Experimental Investigation of Industrial Noise Intrusion in the Residential Areas as an Effect of Settlement Pattern and Land Use Planning

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Abstract

This study investigated the intrusion level of industrial noise from five factories in 40 surrounding residences in Anambra state, Nigeria as an effect of settlement pattern and land use planning. Three categories of measurements were considered: engagement of electric power generators, job operation dependency on the national on-grid connection – Power Holding Company of Nigeria (PHCN), and off-work hours. All measurements were conducted in compliance with the Nigerian Environmental Standards and Regulation Enforcement Agency using a digital sound level meter. A-weighted equivalent sound pressure level (LA_{eq}) for the measured noise levels at each assessed residence was evaluated. The result showed the following LA_{eq} value ranges: 63.2 - 78.7 dBA for factory operations during generator use; 44.5 - 62.9 dBA for PHCN use; and 41.1 - 59.7 dBA for off-work hours. Based on the recommendations from the World Health Organization and the US Department of Housing and Urban Development for acceptable noise levels in residential areas, the analysis of the data showed that significant unacceptable noise levels were present only during generator use, leading to issues of temporal hearing impairment and moderate to serious levels of annoyance. The multiple independent t-tests analyses of the LA_{eq} categories disclosed $p < 0.05$ – significant in all cases. This study concluded that clustered and intermixed development of the residences and industries in the same area can create significant noise hazards for the residential areas.

***Keywords**:* noise, generator, grid-connection, residences, factories, dBA

1. Introduction

Various environmental and human health problems that endanger populations' standard of living and psychological well-being stem from the physical forms and functional roles of land use in that particular environment. Virtually, all cities in the world have their own peculiarities in their historical origins, some degree of formal planning, growth patterns, economic structure and levels of infrastructure (Izueke and Eme, 2013).

One of the safety aspects that urban development planning covers is noise pollution, which has become a major fallout of rapid urbanization, population growth, industrialization, and technological innovation. Azodo and Adejuyigbe (2013) pointed out that most urban areas from developing countries are besotted with enormous amounts of noise pollution from on-road vehicles, industrial equipment and tools, and electricity generating plants. Many studies have identified the major sources of noise pollution, the causation factors and the effects on both human populations and the environment (Bisong *et al.*, 2004; Otutu, 2011; Oguntoke *et al.*, 2012; Aderoju *et al.,* 2013; Azodo *et al.*, 2018a).

The generator use factor has demonstrated a predominant use of portable generators within the residential, commercial, administrative and educational sectors (Azodo and Adejuyigbe, 2013; Babawuya *et al.*, 2016; Onwuka *et al.*, 2017; Azodo *et al.*, 2018b). Studies found that power generator noise is a major contributor to environmental noise pollution wherever they are used (Iqbal and Lodhi, 2014; John and Dewan, 2015). Typically, diesel generators are widely used in many areas where electrical power is unreliable or non-existent. Diesel generators are utilized as supplement to the main power supply or as the main power supply itself, as well as emergency backup for hospitals, banking sectors, learning institutions and telecommunication networks (Aderoju *et al.,* 2013; Nwogu *et al.,* 2017). Irrespective of the need and purpose, generator use has been regulated as to its healthy dose exposure rate to noise (Association of Municipal Electricity Undertakings [AMEU] – South Africa, 2015).

The Nigerian Environmental Standards and Regulation Enforcement Agency (NESREA) identified the unlawful production of noise as a punishable criminal offense. The said agency has also prescribed regulations on the maximum permissible noise levels of a facility or activity to which a person may be exposed, as well as the noise control and mitigation measures to ensure maintenance of a healthy environment for all Nigerian people. For a healthy residential environment, the maximum permissible noise level set by this body is 60 dBA in the day-time and 40 dBA at night (10:00 PM to 6:00 AM) (Federal Republic of Nigeria Official Gazette, 2009).

