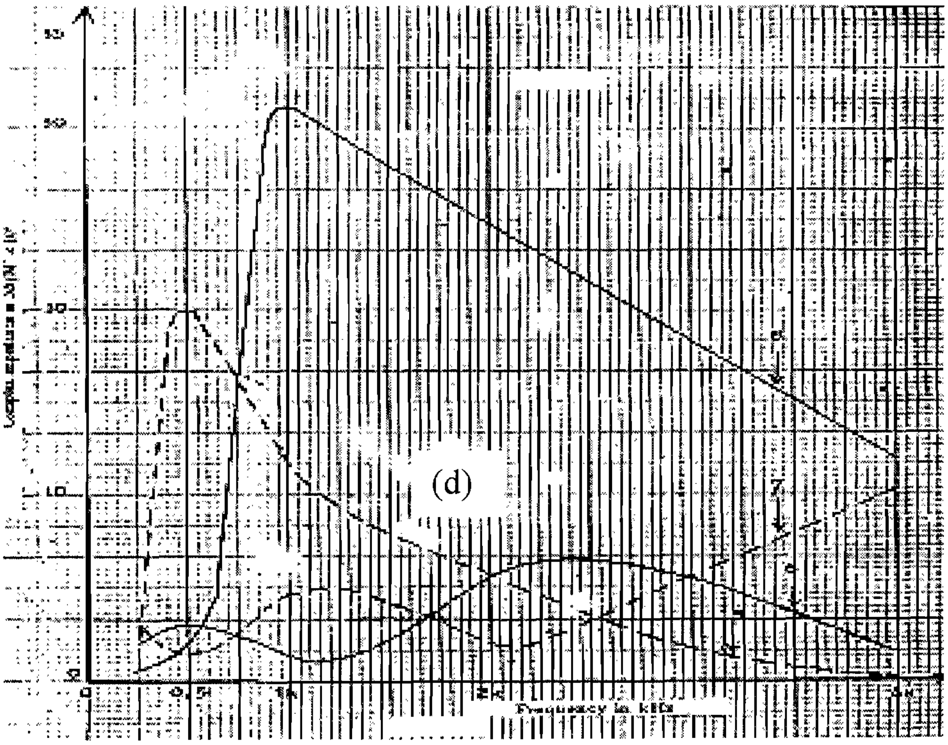
Fig. 1: Character istics of two common acoustic materials (Menkiti and Etiename-Umoh, 1994); (a) absorption coefficient vs frequency for polyurethane foam for (Pritex)



(b) Absorption coefficient vs frequency for acoustic plaster board



(c) complex impedance vs frequency for polyurethane foam (pirex)



(d) Complex impedance vs frequency for acoustic plaster board.

Table 1a: Isolator Materials (Onuu *et al.*, 2000)

	Isolators	Dimension (± 0.01cm)	No. of turns
a. Metal Springs	Cylindrical compressing spring	L = 2.70, d = 0.30, N = 20	N = 20
	Conical compression spring	L = 4.00, d1 = 1.80, d2 = 0.50	N = 8
	Tension spring	L = 9.0, d 2.00	N = 10
b. Rubber	Polymerised rubber	L = 6.50, B = 1.30, t = 0.25	NA
	Brittle (Elastoplast) rubber	L = 4.60, B = 0.65, t = 0.65	NA
	Normal (natural) rubber	L = 8.00, B = 2.30, t = 0.17	NA
c. Cork	Polymerized cork	L = 16.30, d = 1.50	NA
	Light paper cork	L = 14.00, d = 1.20	NA
d. Composite Material	Compressed asbestos fibre	L = 17.50, B = 1.40 t = 0.70	NA

- L is length, B, breadth; t, thickness; d, diameter (d_1, base diameter and d_2, peak diameter), NA = not applicable

Table 1b: Static deflection and natural frequency of some vibration and structure-borne noise isolatos (Onuu *et al.*, 2000)

Isolators	Static deflection (mm)	Natural frequency (Hz)
Conical compression spring	26.00	3.1
Cylindrical compression spring	24.00	3.2
Polymerized rubber	3.00	9.4
Brittle rubber	2.70	9.6
Normal rubber	1.89	11.5
Compressed asbestos fibre	0.26	31.0
Polymerized cork (composite pad)	0.25	31.4
Light paper cork	0.23	33.3

Table 1 c: Summary of results (eqn. (3) and Fig. 3(c) at $\omega/\omega_n = 2$ (Onuu *et al.*, 2000)

Damping factor, D	Transmissibility, T	Isolation efficiency (1-T) x 100%
1.0	0.82	18
0.8	0.75	25
0.6	0.65	35
0.5	0.62	38
0.4	0.53	47
0.2	0.40	60
0.1	0.36	64
0.0	0.33	67

4.2.3 Traffic noise

Studies of traffic noise in Nigeria have received considerable attention. Aircraft noise investigations were conducted by Menkiti and Ajah (1993) and Onuu and Obisung (2005). Those results are shown in Tables 2 and Fig. 2. They show that noise levels of aircraft, and noise and number indices of aircraft noise are highest during landing and take-off (Tables 2a and 2b). The percentage of respondents reporting that they are very much bothered are also greatest for all grouped values of *NNI* (Table 2c). The relationships between maximum number of passengers and engine capacity of aircraft (Fig.2a), and between maximum noise level of aircraft and engine capacity (Fig.2b) are shown.

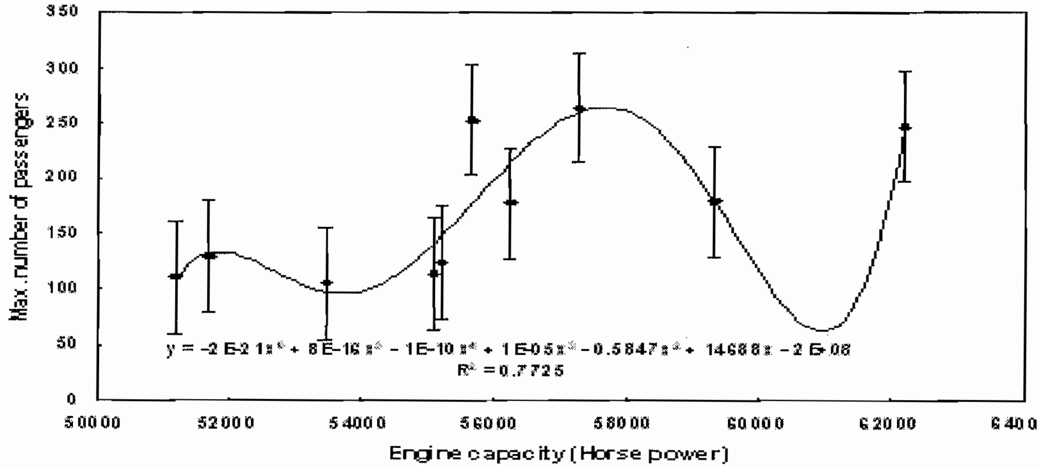


Fig. 2a: Max. number of passengers versus engine capacity of aircraft (Onuu and Obisung, 2005)

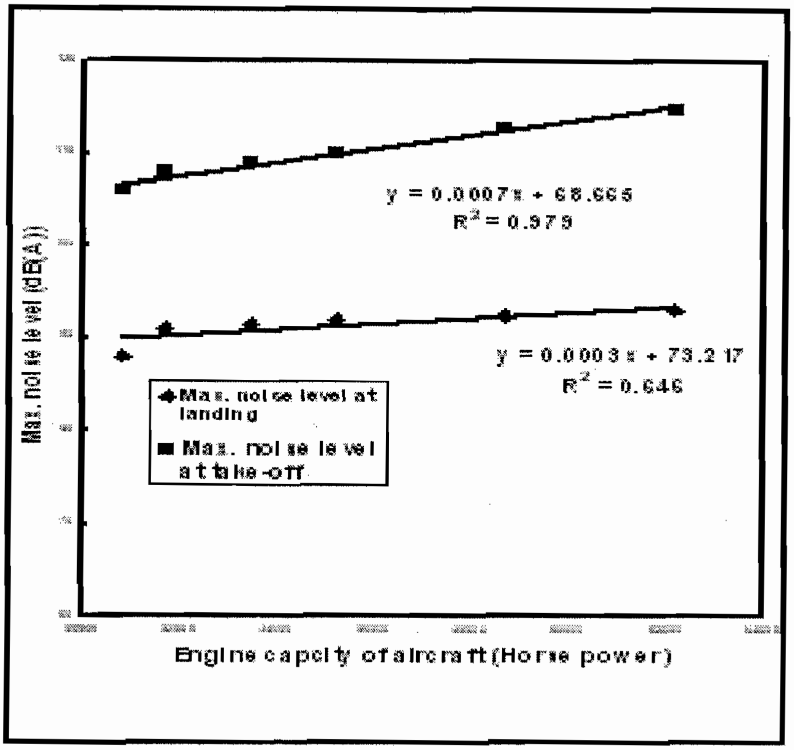
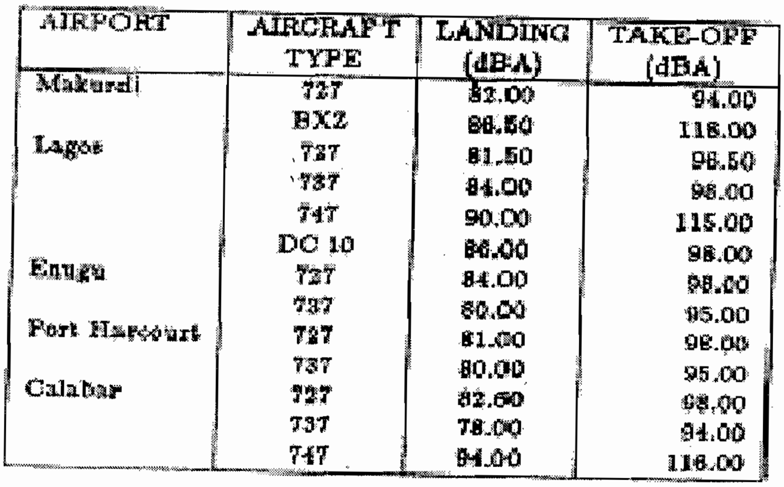


Fig. 2b: Max. noise level of aircraft versus engine capacity (Onuu and Obisung, 2005)

Little attention is paid to the parameters of the aircraft that cause the higher noise levels. Council Directive 89/629/EEC (1989) has expressed the need to further reduce aeroplane noise by taking into account technical feasibility among others. This Directive applies to aeroplanes with a take-off mass greater than 34,000 kg and a capacity of more than 19 seats.

Table 2a: Noise levels of aircraft in some Nigerian Airports during landing and take-off (Menkiti and Ajah, 1993)



AIRPORT	AIRCRAFT TYPE	LANDING (dBA)	TAKE-OFF (dBA)
Makurdi	727	82.00	94.00
	BX2	88.50	118.00
Lagos	727	81.50	98.50
	737	84.00	98.00
	747	90.00	115.00
	DC 10	86.00	98.00
Enugu	727	84.00	98.00
	737	80.00	95.00
Port Harcourt	727	81.00	98.00
	737	80.00	95.00
Calabar	727	82.60	98.00
	737	78.00	94.00
	747	84.00	118.00

Table 2b: Noise and number index (NNI) of aircraft of aircraft during operation (Menkiti and Ajah, 1993).

Airports	**Noise and Number Index**		
	Landing	**Take-off**	**Total (approx)**
Makurdi	**22.30**	**52.53**	**75.00**
Lagos	**28.50**	**51.24**	**80.00**
Enugu	**24.49**	**34.28**	**59.00**
PortHarcourt	**21.05**	**35.05**	**56.00**
Calabar	**29.79**	**51.48**	**81.00**

Table 2c: NNI – bother relation (Menkiti and Ajah, 1993)

NN1	22-30	30-40	40-50	50-66
ANAS Scale	Percentage			
Very much bothered	40	49	62	72
Moderately bothered	35	33	26	18
A little bothered	18	12	09	07

There is a project involving jet engines in order to reduce noise at take-off (Dowling, 2004). This project involves developing a computer model capable of predicting jet noise, improving understanding of noise source mechanisms, and identifying these mechanisms. This silent aircraft initiative (SAI), as it is called, is aimed to have impact on the aerospace industry, and people living near airports by developing designs and operational procedures for a radically type of aircraft. This will be a right step in the right direction in the war against noise, major aviation issue that will become even more pressing in future, with a 300% increase in air traffic forecast by 2020(Dowling, 2004). It has been concluded that the models developed in Nigeria will be useful to aircraft engineers and designer in the quest to *design-out* noise (Onuu and Obisung, 2005).

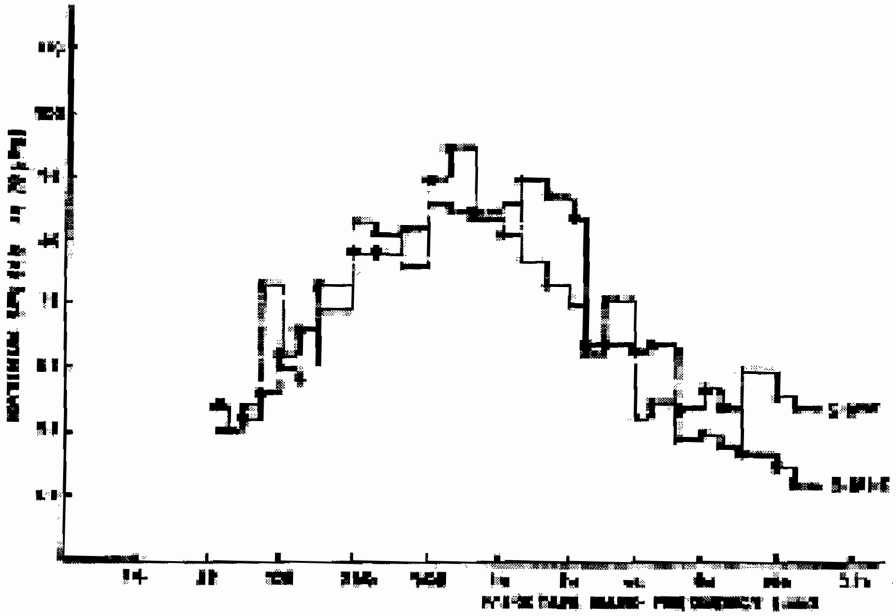


Fig. 3: Road traffic spectrum for Aba (Onuu and Menkiti, 1993)

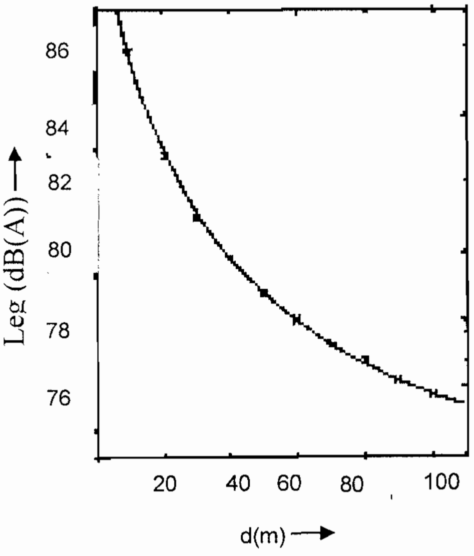
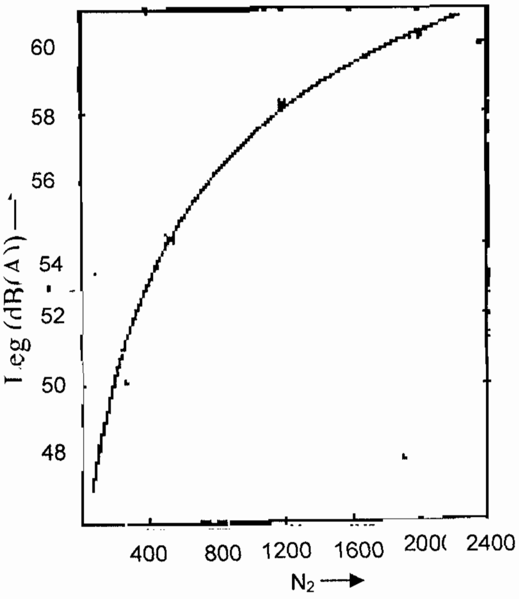


Fig. 4a: Graph of L_{eq} versus d for $N_1 = 3N_2 = 3000$ and $L_{eq}^{(o)} - 50 - 70$ Db(A) (Onuu and Menkiti, 1997)



60

Fig. 4b: Graph of L_{eq} versus N_2, for d = 50m and $L_{eq}^{(o)}$ = 50 – 70 bB(A) (Onuu and Menkiti, 1997)

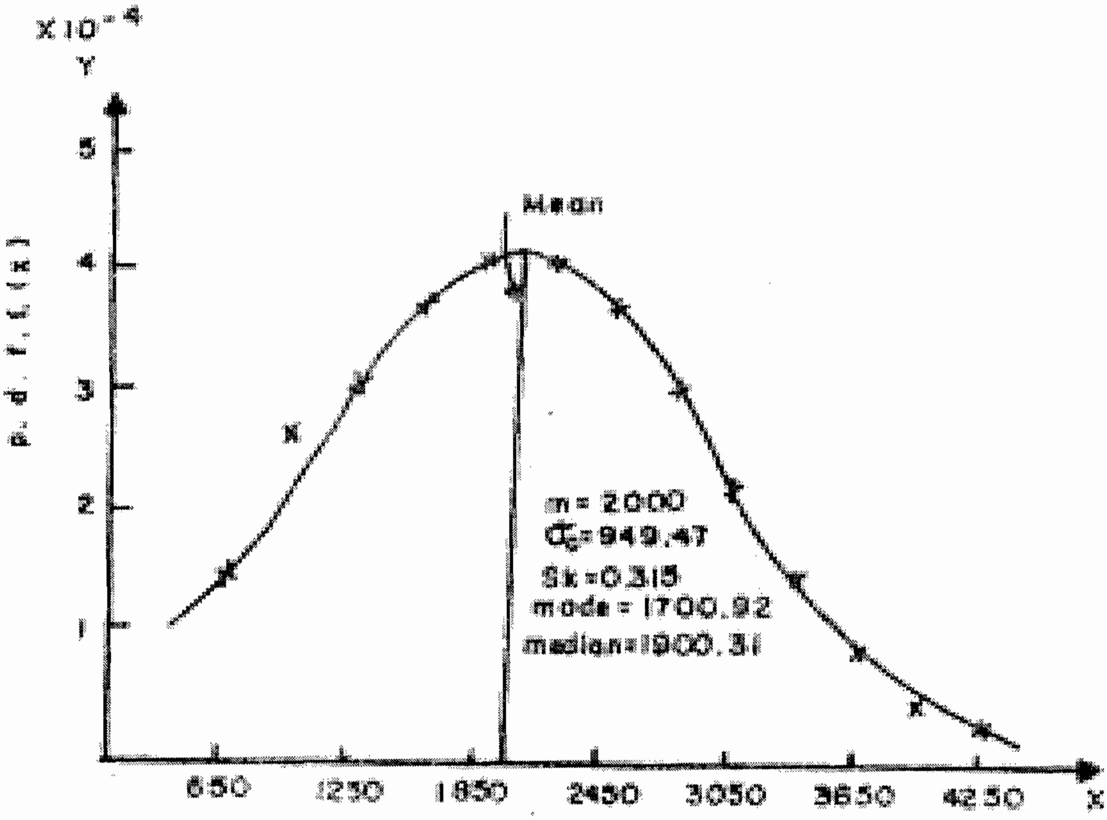


Fig. 5a: Plot of probability distribution function of road traffic in South-Eastern Nigeria (Onuu, 1999b)

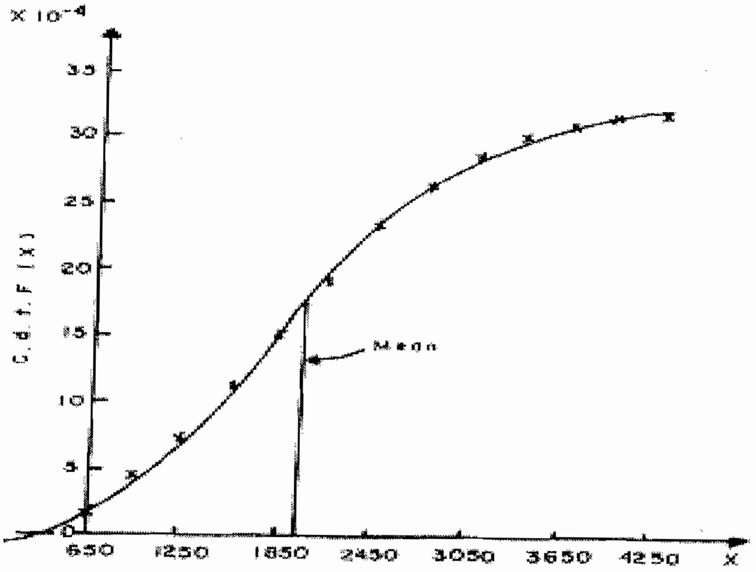


Fig. 5b: Plot of cumulative distribution of road traffic in South-Eastern Nigeria. (Onuu, 1999b)

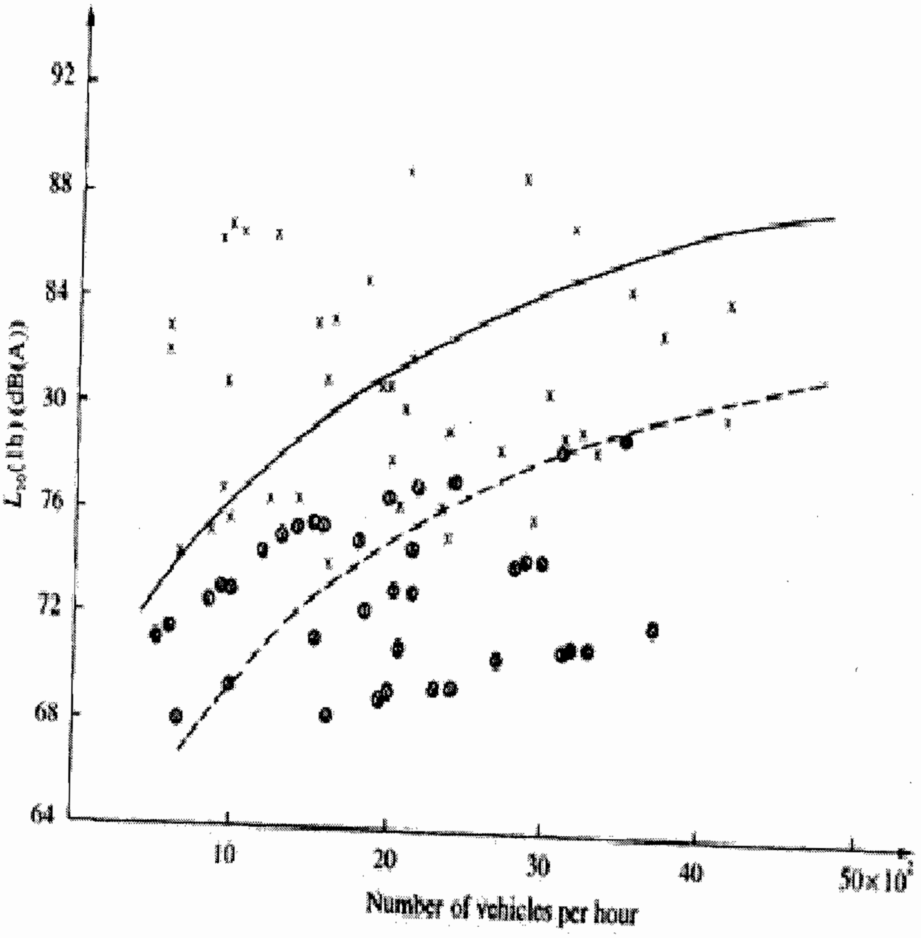


Fig. 6: L_{10} and its relation to the number to the number of vehicles per hour (VPH) ---⊗, calculated level using equation (3) xxxxx, measured values; -------, mean values of measured results (Onuu, 2000b)