Noise, as an acoustic contaminant, and aural litter or audible trash, demands that its source(s) should be identified and evaluated in order to establish and implement efficient means for communicating impact information, applying control actions and mitigation measures, and thus decreasing the potential adverse effects. Once noise levels are measured, the identification and rank order of the noise sources responsible for the excessive noise is determined, and the required reductions are subsequently identified (Hansen and Goelzer, 2001). Unpleasant or unwanted outdoor noise in the environment disrupts human activity (Ohwovoriole *et al.*, 2016). The range of possible outdoor noise levels is extremely large – ranging from the tranquil quiet of the wilderness to the noisy urban environment (Goodfriend, 1977). Mohd (2011) put forth that most people are affected by noise exposure more than any other environmental stimulus. When the ambient noise level is caused to rise above the designated zone level or ambient noise level in a particular district, then it is termed disturbing noise (AMEU – South Africa, 2015). Tranquility is a fundamental environmental health factor for residential areas – elevating populations' standard of living and their psychological well-being. The persistent intrusion of high noise levels might deprive populations of one, or both, of these benefits. As stated by Awofeso (2010), the proximity of generators to homes and prolonged duration of use can pose significant risks to human health and to the environment. Within this context, this study investigated the levels of industrial noise intrusion in the residential areas, located around factories in Anambra state, in accordance with the acceptable noise limits as established by the US Department of Housing and Urban Development (HUD) using an experimental survey design.

2. Methodology

2.1 Geographical Information of the Study Area

Anambra state is one of the five South Eastern states out of the 36 states that compose Nigeria (Latitudes 5° 47' N and 6° 48' N, Longitudes 6° 38' E and 7° 21' E). As per the 2006 National Population Census, Anambra has a population of 4,182,032 (2,007,391 males and 2,174,641 females) making it the ninth most populous state nationwide (Ugonabo and Emoh, 2013).

With a total land mass of 4,416 km, Anambra is bounded by Enugu to the East, Delta to the West, Imo to the South, and Kogi to the North. The state has 177 communities (towns) in 21 local government areas (Ugonabo and Emoh, 2013) of which Awka, Onitsha, Nnewi, Ihiala, Ekwulobia, Otuocha, and Ogidi (Figure 1) are recognized as urban areas by the Anambra State Government (Onwuka *et al*., 2017). Although 2/3 of the Anambra territory has been classified as rural because of its relatively small landmass, the state is experiencing rapid urbanization and is virtually becoming one huge, contiguous urban area. The population growth rate of the state is 2.21% per annum with 62% of the total population residing in urban areas (UN-Habitat, 2009; Ugonabo and Emoh, 2013). Consequently, it has one of the highest population densities in Africa with 947 persons living within every square kilometer (Ugonabo and Emoh, 2013).

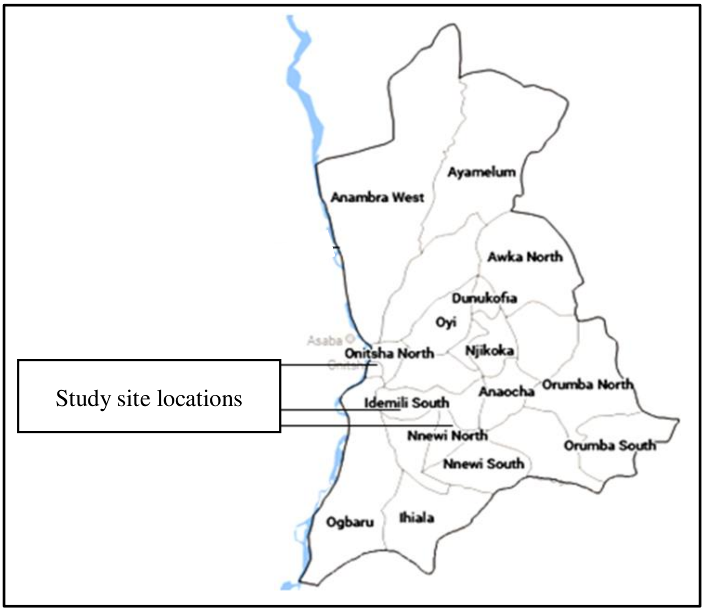

Figure 1. Map of Anambra state, Nigeria
(Source: apexnews.com)

2.2 Study Site Locations

Locations considered for assessment were areas where the factories had adopted the maximizing distance strategy in order to reduce generator noise within the industrial sites. The residences around these factories were contacted for the purpose of obtaining permission to carry out the study on their properties. Residential structures in the five study site locations were all constructed with blocks and free standing. Each residence is demarcated from each other using a block wall.