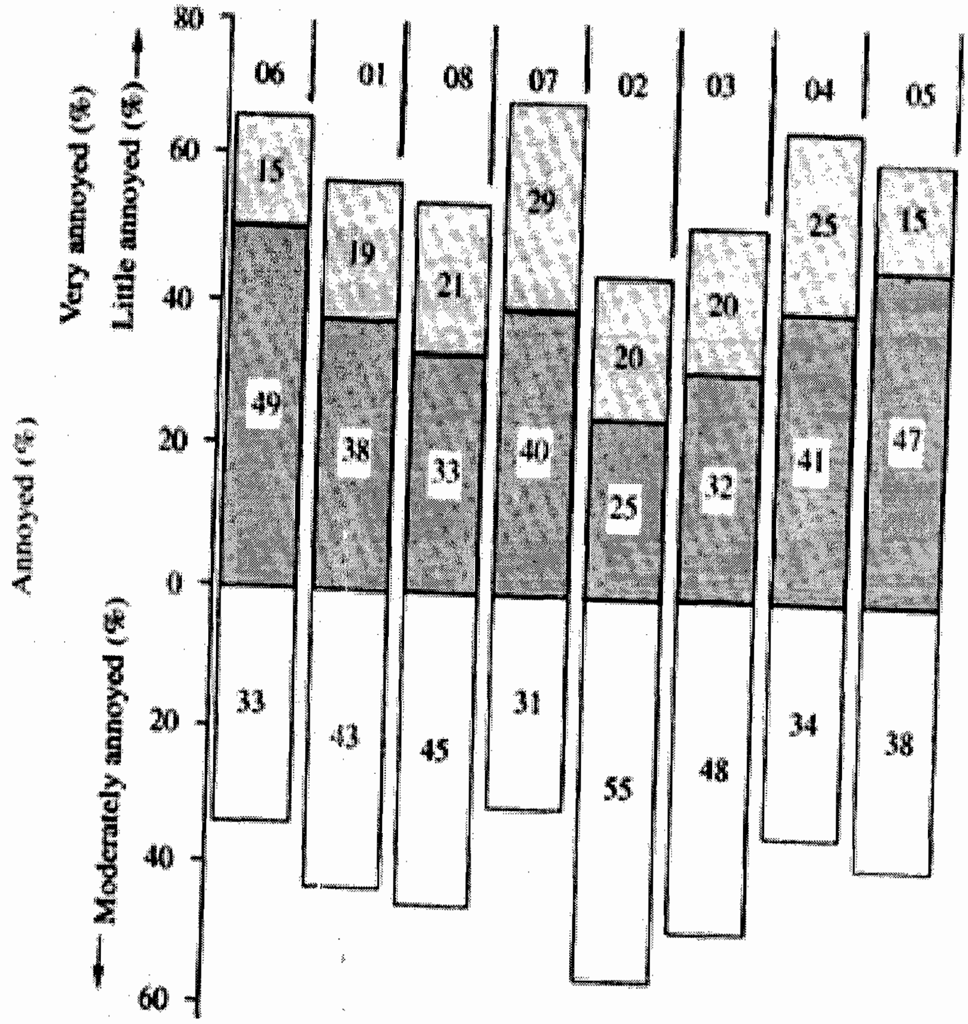


Fig. 7: Feeling about road traffic noise; ▩%, very annoyed; ▨%, little annoyed; ☐%, moderately annoyed. 06 – OWERRI, 01 – ABA, 08- UYO, 07 – PORT HARCOURT, 03 – ENUGU, 04-IKOT -EKPENE, 05 – ONITSHA, 02 – CALABAR. (Onuu, 2000)

Researches on road traffic noise have also been conducted in Nigeria (Onuu and Menkiti, 1993,1996,1997; and Onuu, 1999 and 2000). Figures 3-7 and Tables 3-6 show some of the results obtained in the road traffic noise investigation. From these investigations it was concluded that: road traffic noise is a major environmental problem in South Eastern Nigeria, and noise levels are higher than those measured in cities in well planned and developed countries; road traffic noise has components that are predominantly in the low frequency spectrum (mainly between 500 and 800 Hz) most probably because of the use of low gears in most areas since most of the roads are built on hills; and the spectral acoustic energy distribution could be used to determine the character of a city or the degree of urbanization.

The spectra are within the range of other work (Lewis, 1973) as well as the investigation carried out in Jeddah (El-sharkawy and Aboukhashaba, 1983) and Amman in Jordan, and London (Hammad and Abdelazeez, 1987). Thus, road traffic noise spectrum in South Eastern Nigeria is similar to those of Jeddah, Amman in Jordan, and London.

Table 3a: Results of acoustic power spectral analysis (Onuu and Menkiti, 1997)

	Noise Parameters			
Town/Site*	Power Spectrum W_s(W)	Speed Parameter Rm (Hz^{-1})	Frequency Weighted N_x(W)	Correlation Coefficient R
Aba (01)				
S 011 F	9.31×10^{-5}	2.34×10^{-4}	0.45	-0.1194
S 012 C	1.84×10^{-4}	1.05×10^{-3}	0.12	-0.8124
Calabar (02)				
S 023 F	9.81×10^{-4}	4.56×10^{-4}	0.24	-0.4163
S 024 C	9.66×10^{-5}	7.68×10^{-4}	0.11	-0.5302
Enugu (03)				
S 031 F/C	3.14×10^{-4}	8.33×10^{-4}	0.30	-0.7138
S 032 F	9.14×10^{-4}	9.01×10^{-4}	0.77	-0.7848
Ikot Ekpene(04)				
S 041 F	9.30×10^{-4}	4.86×10^{-4}	2.05	-0.4321
S 042 F	2.15×10^{-4}	8.70×10^{-4}	0.19	-0.6451
Onitsha				
S 052 F/C	5.06×10^{-5}	1.31×10^{-3}	2.10	-0.6957
S 053 F	5.17×10^{-5}	8.99×10^{-4}	0.04	-0.8471
Owerri				
S 061 C	9.86×10^{-4}	6.44×10^{-4}	1.45	-0.8195
S 062 F	7.85×10^{-5}	1.35×10^{-3}	0.30	-0.9898
S 063 F	5.30×10^{-5}	9.86×10^{-4}	3.79	-0.8342
Port Harcourt(07)				
S 071 F	2.03×10^{-5}	7.91×10^{-4}	2.15	-0.4491
S 072 F	9.41×10^{-4}	1.08×10^{-3}	0.57	-0.5922
Uyo (08)				
S 081 F	1.81×10^{-4}	1.00×10^{-3}	0.13	-0.5501
S 082 F	9.69×10^{-5}	1.62×10^{-3}	0.56	-0.8407

*F.C. and FAC indicate sites having free. How congested and fee flow/congested road traffic conditions

Table 3b: Results of acoustic power spectral analysis (Onuu and Menkiti, 1997)*

Parameter	Regression Equation	Correlation Coefficient, R.
Summation Spectrum, $W_s(f)$	$W_s(f) = 2.20 \times 10^{-5} \exp(-0.00134f)$	-0.9956
Spectral Width, z(f)	$Z(f) = 7.83 \times 10^{-2} \exp(-0.0011f)$	-0.9880
Lower bound spectrum, $W_l(f)$	$W_l(f) = 1.84 \times 10^{-4} \exp(-0.00105f)$	-0.8124
Upper bound spectrum, $W_u(f)$	$W_u(f) = 5.30 \times 10^{-5} \exp(-0.00986f)$	-0.8342

*The regressions are valued within the frequency range 50 to 10,000Hz.

Table 4a: Noise levels and noise parameters for the sites (d =8m) (Onuu, 1999a)

No. Of light Vehicles (N_l)	No. Of Heavy Vehicles (N_h)	Equivalent Background Noise Level $L_{eq}^{(o)}$	Background Noise Level Values L_{eq}	
			Measured	Theoretical Values (Equ. 11)
22728	5992	60.0	79.9	73.5
14592	7704	60.2	76.9	73.4
16568	2888	52.4	77.6	71.3
6752	3744	54.0	74.2	70.2
9264	2400	52.0	76.2	69.5
10848	3800	58.0	74.1	71.0
20808	3184	56.4	75.0	72.0
15856	4280	52.8	76.8	72.0
2016	864	50.8	75.8	64.2
5832	4008	54.6	61.2	70.2
7088	4224	58.4	68.6	70.6
9216	1248	56.2	69.0	68.3
10944	2064	56.6	70.8	69.6
11368	4552	54.4	66.6	71.5
7752	6176	56.2	67.5	71.9
13304	8064	56.8	78.7	73.4
14664	3584	58.2	68.1	71.4
8192	4112	60.1	65.8	70.7
12240	5296	58.8	67.4	72.0
25920	6480	59.8	70.2	73.9

Table 4b: Equivalent noise level Leq. calcated using Makarewicz's formula (equation (11) for $L_{eq}^{(o)}$ – 50 to 70 Db(A) (Onuu, 1999a)

No. Of Light Vehicles (N_l)	No. Of Heavy Vehicles (N_h)	Equivalent Noise Level (L_{eq})
2016	192	61.2
1000	500	61.6
3240	800	64.9
4000	2000	67.6
5000	2500	68.6
6000	3000	69.4
8000	4000	70.6
10000	5000	71.6

Fig. 5: Showing sound levels (recorded and calculated) and the percentage of vehicles per hour (Onuu, 2000b)

City	Measured noise levels (dB (A))				Calculated noise levels (dB (A))			Vol. of vehicle per hour (%)				Total no. of vehicle per hour
	L_{10}	L_{50}	L_{90}	L_{max}	L_{10}	L_{eq}	L_{dn}	Heavies	Buses	Cars	Motor cycles	
Aba (01)	85·0	78.4	75·7	104	79·2	80·0	63·0	14·5	12·8	51·8	20·8	3520
Calabar (02)	80·8	75·0	68·0	98	69·9	77·7	62·4	6·3	0·00	25·4	68·3	2376
Enugu (03)	87·8	76·0	63·0	101	72·7	86·3	70·0	14·3	15·0	69·2	1·5	1896
Ikot Ekpene (04)	85·5	77·0	64·2	99	71·2	90·8	69·4	13·5	3·1	60·0	23·1	2493
Onitsha (05)	89·3	82·0	76·4	105	74·1	84·6	68·0	12·8	21·3	58·3	7·6	2820
Owerri (06)	87·5	83·8	80·5	102	72·1	81·2	64·2	4·6	9·6	79·5	10·3	1812
Port-Harcourt (07)	84·5	78·5	73·8	103	80·0	80·4	62·6	8·5	12·9	77·6	3·0	4176
Uyo (08)	80·8	76·1	69·6	100	71·4	78·2	62·8	9·6	10·9	41·0	38·4	3090

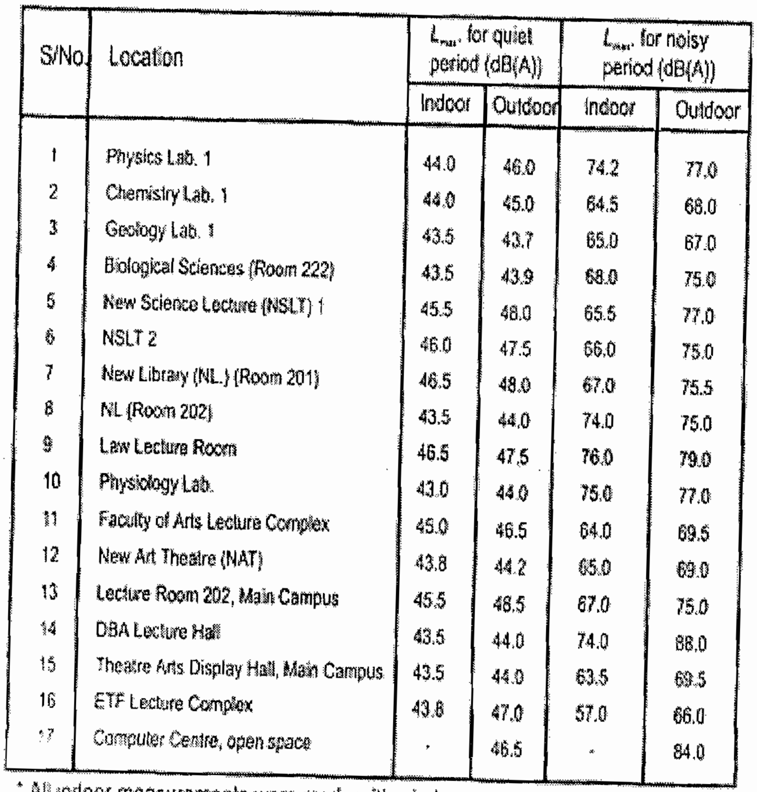
Table 6: Vehicle composition and volume (Onuu, 1999b)

Site code	Volume of vehicle per hour (%)				
	Heavies	Buses	Cars	Motor-cycles	Total
S 011	96(17.8)	36(6.7)	324(60.4)	84(15.6)	540
S 012	433(11.6)	316(8.4)	2841(76.0)	150(4.0)	3,738
S 013	24(1.1)	30(1.4)	1353(63.0)	714(34.5)	2,154
S 014	512(14.5)	451(12.8)	1824(51.8)	733(20.8)	3,520
S 015	329(10.5)	332(10.6)	2071(65.9)	410(13.0)	3,142
S 021	75(6.2)	294(24.1)	663(54.4)	186(15.3)	1,218
S 022	84(4.1)	378(18.7)	844(41.7)	720(35.5)	2,026
S 023	64(6.3)	0.00(0.00)	216(25.4)	582(68.3)	857
S 024	42(2.2)	24(1.3)	804(42.3)	1020(54.0)	1,890
S 025	30(1.3)	270(11.4)	1158(48.7)	918(38.6)	2,376
S 026	54(2.5)	168(7.7)	780(35.6)	1176(54.0)	2,178
S 027	48(2.6)	198(10.5)	666(35.4)	972(51.6)	1,882
S 031	39(2.1)	435(22.9)	1356(71.5)	66(3.5)	1,896
S 032	114(14.3)	120(15.0)	552(69.2)	12(1.5)	796
S 033	30(1.9)	162(10.5)	1158(75.1)	192(12.6)	1,542
S 034	6(0.007)	126(14.3)	678(76.9)	72(8.2)	888
S 035	137(4.1)	261(7.8)	2601(77.8)	621(18.6)	3,345
S 036	311(10.8)	224(7.8)	1982(69.0)	356(12.4)	2,872
S 041	108(13.5)	24(3.1)	468(60.0)	180(23.1)	785
S 042	96(17.4)	12(3.2)	252(45.7)	194(34.8)	552
S 043	294(11.8)	287(11.5)	1300(52.9)	592(23.7)	2,493
S 051	162(11.4)	339(23.8)	729(51.3)	192(13.5)	1,422
S 052	108(5.3)	450(22.2)	1248(61.5)	222(10.9)	2,028
S 053	216(14.2)	312(20.1)	882(56.0)	111(7.3)	1,521
S 054	542(17.1)	571(18.1)	1823(57.7)	226(7.1)	3,162
S 055	361(12.8)	602(21.3)	1644(58.3)	213(7.6)	2,820
S 061	54(3.3)	102(6.3)	1152(71.6)	300(18.7)	1,608
S 062	60(4.4)	24(1.8)	996(73.1)	282(20.7)	1,362
S 063	84(4.6)	174(9.6)	1368(75.5)	186(10.3)	1,812
S 064	326(15.0)	243(11.2)	1421(65.3)	186(8.5)	2,176
S 065	376(19.9)	396(20.9)	969(51.2)	151(8.0)	1,898
S 071	354(8.5)	456(10.9)	3240(77.6)	126(3.0)	4,176
S 072	102(6.8)	444(29.6)	840(58.0)	84(5.6)	1,500
S 073	102(15.1)	60(8.9)	480(71.4)	30(4.5)	673
S 074	467(15.1)	541(17.5)	1663(53.8)	419(13.6)	3,090
S 075	251(9.2)	197(7.2)	1833(67.4)	432(15.9)	2,718
S 081	12(6.4)	48(6.5)	360(48.9)	316(42.9)	734
S 082	60(6.4)	60(6.4)	384(41.0)	432(46.2)	939
S 084	241(9.6)	273(10.9)	1024(41.0)	960(38.4)	2,498
S 084	301(9.4)	361(11.2)	1530(47.6)	1024(31.8)	3,216

4.2.4 Community/indoor noise

Quite a number of investigations on community noise have been conducted in Nigeria. Some of them are those of Menkiti (1979b,1985a) Abumere *et. al.*, (1999), Asuquo *et al.*, (2001), and Onuu and Inyang (2004). Outdoor day-night levels, L_{dn}, were calculated in the University of Calabar. Noise levels in the University of Calabar at different locations are shown in Table 7. These varied from minimum of 71.9 to a maximum of 81.7dB(A). A new set of empirical relationships between sound pressure levels and objectionable qualities of sound are shown in Table 8. A minimum indoor, $L_{max.}$, for quite period of 43.0 and a maximum of 48.0 dB(A) were measured (Table 8).Table 8 also shows minimum and maximum out-door values of L_{max}. for noisy (peak) period of 63.5 and 84.0dB (A) respectively. $L_{max.}$ in churches were found to be as high as 100 dB (A) sometimes. The results of the acoustical and social surveys have led to the conclusion that although environmental noise poses a serious threat and bodes ill to Nigerian Universities, noise levels inside class room are lower than those measured in the new industrialized countries and sentence intelligibility is still as low as 45% in most locations within which sentence intelligibility will not be negatively affected in class rooms (McNulty, 1987).

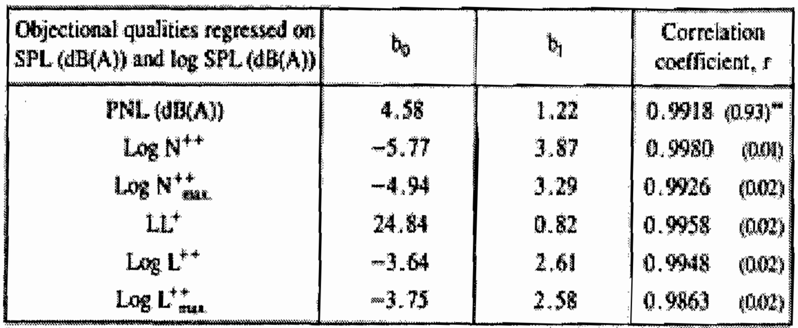
Table 7: Maximum noise levels at various locations in the University of Calabar (Onuu and Inyang, 2004)



S/No.	Location	L_{max}. for quiet period (dB(A))		L_{max}. for noisy period (dB(A))	
		Indoor	Outdoor	Indoor	Outdoor
1	Physics Lab. 1	44.0	46.0	74.2	77.0
2	Chemistry Lab. 1	44.0	45.0	64.5	68.0
3	Geology Lab. 1	43.5	43.7	65.0	67.0
4	Biological Sciences (Room 222)	43.5	43.9	68.0	75.0
5	New Science Lecture (NSLT) 1	45.5	48.0	65.5	77.0
6	NSLT 2	46.0	47.5	66.0	75.0
7	New Library (NL.) (Room 201)	46.5	48.0	67.0	75.5
8	NL (Room 202)	43.5	44.0	74.0	75.0
9	Law Lecture Room	46.5	47.5	76.0	79.0
10	Physiology Lab.	43.0	44.0	75.0	77.0
11	Faculty of Arts Lecture Complex	45.0	46.5	64.0	69.5
12	New Art Theatre (NAT)	43.8	44.2	65.0	69.0
13	Lecture Room 202, Main Campus	45.5	48.5	67.0	75.0
14	DBA Lecture Hall	43.5	44.0	74.0	88.0
15	Theatre Arts Display Hall, Main Campus	43.5	44.0	63.5	69.5
16	ETF Lecture Complex	43.8	47.0	57.0	66.0
17	Computer Centre, open space	-	46.5	-	84.0

* All indoor measurements were made with windows open.

Table 8: Parameter estimates of regression lines* (Onuu, 1999)



Objectional qualities regressed on SPL (dB(A)) and log SPL (dB(A))	b_0	b_1	Correlation coefficient, r
PNL (dB(A))	4.58	1.22	0.9918 (0.93)**
Log N^{++}	−5.77	3.87	0.9980 (0.01)
Log N^{++}_{max}	−4.94	3.29	0.9926 (0.02)
LL^{+}	24.84	0.82	0.9958 (0.02)
Log L^{++}	−3.64	2.61	0.9948 (0.02)
Log L^{++}_{max}	−3.75	2.58	0.9863 (0.02)

*Equation estimated is $y = b_1x + b_0$, where y = a particular objectionable quality, x = SPL (dB(A)) (for+) or log SPL (dB(A)) (for++) being regressed on.

**Numbers in parentheses are standard errors of parameter estimates.

Results of indoor noise studies by Onuu (1999) have led to the spectral plots of typical indoor noises and the development of new set of empirical relationships between sound pressure levels and objectionable qualities of noise (Figs.8-10).

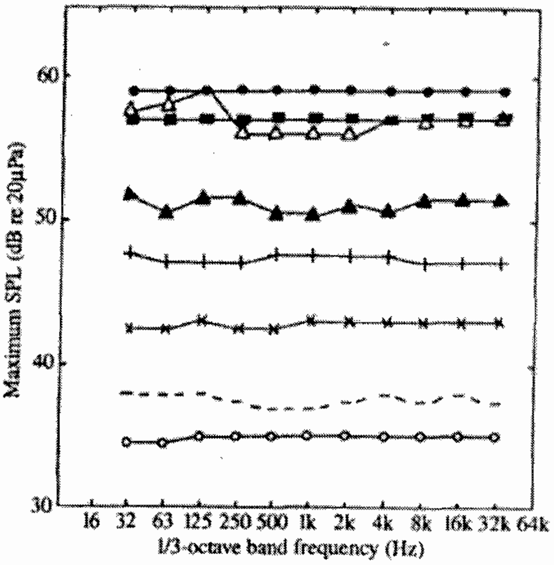


Fig. 8:

Indoor noise spectra. (Onuu, 1999a)

○ – water flowing into WC tank;
- - - - – frying
× – water running into a bath;
+ – flushing of WC toilet;
▲,△ – grinding in kitchen (▲, with load; △ without load) and
■,● – power change-over (■, TV receiver; ●, radio receiver.