Data was analyzed only from residences where permissions were granted. Eight residences were selected around each of five food and drug factories, comprising a total of 40 study site locations. The range of actual distances between the points of measurements at the residence and each of the factories is presented in Table 1.

Table 1. Actual distance between the points of measurements at the residences and each of the factories

Factory	Actual distance between the residences and the factory	
	Maximum (m)	Minimum (m)
1	48.25	10.66
2	46.39	16.98
3	53.11	20.84
4	64.31	20.78
5	47.91	25.03

2.3 Instrumentation and Data Collection

All measurements were conducted outdoors on the property of the selected residences, using a factory calibrated sound level meter (Benetech GM 1352, China). Noise levels were evaluated in dBA (range set to 30 - 130 dBA), at a 0.1 dB resolution, and limited to the frequency range of 31.5 Hz - 8 KHz. The sound level meter was hand held at an average height of approximately 1.5 m from the ground and 1.5 m away from any structure (reflecting surface) at the residences. The measurements were taken when the atmosphere was still to avoid aerodynamic effect on the sound level meter microphone.

All measurements were carried out during day-time hours, as specified by NESREA (6:00 AM - 10:00 PM), in the months of October to December 2018. At each of the selected residences, A-weighted sound pressure levels were registered four times at the intervals of two minutes, each with a 30-second sampling time. A digital professional handheld liquid crystal display (LCD) stopwatch (Shenzhen, China) was used for exposure and interval time measurements. Three categories of measurements were considered: a) job operation dependent on generators, b) job operation dependent on national electrical grid, and c) off-work hours. For each of these measurement categories, each of the study sites (residences) considered was assessed 16 times making a total number of 48 visits to the residences for the noise level measurement.

2.4 Data Analysis

Sound level meters used in the measurement of the noise intrusion level, from the factories to residential areas, is generally a good indicator of the noise impact of a single acoustic event on the human ear. It is, however, necessary to ascertain the intrusion of the continuous and unvarying noise level and its duration because factory power usage and operation is neither a moment nor an event. Different measurements taken to estimate a series of noises during the assessment period allow for the subsequent calculation of the equivalent energy noise level (L_{eq}), or energy mean sound level, and which simultaneously incorporates the intensity and exposure time of acoustical environment. Data obtained in each residence was computed to an A-weighted equivalent sound pressure level (LA_{eq}) so as to obtain a single value reflecting a constant noise level that would result in the same total sound energy being produced over a given time period. For this purpose, the following mathematical formula was used:

$$LA_{eq} = 10\log_{10}\left[\frac{1}{N}\sum_{i=1}^{N}\left(anti\log\frac{L_{Ai}}{10}\right)\right] \quad (1)$$

where:

LA_{eq} = A-weighted equivalent sound pressure level
LA_i = A-weighted sound pressure level (dBA)
$i = 1, 2, 3\ldots N$
N = total number of measurements

The computed LA_{eq} sound pressure level values were then compared to the residential noise levels as recommended by HUD (Table 2).

Table 2. Range of LA_{eq} and levels of acceptability as recommended by HUD

LA_{eq} Level (dBA)	Acceptability
≤ 49	Clearly acceptable
>49 to ≤62	Normally acceptable
>62 to ≤76	Normally unacceptable
>76	Clearly unacceptable

*Adapted from Girardet (1992) and Babawuya *et al*. (2016)

Noise from a particular source might be offensive if it is clearly audible, distinct from the prevailing background noise. A noise is also invasive if it has a volume or character that a reasonable person would be conscious of the intrusion and find it annoying or disruptive. The health effects of intrusive noise were analyzed as per the standard outdoor living environmental guideline value established by the World Health Organization (WHO) for hearing impairment and annoyance (Olayinka, 2013). These guideline values for annoyance have been set at 50 dBA for moderate annoyance and 55 dBA for serious annoyance. For hearing impairment, WHO guideline values are 60 dBA for temporary hearing impairment and 100 dBA for permanent impairment tendencies (Olayinka, 2013).