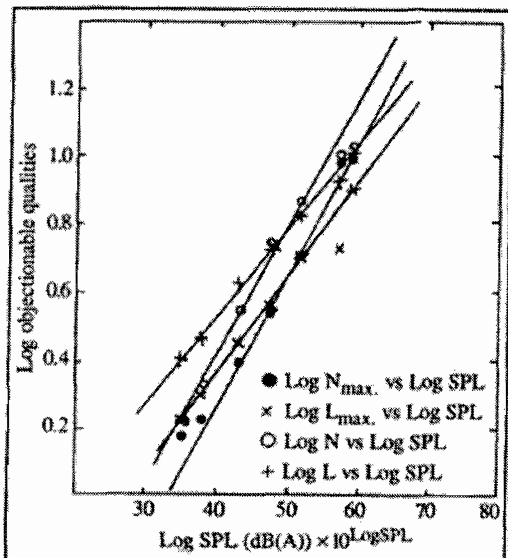


Fig. 9: Objectionable qualities vs SPL (Db(A) Log-log plot (Onuu, 1999a)

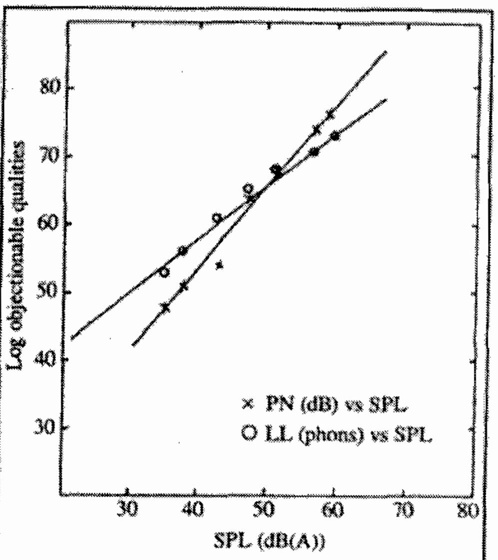
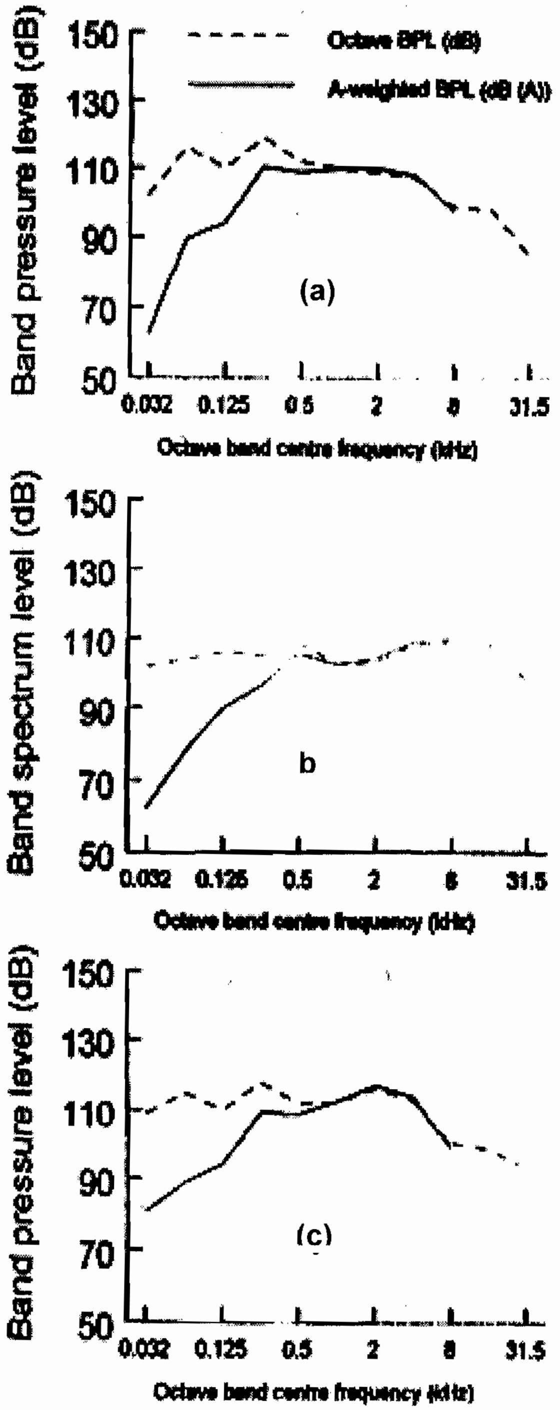


Fig. 10: Objectionable qualities (PN and LL) vs SPL (Db(A) (Onuu, 1999a)

4.2.5 Industrial and occupational noise

Industrial and occupational noise is another favoured area of research in this country. This started with the work of Menkiti (1994) who conducted noise studies an oil drilling environmental. Following was the work of Onuu *et al.* (1996) on spectral analysis of industrial noise in Calabar, Nigeia. Others include those of Onuu (2002), Akpan *et al.* (2003), Akpan and Onuu (2004), Onuu and Tawo (2005), Onuu and Akpan, (2006) and Olaminiokuma *et al.* (2007).



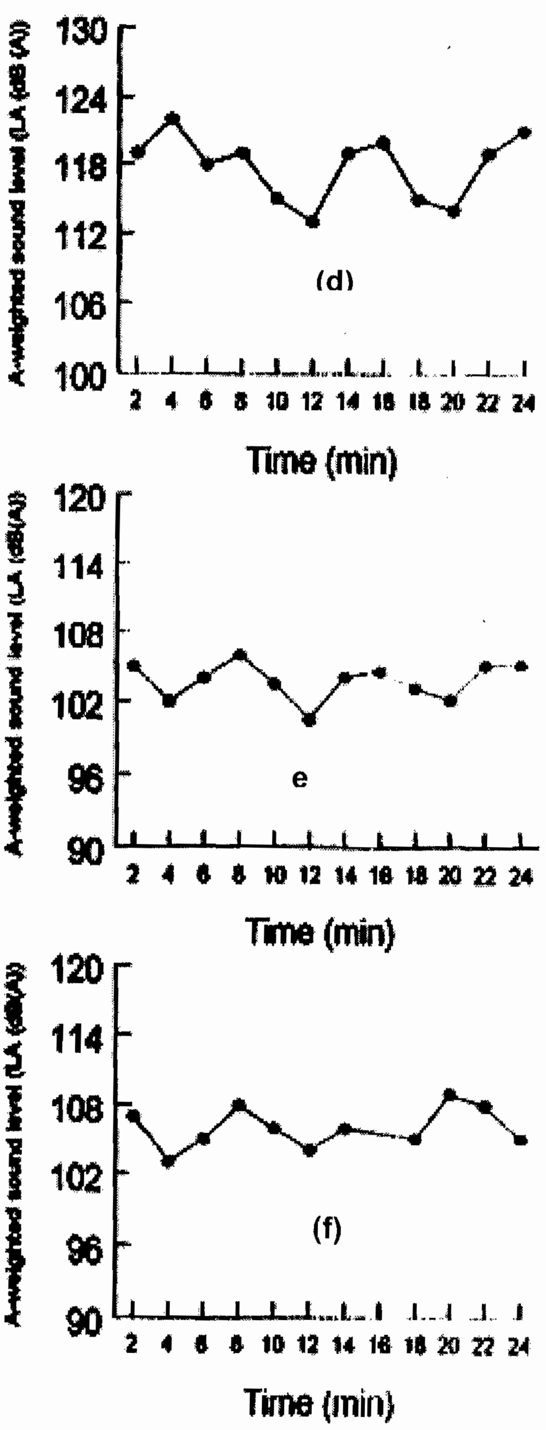


Fig. 11(a – c): Noise spectrum for Crush Rock Company, Akamkpa Cross River State. Peacock Paints Ltd. Etinan, Akwa Ibom State and Bertola Machine Tools Ltd. Port Harcourt, Rivers State, respectively (Akpan and Onuu, 2004).

Fig. 11(d-f): Temporal pattern of noise for Crush Rock company, Akamkpa. Cross River State Peacock Paints Ltd, Etinan, Akwa Ibom State and Bertola Machine Tools, Ltd Port-Harcourt, Rivers State respectively (Akpan and Onuu, 2004).

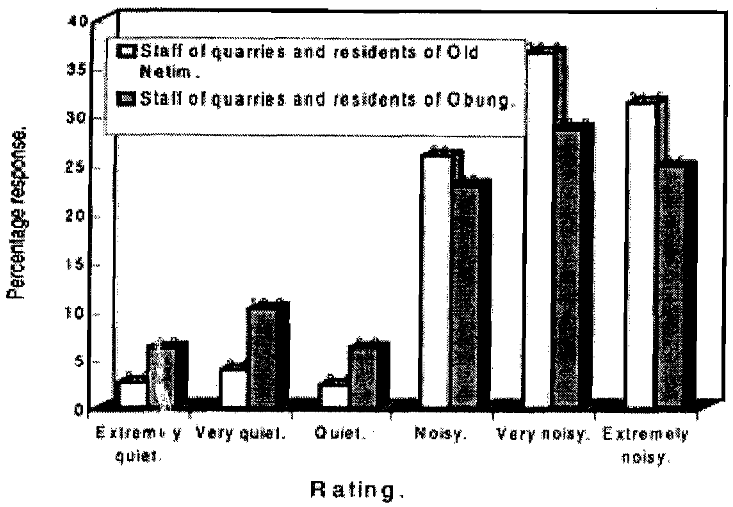


Fig. 12a: Rating of noise by quarry staff and community residents (Onuu and Tawo, 2005)

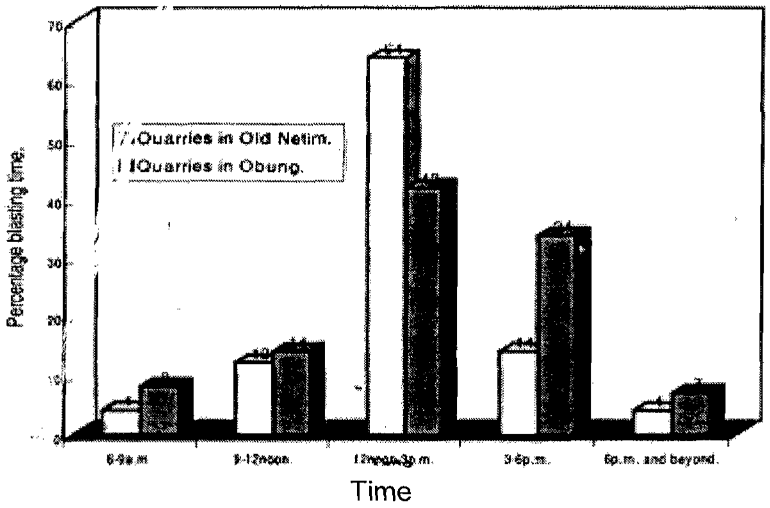


Fig. 12b: Rock blasting by the quarries (Onuu and Tawo, 2005)

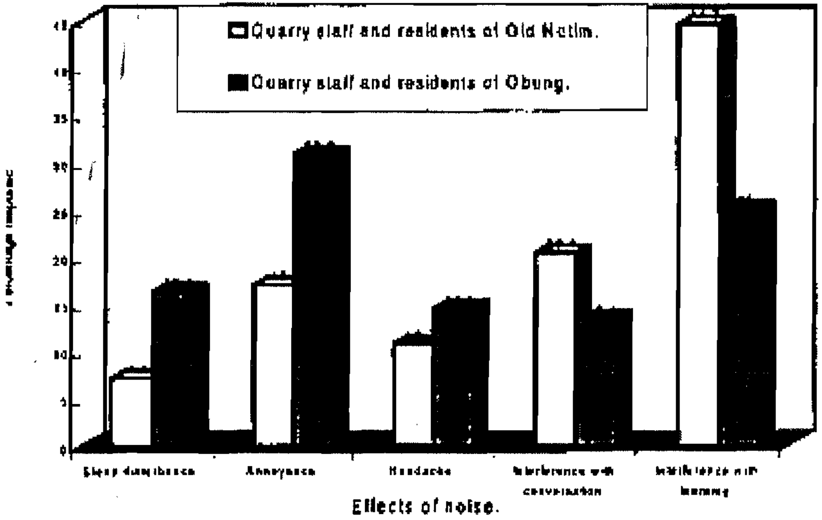


Fig. 12c: Effect of noise on quarry staff and community residents (Onuu and Tawo, 2005)

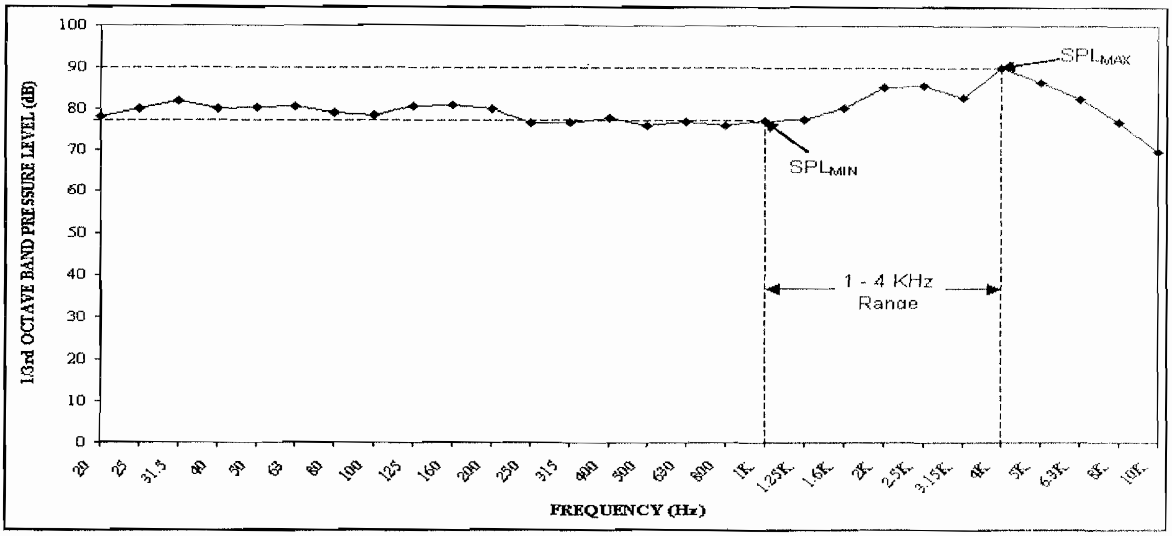


Fig. 13a: Noise spectrum for zone 2 (Olaminiokuma *et al.*, 2007)