Multiple independent-sample t-test analyses on the A-weighted sound pressure levels measured at the residences data were conducted. All working-hour samples for the five factories fell within stipulated daytime-hour (6:00 AM to 10:00 PM) by NESREA for the maximum permissible noise levels regulations and these were split into two groups: running on generators or running on the grid. Multiple independent t-tests were used for noise level comparisons between a) factory operating with generators and on grid; b) operating with generators and off-work hours; and c) operating on the grid and off-work hours. The level of significance was set at $p < 0.05$. The independent variables were the sources of power (noise intrusion during working hours [generator and grid] and off-work hours) and the dependent variable was the measured noise level. Analyses were carried out using the statistical package for social science (SPSS) version 16.0 and Microsoft Excel 2007.

3. Results and Discussion

3.1 Analysis of Outdoor Noise Levels: Comparison with HUD Recommended Values

Table 3 shows the computed LA_{eq} values of the outdoor noise levels measured at the 40 selected residences located in the vicinity of the five factories. Residential outdoor LA_{eq} values ranged from 63.2 to 78.7 dBA during generator operations, 44.5 to 62.9 dBA during grid operations, and 41.1 - 59.7 dBA during off-work hours (Table 3). According to WHO recommendations, a 60 dBA sound level can result to temporary hearing impairment. Applying this value to the data obtained herein shows that during factory generator operations all residences (100%) were susceptible to temporary hearing impairment, compared to only 2.5% during factory grid operation and 0% during off-work hours. No residence measured a LA_{eq} up to 100 dBA, and therefore permanent hearing loss did not seem to be an issue.

Table 3. Results of all measurements computed into LA_{eq} values, per each of the eight residences in the vicinity of the five Factories, as in accordance with the regimen of factory operations

Residences		1	2	3	4	5	6	7	8
		Factory 1							
Work hours	Generators	72.0	69.4	72.5	65.7	63.8	69.4	67.0	65.6
	Grid	53.7	54.2	49.9	55.5	46.3	47.9	55.6	55.7
Off Hours		47.7	45.6	48.5	59.4	48.8	48.8	45.9	47.0
		Factory 2							
Work hours	Generators	65.6	71.8	70.2	76.0	76.7	71.5	75.4	77.4
	Grid	53.9	62.9	56.1	59.4	52.1	58.1	46.3	47.9
Off Hours		42.5	57.4	47.0	43.5	45.9	44.0	47.7	46.5
		Factory 3							
Work hours	Generators	63.5	75.4	77.8	63.2	75.1	77.0	68.3	63.3
	Grid	55.6	55.1	50.9	49.6	53.6	44.5	55.4	50.6
Off Hours		48.3	56.1	42.1	45.3	41.1	59.7	45.7	41.9
		Factory 4							
Work hours	Generators	77.6	72.6	77.3	74.8	66.7	76.8	78.7	63.4
	Grid	46.7	56.6	52.7	48.1	48.1	49.6	52.6	47.3
Off Hours		48.1	42.6	45.8	42.1	44.2	44.4	42.8	58.5
		Factory 5							
Work hours	Generators	75.6	77.6	65.0	66.4	78.3	73.8	71.1	76.4
	Grid	59.1	54.3	58.4	54.7	57.9	55.9	57.7	53.9
Off Hours		45.8	41.9	42.5	55.5	45.3	53.0	44.6	54.0

Following the NESREA recommendation for residential area daytime outdoor noise level and WHO guideline value for average outdoor noise levels regarding serious annoyance (55 dBA), the data collected herein shows that 100% of the residences had a tendency for serious annoyance during factory generator operations, 40% during factory grid operations, and 15% during off-work hours. For moderate annoyance, it was 100% for generator operations, 70% for grid operations, and 20% during off-work hours. Babawuya *et al.* (2016) reported similar observations as a result of generator use – showing that noise levels during factory working hours affected residential quality of life. This is also in agreement with Oyedepo (2013) who showed that a functional, livable, and aesthetically pleasing status in the Nigerian city under study was worrisome.

Table 4 shows the analysis of outdoor noise levels for the assessed residences on HUD recommendation for outdoors noise level. The result showed that during off-work hours, the noise levels at 80% of the assessed residences was clearly acceptable noise level followed by 20% of the residences which experienced normally acceptable. Working hours' dependency on PHCN as power source for the job operation showed 75% normally acceptable noise level followed by 22.5% clearly acceptable. Engagement of generator resulted in the normally unacceptable noise level of 72.5% of the residences followed by the clearly unacceptable noise level of 27.5% residences (Table 4). This study agreed with Iqbal and Lodhi (2014) and John and Dewan (2015) that power generator noise is a major contributor to environmental noise pollution wherever they are used.