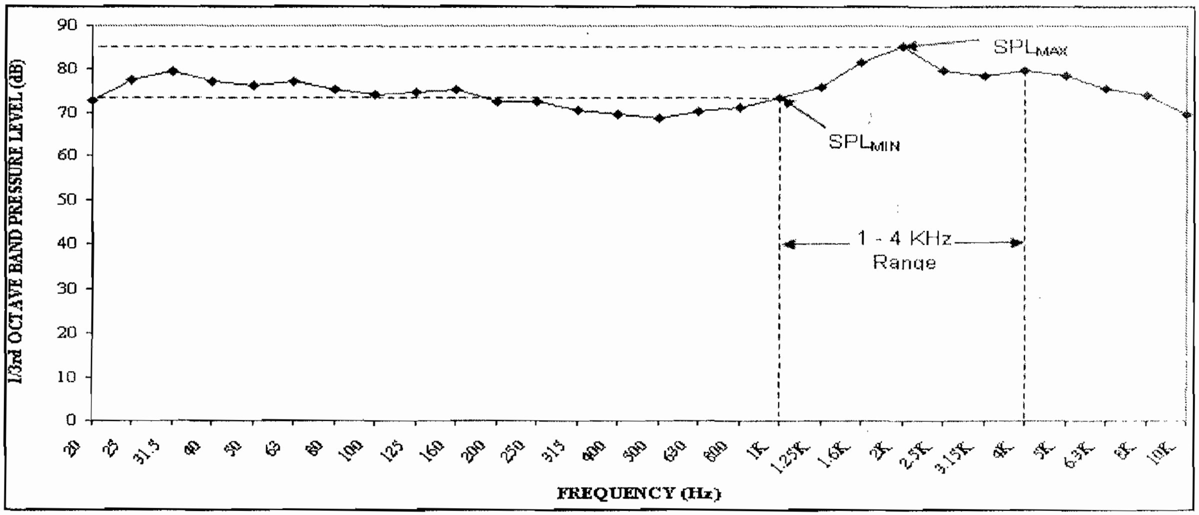


Fig. 13b: Noise spectrum for zone 3 (Olamininiokuma *et al.*, 2007)

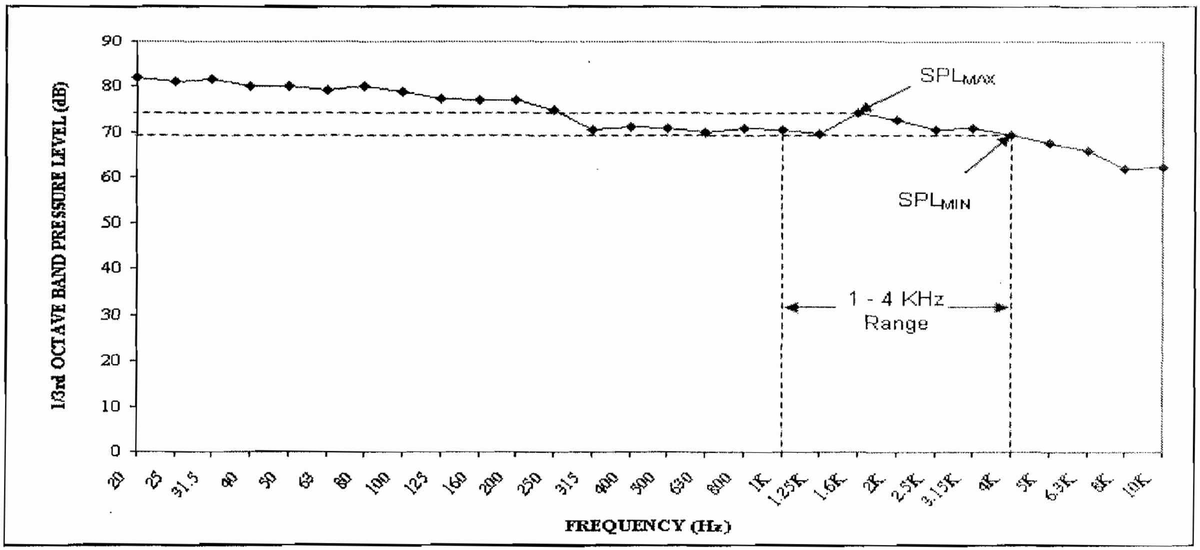


Fig. 13c: Noise spectrum for zone 4 (Olaminiokuma *et al.*, 2007)

Some of the results obtained in these investigations are shown (Figs.11-13 and Tables 9-13). From these results, the following conclusions were made: industrial/occupational noise in South – Eastern Nigeria is a significant problem for many workers as the levels are well above permissible noise exposure limits for the country, Industrial workers should be provided with ear protection devices and should be paid compensation by employers, among others.

Table 9: Industries in south-eastern Nigeria included in Industrial noise survey (Onuu and Akpan, 2006)

S/No	Industry	Activity
	A. Cross River State	
1.	Strabag Company, Old Netim, Akamkpa	Road construction
2.	Crushed Rock Company, Old Netim, Akamkpa	Stone breaking
3.	Hi-tech Company, Old Netim, Akamkpa	Stone breaking
4.	Pamol (Nig.) Ltd, Calabar	Rubber production
5.	Pamol, Plastic Division, Calabar	Plastic production
6.	System Metal Company, Calabar	Roofing sheets production
7.	Mechanical Workshop, University of Calabar	Cutting, fitting and welding
8.	Bao Yoa Huan Jian Iron/Steel Co. Calabar	Iron and steel production
9.	Kevin Wood Industry, Calabar	Wood processing
10.	Ayos Wood Int'l Company, Calabar	Wood processing
11.	Larna Gold Industry, Calabar	Textile production
12.	Niger Mills Company, Calabar	Flour production
	B. Akwa Ibom State	
13.	AK- RUWATSAN, Uyo	Bore-hole drilling
14.	Plasto-Crown (Nig.) Ltd., Uyo	Plastic making
15.	Agrofeed Mills (Nig.) Ltd., Uyo	Animal food production
16.	Peacock Paints Ltd., Etinan	Paint production
17.	Uso Metal Construction Co., Ikot-Ekpene	Metalwork and welding
18.	Samcolee Construction Co., Ikot-Ekpene	Metalwork and welding
19.	Ibok Construction Co., Ikot- Ekpene	Metalwork and welding
	C. Rivers State	
20.	Snig (Nig.) Ltd., Trans-Amadi, Port Harcourt	Machine tool manufacturing
21.	ACM (Nig.) Ltd; Trans-Amadi, Port Harcourt	Machine tool manufacturing
22.	Bertola Machine Tools (Nig.), Port Harcourt	Machine tool manufacturing
23.	Galloa (Nig.) Ltd., Trans-Amadi, Port Harcourt	Machine tool manufacturing
24.	Eastern Bulkcem Cement, Port Harcourt	Cement production
25.	Crushed Rock Company Ltd., Port Harcourt	Stone breaking
26.	Zenith Plastic Company Ltd., Port Harcourt	Plastic making
27.	Port Harcourt Flour Mills, Port-Harcourt	Flour production.

Table 10: Permissible noise exposure time per day allowed under the limit 90 dB(9A) (Shaikh, 1999)

90	8	00	00
91	6	00	00
92	5	00	00
93	4	00	00
94	3	00	00
95	2	30	00
96	2	00	00
97	1	30	00
98	1	15	00
99	1	00	00
100	0	45	00
101	0	37	30
102	0	30	00
103	0	22	30
104	0	18	45
105	0	15	00
106	0	11	15
107	0	09	23
108	0	07	30
109	0	05	38
110	0	04	42
111	0	03	45
112	0	02	49
113	0	02	21
114	0	01	53
115	0	01	25

Table 11: Occupational noise levels in south-eastern Nigeria, working schedule, permissible exposure time and percentage of over exposure per day (Onuu and Akpan, 2006)

S/N	Industry	A-Weighted SPL dB(A)	Working schedule (h/week)	Permissible exposure time (h/day)			*Permitted duration (hrs)	Percentage of overexposure per day
				hr	mm	sec.		
	A. Cross River State							
1.	Strabag Company	120	30–60	0	00	00	0 (0)	>33798
2.	Crushed Rock Company	116	30–60	0	00	00	0 (0)	>33798
3.	Hi-tech Company	119	30–60	0	00	00	0 (0)	>33798
4.	Pamol (Nig.) Ltd	123	40	0	00	00	0 (0)	>33798
5.	Pamol Plastic Division	113	40	0	02	21	15min(15)	20308
6.	System Metal Company	112	40	0	02	49	2(≥150)	16958
7.	W/Shop, University of Calabar	102	40	0	30	00	1(3)	150
8.	Bao Yoa Huan Jian Iron/Steel Co.	111	45–60	0	03	45	4min(1)	12700
9.	Kevin Wood Industry,	102	30–60	0	30	00	1min(3)	1500
10.	Ayos Wood Int'l Company	110	40	0	04	42	30min(7)	967
11.	Larna Gold Industry	105	30–60	0	15	00	1(7)	3100
12.	Niger Mills Company	129	30–60	0	00	00	0(0)	>33798
	B. Akwa Ibom State							
13.	AK- RUWATSAN	115	40–60	0	01	25	8min(3)	33798
14.	Plasto-Crown (Nig.) Ltd	109	40	0	05	38	1(15)	8421
15.	Agrofeed Mills (Nig.) Ltd	103	40	0	22	30	2(15)	2033
16.	Peacock Paints Ltd	109	40	0	05	38	1(15)	8421
17.	Uso Metal Construction Co.	101	40	0	37	30	30min(1)	1180
18.	Samcolee Construction Company	104	40	0	18	45	15min(1)	2420
19.	Ibok Construction Company	114	40	0	01	53	30min(15)	25378
	C. Rivers State							
20.	Snig (Nig.) Ltd., Trans-Amadi	101	40	0	37	30	30min(1)	1180
21.	ACM (Nig.) Ltd; Trans-Amadi	114	40	0	01	53	30min(15)	25378
22.	Bertola Machine Tools	112	40	0	02	49	2(≥150)	16941
23.	Galloa Ltd.	110	40	0	04	42	15min(3)	10113
24.	Eastern Bulkcem Cement Company	119	40	0	05	38	0(0)	>33798
25.	Crushed Rock Company Ltd.	115	40	0	01	25	8min(3)	33798
26	Zenith Plastic Company Ltd.	107	40	0	09	23	30min(3)	5015
27.	Port Harcourt Flour Mills	127	40	0	00	00	0(0)	>33798

*Numbers in parentheses indicate the number of noise interval exposures per 8-h workday

Table 12: Summary of results (Onuu and Akpan, 2006)

(a): Summary of occupational noise levels in South-Eastern Nigeria.

State	Background noise level (±5dB(A))	A-weighted sound level (±5dB(A))	L_{max} (±5dB(A))	Deafening level (±5dB(A)
Cross River	42.5 - 61.0	101.5 - 129.0	108.5 - 131.0	87.5 - 114.0
Akwa Ibom	45.5 - 64.0	101.0 - 115.0	108.0 - 119.5	86.5 - 100.5
Rivers	45.5 - 68.5	100.5 - 127.0	104.0 - 130.5	86.0 - 112.5

(b): Age distribution of workers in South-Eastern Nigeria

State	**Age distribution (years)** **21-30**	**31-40**	**41-50**	**51-60**	**>60**
Cross River	68	114	35	15	0
Akwa Ibom	45	52	30	2	0
Rivers	58	129	38	3	0

(c): Percentage response of workers to social survey

State	**Percentage response** **Questionnaire Administered**	**Total response**	**Total percentage response**
Cross River	320	233	72.8
Akwa Ibom	155	126	81.3
Rivers	275	227	82.6

(d): Summary of hourly exposure of workers

State	**Exposure (hrs)** **3-5**	**6-8**	**9-11**	**>11**
Cross River	14	160	56	0
Akwa Ibom	1	112	12	0
Rivers	2	225	1	0

(e): Summary of effects of occupational noise

State	**Effects of occupational noise** **Annoyance**	**Headache**	**Dizziness**	**Irritation of the ear**	**Anxiety**	**Disruption to Conversation**	**Sleeplessness**
Cross River	6	74	5	102	12	28	3
Akwa Ibom	8	62	18	17	12	7	2
Rivers	10	125	4	57	0	30	0

(f): Workers' opinion on who should control industrial noise

State	Workers opinion The industry	Government	Workers	Community
Cross River	149	32	26	15
Akwa Ibom	91	34	0	0
Rivers	220	6	0	0

Table 13: Noise levels at various locations in the quarries and environ (Onuu and Tawo, 2005)

Location	Noise levels (dB(A)
* Generator house	96.0 –99.0
* First crusher stage	92.0 – 98.5
Main gate	60.0 – 89.0
Office (inside)	69.0 – 85.0
Office (outside)	74.0 – 88.0
Nearest community house (at façade)	59.8 – 68.0
Primary School	53.0 – 70.2
Administrative managers' offices	50.4 – 56.5
Project managers' offices	51.2 – 69.0
*Drilling blasting point	107.4 – 109.6

* Measurements were made 2 metres from noise source.

4.2.6 Atmospheric and jungle acoustics

Effects of atmospheric attenuation and shielding on road traffic noise along Nigerian highways have been investigated by Onuu (2003). Measurements and prediction of sound pressure band levels using pressure/distance inverse law, and the U.K calculation of road traffic noise (CRTN), 1998, for four (4) sites which included: horizontally separated carriageways, elevated road on grass banks, roads with purpose-built noise barriers and a curved road to which a two segment approximation was applied have been conducted. It was found that: the acoustic energy (for the mixed sources) is at its peak at 32-63 Hz and then decreases at the rate of 5-12 dB per decade above 2 kHz; the dominant low frequency energy observed in the spectra could result from wide-range use of low gears by motorists and Karman vortex sound due to the interaction of wind and stationary objects near the ground such as trees and buildings; prediction and accuracy appears to be better for quite periods than for noisy ones.

Table 14a: Summary of excess noise attenuation by grass and trees (forest) at various octave band centre frequencies and distances (Onuu and Obisung, 2005)

Distance, d(m)	Octave band centre Frequency, f_c (kHz)	Excess noise attenuation, ΔL (dB)		Distance, d (m)	Octave band centre Frequency, f_c (kHz)	Excess noise attenuation ΔL (dB)	
		Grass ΔL_g	Trees (Forest) ΔL_t			Grass ΔL_g	Trees (forest) ΔL_t
50	1	2.0	1.0	150	1	9.0	3.8
	2	2.5	1.3		2	10.3	4.5
	4	3.0	1.5		4	12.5	6.0
	8	3.8	2.5		8	14.8	7.3
	16	4.3	3.0		16	17.0	9.5
100	1	5.5	2.3	200	1	11.3	5.0
	2	6.0	3.0		2	14.3	6.3
	4	8.3	3.8		4	16.0	7.8
	8	10.0	4.8		8	19.8	8.0
	16	10.3	5.8		16	22.0	12.5

Table 14b: Summary of empirical relationships between excess noise attenuation by grass and trees (forest) and octave band centre frequencies at various distance (Onuu and Obisung, 2005)

Regression parameters	Distance from source, d(m)	Regression coefficient		Correlation coefficient, r	Relationship
$\Delta L_g/f_c$		a_0	a_1		
	50	-8.9284	0.9825	0.9976	$L_g = 0.9825 \ln f_c$ 3.9284
	100	-7.2342	1.8959	0.9988	$L_g = 1.8959 \ln f_c$ 7.2342
	150	-11.558	2.9281	0.9998	$L_g = 2.9281 \ln f_c$ 11.58
	200	-15.291	3.8771	0.9999	$L_g = 3.877 \ln f_c$ 15.291
$\Delta L_g/\log f_c$		a_0	b_1		
	50	-3.9484	2.2687	0.9976	$L_g = 2.2687 \log f_c - 3.9484$
	100	-7.2687	4.3776	0.9987	$L_g = 4.3776 \log f_c - 7.2687$
	150	-11.612	6.7612	0.9998	$L_g = 6.7612 \log f_c - 11.612$
	200	-15.362	8.9523	0.9999	$L_g = 8.9523 \log f_c - 15.362$
$\Delta L_t/f_c$		m	n		
	50	0.1372	0.3224	0.9962	$L_t = 0.1372 f_c^{0.3224}$
	100	0.254	0.333	0.9985	$L_t = 0.254 f_c^{0.333}$
	150	0.3619	0.3349	0.9975	$L_t = 0.3619 f_c^{0.3349}$
	200	0.505	0.334	0.9984	$L_t = 0.505 f_c^{0.334}$
$\mathrm{Log}\,\Delta L_t / \mathrm{Log}\, f_c$		k	k^1		
	50	-0.8485	0.3186	0.9946	$\mathrm{Log}\ L_t = 0.3186 \log f_c - 0.8485$
	100	-0.6075	0.337	0.9984	$\mathrm{Log}\ L_t = 0.337 \log f_c - 0.6075$
	150	-0.4672	0.3434	0.9968	$\mathrm{Log}\ L_t = 0.3434 \log f_c - 0.4672$
	200	-0.2836	0.3313	0.9945	$\mathrm{Log}\ L_t = 0.3313 \log f_c - 0.2836$

Table 15: Annoyance level of noise spectra for the entire gas plant (Olaminiokuma *et. al*, 2007)

ZONES / MEASURE OF ANNOYANCE	1 Office and water utility area	2 Trains area	3 Process area	4 Hot oil area	5 Pig Launcher/Receiver and Slug Catcher area	6 LPG Storage area	7 Deluge equipment, Custody meter area
SPL (Max. – Min) in the range[1 – 4 Hz](dB)	5.3	12.7	11.7	5.0	3.8	2.9	7.3

On jungle acoustics, sound propagation of grass (Onuu, 2000c) and modelling of excess noise attenuation by grass and trees (forest) (Onuu, 2006) have been investigated. It was shown that the grass, *panicum maximum* acts as a high pass filter of sound waves propagating over it; the observed excess attenuation at low and mid-frequencies is due to absorption by the grass rather than absorption by air and scattering and that *panicum maximum* can find possible application in environmental noise control. Excess noise attenuation by grass, ΔL_g and trees, ΔL_t, were regressed on the octave band centre frequency, f_c, in order to establish the empirical relationships between them at various distances, *d*, from the noise source. Some conclusions deduced from the work on jungle acoustics are: grass introduces excess noise attenuation about twice that of forest at all frequencies; grass and trees are considered a fairly good noise barrier and so could be used for noise control especially at frequencies between 1,000 and 4000 Hz where the normal human ear is very sensitive; excess noise attenuation rate by grass and tress are characterized by three distinct parts namely, rapid decrease, gradual decrease and constant decrease at octave band centre frequencies of 31.5-8, 000 Hz, 8,000-16,000 Hz and above 16,000 Hz, respectively; the best models for excess noise attenuation and octave band centre frequency is logarithmic for grass while power law is the most appropriate for the family of curves for excess noise attenuation by trees or forest.

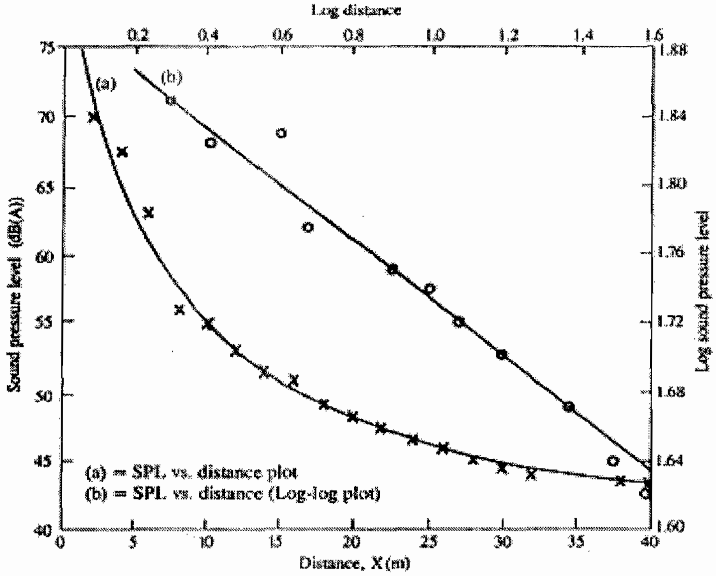


Fig. 14: Plot of sound pressure level against distance from source at the open area; (a) SPL vs. distance plot, (b) Log- log plot (Onuu, 2000d).

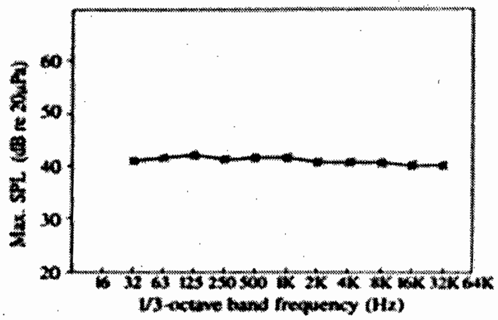
4.3 Future

From the foregoing, it is clear that the future of acoustics in Nigeria is bright. Awareness of the effects of environmental noise pollution and complaint against noise will increase. Legal actions against *noise makers* as more people will be aware that it is their right to quiet and good living will also be on the increase. Many more people are expected to complain about poor sound quality of the churches, studios and halls used for speech making in Nigeria as reverberant sound fields persist.

Railway noise is an aspect of traffic noise that has attracted little or no attention in Nigeria. This is not surprising as transportation by rail is on the decline and near extinction in this country. Despite this, interest has been shown here and there especially in those cities where railway terminal still exists in the country.

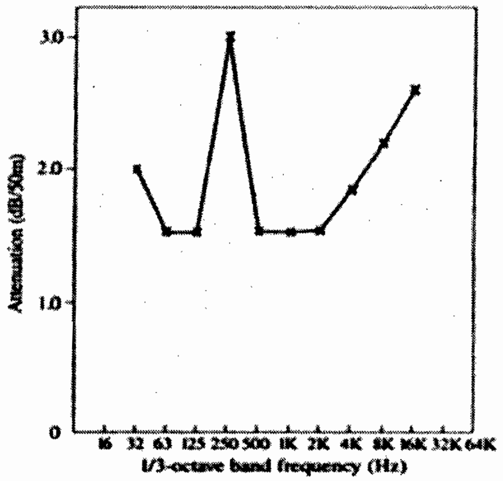
Research on under-water acoustics is expected to receive considerable attenuation in future. Acoustic mapping of ocean (seafloor) for environmental, research, oil and gas exploration, marine and coastal resource management, fishing and other economic interest will likely attract more attention.

Sonar systems are tunable, i.e. they operate at different frequencies. Because of this interesting feature of acoustic systems, the travel time of the acoustic pulse and the strength of the return signals are used to measure the depth to the seafloor (bathymetry), depth to sub-surface sediment layers (sub-bottom), and the *reflectance* of the seafloor (intensity of backscattered energy). The collaborative work between the Department of Physics, University of Calabar, Calabar, Cross River State and the Institute of Oceanography of the same University is likely going to focus more in acoustics especially as some of the students of physical oceanography graduate, proceed for further studies and take up appointments in Universities and Research Institutes in Nigeria.