Table 4. Percentage of the outdoor residential noise levels

Levels of acceptability	Work Hours		Off-work
	Generator (%)	Grid (%)	Hours (%)
Clearly acceptable noise level	0	22.5	80
Normally acceptable noise level	0	75	20
Normally unacceptable noise level	72.5	2.5	0
Clearly unacceptable noise level	27.5	0	0

3.2 Independent Sample T-test Analysis between Factory Generator Operation and Factory Grid Operation

The independent t-tests showed statistically significantly higher mean noise level values during generator operation (71.64 ± 5.19) when compared to grid operation (53.11 ± 4.33) with p = 0.00 (Table 5). The groups' means are significantly different as the value of "Sig. (2-tailed)" is less than 0.05. This implies that residential noise levels supersede the ambient noise levels when factories are engaged in generator operations, as compared to when they are engaged in grid operations.

Table 5. Independent sample t-test for noise level between running on generator and grid

Descriptive Statistics					t-test for Equality of Means		
Work Hours	N	Mean	Std. Deviation	Std. Error Mean	t	df	P-value (Sig. [2-tailed])
Generator	40	71.64	5.19	0.82	17.35	78	0.00
Grid	40	53.11	4.33	0.68			

3.3 Independent Sample T-test Analysis between Factory Generator Operation and Off-Work Hours

The independent-sample t-test showed that factory generator operation had statistically significant higher mean values (mean = 71.64 ± 5.19, SEM = 0.82) compared to off-work hours (mean = 47.44 ± 5.24) with p = 0.00 (Table 6). The groups' means are significantly different because of the value of "Sig. (2-tailed)" is less than 0.05. This implies that outdoor residential noise levels are statistically significantly higher when factories engage generator operations than during off-work hours.

Table 6. Independent sample t-test for noise level between factory generator operation and off-work hours

Work hours	Descriptive statistics				t-test for Equality of Means		
	n	Mean	Std. Deviation	Std. Error Mean	t	df	P-value (Sig. [2-tailed])
Generator	40	71.64	5.19	.82	20.77	78	.00
Off-work	40	47.44	5.24	.83			

3.4 Independent Sample T-test Analysis between Factory Grid

The independent-sample t-test showed that the mean outdoor residential noise levels during factory grid operation were statistically, significantly higher (mean = 53.11 ± 4.33) when compared to off-work hours (mean = 47.44 ± 5.24) with p = 0.00 (Table 7). The groups' means are significantly different because of the value of "Sig. (2-tailed)" is less than 0.05. These findings showed that outdoor residential noise levels are high due to an elevated level of noise intrusion.

Table 7. Independent sample t-test for noise level between factory grid operation and off-work hours

Work hours	Descriptive statistics				t-test for Equality of Means		
	n	Mean	Std. Deviation	Std. Error Mean	t	df	P-value (Sig. [2-tailed])
Grid	40	53.11	4.33	0.68	5.28	78	0.00
Off-work hour	40	47.44	5.24	0.83			

4. Conclusion and Recommendation

Technological and developmental advancement, intended for the improvement of quality of life, can be either beneficial or detrimental to human health and the environment depending on the implemented planning and control management. The safety aspect of the urban development plan covers the protection against many public health and environmental hazards, both natural and artificial. This experimental study on the intrusion of industrial noise in residential areas as an effect of settlement pattern and land use planning in Anambra state, Nigeria found that regardless of the sources of factory power (generators or grid connection), the clustered and intermixed development of residential and industrial areas creates unacceptable levels of residential noise – hazardous to the public health and safety. Considering the cost implication of relocating either the sector or the issues of objections concerning who came first, in addition to the possession of development permits for land use issued by the local jurisdictions, it is suggested that factories should adopt either active or passive noise control methods to achieve the recommended noise levels for the continued coexistence of the residences and factories in the same location. Lastly, the authors call for effective urban development planning to avoid future challenges.

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