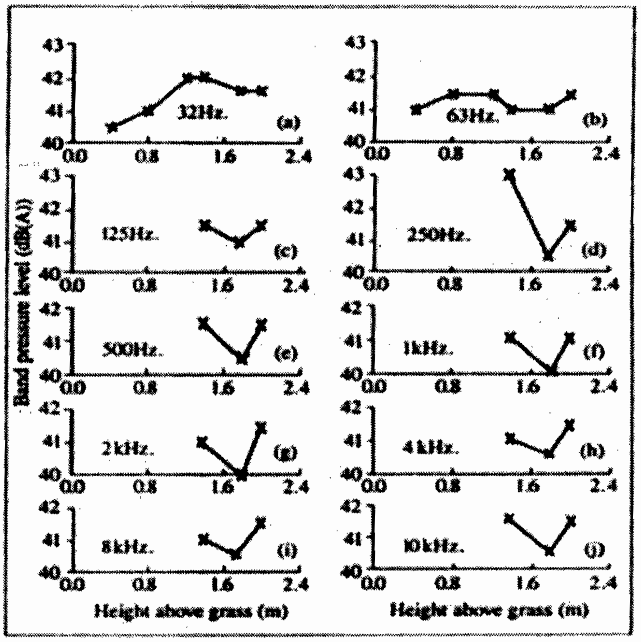
(a)

Noise spectrum of the generator set, at a distance of 50m from source.



(b)

Mean attenuation spectra at height 1.4m above grass (50m from source).



(c)

Band Pressure Level at various heights above the grass.

Fig. 15: Some results on sound propagation over grass (Onuu, 2000d)

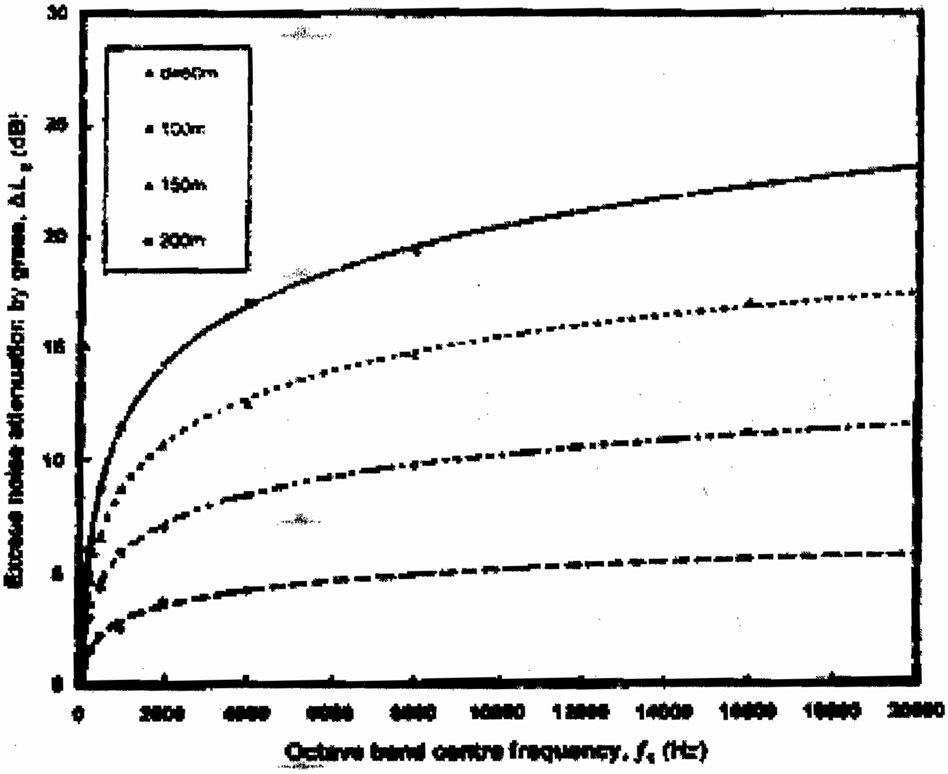


Fig. 16a: Excess noise attenuation by grass at various oclave band centre frequencies and distances (Onuu, 2006)

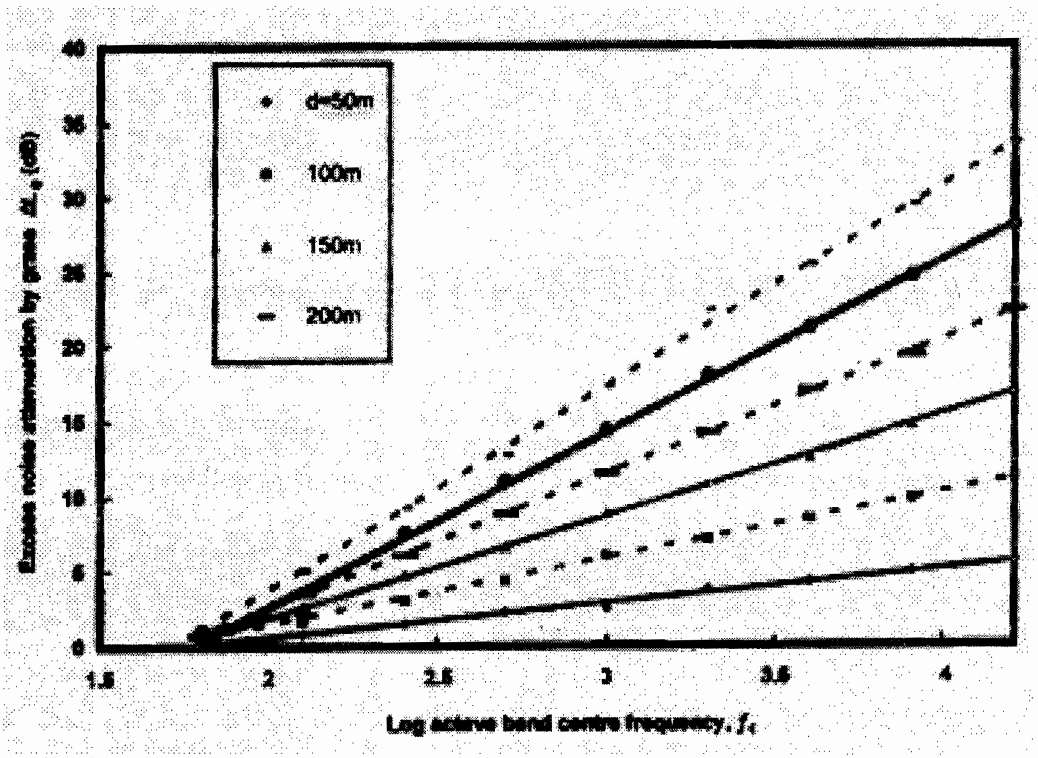


Fig. 16b: Semi log plot of excess noise attenuation by grass at various octave band centre frequencies and distances (Onuu, 2006)

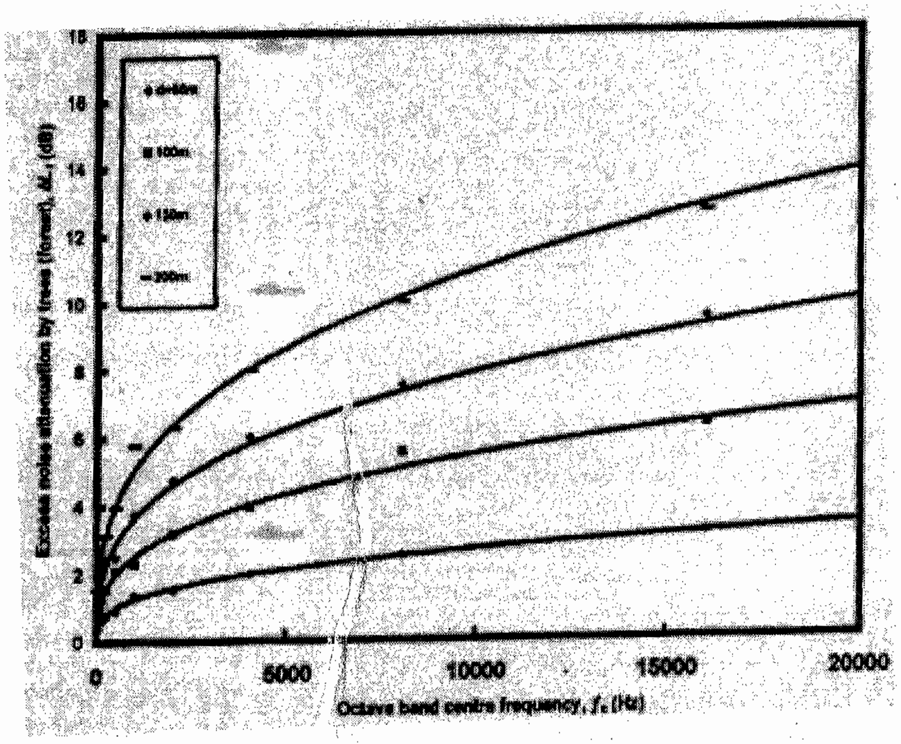


Fig. 17a: Excess noise attenuation by trees (forest) at various octave band centre frequencies and distances (Onuu, 2006)

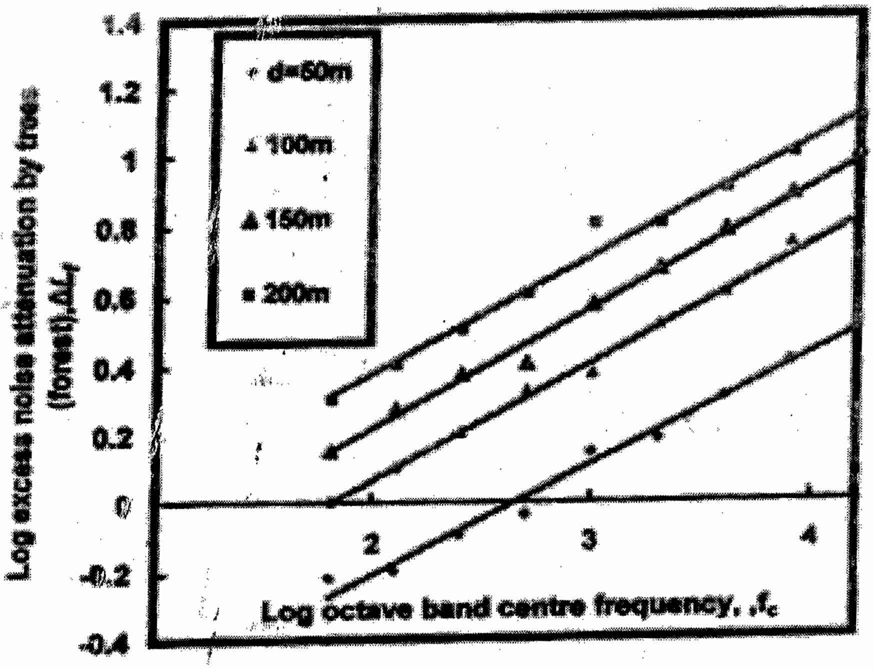


Fig. 17b: Excess noise attenuation by trees (forest) at various octave band centre frequencies and distances (Onuu, 2006)

Generally, as awareness of the physics of acoustics continues, through its introduction as a course or programme in Nigerian Universities and campaign against noise pollution by environmental and occupational noise pollution experts with the cooperation of the press and other stakeholder, research in all aspects of acoustics is likely going to increase in Nigeria.
Finally, there will be the birth of Acoustical Society of Nigeria, (ASN) that will regulate acoustical practice in the country.

5. Conclusion

In attempt to x-ray the status of acoustics in Nigeria, many researchers of various nationalities in acoustical physics have been highlighted. This is followed by a theoretical framework or foundation upon which the results obtained by our Nigerian investigators are based. The efforts of the Federal and State Governments in Nigeria and the Press and some Nigerians in the formulation of anti-noise laws, ordinances and other governmental acoustical matters that bother on noise have been discussed. Some research findings in acoustics in this country have been presented; and the future of acoustics in Nigeria discussed.

Acknowledgement

The author wishes to thank all those whose materials have been used in this study.

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